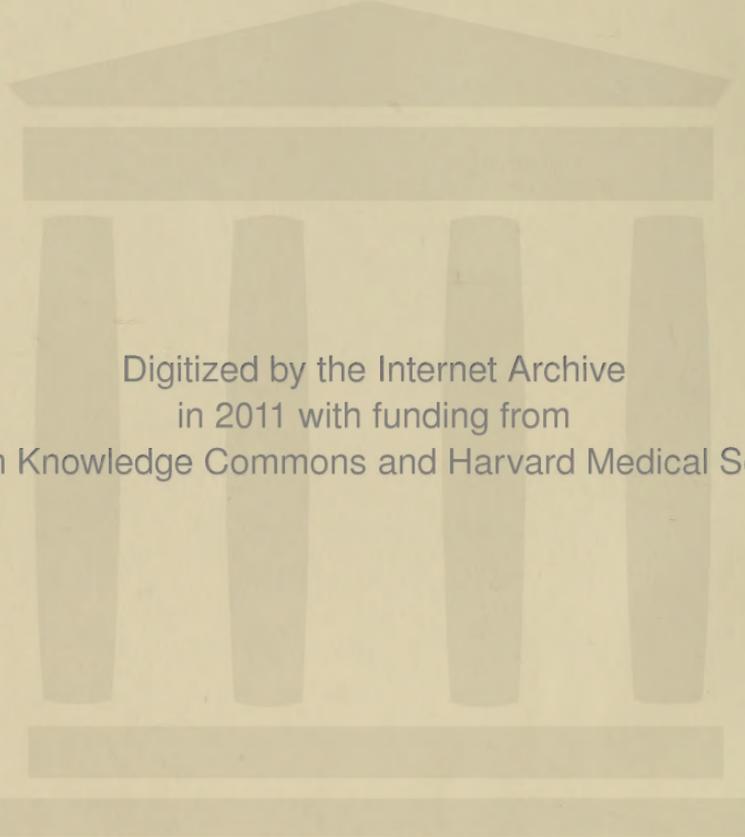


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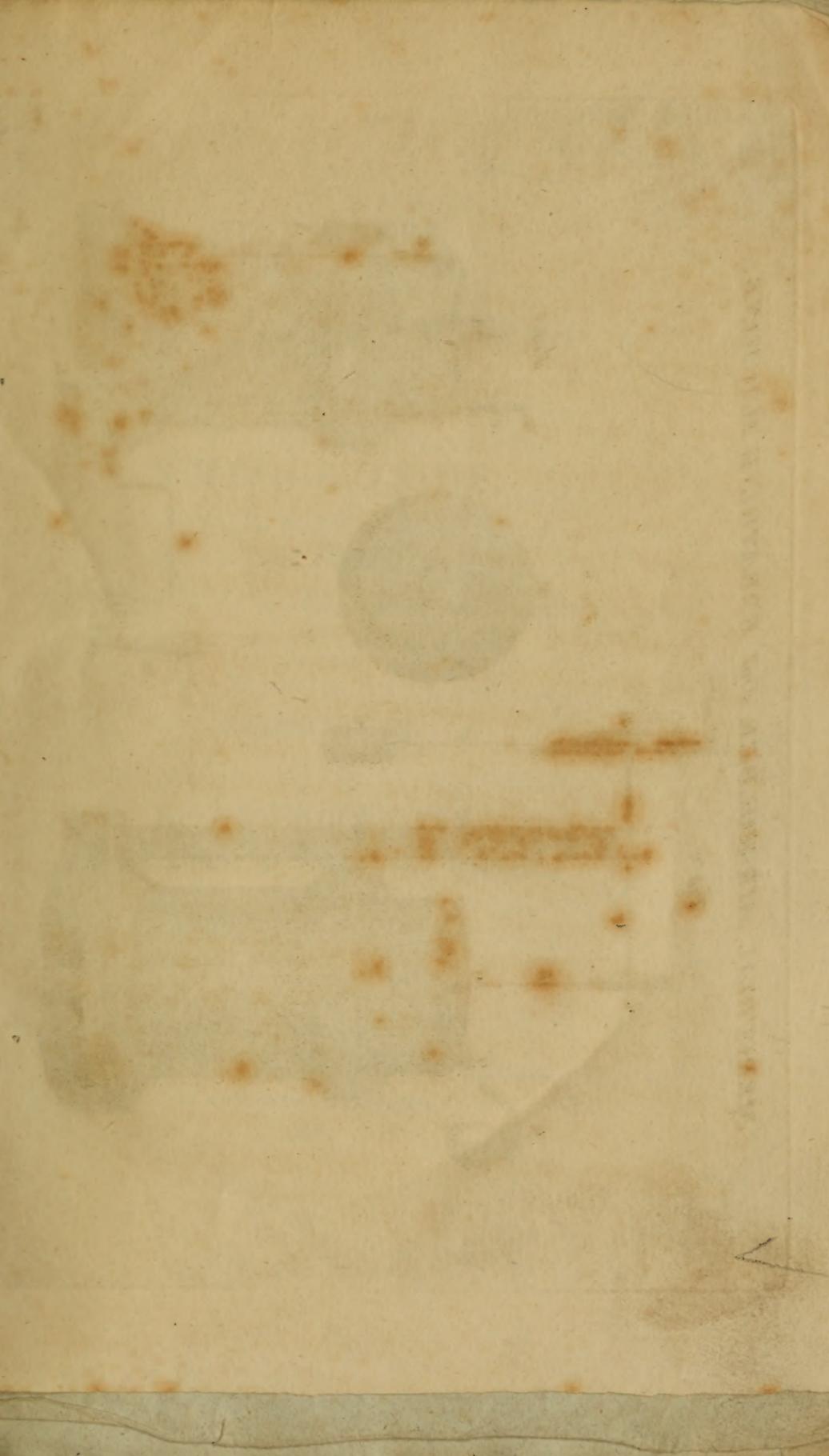
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MERCURIAL AIR-HOLDER and BREATHING MACHINE.

Fig. 2.

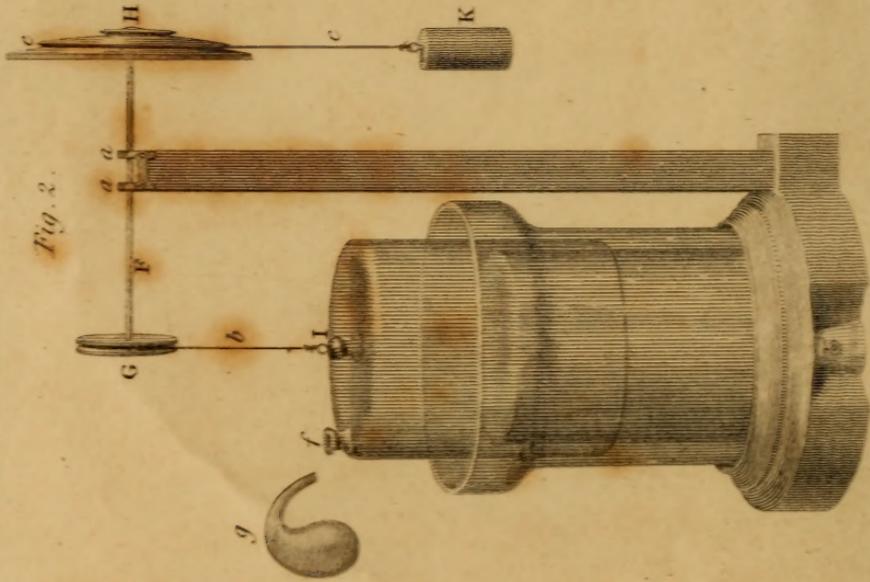


Fig. 3.

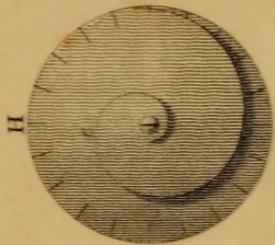
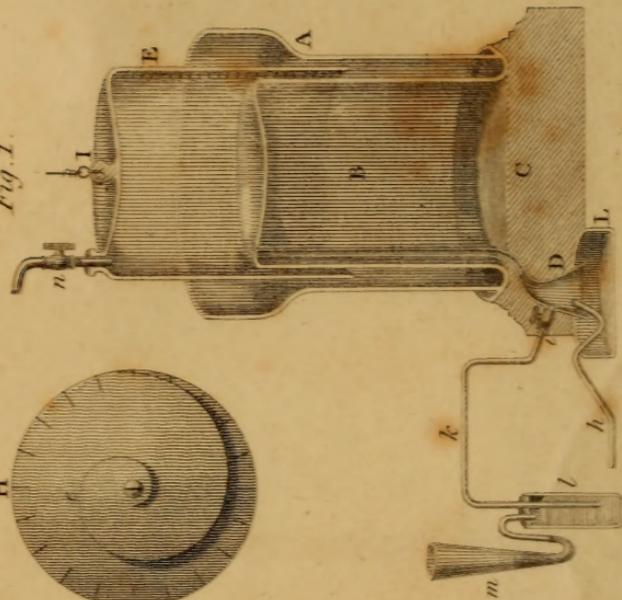


Fig. 1.



Lowry sculp.

A. C. C. Knolly
1812

RESEARCHES,
CHEMICAL AND PHILOSOPHICAL;

CHIEFLY CONCERNING

NITROUS OXIDE,

OR

DEPHLOGISTICATED NITROUS AIR,

AND ITS

RESPIRATION.

By HUMPHRY DAVY,

SUPERINTENDENT OF THE MEDICAL PNEUMATIC
INSTITUTION.

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INTRODUCTION.

IN consequence of the discovery of the respirability and extraordinary effects of nitrous oxide, or the dephlogisticated nitrous gas of Dr. Priestley, made in April 1799, in a manner to be particularly described hereafter, * I was induced to carry on the following investigation concerning its composition, properties, combinations, and mode of operation on living beings.

In the course of this investigation, I have met with many difficulties; some arising from the novel and obscure nature of the subject, and

* A short account of this discovery has been given in Dr. Beddoes's Notice of some Observations made at the Pneumatic Institution, and in Mr. Nicholson's Phil. Journal for May and December 1799.

others from a want of coincidence in the observations of different experimentalists on the properties and mode of production of the gas. By extending my researches to the different substances connected with nitrous oxide; nitrous acid, nitrous gas and ammoniac; and by multiplying the comparisons of facts, I have succeeded in removing the greater number of those difficulties, and have been enabled to give a tolerably clear history of the combinations of oxygen and nitrogen.

By employing both analysis and synthesis whenever these methods were equally applicable, and comparing experiments made under different circumstances, I have endeavoured to guard against sources of error; but I cannot flatter myself that I have altogether avoided them. The physical sciences are almost wholly dependant on the minute observation and comparison of properties of things not immediately obvious to the senses; and from the difficulty of discovering every possible mode of examination, and from the modification of per-

ceptions by the state of feeling, it appears nearly impossible that all the relations of a series of phænomena can be discovered by a single investigation, particularly when these relations are complicated, and many of the agents unknown. Fortunately for the active and progressive nature of the human mind, even experimental research is only a method of approximation to truth.

In the arrangement of facts, I have been guided as much as possible by obvious and simple analogies only. Hence I have seldom entered into theoretical discussions, particularly concerning light, heat, and other agents, which are known only by isolated effects.

Early experience has taught me the folly of hasty generalisation. We are ignorant of the laws of corpuscular motion; and an immense mass of minute observations concerning the more complicated chemical changes must be collected, probably before we shall be able to ascertain even whether we are capable of discovering them. Chemistry in its present state, is simply a partial

history of phænomena, consisting of many series more or less extensive of accurately connected facts.

With the most important of these series, the arrangement of the combinations of oxygene or the antiphlogistic theory discovered by Lavoisier, the chemical details in this work are capable of being connected.

In the present state of science, it will be unnecessary to enter into discussions concerning the importance of investigations relating to the properties of physiological agents, and the changes effected in them during their operation. By means of such investigations, we arrive nearer towards that point from which we shall be able to view what is within the reach of discovery, and what must for ever remain unknown to us, in the phænomena of organic life. They are of immediate utility, by enabling us to extend our analogies so as to investigate the properties of untried substances, with greater accuracy and probability of success.

The first Research in this work chiefly relates to the production of nitrous oxide and the analysis of nitrous gas and nitrous acid. In this there is little that can be properly called mine; and if by repeating the experiments of other chemists, I have sometimes been able to make more minute observations concerning phænomena, and to draw different conclusions, it is wholly owing to the use I have made of the instruments of investigation discovered by the illustrious fathers of chemical philosophy,* and so successfully applied by them to the discovery of truth.

In the second Research the combinations and composition of nitrous oxide are investigated, and an account given of its decomposition by most of the combustible bodies.

The third Research contains observations on the action of nitrous oxide upon animals, and

* Cavendish, Priestley, Black, Lavoisier, Scheele, Kirwan, Guyton, Berthollet, &c.

an investigation of the changes effected in it by respiration.

In the fourth Research the history of the respirability and extraordinary effects of nitrous oxide is given, with details of experiments on its powers made by different individuals.

I cannot close this introduction, without acknowledging my obligations to Dr. Beddoes. In the conception of many of the following experiments, I have been aided by his conversation and advice. They were executed in an Institution which owes its existence to his benevolent and philosophic exertions.

Dorvry-Square, Hotwells, Bristol.

June 25th, 1800.

RESEARCH I.

CONCERNING THE ANALYSIS

OF

NITRIC ACID AND NITROUS GAS.

AND

THE PRODUCTION OF

NITROUS OXIDE.



RESEARCH I.
INTO THE PRODUCTION AND ANALYSIS
OF
NITROUS OXIDE,
AND
THE AERIFORM FLUIDS RELATED TO IT.

DIVISION I.

EXPERIMENTS and OBSERVATIONS on the composition of NITRIC ACID, and on its combinations with WATER and NITROUS GAS.

I. **T**HOUGH since the commencement of Pneumatic Chemistry, no substance has been more the subject of experiment than Nitrous Acid; yet still the greatest uncertainty exists with regard to the quantities of the principles entering into its composition.

In comparing the experiments of the illustrious Cavendish on the synthesis of nitrous acid, with those of Lavoisier on the decomposition of nitre by charcoal, we find a much greater difference in the results than can be

accounted for by supposing the acid formed, and that decomposed, of different degrees of oxygenation.

In the most accurate experiment of Cavendish, when the nitrous acid appeared to be in a state of deoxygenation, 1 of nitrogene combined with about 2,346 of oxygene.* In an earlier experiment, when the acid was probably fully oxygenated, the nitrogene employed was to the oxygene nearly as 1 to 2,92.†

Lavoisier, from his experiments on the decomposition of nitre, and combination of nitrous gas and oxygene, concludes, that the perfectly oxygenated, or what he calls nitric acid, is composed of nearly 1 nitrogene, with 3,9 of oxygene; and the acid in the last state of deoxygenation, or nitrous acid, of about 3 oxygene with 1 nitrogene.‡

* Phil. Transf. v. 78, p. 270. † Phil. Transf. v. 75, p. 381.

‡ Elem. Kerr's Transf. page 76, and 216, and Mem. des Sav. Etrang. tom. 7, page 629.

Great as the difference is between the estimations of these philosophers, we find differences still greater in the accounts of the quantities of nitrous gas necessary to saturate a given quantity of oxygene, as laid down by very accurate experimentalists. On the one hand, Priestley found 1 of oxygene condensed by 2 of nitrous gas, and Lavoisier by $1\frac{7}{8}$. On the other, Ingenhouz, Scherer, and De la Metherie, state the quantity necessary to be from 3 to 5.* Humbolt, who has lately investigated Eudiometry with great ingenuity, considers the mean quantity of nitrous gas necessary to saturate 1 of oxygene, as about 2,55.†

II. To reconcile these different results is impossible, and the immediate connection of the subject with the production of nitrous oxide, as well as its general importance, obliged me to search for means of accurately deter-

* Ingenhouz sur les Vegetaux, pag. 205. De la Metherie. Essai sur differens Airs, pag. 252.

† Annales de Chimie, tome 28, p. 168.

mining the composition of nitrous acid in its different degrees of oxygenation.

The first desideratum was to ascertain the nature and composition of a fluid acid, which by being deprived of, or combined with nitrous gas, might become a standard of comparison for all other acids.

To obtain this acid I should have preferred the immediate combination of oxygen and nitrogen over water by the electric spark, had it been possible to obtain in this way by a common apparatus sufficient for extensive examination; but on carefully perusing the laborious experiments of Cavendish, I gave up all thoughts of attempting it.

My first experiments were made on the decomposition of nitre, formed from a known quantity of pale nitrous acid of known specific gravity, by phosphorus, tin, and charcoal: but in those processes, unascertainable quantities of nitrous acid, with excess of nitrous gas, always escaped undecomposed, and from the non-coincidence of results, where different quanti-

ties of combustible substances were employed, I had reasons for believing that water was generally decomposed.

Before these experiments were attempted, I had analyzed nitrous gas and nitrous oxide, in a manner to be particularly described hereafter; so that a knowledge of the quantities of nitrous gas and oxygen entering into the composition of any acid, enabled me to determine the proportions of nitrogen and oxygen it contained. In consequence of which I attempted to combine together oxygen and nitrous gas, in such a manner as to absorb the nitrous acid formed by water, in an apparatus by which the quantities of the gases employed, and the increase of weight of the water, might be ascertained; but this process likewise failed. It was impossible to procure the gases perfectly free from nitrogen, and during their combination, this nitrogen made to pass into a pneumatic apparatus communicating with a vessel containing the water carried over with it, much nitrous acid vapor, of different composition from the acid absorbed.

After many unsuccessful trials, Dr. Priestley's experiments on nitrous vapor * induced me to suppose that oxygene and nitrous gas, made to combine out of the contact of bodies having affinity for oxygene, would remain permanently aëriform, and on throwing them separately into an exhausted glass balloon, I found that this was actually the case; increase of temperature was produced, and orange colored nitrous acid gas formed, which after remaining for many days in the globe, at a temperature below 56°, did not in the slightest degree condense.

This fact afforded me the means not only of forming a standard acid, but likewise of ascertaining the specific gravity of nitrous acid in its aëriform state.

III. Previous to the experiment, for the purpose of correcting incidental errors, I was induced to ascertain the specific gravity of the

* Experiments and Observations, Vol. iii. last edition, page 105, &c.

into an exhausted balloon, increased it in weight 25,5 grains ; thermometer being 56° , and barometer 30,9. And allowing for the small quantity of nitrogene in the gas, 100 cubic inches of it will weigh 34.3 grains.

One hundred and thirty cubic inches of oxygene were procured from oxide of manganese and sulphuric acid, by heat, and received in another mercurial airholder.

10 measures of it, mingled with 26 of the nitrous gas, gave, after the residuum was exposed to solution of sulphate of iron, rather more than one measure. Hence we may conclude that it contained about 0,1 nitrogene.

60 cubic inches of it weighed 20,75 grains ; and accounting for the nitrogene contained in these, 100 grains of pure oxygene will weigh 35,09 grains.

Atmospherical air was decomposed by nitrous gas in excess; and the residuum washed with solution of sulphate of iron till the Nitrogene remained pure ; 87 cubic inches of it weighed 26,5 grains, thermometer being 48° , barometer 30,1 ; 100 will consequently weigh 30,45.

90 cubic inches of the air of the laboratory not deprived of its carbonic acid, weighed 28,75 grains; thermometer 53, barometer 30: 100 cubic inches will consequently weigh 31,9.* 16 measures of this air, with 16 nitrous gas, of known composition, diminished to 19. Hence it contained about ,26 oxygene.‡

In comparing my results with those of Lavoisier and Kirwan, the estimation of the weights of nitrogene and oxygene is very little different, the corrections for temperature and pressure being made, from that of those celebrated philosophers. The first makes oxygene to weigh † 34,21, and nitrogene 30,064 per cent; and the last, oxygene 34, † and nitrogene 30,5.

* A table of the specific gravities of these gases, and other gases, hereafter to be mentioned, reduced to a barometrical and thermometrical standard, will be given in the appendix.

‡ 40 measures, exposed to solution of potash, gave an absorption of not quite a quarter of a measure: hence it contained an inconsiderable quantity of carbonic acid.

† *Traité Elementaire.*

‡ *Essai sur le phlogistique, page 30.*

gases employed, particularly as I was unacquainted with any process by which the weight of nitrous gas had been accurately determined. Mr. Kirwan's estimation, which is generally adopted, being founded upon the comparison of the loss of weight of a solution of copper in dilute nitrous acid, with the quantity of gas produced.*

The instruments that I made use of for containing and measuring my gases, were two mercurial airholders graduated to the cubic inch of Everard, and furnished with stop cocks.†

* When copper is dissolved in dilute nitrous acid, certain quantities of nitrogene are generally produced, likewise the nitrous gas carries off in solution some nitrous acid.

† This airholder, considered as a pneumatic instrument, is of greater importance, and capable of a more extensive application than any other. It was invented by Mr. W. CLAYFIELD, and in its form is analogous to Mr. WATT's hydraulic bellows, consisting of a glass bell playing under the pressure of the atmosphere, in a space between two cylinders filled with mercury. A particular account of it will be given in the appendix.

They were weighed in a glass globe, of the capacity of 108 cubic inches, which with the small glass stop-cock affixed to it, was equal, when filled with atmospheric air, to 1755 grains. The balance that I employed, when loaded with a pound, turned with less than one eighth of a grain.

Into a mercurial airholder, of the capacity of 200 cubic inches, 160 cubic inches of nitrous gas were thrown from a solution of mercury in nitrous acid.

70 measures of this were agitated for some minutes in a solution of sulphate of iron,* till the diminution was complete. The nitrogene remaining hardly filled a measure; and if we suppose with Humbolt † that a very small portion of it was absorbed with the nitrous gas, the whole quantity it contained may be estimated at 0,0142, or $\frac{1}{70}$.

75 cubic inches received from the airholder

* This absorption will be hereafter particularly treated of.

† Annales de Chimie. Tome xviii. page 139.

The specific gravity of nitrous gas, according to Kirwan, is to that of common air as 1194 to 1000. Hence it should weigh about 37 grains per cent. This difference from my estimation is not nearly so great as I expected to have found it. §

IV.* The thermometer in the laboratory standing at 55°, and the barometer at 30,1, I now proceeded to my experiment. The oxygene that I employed was of the same composition as that which I had previously weighed. The nitrous gas contained ,0166 nitrogene.

For the purpose of combining the gases, a glass balloon was procured, of the capacity of 148 cubic inches, with a glass stop-cock adapted to it, having its upper orifice tubulated and graduated for the purpose of containing and measuring a fluid. The whole weight of this globe and its appendages, when filled with common air, was 2066,5 grains.

§ The diminution of the specific gravity of the gas from the quantity of nitrogene evolved in his experiment, probably destroyed, in some measure, the source of error from the nitrous acid carried over.

* Experiment I.

It was partially exhausted by the air-pump, and lost in weight just 32 grains. From whence we may conclude that about 15 grains of air remained in it.

In this state of exhaustion it was immediately cemented to the stop-cock of the mercurial airholder, and the communication being made with great caution, 82 cubic inches of nitrous gas rushed into the globe, on the outside of which a slight increase of temperature was perceived, while the gases on the inside appeared of a deep orange.

Before the common temperature was restored, the communication was stopped, and the globe removed. The increase of weight was 29,25 grains; whence it appeared that 1,14 grains of common air, part of which had been contained in the stop-cocks, had entered with the nitrous gas.

Whilst it was cooling, from the accidental loosening of the stopper of the cock, 3 grains more of common air entered.*

* That no greater contraction took place depended on the solution of the nitrous acid formed in the nitrous gas; a phenomenon to be explained hereafter.

The communication was now made between the globe and the mercurial airholder containing oxygene. 64 cubic inches were slowly pressed in, when the outside of the globe became warmer, and the color on the inside changed to a very dark orange. As it cooled, 6 cubic inches more slowly entered; but no new increase of temperature, or change of color took place.

The globe being now completely cold, was stopped, removed, and weighed; it had gained 24,5 grains, from whence it appears that 0,4 grains of common air contained in the stop-cocks, had entered with the oxygene.*

To absorb the nitrous acid gas, 41 grains of water were introduced by the tube of the stop-cock, which though closed as rapidly as possible, must have suffered nearly ,5 grains of air to

* I judged it expedient always to ascertain the quantity of air in the stop-cocks by weight, as it was impossible to join them so as to have always an equal capacity. The upper tubes of the two stop-cocks not joined, contained nearly an inch and half.

enter at the same time, as the increase of weight was 41,5 grains. The dark orange of the globe diminished rapidly; it became warm at the bottom, and moist on the sides. After a few minutes the color had almost wholly disappeared.

To ascertain the quantity of aëriform fluid absorbed, the globe was again attached to the mercurial air apparatus, containing 140 cubic inches of common air. When the communication was made, 51 cubic inches rushed in, and it gained in weight 16,5 grains.

A quantity of fluid equal to 54 grains was now taken out of the globe. On examination it proved to be slightly tinged with green, and occupied a space equal to that filled by 41,5 grains of water. Its specific gravity was consequently 1,301.

To ascertain if any unabsorbed aëriform nitrous acid remained in the globe, 13 grains of solution of ammonia were introduced in the same manner as the water, and after some minutes, when the white vapor had condensed,

the communication was again made with the mercurial airholder containing common air. A minute quantity entered, which could not be estimated at more than three fourths of an inch, and the globe was increased in weight about 13,25 grains.*

Common air was now thrown into the globe till the residual gases of the experiment were judged to be displaced; it weighed 2106,5 grains, that is, 40 grains more than it had weighed when filled with common air before the experiment.†

* That is, by the solution of ammonia, and air.

† The following is an account of the increase and diminution of weight of the globe, as it was noted in the journal.

Globe filled with common air	- gr.	2066,5
After exhaustion	- - -	2034,5
After introduction of nitrous gas, 82 cubic inches	- - -	2064,25
After the accidental admission of common air	- - -	2067,25
After the admission of oxygen	- - -	2091,75
— — 41 grains of water	- - -	2133,25
— — 51 cubic inches of air	- - -	2149,75
Taken out 54 grains of solution	- - -	2095,75
Introduced 13 grains of ammoniacal solution	- - -	2109,25
After introduction of common air	- - -	2106,5

And if from those 40 grains we take 13 for the solution of ammonia introduced, the remainder, 27, will be the quantity of solution of nitrous acid in water remaining in the globe, which added to 54, equals 81 grains, the whole quantity formed ; but if from this be taken 41 grains, the quantity of water, the remainder 40 grains, will be the quantity of nitrous acid gas absorbed in the solution.

To find the absolute quantity of nitrous acid formed, we must find the specific gravity of that absorbed ; but as during, and after its absorption, 17 grains of air, equal to 53,2 cubic inches entered, it evidently filled such a space. 53,2 cubic inches of it consequently weigh 40 grains, and 100 cubic inches 75,17 grains. Then ,75 cubic inches weigh ,56 grains, and this added to 40, makes 40,56 grains, equal to 57,0 cubic inches, the whole quantity of aëriform nitrous acid produced.

But the quantity of nitrous gas entering into this, allowing for the nitrogen it contained, is

27,6 grains, equal to about 80,5 cubic inches ; and the oxygene is $40,56 - 27,6 =$ to 12,96 grains, or 36,9 cubic inches.

V. There could exist in this experiment no circumstance connected with inaccuracy, except the impossibility of very minutely determining the quantities of common air which entered with the gases from the stop-cocks. But if errors have arisen from this source, they must be very inconsiderable ; as will appear from a calculation of the specific gravity of the nitrous acid gas, founded on the volume of the gases that entered the globe.

The air that remained in the globe

after exhaustion was 15 grains $= 47^*$ cub. in.

The nitrous gas introduced was 82

Common air - - - - 13

Oxygene - - - - 70

Common air - - - - 1

* Decimals are omitted, because the excess of the two first numbers is exactly corrected by the deficiency of the last.

Whole quantity of air thrown into	
the globe	213
From which subtract its capacity	148
The remainder is	<u>65</u>

And this remainder taken from 80,5 nitrous gas + 36,9 oxygene, leaves 52,4 cubic inches, which is the space occupied by the nitrous acid gas, and which differs from 53,95 only by 1,55 cubic inches.

I ought to have observed, that before this conclusive experiment, two similar ones had been made. In comparing the results of one of them, performed with the assistance of my friend, Mr. JOSEPH PRIESTLEY, Dr. PRIESTLEY's eldest son, and chiefly detailed by him in the journal, I find a coincidence greater than could be even well expected, where the processes are so complex. According to that experiment, 41,5 grains of nitrous acid gas fill a space equal to 53 cubic inches, and are composed of nearly 29 nitrous gas, and 12,5 oxygene.

We may then conclude, First, that 100 cubic inches of nitrous acid, such as exists in the * aëriform state saturated with oxygen, at temperature 55°, and atmospheric pressure 30,1 weigh 75,17 grains.

Secondly, that 100 grains of it are composed of 68,06 nitrous gas, and 31,94 oxygen. Or assuming what will be hereafter proved, that 100 parts of nitrous gas consist of 55,95 oxygen, and 44,05 nitrogen, of 29,9 nitrogen, and 70,1 oxygen; or taking away decimals, of 30 of the one to 70 of the other.

Thirdly, that 100 grains of pale green solution of nitrous acid in water, of specific gravity 1,301, is composed of 50,62 water, and 49,38 acid of the above composition.

VI. Having thus ascertained the composition of a standard acid, my next object was to obtain it in a more condensed state, as it was otherwise impossible to saturate it to its full

* As is evident from the superabundant quantity of oxygen thrown into the globe.

extent with nitrous gas. But this I could effect in no other way than by comparing mixtures of known quantities of water, and acids of different specific gravities and colors, with the acid of 1,301.

For the purpose of combining my acids with water, I made use of a cylinder about 8 inches long, and 3 inches in diameter, accurately graduated to grain measures, and furnished with a very tight stopper.

The concentrated acid was first slowly poured into it, and the water gradually added till the required specific gravity was produced;* the cylinder being closed and agitated after each addition, so as to produce combination without any liberation of elastic fluid.

After making a number of experiments with

* The weight of the acid poured into the cylinder being known, its specific gravity was known from the space it occupied in the phial. The weight of water being likewise known, the specific gravity of the solution, when the common temperature was produced, was given by the condensation.

acids of different colors in this advantageous way, I at length found that 90 grains of a deep yellow acid, of specific gravity 1,5, became, when mingled at 40° with 77,5 grains of water, of specific gravity 1,302, and of a light green tinge, as nearly as possible resembling that of the standard acid.

Supposing, then, that these acids contain nearly the same relative proportions of oxygene and nitrogene, 100 grains of the deep yellow acid of 1,5, are composed of 91,9 grains true nitrous acid,† and 8,1 grains of water.

To ascertain the difference between the composition of this acid, and that of the pale, or nitric acid, of the same specific gravity, I inserted 150 grains of it into a small cylindrical mattrafs of the capacity of ,5 cubic inches, accurately graduated to grain measures, and connected by a curved

† That is, such as it exists in the æriform state at 55°. From the strong affinity of nitrous acid for water, we may suppose that this acid gas contains a larger proportion of it than the other gases.

tube with the water apparatus. After heat had been applied to the bottom of the mattrafs for a few minutes, the color of the fluid gradually changed to a deep red, whilst the globules of gas formed at the bottom of the acid, were almost wholly absorbed in passing through it. In a short time deep red vapour began to fill the tube, and being condensed by the water in the apparatus, was converted into a bright green fluid, at the same time that minute globules of gas were given out. As the heat applied became more intense, a very singular phænomenon presented itself; the condensed vapor, increased in quantity, at length filled the curvature of the tube, and when expelled, formed itself into dark green spherules, which sunk to the bottom of the water, rested for a moment, and then resolved themselves into nitrous gas.*

When the acid was become completely pale, it was suffered to cool, and weighed. It had lost near 15 grains, and was of specific gravity

* This appearance will be explained hereafter.

1,491. 2 cubic inches and quarter of nitrous gas only were collected.

From this experiment evidently no conclusions could be drawn, as the nitrous gas had carried over with it much nitrous acid (in the form of what Dr. Priestley calls nitrous vapor) and was partially dissolved with it in the water.†

To ascertain, then, the difference between the pale and yellow acids, I was obliged to make use of synthesis, compared with analysis, carried on in a different mode, by means of the following apparatus.

VII. To the stop-cock of the upper cylinder of the mercurial airholder, a capillary tube was adapted, bent so as to be capable of introduction into an orifice in the stopper of a graduated phial similar to that employed for mingling acids with water, and sufficiently long to reach the bottom. With another orifice in the stopper of the phial was connected a similar tube cur-

† This phenomenon will be particularly explained hereafter.

ved, for the purpose of containing a fluid, and of increased diameter at the extremity.*

50 cubic inches of pure nitrous gas † were thrown into the mercurial apparatus. The graduated phial, containing 90 grains of nitric acid, of specific gravity 1.5, was placed on the top of the airholding cylinder, and made to communicate with it by means of the stop-cock and first tube. Into the second tube a small quantity of solution of potash was placed. When all the junctures were carefully cemented, by pressing on the air-holder, the nitrous gas was slowly passed into the phial, and absorbed by the nitrous acid it contained; whilst the small quantities of nitrogene evolved, slowly drove forward the solution in the curved tube; from the height of which, as compared with that of the mercury in the conducting tube, the pressure on the air in the cylinder was known.

* The outline only of this apparatus is given here, as far as was necessary to make the experiment intelligible; a detailed account of it, and of its general application, will be given in the appendix.

† That is, from nitrous acid and mercury.

In proportion as the nitrous gas was absorbed, the phial became warm, and the acid changed color; it first became straw-colored, then pale yellow, and when about $7\frac{1}{2}$ cubic inches had been combined with it, bright yellow. It had gained in weight nearly 3 grains, and was become of specific gravity 1,496.

This experiment afforded me an approximation to the real difference between nitric and yellow nitrous acid; and learning from it that nitric acid was diminished in specific gravity by combination with nitrous gas, I procured a pale acid of specific gravity 1,504.* After this acid had been combined in the same manner as before, with about 8 cubic inches of nitrous gas,§ it became nearly of specific gravity 1,5, and had gained in weight about 3 grains.

* A pale acid of 1.52, by being converted into yellow acid, became nearly of specific gravity 15,1.

§ It is impossible to ascertain the quantity of gas absorbed to more than a quarter of a cubic inch, as the first portions of nitrous gas thrown into the graduated cylinder are combined with the oxygene of the common air in it, to form nitrous acid, and hence the slight excess of weight.

Assuming the accuracy of this experiment as a foundation for calculation, I endeavoured in the same manner to ascertain the differences in the composition of the orange-colored acids, and the acids containing still larger proportions of nitrous gas.

93 grains of the bright yellow acid of 1,5 became, when 6 cubic inches of gas had been passed through it, orange colored and fuming, whilst the undissolved gas increased in quantity so much as to render it impossible to confine it by the solution of potash. When 9 cubic inches had passed through, it became dark orange. It had gained in weight 2,75 grains, and was become of specific gravity 1,48 nearly. Hence it was evident that much nitrous gas had passed through it undissolved. 25 cubic inches more of nitrous gas were now slowly sent through it: it first became of a light olive, then of a dark olive, then of a muddy green, then of a bright green, and lastly of a blue green. After its assumption of this color, the gas appeared to pass through it unaltered, and large globules

of fluid, of a darker green than the rest, remained at the bottom of the cylinder, and when agitated, did not combine with it. The increase of weight was only 1 grain, and the acid was of specific gravity 1,474 nearly.

In this experiment it was evident that the unabforbed nitrous gas had carried over with it a considerable quantity of nitrous acid. I endeavoured to correct the errors resulting from this circumstance, by connecting the curved tube first with a small water apparatus, and afterwards with a mercurial apparatus; but when the water apparatus was used, the greater part of the unabforbed gas was dissolved with the nitrous acid it held in solution, by the water; and when mercury was employed, the nitrous acid that came over was decomposed, and the quantity of nitrous gas evolved, in consequence increased.

As it was possible that a small deficiency of weight might arise from the red vapor given out during the processes of weighing and examining the acid in the last experiment,

35 cubic inches of nitrous gas were very slowly passed through 90 grains of pale nitrous acid, of specific gravity 1,5 : it became of similar appearance to that just described, had gained in weight 6,75 grains, and was become of specific gravity 1,475.

These experiments did not afford approximations sufficiently accurate towards the composition of deoxygenated acids, containing more nitrous gas than the dark orange colored. To obtain them, a solution consisting of 94,25 grains of blue green, or perfectly nitrated acid, (if we may be allowed to employ the term), of specific gravity 1,475, was inserted into a graduated phial, and connected by a curved tube, with the mercurial airholder ; in the conductor of which a small quantity of water was inserted to absorb the nitrous acid which might be carried over by the gas. Heat was slowly applied to the phial, and nitrous gas given out with great rapidity. When 4 cubic inches were collected, the acid became dark olive, when 9 dark red, when 13 bright

orange, and when 18 pale. It had lost 31 grains, and when completely cool, was of specific gravity 1,502 nearly. The water in the apparatus was tinged of a light blue; from whence we may conclude that some of the nitrous gas was absorbed by it with the nitrous acid: but it will be hereafter proved that the orange colored acid is the most nitrated acid capable of combining undecomposed with water, and that the color it communicates to a large quantity of water, is light blue. If then we take 6,1 grains, the quantity of gas collected, from 31 the loss, the remainder is 24,9, which reasoning from the synthetical experiment, may be supposed to contain nearly 3 cubic inches of nitrous gas. Consequently, 94,25 grains of dark green acid, of specific gravity 1,475, are composed of nearly 21 cubic inches, or 7,2 grains of nitrous gas, and 87,05 grains of pale nitrous acid, of 1,504.

VIII. Comparing the different synthetical and analytical experiments, we may conclude with tolerable accuracy, that 92,75 grains of bright

yellow, or standard acid of 1,5, are composed of 2,75 grains of nitrous gas, and 90 grains of nitric acid of 1,504; but 92,75 grains of standard acid contain 85,23 grains of nitrous acid, composed of about 27,23 of oxygen, and 58, nitrous gas: now from 58, take 2,75, and the remainder 55,25, is the quantity of nitrous gas contained in 90 grains of nitric acid of 1,504; consequently, 100 grains of it are composed of 8,45 water, and 91,55 true acid, containing 61,32 nitrous gas, and 30,23 oxygen; or 27,01 nitrogen, and 64,54 oxygen: and the nitrogen in nitric acid, is to the oxygen as 1 to 2,389.

IX. My ingenious friend, Mr. JAMES THOMSON, has communicated to me some observations relating to the composition of nitrous acid (that is, the orange-colored acid), from which he draws a conclusion which is, in my opinion, countenanced by all the facts we are in possession of, namely, "that it ought
 " not to be considered as a distinct and less

“ oxygenated state of acid, but simply as nitric
 “ or pale acid, holding in solution, that is,
 “ loosely combined with, nitrous gas.”*

It is impossible to call any substance a simple acid that is incapable of entering undecomposed into combination with the alkalies, &c ; but it will appear hereafter that the salts called in the

* In a letter to me, dated Oct. 28, 1799, after giving an account of some experiments on the phlogification of nitric acid by heat and light, he says, “ It was from an
 “ attentive examination of the manner in which the nitric
 “ acid was phlogificated in these experiments, that I was
 “ confirmed in the suspicion I had long before entertained,
 “ of the real difference between the *nitrous* and *nitric* acids.
 “ It is not enough to shew that in the *nitrous* acid, (that is,
 “ the nitric holding nitrous gas in solution), the proportion
 “ of oxygene in the whole compound is less than that enter-
 “ ing into the composition of the nitric acid, and that it is
 “ therefore less oxygenated. By the same mode of reasoning
 “ we might prove that water, by absorbing carbonic acid
 “ gas, became less oxygenated, which is absurd. Should
 “ any one attempt to prove (which will be necessary to sub-
 “ stantiate the generally received doctrine) that the oxygene
 “ of the nitrous gas combines with the oxygene of the acid,
 “ and the nitrogene, in like manner, so that the resulting acid,
 “ when nitrous gas is absorbed by nitric acid, is a binary
 “ combination of oxygene and nitrogene, he would find it
 “ somewhat more difficult than he at first imagined; it ap-
 “ pears to me impossible. It is much more consonant with

new nomenclature *nitrites*, cannot be directly formed. If, indeed, it could be proved, that the heat produced by the combination of nitrous acid with salifiable bases, was the only cause of the partial decomposition of it, and that when this process was effected in such a way as to prevent increase of temperature, no nitrous gas was liberated, the common

“ experiment to suppose that nitrous acid is nothing more
 “ than nitric acid holding nitrous gas in solution, which
 “ might in conformity to the principles of the French
 “ nomenclature, be called nitrate of nitrogene. The difficulty,
 “ and in some cases the impossibility, of forming nitrites,
 “ arises from the weak affinity which nitrous gas has for
 “ nitric acid, compared with that of other substances; and
 “ the decomposition of nitrous acid) that is, nitrate of
 “ nitrogene) by an alkaline or metallic substance, is perfectly
 “ analogous to the decomposition of any other nitrate, the
 “ nitrous gas being displaced by the superior affinity of the
 “ alkali for the acid.

“ Agreeable to this theory, the salts denominated
 “ *nitrites* are in fact triple salts, or ternary combinations of
 “ nitric acid, nitrous gas, and salifiable bases.”

This theory is perfectly new to me. Other Chemists to whom I have mentioned it, have likewise considered it as new. Yet in a subsequent letter Mr. Thomson mentions that he had been told of the belief of a similar opinion among the French Chemists.

theory might have some foundation ; but though dilute phlogificated nitrous acid combines * with alkaline solutions without decomposition, yet no excess of nitrous gas is found in the solid salt : it is either disengaged in proportion as the water is evaporated, or it absorbs oxygen from the atmosphere, and becomes nitric acid.

In proportion as the nitrous acids contain more nitrous gas, so in proportion do they more readily give it out. From the blue green acid it is liberated slowly at the temperature of 50° , and from the green likewise on agitation. The orange-coloured and yellow acids do not require a heat above 200° to free them of their nitrous gas ; and all the

* In some experiments made on the nitrites of potash, and of ammoniac, before I was well acquainted with the composition of nitric acid, I found that a light olive-colored acid of 1,28, was capable of being saturated by weak solutions of potash and ammoniac, without losing any nitrous gas ; but after the evaporation of the neutralised solution, at very low temperatures, the salts in all their properties resembled *nitrates*.

colored acids, when exposed to the atmosphere absorb oxygene, and become by degrees pale.

If the nitrous vapour, i. e. such as is disengaged during the *denitration* of the colored acids, was capable of combining with the alkalies, it might be supposed a distinct acid, and called nitrous acid; and the acids of different colors might be considered simply as compounds of this acid with nitric acid; but it appears to be nothing more than a solution of nitric acid in nitrous gas, incapable of condensation, undecomposed, and when decomposed and condensed, constituting the dark green acid, which is immiscible with water,† and uncombinable with the alkalies.‡

It seems therefore reasonable, till we are in possession of new lights on the subject, to consider, with Mr. Thomson, the deoxygenated or nitrous acids simply as solutions of nitrous gas

† As is evident from the curious appearance of the dark green spherules, repulsive both to water, and light green acid.

‡ That is, undecomposed.

in nitric acid, and as analogous to the solutions of nitrous gas in the sulphuric and marine acids, &c. and the salts called nitrites, ternary combinations, similar to the triple compounds composed of sulphuric acid, metallic oxides, and nitrous gas.*

Supposing the truth of these principles according to the logic of the French nomenclature, there is no acid to which the term nitrous acid *ought* to be applied; but as it has been used to signify the acids holding in solution nitrous gas, it is perhaps better still to apply it to those substances, than to invent for them new names. A nomenclature, accurately expressing their constituent parts, would be too complex, and like all other nomenclatures founded upon theory, liable to perpetual alterations. Their composition is known from their specific gravity and their colors; hence it is better to denote it by those physical properties: thus orange nitrous acid, of specific gravity 1,480, will signify a solution of nitrous

* The existence of these bodies will be hereafter proved.

gas in nitric acid, in which the nitric acid is to the nitrous gas, nearly as 87 to 5, and to the water as 11 to 1.

X. The estimation of the composition of the yellow and orange colored nitrous acids given in the following table, may be considered as tolerably accurate, being deduced from the synthetical experiments in the sixth section, compared with the analytical ones. But as in the synthetical experiment, when the acid became green, it was impossible to ascertain the quantity of nitrous gas that passed through it unabsorbed, and as in the analysis the quantity of nitrous gas dissolved by the water at different periods of the experiment could not be ascertained, the accounts of the composition of the green acids must be considered only as very imperfect approximations to truth.

TABLE I.

Containing Approximations to the quantities of NITRIC ACID, NITROUS GAS, and WATER in NITROUS ACIDS, of different colors and specific gravities.

100 Parts	Specific gra.	Nitric Acid	Water	Nitrous gas.
Sol. Nitric Acid	1,504	91,55	8,45	---
Yellow Nitrous ‡	1,502	90,5	8,3	1,2
Bright Yellow of	1,500	88,94	8,10	2,96
Dark Orange	1,480	86,84	7,6	5,56
Light Olive ‡	1,479	86,00	7,55	6,45
Dark Olive ‡	1,478	85,4	7,5	7,1
Bright Green ‡	1,476	84,8	7,44	7,76
Blue Green*	1,475	84,6	7,4	8,00

* The blue green acid is not homogeneal in its composition, it is composed of the blue green spherules and the bright green acid. The blue green spherules are of greater specific gravity than the dark green acid, probably because they contain little or no water.

‡ The composition of the acids thus marked, is given from calculations.

TABLE II.

*Binary Proportions of OXYGENE and NITROGENE
in NITRIC and NITROUS ACIDS.**

100 Parts.		Oxy- gene	Nitro- gene	Unity.	Nitro- gene	Oxy- gene
Nitric Acid	contain	70,50	29,50	Proportions. Nitro- gene.	1	2,389
Bright yellow Nitrous		70,10	29,90		1	2,344
Orange coloured		69,63	30,37		1	2,292
Dark Green		69,08	30,92		1	2,230

XI. I have before mentioned that dilute nitric acids are incapable of dissolving so much nitrous gas in proportion to their quantities of true acid, as concentrated ones. During their absorption of it, they go through similar changes of color; 330 grains of nitric acid, of specific gravity 1,36, after 50 cubic inches of gas had been passed through it, became blue green, and

* Nitrous gas contains 44,05 Nitrogene, and 55,95 Oxygene, as has been said before.

of specific gravity 1,351. It had gained in weight but 3 grains; and when the nitrous gas was driven from it by heat into a water apparatus, but 7 cubic inches were collected.*

From the diminution of specific gravity of nitric acid by combination with nitrous gas, and from the smaller attraction of nitric acid for nitrous gas, in proportion as it is diluted, it is probable that the nitrated acids, in their combinations with water, do not contract so much as † nitric acids of the same specific gravities. The affinities resulting from the small attraction of nitrous gas for water, and its greater attraction for nitric acid, must be such as to lessen the affinity of nitric acid and water for each other.

Hence it would require an infinite number of experiments to ascertain the real quantities of acid, nitrous gas, and water, contained in the

* A great portion of it, of course, dissolved in the water with the nitrous acid carried over.

† Their changes of volume, corresponding to changes of temperature, most probably, are likewise different.

different diluted nitrous acids; and after these quantities were determined, they would probably have no important connection with the chemical arrangement. As yet, our instruments of experiment are not sufficiently exact to afford us the means of ascertaining the ratio in which the attraction of nitric acid* for water diminishes in its progress towards saturation.

The estimations in the following table, of the real quantities of nitric acid in solutions of different specific gravities, were deduced from experiments made in the manner described in section VI, except that the phial employed was longer, narrower, and graduated to half grains. The temperature, at the time of combination, was from 40° to 46°.

* Probably in the ratio of the square of the quantity of water united to it.

TABLE III.

*Of the Quantities of True NITRIC ACID in solutions
of different SPECIFIC GRAVITIES.*

100 Parts Nitric Acid of specific gravity		True Acid*	Water
1,5040	contain	91,55	8,45
1,4475		80,39	19,61
1,4285		71,65	28,35
1,3906		62,96	37,04
1,3551		56,88	43,12
1,3186		52,03	47,97
1,3042		49,04	50,96
1,2831		46,03	53,97
1,2090		45,27	54,73

* The quantities of Oxygen and Nitrogen in any solution, may be thus found — Let A = the true acid, X the oxygen, and Y the nitrogen,

$$\text{Then } X = \frac{238 A}{239} \text{ and } Y = \frac{A}{239}$$

XII. The blue green spherules mentioned in section V. produced by the condensation of nitrous vapor, and by the combination of nitric acid with nitrous gas, may be considered as saturated solutions of nitrous gas in nitric acid. The combinations of nitric acid and nitrous gas containing a larger proportion of nitrous gas, are incapable of existing in the fluid state at common temperatures; and, as appears from the first experiment, an increase of volume take place during their formation. They consequently ought to be looked upon as solutions of nitric acid in nitrous gas, identical with the nitrous vapor of Priestley.

From the researches of this great discoverer, we learn that nitrous vapor is decomposable, both by water and mercury. Hence it is almost impossible accurately to ascertain its composition. In one of his experiments, † when more than 130 grains of strong nitrous acid were exposed

† Experiments and Observations; last edition, vol. 1, page 384.

for two days to nearly 247 cubic inches of nitrous gas, over water: about half of the acid was dissolved, and deposited with the gas in the water. §

XIII. In comparing the results of my fundamental experiment on the composition of nitrous acid, with those of Cavendish, the great coincidence between them gave me very high satisfaction, as affording additional proofs of accuracy. If the acid formed in the last experiment of this illustrious philosopher be supposed analogous to the light green acid formed in my first experiment, our estimations will be almost identical.

Lavoisier's account of the composition of the nitric and nitrous acids, has been generally adopted. According to his estimation, these substances contain a much larger quantity of oxygene than I have assigned to them.

§ Nitrous gas, holding in solution nitrous acid, is more readily absorbed by water than when in its pure form, from being presented to it in a more condensed state in the green acid, formed by the contact of water and nitrous vapor.

The fundamental experiments of this great philosopher were made at an early period of pneumatic chemistry,* on the decomposition of nitre by charcoal; and he considered the nitrogene evolved, and the oxygene of the carbonic acid produced in this process, as the component parts of the nitric acid contained in the nitre.

I have before mentioned the liberation of nitrous acid, in the decomposition of nitre by combustible bodies; and I had reasons for suspecting that this circumstance was not the only source of inaccuracy.

That my suspicions were well founded, will appear from the following experiments:

EXPERIMENT a. I introduced into a strong glass tube, 3 inches long, and nearly 3 wide, a mixture of 10 grains of pulverised, well burnt charcoal, and 60 grains of nitre. It was fired by means of touch-paper, and the tube instantly plunged under a jar filled with

* Mem. des Savans Etrangers, v. xi. 226. Vide Kirwan sur le phlogistique pag. 110.

dry mercury. A quantity of gas, clouded with dense white vapor was collected. When this vapor was precipitated, so that the surface of the mercury could be seen, it appeared white, as if acted on by nitrous acid. On introducing a little oxygen into the jar, copious red fumes appeared.

EXP. *b.* A similar mixture was fired* under the jar, the top of the mercury being covered with a small quantity of red cabbage juice, rendered green by an alkali. This juice, examined when the vapor was precipitated, was become red, and on introducing to it a little carbonate of potash, a slight effervescence took place.

EXP. *c.* Five grains of charcoal, and 20 of nitre, were now fired in the same manner as before, the mercury being covered with a stratum of water. After the precipitation of the vapor

* In this experiment, as well as in the last, some of the mixture was thrown into the jar undecomposed.

on the introduction of oxygene, no red fumes were perceived.

EXP. *d.* 30 grains of nitre, 5 of charcoal, and five of filicious earth,* were now mingled and fired. The gas received under mercury was composed of 18 carbonic acid, and nearly 12 nitrogene.† A little muriatic acid was poured on the residuum in the tube; a slight effervescence took place.

EXP. *e.* The top of the mercury in the jar was now covered with a little diluted muriatic acid, and a small glass tube filled with a mixture of 3 grains of charcoal, and 20 nitre. After the deflagration, the tube itself with the residuum it contained, were thrown into the jar. The carbonic acid was quickly detached from them by the muriatic acid, and the whole quan-

* To detach the potash from the carbonic acid.

† This nitrogene contained a little nitrous gas, as it gave red fumes when exposed to the air. The free nitrous acid was decomposed by the mercury, as it was not covered with water.

tity of gas generated in the process, obtained ; it measured 15 cubic inches.

4 cubic inches of it exposed to solution of potash, diminished to $1\frac{4}{10}$; 7 of the remainder, with 8 of oxygene, gave only 12.

EXP. *f.* 60 grains of nitre, and 9 of charcoal were fired, the top of the mercury in the jar being covered with water. After the deflagration, the tube that had contained them was introduced, and the carbonic acid contained by the carbonate of potash, disengaged by muriatic acid. 30 measures of the gases evolved were exposed to caustic potash ; 20 exactly were absorbed, the 10 remaining, with 10 of oxygene, diminished to 17.

EXP. *g.* A mixture of nitre and charcoal were deflagrated over a little water in the mercurial jar : after the precipitation of the vapor, the water was absorbed by filtrating paper. This filtrating paper, heated in a solution of potash, gave a faint smell of ammoniac.

EXP. *h.* Water impregnated with the vapor produced in the deflagration, was heated

with quicklime, and presented separately to three persons accustomed to chemical odors. Two of them instantly recognised the ammoniacal smell, the other could not ascertain it. Paper reddened with cabbage juice was quickly turned green by the vapor.

These experiments are sufficient to shew that the decomposition of nitre by charcoal is a very complex process, and that the intense degree of heat produced may effect changes in the substances employed, which we are unable to estimate.

The products, instead of being simply carbonic acid, and nitrogene, are carbonic acid, nitrogene, nitrous acid, probably ammonia, and sometimes nitrous gas. The nitrous acid is disengaged from the base by the intense heat. Concerning the formation of the ammonia, it is useless to reason till we have obtained unequivocal testimonies of its existence; it may be produced either by the decomposition of the water contained in the nitre, by the combination of its oxygene with the charcoal, and of its nascent hydrogen with the nitrogene of

the nitric acid ; or from some unknown decomposition of the potash.

As neither Lavoisier nor Berthollet found nitrous gas produced in the decomposition of nitre by charcoal, when a water apparatus was employed ; and as it was not uniformly evolved in my experiments, the most probable supposition is, that it arises from the decomposition of a portion of the free nitrous acid intensely heated, by the mercury.

In none of my experiments was the whole of the nitre and charcoal decomposed, some of it was uniformly thrown with the gases into the mercurial apparatus. The nitrogen evolved, as far as I could ascertain by the common tests, was mingled with no inflammable gas.

If we consider experiment *f* as accurate, with regard to the relative quantities of carbonic acid and nitrogen produced, they are to each other nearly as 20 to 8 ; that is, allowing 2 for the nitrous gas, and consequently, reasoning in the same manner as Lavoisier, concerning the composition of nitric acid, it should be composed



of 1 nitrogene to 3,38 oxygene. But though the quantity of oxygene in this estimation is far short of that given in his, yet still it is too much. From whatever source the errors arise, whether from the evolution of phlogisticated nitrous acid, or the decomposition of water, or the production of nitrous gas, they all tend to increase the proportion of the carbonic acid to the nitrogene.

I am unacquainted with any experiment from which accurate opinions concerning the different relative proportions of oxygene and nitrogene in the nitric and nitrous acids could be deduced. Lavoisier's calculation is founded on his fundamental experiment, and on the combination of nitrous gas and oxygene.

Dr. Priestley's experiment mentioned in section 12, on the absorption of nitrous gas by nitrous acid, from which Kirwan* deduces the composition of the differently colored nitrous acids, was made over water, by which, as is

* Essay on phlogiston.

evident from a minute examination of the facts†, the greater portion of the nitrous gas employed was absorbed.

XIV. The opinions heretofore adopted respecting the quantities of real or true acid in solutions of nitrous acid of different specific gravities, have been founded on experiments made on the nitro-neutral salts, the most accu-

† Dr. Priestley says, " Having filled a phial containing exactly the quantity of four pennyweights of water, with strong, pale, yellow spirit of nitre, with its mouth quite close to the top of a large receiver standing in water, I carefully drew out almost all the common air, and then filled it with nitrous air; and as this was absorbed, I kept putting in more and more, till in less than two days it had completely absorbed 130 ounce measures. Presently after this process began, the surface of the acid assumed a deep orange color, and when 20 or 30 ounce measures of air were absorbed, it became green at the top: this green descended lower and lower, till it reached the bottom of the phial. Towards the end of the process, the evaporation was perceived to be very great, and when I took it out, the quantity was found to have diminished to one half. Also it had become, by means of this process, and the evaporation together, exceeding weak, and was rather blue than green."

Experiments and Observations, vol. 1, p. 384. Last edition,

rate of which are those of Kirwan, Bergman, and Wenzel. The great difference in the results of these celebrated men, proves the difficulty of the investigation, and the existence of sources of error.* Kirwan deduces the composition of the solutions of nitrous acid in water, from an experiment on the formation of nitrated soda. In this experiment, 36,05 grains of soda were saturated by 145 grains of nitrous acid, of specific gravity 1,2754. By a test experiment, he found the quantity of salt formed to be 85,142 grains.† Hence he concludes that 100 parts of nitrous acid, of specific gravity 1,5543, contain 73,54 of the strongest, or most concentrated acid.

Supposing his estimation perfectly true, 100 parts of the æriform acid of 55° would be composed of 74,54 of his real acid, and 25,46 water. In examining, however, one of his later

* See Mr. Keir's excellent observations on this subject. Chem. Dict. Art. Acid.

† Irish Transactions, vol. 4, p. 34.

experiments,* we shall find reasons for concluding, that the acid in nitrated soda cannot contain much less water than the æriform acid. A solution of carbonated soda, containing 125 grains of real alkali, was saturated by 306,2 grains of nitrous acid, of specific gravity 1,416. The evaporation was carried on in a temperature not exceeding 120°, and the residuum exposed to a heat of 400° for six hours, at the end of which time it weighed 308 grains. Now according to my estimation, 306 grains of nitric acid, of 1,416, should contain 215 true acid; and we can hardly suppose, but that during the evaporation and consequent long exposure to heat, some of the nitrated soda was lost with the water.

Bergman estimates the quantity of water in this salt at 25, and the acid at 43 per cent; but his real acid was not so concentrated as Kirwan's, consequently the nitric acid in nitrated soda should contain more water than my true acid.

* Addit. Obs. pag. 74.

Wenzel, from an experiment on the composition of nitrated soda, concludes that it contains 37,48 of alkali, and 62,52 of nitrous acid; and 1000 of this acid, from Kirwan's calculation, contain 812,6 of his real acid; consequently, 100 parts of my aëriform acid should contain 93,28 of Wenzel's acid, and 6,72 of water.

I saturated with potash 54 grains of solution of nitric acid, of specific gravity 1,301. Evaporated at about 212°, it produced 66 grains of nitre. This nitre exposed to a higher temperature, and kept in fusion for some time, was reduced to 60 grains.

Now from the table, 54 of 1,301, should contain 26,5 of true acid. But according to Kirwan's estimation, 100 parts of dry nitre contain 44* of his real acid, with 4 water; consequently 60 should contain 26,4.

Again, 90 grains of acid, of specific gravity 1,504, saturated with potash, and treated in

* Additional Observations, page 70.

the same manner, gave 173 grains of dry nitre. Consequently, 100 parts of it should contain 47,3 grains of true acid.

Now Lavoisier † allows about 51 of dry acid to 100 grains of nitre, and Wenzel 52.

From Berthollet's ‡ experiments, 100 grains of nitre, in their decomposition by heat, give out nearly 49 grains of gas. §

Hence it appears that the aëriform acid, that is, the true acid of my table, contains rather less water than the acid supposed to exist in nitre.

† Elements, pag. 103, Kerr's Translation.

‡ Mem. Acad. 1787.

§ As well as oxygene and nitrogene, Mr. Watt's experiments prove that much phlogificated nitrous acid is produced.

DIVISION II.

EXPERIMENTS and OBSERVATIONS on the composition of AMMONIAC and on its combinations with WATER and NITRIC ACID.

I. Analysis of AMMONIAC or VOLATILE ALKALI.

THE formation and decomposition of volatile alkali in many processes, was observed by Priestley, Scheele, Bergman, Kirwan, and Higgins; but to Berthollet we owe the discovery of its constituent parts, and their proportions to each other. These proportions this excellent philosopher deduced from an experiment on the decomposition of æriform ammoniac by the electric spark :* a process in which no apparent source of error exists.

* *Journal de Physique.* 1786. Tom. 2, pag. 176.

Since, however, his estimations have been made, the proportions of oxygene and hydrogen in water have been more accurately determined. This circumstance, as well as the conviction of the impossibility of too minutely scrutinizing facts, fundamental to a great mass of reasoning, induced me to make the following experiments.

A porcelain tube was provided, open at both ends, and well glazed inside and outside, its diameter being about .5 inches. To one end of this, a glass tube was affixed, curved for the purpose of communicating with the water apparatus. With the other end a glass retort was accurately connected, containing a mixture of perfectly caustic slacked lime, and muriate of ammoniac.

The water in the apparatus for receiving the gases had been previously boiled, to expel the air it might contain, and during the experiment was yet warm.

When the tube had been reddened in a furnace adapted to the purpose, the flame of a

spirit lamp was applied to the bottom of the retort. A great quantity of gas was collected in the water apparatus; of this the first portions were rejected, and the last transferred to the mercurial trough.

A small quantity examined, did not at all diminish with nitrous gas, and burnt with a lambent white flame, in contact with common air.

$2\frac{3}{4}$ of this gas, equal to 110 grain measures, were fired with 2, equal to 80, of oxygene, in a detonating tube, by the electric spark. They were reduced to $2\frac{1}{4}$, or 90. On introducing to the remainder a solution of strontian, it became slightly clouded on the top, and an absorption of some grain measures took place.

It was evident, then, that in this experiment, charcoal * had been somehow present in the

* Though the tube had never been used, and was apparently clean and dry on the inside, it must have contained something in the form of dust, capable of furnishing either hydro-carbonate, or charcoal.

tube; which being dissolved by the nascent hydrogen, had rendered it slightly carbonated, and in consequence made the results inconclusive.

A tube of thick green glass carefully made clean, was now employed, inclosed in the porcelain tube. Every other precaution was taken to prevent the existence of sources of error, and the experiment conducted as before.

140 grain measures of the gas produced, fired with 120 of oxygen, left, in two experiments, nearly 110. Solution of strontian placed in contact with the residuum, did not become clouded, and no absorption was perceived.

Now 150 measures of gas were destroyed, and if we take Lavoisier's and Meusnier's estimation of the composition of water, and suppose the weight of oxygen to be 35 grains, and that of hydrogen 2,6 the hundred cubic inches; the oxygen employed will be to the hydrogen as 243 to 576. Put x for the oxygen, and y for the hydrogen.

$$\text{Then } x + y = 150$$

$$x : y :: 243 : 576$$

$$x = \frac{243 y}{576}$$

$$819 y = 86400$$

$$y = 105 \quad x = 45$$

$$\text{And } 140 - 105 = 35$$

Consequently, the nitrogene in ammoniac is to the hydrogene as 35 : 105 in volume ; and 13,3 grains of ammoniac are composed of 10,6 nitrogene, (supposing that 100 cubic inches weigh 30,45 grains) and 2,7 hydrogene.

According to Berthollet, the weight of the nitrogene in ammoniac is to that of the hydrogene as 121 to 29.* The difference between this estimation and mine is so small as to be almost unworthy of notice, and arises most probably from the slight difference between the accounts of Lavoisier and Monge, of the composition of water, and the different weights assigned to the gases employed.

* Journal de Physique, 1786, t. 2, 177.

We may then conclude, that 100 grains of ammoniac are composed of about 80 nitrogene, and 20 hydrogene.

The decomposition of ammoniac by heat, as well as by the electric spark, was first discovered by Priestley. In an experiment* when aëriform ammoniac was sent through a heated tube from a caustic solution of ammoniac in water, this great discoverer observed that an inflammable gas was produced, though in no great quantity, and that a fluid blackened by matter, probably carbonaceous, likewise came over.

In my experiments the whole of the ammoniac appeared to be decomposed; the quantity of gas generated was immense, and not clouded, as is usually the case with gases generated at high temperatures. It is possible, that the larger quantity of water carried over in his experiment, by its strong attraction for ammoniac in the aëriform state, might have, in some measure, retarded the decomposition. It is how-

* Phil. Transf. vol. 79, page 294.

ever, more probable to suppose, that a fissure existed in the earthen tube he employed, through which a certain quantity of gas escaped, and coaly matter entered.

Priestley found that the metallic oxides when strongly heated, decomposed ammoniac, the metal being revived and water and nitrogene produced.* The estimations of the composition of ammoniac that may be deduced from his experiments on the oxide of lead, differ very little from those already detailed.

II. *Specific gravity of Ammoniac.*

From the great solubility of ammoniac in water, it is difficult to ascertain its specific gravity in the same manner as that of a gas combinable to no great extent with that fluid. It is impossible to prevent the existence of a

to communicate with the airholder, the curved tube containing a small quantity of water. The gas was slowly passed into the fluid, and the globules wholly absorbed before they reached the top; much increase of temperature being consequent. When the absorption was complete, the phial was increased in weight exactly 9 grains.

This experiment was repeated three times. The difference of weight, which was probably connected with alterations of temperature and pressure, never amounted to more than one sixth of a grain.

We may then conclude, that at temperature 58° , and atmospheric pressure 29,6, 100 cubic inches of ammoniac weigh 18 grains.

According to Kirwan, 100 cubic inches of alkaline air * weigh 18,16 grains; barometer 30, thermometer 61. The difference between these estimations, the corrections for temperature and pressure being made, is trifling.

* Additional Observations, page 107.

small quantity of solution of ammoniac in the mercurial airholder, † or apparatus containing the gas; and during the diminution of the pressure of the atmosphere on this solution, ‡ a certain quantity of gas is liberated from it, and hence a source of error.

To ascertain, then, the weight of ammoniac, I employed an apparatus similar to that used for the absorption of nitrous gas by nitric acid.

50 cubic inches of gas were collected in the mercurial airholder, from the decomposition of muriate of ammoniac by lime; thermometer being 58°, and barometer 29,6.

100 grains of diluted sulphuric acid were introduced into the small graduated cylinder, which after being carefully weighed, was made

† Ammoniac generated at a temperature above that of the atmosphere, always deposits ammoniacal solution during its reduction to the common temperature.

‡ By the introduction of æriform ammoniac into the exhausted globe.

III. *Of the quantities of true Ammoniac in Aqueous Ammoniacal Solutions, of different specific gravities.*

To ascertain the quantities of ammoniac, such as exists in the aëriform state, saturated with moisture, in solutions of different specific gravities, I employed the apparatus for absorption so often mentioned. Thermometer being 52°, the mercurial airholder was filled with ammoniacal gas, and the graduated phial, containing 50 grains of pure water, connected with it. During the absorption of the gas, the phial became warm. When about 30 cubic inches had been passed through, it was suffered to cool, and weighed: it had gained 5,25 grains, and the fluid filled a space equal to that occupied by 57* grains of water.

* It is necessary in these experiments, that the greatest care be observed in the introduction and extraction of the capillary tube. If it is introduced dry, there will be a source of error from the moisture adhering to it when taken out. I therefore always wetted it before its introduction, and took care that no more fluid adhered to it after the experiment, than before.

Consequently, 100 grains of solution of ammoniac in water of specific gravity ,9684 contain 9,502 grains of ammoniac.

The apparatus being adjusted as before, 50 grains of pure water were now perfectly saturated with ammoniac. They gained in weight 17 grains, and when perfectly cool, filled a space equal to 74 of water. Consequently 100 grains of aqueous ammoniac solution of specific gravity ,9054 contain 25,37 grains of ammoniac.

The two solutions were mingled together; but no alteration of temperature took place. Consequently the resulting specific gravity might have been found by calculation.

On mingling a large quantity of caustic solution of ammoniac with $\frac{1}{4}$ of its weight of water, of exactly the same temperature, no alteration of it was perceptible by a sensible thermometer.— Hence the two experiments* being assumed as

* Previous to those experiments, I had made a number of others on the combination of ammoniac with water.— My design was, to ascertain the diminution of specific

data, the intermediate estimations in the following table, were found by calculation.

gravity for every three grains of ammoniac absorbed; but this I found impossible. The capillary tube, when taken out of the phial, always carried with it a minute portion of the solution, which partially evaporated before it could be again introduced; and thus the sources of error increased in proportion to the number of examinations.

Time	Weight	Gravity
1.00	1.00	1.00
1.30	1.05	1.05
2.00	1.10	1.10
2.30	1.15	1.15
3.00	1.20	1.20
3.30	1.25	1.25
4.00	1.30	1.30
4.30	1.35	1.35
5.00	1.40	1.40
5.30	1.45	1.45
6.00	1.50	1.50
6.30	1.55	1.55
7.00	1.60	1.60
7.30	1.65	1.65
8.00	1.70	1.70
8.30	1.75	1.75
9.00	1.80	1.80
9.30	1.85	1.85
10.00	1.90	1.90
10.30	1.95	1.95
11.00	2.00	2.00
11.30	2.05	2.05
12.00	2.10	2.10

TABLE IV.

Of approximations to the quantities of AMMONIAC, such as exists in the aëriform state, saturated with water at 52°, in AQUEOUS AMMONIACAL SOLUTIONS of different specific gravities.

100 Specific gra.		Ammoniac	Water.
9054	contain	25,37	74,63
9166		22,07	77,93
9255		19,54	80,46
9326		17,52	82,48
9385		5,88	84,12
9435		14,53	85,47
9476		13,46	86,54
9513		12,40	87,60
9545		11,56	88,44
9573		10,82	89,18
9597		10,17	89,83
9619		9,60	90,40
9684		9,50	90,5
9639		9,09	90,91
9713		7,17	92,83

* As yet no mode has been discovered for obtaining gases in a state of absolute dryness; consequently we are ignorant of the different quantities of water they hold in solution at different temperatures. As far as we are acquainted with the combinations of ammoniac, there is no state in which it exists so free from moisture, as when aëriform, at low temperatures.

That no considerable source of error existed in the two experiments, is evident from the trifling difference between the estimations of the quantities of real ammoniac, in the solution of ,9684, as found in the first experiment, and as given by calculation from the last.

The quantity of ammoniac in a solution of specific gravity not in the table, may be thus determined—Find the difference between the two specific gravities nearest to it in the table; d , and the difference between their quantities of alkali, b ; likewise the difference between the given specific gravity and that nearest to it, c .

then $d : b :: c : x$ and $x = \frac{b c}{d}$

Which, added to the quantity of the lower specific gravity, is the alkali sought.

The differences in specific gravity of the solutions of ammoniac at temperatures between 40° and 65° * are so trifling as to be hardly

* The expansion from increase of temperature is probably great in proportion to the quantity of ammoniac in the solution.

ascertainable, by our imperfect instruments, and consequently are unworthy of notice.

It is possible at very low temperatures to obtain ammoniacal solutions of less specific gravity than ,9, but they are incapable of being kept for any length of time under the common pressure of the atmosphere.

IV. *Combinations of Ammoniac with Nitric Acid. Composition of Nitrate of Ammoniac, &c.*

200 grains of ammoniacal solution, of specific gravity ,9056, were saturated by 385,5 grains of nitric acid, of specific gravity 1,306. The combination was effected in a long phial, the nitrous acid added very slowly, and the phial closed after every addition, to prevent any evaporation in consequence of the great increase of temperature.† The specific gravity of the solution, when reduced to the common temperature, was 1,15. Evaporated at a heat of

† From the combination.

212°, † it gave 254 grains of salt of fibrous crystallization. This salt was dissolved in 331 grains of water; the specific gravity of the solution was 1,148 nearly.

Hence it was evident that some of the salt had been lost during the evaporation.

To find the quantity lost, fibrous nitrate of ammoniac was dissolved in small quantities in the solution, the specific gravity of which was examined after every addition of 3 grains. When 16 grains had been added to it, it became of 1,15.

Consequently, the solution composed of 200 grains of ammoniacal, and of 385,5 of nitric acid solution, contained 262 grains of salt of fibrous crystallization, and of this salt 8 grains were lost during the evaporation.

But the alkali in 200 grains of ammoniacal solution of ,9056 = 50,5 grains. And the true nitric acid in 385,5 grains of solution of 1,306 = 190 grains.

† I had before proved that at this temperature the salt neither decomposed nor sublimed.

Then $262 - 240,5 = 21,5$, the quantity of water.

And 262 grains of fibrous crytalized nitrate of ammoniac, contain 190 grains true acid, 50,5 ammoniac, and 21,5 water. And 100 parts contain 72,5 acid, 19,3 ammoniac, and 8,2 water.

In proportion as the temperature employed for the evaporation of nitro-ammoniacal solutions, is above or below 212° , so in proportion does the salt produced contain more or less water than the fibrous nitrate. But whatever may have been the temperature of evaporation, the acid and alkali appear always to be in the same proportions to each other.

Of the salts containing different quantities of water, two varieties must be particularly noticed. The prismatic nitrate of ammoniac, produced at the common temperatures of the atmosphere, and containing its full quantity of water of crytallisation; and the compact nitrate of ammoniac, either amorphous, or composed of delicately needled crytals, formed at 300° , and containing

but little more water than exists in nitric acid and ammoniac.

To discover the composition of the prismatic nitrate of ammoniac, 200 grains of fibrous salt were dissolved in the smallest possible quantity of water, and evaporated in a temperature not exceeding 70°. The greater part of the salt was composed of perfectly formed tetrahædral prisms, terminated by tetrahædral pyramids. It had gained in weight about 8,5 grains.

Consequently 100 grains of prismatic nitrate of ammoniac may be supposed to contain 69,5 acid, 18,4 ammoniac, and 12,1 water.

To ascertain the composition of the compact nitrate of ammoniac, I exposed in a deep porcelain cup, 400 grains of the fibrous salt, in a temperature below 300°. It quickly became fluid, and slowly gave out its water without any ebullition, or liberation of gas. When it was become perfectly dry, it had lost 33 grains. I suspected, that in this experiment some of the salt had been carried off with the water; to determine this, I introduced into a small glass

retort, 460 grains of fibrous salt; it was kept at a heat below 320° , in communication with a mercurial apparatus, in a regulated air-furnace, till it was perfectly dry: it had lost 23 grains. No gas, except the common air of the retort came over, and the fluid collected had but a faint taste of nitrate of ammoniac.

Though in this experiment I had removed all the fluid retained in the neck of the retort, still a few drops remained in the head, and on the sides, which I could not obtain. It was of importance to me to be accurately acquainted with the composition of the compact salt, and for that reason I compared these analytical experiments with a synthetical one.

I saturated 200 grains of solution of ammoniac, of .9056 with acid, ascertained the specific gravity of the solution, evaporated it at 212° , and fused and dried it at about 300° — 260° . It gave 246 grains of salt, and a solution made of the same specific gravity as that evaporated, indicated a loss of 9 grains. Consequently, 255 grains of this salt contain 50.5

grains alkali, 190 grains acid, and 14,5 grains water.

We may then conclude, that 100 parts of compact nitrate of ammoniac contain 74,5 acid, 19,8 alkali, and 5,7 water.

V. *Decomposition of Carbonate of Ammoniac by Nitric Acid.*

In my first experiments on the production of nitrate of ammoniac, I endeavoured to ascertain its composition by decomposing carbonate of ammoniac by nitric acid; and in making for this purpose, the analysis of carbonate of ammoniac, I discovered that there existed many varieties of this salt, containing very different proportions of carbonic acid, alkali, and water; the carbonic acid and water being superabundant in it, in proportion as the temperature of its formation was low, and the alkali in proportion as it was high: and not only that a different salt was formed at every different temperature, but likewise that the difference in

them was so great, that the carbonate of ammoniac formed at 300° contained more than 50 per cent alkali, whilst that produced at 60° contained only 20.*

I found 210 grains of carbonate of ammoniac, which from comparison with other salts previously analysed, I suspected to contain about 20 or 21 per cent alkali, saturated by 200 grains of nitric acid of 1,504. But though the carbonate was dissolved in much water, still, from the smell of the carbonic acid generated, I suspect that a small portion of the nitric acid was dissolved, and carried off by it. The solution, evaporated at about 200°, and afterwards exposed to a temperature below 300°, gave 232 grains of compact salt. But reasoning from the quantity of acid in 200 grains of nitric acid of 1,504, it ought to have given 245. Consequently 13 were lost by

* A particular account of the experiments from which these facts were deduced, was printed in September, and will appear in the first volume of the *Recherches*.

evaporation ; and this loss agrees with that in the other experiments.

V. *Decomposition of Sulphate of Ammoniac by Nitre.*

As a cheap mode of obtaining nitrate of ammoniac, Dr. BEDDOES proposed to decompose nitre by sulphate of ammoniac, which is a well known article of commerce. From synthesis of sulphate of ammoniac, compared with analysis made in August 1799,* I concluded that 100 grains of prismatic salt were composed of about 18 grains ammoniac, 44 acid, and 38 water ; and supposing 100 grains of nitre to contain 50 acid, 100 grains of sulphate of ammoniac will require for their decomposition 134 grains of nitre, and form 90,9 grains of compact nitrate of ammoniac.

* And which will be published, with an account of its perfect decomposition at a high temperature, in the *Researches*.

To ascertain if the sulphate of potash and nitrate of ammoniac could be easily separated, I added to a heated saturated solution of sulphate of ammoniac, pulverised nitre, till the decomposition was complete. After this decomposition, the solution contained a slight excess of sulphuric acid, which was combined with lime, and the whole set to evaporate at a temperature below 250°. As soon as the sulphate of potash began to crystallise, the solution was suffered to cool, and then poured off from the crystallised salt, which appeared to contain no nitrate of ammoniac. After a second evaporation and crystallisation, almost the whole of the sulphate appeared to be deposited, and the solution of nitrate of ammoniac was obtained nearly pure: it was evaporated at 212°, and gave fibrous crystals.

VI. *Non-existence of Ammoniacal Nitrites.*

I attempted in different modes to combine *nitrous* acids with ammoniac, so as to form the salts which have been supposed to exist, and

called *nitrites* of ammoniac ; but without success.

I first decomposed a solution of carbonate of ammoniac by dilute olive colored acid ; but in this process, though no heat was generated, yet all the nitrous gas appeared to be liberated with the carbonic acid.* I then combined a small quantity of nitrous gas, with a solution of nitrate of ammoniac. But after evaporating this solution at 70° — 80° , I could not detect the existence of nitrous gas in the solid salt ; it was given out during the evaporation and crystallisation, and formed into nitrous acid by the oxygen of the atmosphere. I likewise heated nitrate of ammoniac to different degrees, and partially decomposed it, to ascertain if in any case the acid was phlogisticated by heat : but in no experiment could I detect the existence

* When nitrous gas exists in neutro-saline solutions, they are always colored more or less intensely, from yellow to olive, in proportion to the quantity combined with them.

of *nitrous acid* in the heated salt, when it had been previously perfectly neutralised.

When nitrate of ammoniac, indeed, with excess of nitric acid, is exposed to heat, the superabundant nitric acid becomes phlogisticated, and is then liberated from the salt, which remains neutral.*

We may therefore conclude that nitrous gas has little or no affinity for solid nitrate of ammoniac, and that no substance exists to which the name *nitrite* of ammoniac can with propriety be applied.

VII. *Of the sources of error in Analysis.*

To compare my synthesis of nitrate of ammoniac with analysis, I endeavoured to separate the ammoniac and nitric acid from each other, without decomposition. But in going through the analytical process, I soon discovered that

* Hence a nitrate of ammoniac with excess of acid, when exposed to heat, first becomes yellow, and then white.

it was impossible to make it accurate, without many collateral laborious experiments on the quantities of ammoniac soluble in water at different temperatures.

At a temperature above 212° , I decomposed; by caustic slacked lime, 50 grains of compact nitrate of ammoniac in a retort communicating with the mercurial airholder, the moisture in which had been previously saturated with ammoniac. 22 cubic inches of gas were collected at 38° , and from the loss of weight of the retort, it appeared that 13 grains of solution of ammoniac in water, had been deposited by the gas.

Now evidently, this solution must have contained much more alkali in proportion to its water than that of 55° , otherwise the quantity of ammoniac in 50 grains of salt would hardly equal 8 grains.*

* The accounts given by different chemists of the composition of nitrate of ammoniac, are extremely discordant; they have been chiefly deduced from decompositions of carbonate of ammoniac (the varieties of which have been

VIII. *Of the loss of Solutions of Nitrate of Ammoniac during evaporation.*

The most concentrated solution of nitrate of ammoniac capable of existing at 60° , is of specific gravity 1,304, and contains 33 water, and 67 fibrous salt, per cent. When this solution is evaporated at temperatures between 60° and 100, the salt is increased in weight by the addition of water of crystallisation, and no portion of it is lost.

During the evaporation of solutions of specific gravity 1,146 and 1,15, at temperatures below 120° , I have never detected any loss of salt. When the temperature of evaporation is 212° , the loss is generally from 3 to 4 grains per cent; and when from 230° to the standard of their ebullition, from 4 to 6 grains.

heretofore unknown) by nitrous acids of unknown degrees of nitration. Hence they are particularly erroneous with regard to the alkaline part. Wenzel supposes it to be 32 per cent, and Kirwan 24. *Addit. Observ.* pag. 120.

In proportion as solutions are more diluted, their loss in evaporation at equal temperatures is greater.

DIVISION III.

Decomposition of NITRATE of AMMONIAC: preparation of RESPIRABLE NITROUS OXIDE; its ANALYSIS.

I. *Of the heat required for the decomposition of NITRATE of AMMONIAC.*

THE decomposition of nitrate of ammoniac has been supposed by Cornette* to take place at temperatures below 212° , and its sublimation at 234° .

Kirwan, from the non-coincidence in the accounts of its composition, has imagined that it is partially decomposable, even by a heat of 80° .†

To ascertain the changes effected by increase of temperature in this salt, a glass retort was provided, tubulated for the purpose of introducing

* Mem. Par. 1783. See Irish Transf. vol. 4.

† Addit. Obs. pag. 120

the bulb of a thermometer. After it had been made to communicate with the mercurial air-holder, and placed in a furnace, the heat of which could be easily regulated, the thermometer was introduced, and the retort filled with the salt, and carefully luted; so that the appearances produced by different temperatures could be accurately observed, and the products evolved obtained.

From a number of experiments made in this manner on different salts, the following conclusions were drawn.

1st. Compact, or dry nitrate of ammoniac, undergoes little or no change at temperatures below 260° .

2dly. At temperatures between 275° and 300° , it slowly sublimes, without decomposition, or without becoming fluid.

3dly. At 320° it becomes fluid, decomposes, and still slowly sublimes; it neither assumes, or continuing in, the fluid state, without decomposition.

4thly. At temperatures between 340° and 480° , it decomposes rapidly.

5thly. The prismatic and fibrous nitrates of ammoniac become fluid at temperatures below 300° , and undergo ebullition at temperatures between 360° and 400° , without decomposition.

6thly. They are capable of being heated to 430° without decomposition, or sublimation, till a certain quantity of their water is evaporated.

7thly. At temperatures above 450° they undergo decomposition, without previously losing their water of crystallisation.

II. *Decomposition of Nitrate of Ammoniac ; production of respirable Nitrous Oxide ; its properties.*

200 grains of compact nitrate of ammoniac were introduced into a glass retort, and decomposed slowly by the heat of a spirit lamp. The first portions of the gas that came over were rejected, and the last received in jars containing

mercury. No luminous appearance was perceived in the retort during the process, and almost the whole of the salt was resolved into fluid and gas. The fluid had a faint acid taste, and contained some undecomposed nitrate. The gas collected exhibited the following properties.—

a. A candle burnt in it with a brilliant flame, and crackling noise. Before its extinction, the white inner flame became surrounded with an exterior blue one.

b. Phosphorus introduced into it in a state of inflammation, burnt with infinitely greater vividness than before.

c. Sulphur introduced into it when burning with a feeble blue flame, was instantly extinguished; but when in a state of active inflammation (that is, forming sulphuric acid) it burnt with a beautiful and vivid rose-colored flame.

d. Inflamed charcoal, deprived of hydrogen, introduced into it, burnt with much greater vividness than in the atmosphere.

e. To some fine twisted iron wire a small piece of cork was affixed : this was inflamed, and the whole introduced into a jar of the air. The iron burned with great vividness, and threw out bright sparks as in oxygene.

f. 30 measures of it exposed to water previously boiled, was rapidly absorbed ; when the diminution was complete, rather more than a measure remained.

g. Pure water saturated with it, gave it out again on ebullition, and the gas thus produced retained all its former properties.

b. It was absorbed by red cabbage juice ; but no alteration of color took place.

i. Its taste was distinctly sweet, and its odor slight, but agreeable.

j. It underwent no diminution when mingled with oxygene or nitrous gas.

Such were the obvious properties of the NITROUS OXIDE, or the gas produced by the decomposition of nitrate of ammoniac in a temperature not exceeding 440°. Other proper-

ties of it will be hereafter demonstrated, and its affinities fully investigated.

III. *Of the gas remaining after the absorption of Nitrous Oxide by Water.*

In exposing nitrous oxide at different times to rain or spring water, and water that had been lately boiled, I found that the gas remaining after the absorption was always least when boiled water was employed, though from the mode of production of the nitrous oxide, I had reason to believe that its composition was generally the same.

This circumstance induced me to suppose that some of the residuum might be gas previously contained in the water, and liberated from it in consequence of the stronger affinity of that fluid for nitrous oxide. But the greater part of it, I conjectured to consist of nitrogen produced in consequence of a complete decomposition of part of the acid, by the hydrogen. It was in endeavoring to ascertain the relative

purity of nitrous oxide produced at different periods of the process of the decomposition of nitrate of ammoniac, that I discovered the true reason of the appearance of residual gas.

I decomposed some pure nitrate of ammoniac in a small glass retort; and after suffering the first portions to escape with the common air, I caught the remainder in three separate vessels standing in the same trough, filled with water that had been long boiled, and which at the time of the experiment was so warm that I could scarcely bear my hands in it. The different quantities collected gave the same intense brilliancy to the flame of a taper.

26 measures of each of them were separately inserted into 3 graduated cylinders, of nearly the same capacity, over the same boiled water. As the water cooled, the gas was absorbed by agitation. When the diminution was complete, the residuum in each cylinder filled, as nearly as possible, the same space; about two thirds of a measure.

To each of the residuums I added two mea-

tures of nitrous gas; they gave copious red vapor, and after the condensation filled a space rather less than two measures.

Hence the residual gas contained more oxygen than common air.

I now introduced 26 measures of gas from one of the vessels into a cylinder filled with unboiled spring water of the same kind.* After the absorption was complete, near two measures remained. These added to two measures of nitrous air, diminished to 2,5 nearly.

These experiments induced me to believe that the residual gas was not produced in the decomposition of nitrate of ammoniac, but that it was wholly liberated from the water.

To ascertain this point with precision, I distilled a small quantity of the same kind of water, which had been near an hour in ebullition, into a graduated cylinder containing mercury. To this I introduced about one third

* Two measures of air dispelled from this water by boiling, mingled with 2 of nitrous gas, diminished to 2,4 nearly.

of its bulk, i. e. 12 measures of nitrous oxide, which had been carefully generated in the mercurial apparatus. After the absorption, a small globule of gas only remained, which could hardly have equalled one fourth of a measure. On admitting to this globule a minute quantity of nitrous gas, an evident diminution took place.

Though this experiment proved that in proportion as the water was free from air, the residuum was less, and though there was no reason to suppose that the ebullition and distillation had freed the water from the whole of the air it had held in solution, still I considered a decisive experiment wanting to determine whether nitrous oxide was the only gas produced in the slow decomposition of nitrate of ammoniac, or whether a minute quantity of oxygene was not likewise evolved.

I received the middle part of the product of a decomposition of nitrate of ammoniac, under a cylinder filled with dry mercury, and introduced to it some strong solution of ammoniac. After the white cloud produced by the combi-

nation of the ammoniacal vapor with the nitric acid suspended in the nitrous oxide, had been completely precipitated, I introduced a small quantity of nitrous gas. No white vapor was produced.

Now if any gas combinable with nitrous gas had existed in the cylinder, the quantity of nitrous acid produced, however small, would have been rendered perceptible by the ammoniacal fumes; for when a minute globule of common air was admitted into the cylinder, white clouds were instantly perceptible.

It seems therefore reasonable to conclude,

1. That the residual gas of nitrous oxide, is air previously contained in the water, (which in no case can be perfectly freed from it by ebullition), and liberated by the stronger attraction of that fluid for nitrous oxide.

2. That nitrate of ammoniac, at temperatures below 440° , is decomposed into pure nitrous oxide, and fluid.

3. That in ascertaining the purity of nitrous oxide from its absorption by water, corrections ought to be made for the quantity of gas dif-

pelled from the water. This quantity in common water distilled under mercury being about $\frac{1}{50}$; in water simply boiled, and used when hot, about $\frac{1}{30}$; and in common spring water, $1\frac{1}{12}$.

IV. *Specific gravity of Nitrous Oxide.*

To understand accurately the changes taking place during the decomposition of nitrate of ammoniac, we must be acquainted with the specific gravity and composition of nitrous oxide.

90 cubic inches of it, containing about $\frac{1}{35}$ common air, introduced from the mercurial airholder into an exhausted globe, increased it in weight 44,75 grains; thermometer being 51° , and atmospheric pressure 30,7.

106 cubic inches, of similar composition, weighed in like manner, gave at the same temperature and pressure nearly 52,25 grains; and in another experiment, when the thermometer was 41° , 53 grains.

So that accounting for the small quantity of

common air contained in the gases weighed, we may conclude, that 100 cubic inches of pure nitrous oxide weigh 50,1 grains at temperature 50°, and atmospheric pressure 37.

I was a little surpris'd at this great specific gravity, particularly as I had expected, from Dr. Priestley's observations, to find it less heavy than atmospherical air. This philosopher suppos'd, from some appearances produced by the mixture of it with aëriform ammoniac, that it was even of less specific gravity than that gas.*

V. *Analysis of Nitrous Oxide.*

The nitrous oxide may be analysed, either by charcoal or hydrogen; during the combustion of other bodies in it, small portions of nitrous acid are generally formed, as will be fully explained hereafter.

The gas that I employed was generated from

* Experiments and Observations, vol. 2, pag. 89. Last Edition.

compact nitrate of ammoniac, and was in its highest state of purity, as it left a residuum of 38 only, when absorbed by boiled water.

10 cubic inches of it were inserted into a jar graduated to ,1 cubic inches, containing dry mercury. Through this mercury a piece of charcoal which had been deprived of its hydrogen by long exposure to heat, weighing about a grain, was introduced, while yet warm: No perceptible absorption of the gas took place.*

Thermometer being 46° , the focus of a lens was thrown on the charcoal, which instantly took fire, and burnt vividly for about a minute, the gas being increased in volume. After the vivid combustion had ceased, the focus was again thrown on the charcoal; it continued to burn for near ten minutes, when the process stopped.

The gas, when the original pressure and temperature were restored, filled a space equal to 12,5 cubic inches.

* A minute quantity, however, must have been absorbed, and given out again when the charcoal was heated.

On introducing to it a small quantity of strong solution of ammoniac*, white vapor was instantly perceived, and after a short time the reduction was to about 10,1 cubic inches; so that apparently, 2,4 cubic inches of carbonic acid had been formed. The 10,1 cubic inches of gas remaining were exposed to water which had been long in ebullition, and which was introduced whilst boiling, under mercury. After the absorption of the nitrous oxide by the water, the gas remaining was equal to 5,3.

But on combining a cubic inch of pure nitrous oxide with some of the same water, which had been received under mercury in a separate vessel, nearly $\frac{1}{22}$ remained. Consequently we may conclude, that 5,1 of a gas unabsorbable by water, was produced in the combustion.

This gas extinguished flame, gave no diminution with oxygen, and the slightest possible

* Strong solution of ammoniac has no attraction for nitrous oxide.

with nitrous gas. When, an electric spark was passed through it, mingled with oxygene; no inflammation, or *perceptible* diminution took place.† We may consequently conclude that it was nitrogene, mingled with a minute portion of common air, expelled from the water.

The charcoal was diminished in bulk to one half nearly, but the loss of weight could not be ascertained, as its pores were filled with mercury.

Now 5 cubic inches of nitrous oxide were absorbed by the water, consequently 5 were decomposed by the charcoal; and these produced 5,1 cubic inches of nitrogene; and by giving their oxygene to the charcoal, apparently 2,4 of carbonic acid.

But 5 cubic inches of nitrous oxide weigh 2,5 grains, and 5,1 cubic inches of nitrogene 1,55; then $2,5 - 1,55 = ,95$.

So that reasoning from the relative specific

† The gas was examined by those tests in order to prove that no water had been decomposed.

gravities of nitrogene and nitrous oxide, 2,5 grains of the last are composed of 1,55 nitrogene, and ,95 oxygene.

But from many experiments made on the specific gravity of carbonic acid, in August, 1799, I concluded that 100 cubic inches of it weighed 47,5 grains, thermometer being 60,1°, and barometer 29,5. Consequently, making the necessary corrections, 2,4 cubic inches of it weigh 1,14 grains; and on Lavoisier's and Guyton's * estimation of its composition, these 1,13 grains contain 8,2 of oxygene.

So that, drawing conclusions from the quantity of carbonic acid formed in this experiment, 2,5 grains of nitrous oxide will be composed of ,82 oxygene, and 1,68 nitrogene.

The difference between these estimations is considerable, and yet not more than might have been expected, if we consider the probable sources of error in the experiment.

* See the curious paper of this excellent philosopher, on the combustion of the diamond, in which he proves that charcoal is, in fact, oxide of diamond. *Annales de Chimie.* xxxi.

1. It is likely that variable minute quantities of hydrogen remain combined with charcoal, even after it has been long exposed to a red heat.

2. It is probable that the nitrogen and carbonic acid produced were capable of dissolving more water than that held in solution by the nitrous oxide; and if so, they were more condensed than if saturated with moisture, and hence the quantity of carbonic acid under-rated.

We may consequently suppose the estimation founded on the quantity of nitrogen evolved, most correct; and making a small allowance for the difference, conclude, that 100 grains of nitrous oxide are composed of about 37 oxygen, and 63 nitrogen; existing in a much more condensed state than when in their simple forms.

The tolerable accuracy of this statement will be hereafter demonstrated by a number of experiments on the combustion of different bodies in nitrous oxide, detailed in Research II.

VI. *Minute examination of the decomposition of Nitrate of Ammoniac.*

Into a retort weighing 413,75 grains, and of the capacity of 7,5 cubic inches, 100 grains of pulverised compact nitrate of ammoniac were introduced. To the neck of this retort was adapted a recipient, weighing 711 grains, tubulated for the purpose of communicating with the mercurial airholder, and of the capacity of 8,3 cubic inches.

Temperature being 50°, and atmospheric pressure 30,6, the recipient was inserted into a vessel of cold water, and made to communicate with the airholder. The heat of a spirit lamp was then slowly applied to the retort: the salt quickly began to decompose, and to liquify. The temperature was so regulated, as to keep up an equable and slow decomposition.

During this decomposition, no luminous appearance was perceived in the retort; the gas that came into the airholder was very little

clouded, and much water condensed in the receiver.

After the process was finished, the communication between the mercurial airholder and the recipient was preserved till the common temperature was restored to the retort.

The volume of the gas in the cylinder was 85,5 cubic inches. The absolute quantity of nitrous oxide in those 85,5 cubic inches, it was difficult to ascertain with great nicety, on account of the common air previously contained in the vessels.

45 measures of it, exposed to well boiled water, diminished by agitation to 8 measures. So that reasoning from the quantity of air, which should have been expelled from the water by the nitrous oxide, we may conclude that the 85,5 cubic inches were nearly pure.

The retort now weighed 419,25 grains, consequently 5,5 grains of salt remained in it. This salt was chiefly collected about the lower part of the neck, and contained rather more

water than the compact nitrate, as in some places it was crystalized.

The recipient with the fluid it contained, weighed 759 grains. It had consequently gained in weight 48 grains.

Now the 85,5 cubic inches of nitrous oxide produced, weigh about 42,5 grains; and this added to 48 and 5,5, = 96 grains; so that about 4 grains of salt and fluid were lost, probably by being carried over and deposited by the gas.*

As much of the fluid as could be taken out of the recipient, weighed 46 grains, and held in solution much nitrate of ammoniac with superabundance of acid. This acid required for its saturation, $3 \frac{1}{8}$ of carbonate of ammoniac (containing, as well as I could guess), about 20 per cent alkali.

The whole solution evaporated, gave 18 grains of compact nitrate of ammoniac. But

* This was actually the case; for on examining the conducting tube the day after the experiment, some minute crystals of prismatic nitrate of ammoniac were perceived in it.

reasoning from the quantity of carbonate of ammoniac employed, the free nitric acid was equal to 2,75 grains, and this must have formed 3,56 grains of salt. Consequently the salt pre-existing in the solution was about 14,44 grains,

But besides the fluid taken out of the recipient, 2 grains remained in it: let us suppose this, and the 4 grains lost, to contain 2 of salt, and .6 of free acid.

Then the undecomposed

Salt is	5,5	+	14,4	+	2	=	21,9
The free acid	2,75	+	,6			=	3,35
Gas	-	-	-	-			42,5
Water	-	-	-	-			32,25
							100

Now about 78,1 grains of salt were decomposed, and formed into 42.5 grains of gas, 3,35 grains acid, and 32,25 grains water.

But there is every reason to suppose, that in this process, when the hydrogen of the ammoniac combines with a portion of the oxygen of the nitric acid to form water, and the nitrogen

enters into union with the nitrogene and remaining oxygene of the nitric acid, to form nitrous oxide; that water pre-existing in nitric acid and ammoniac, such as they existed in the aëriform state, is deposited with the water produced by the new arrangement, and not wholly combined with the nitrous oxide formed. Hence it is impossible to determine with great exactitude, the quantity of water which was absolutely formed in this experiment.

78,1 grains of salt are composed of 15,4 alkali, 58 acid, and 4,7 water.

And reasoning from the different affinities of water for nitric acid, ammoniac, and nitrous oxide, it is probable that ammoniac, in its decomposition, divides its water in such a ratio, between the nitrogene furnished to the nitrous oxide, and the hydrogene entering into union with the oxygene of the nitric acid, as to enable us to assume, that the hydrogene requires for its saturation nearly the same quantity of oxygene as when in the aëriform state; or that it certainly cannot require less.

But 15,4 alkali contain 3,08 hydrogene, and 12,32 nitrogene;* and 3,08 hydrogene require 17,4 of oxygene to form 20,48 of water.

Now 32,5 grains of water existed before the experiment; 4,7 grains of water were contained by the salt decomposed, and $32,5 - 4,7 = 27,8$: and $27,8 - 20,48$, the quantity generated, $= 7,52$, the quantity existing in the nitric acid.

But the nitric acid decomposed is $58^{\circ} - 3,35 =$ to 54,7; and $54,7 - 7,5 = 47,2$, which entered into new combinations. These 47,2 consist of 33,2 oxygene, and 14, nitrogene. And $33,2 - 17,4$, the quantity employed to form the water, $= 15,8$, which combined with 14,, nitrogene of the nitric acid, and 12,32 of that of the ammoniac, to form 42,12 of nitrous oxide. And on this estimation, 100 parts of nitrous oxide would contain 37,6 oxygene, and 62,4 nitrogene; a computation much nearer the results of the analysis than could

* Owing part of their weight to an unknown quantity of water.

have been expected, particularly as so many unavoidable sources of error existed in the process.

The experiment that I have detailed is the most accurate of four, made on the same quantity of salt. The others were carried on at rather higher temperatures, in consequence of which, more water and salt were sublimed with the gas.

To Berthollet, we owe the discovery of the products evolved during the slow decomposition of nitrate of ammoniac; but as this philosopher in his examination of this process, chiefly designed to prove the existence of hydrogen in ammoniac, he did not ascertain the quantity of gas produced, or minutely examine its properties; from two of them, its absorption by water and its capability of supporting the vivid combustion of a taper, he inferred its identity with the dephlogisticated nitrous gas of Priestley, and concluded that it was nitrous gas with excess of pure air.*

* Mem. de Paris. 1783, and Journal de Physique, 1786, page 175.

VII. *Of the heat produced during the decomposition of nitrate of ammoniac.*

To ascertain whether the temperature of nitrate of ammoniac was increased or diminished after it had been raised to the point essential to its decomposition, during the evolution of nitrous oxide and water; that is, in common language, whether heat was generated or absorbed in the process; I introduced a thermometer into about 1500 grains of fibrous nitrate of ammoniac, rendered liquid in a deep porcelain cup. During the whole of the evaporation, the temperature was about 380° , the fire being carefully regulated.

As soon as the decomposition took place, the thermometer began to rise; in less than a quarter of a minute it was 410° , in two minutes it was 460° .

The cup was removed from the fire; the decomposition still went on rapidly, and for about a minute the thermometer was stationary. It

then gradually and slowly fell ; in three minutes it was 440° , in five minutes 420° , in seven minutes 405° , in nine minutes 360° , and in thirteen minutes 307° , when the decomposition had nearly ceased, and the salt began to solidify.

From this experiment, it is evident that an increase of temperature is produced by the decomposition of nitrate of ammoniac : though the capacity of water and nitrous oxide for heat, supposing the truth of the common doctrine, and reasoning from analogy, must be considerably greater than that of the salt.

VIII. *Of the decomposition of Nitrate of Ammoniac at high temperatures, and production of Nitrous gas, Nitrogene, Nitrous Acid, and Water.*

At an early period of my investigation relating to the nitrous oxide, I discovered that when a heat above 600° was applied to nitrate of ammoniac, so that a vivid luminous appearance was produced in the retort, certain portions of nitrous gas, and nitrogene, were evolved with the

nitrous oxide. But I was for some time ignorant of the precise nature of this decomposition, and doubtful with regard to the possibility of effecting it in such a manner as to prevent the production of nitrous oxide altogether.

I first attempted to decompose nitrate of ammoniac at high temperatures, by introducing it into a well coated green glass retort, having a wide neck, communicating with the pneumatic apparatus, and strongly heated in an air-furnace. But though in this process a detonation always took place, and much light was produced, yet still the greater portion of the gas generated was nitrous oxide; the nitrous gas and nitrogene never amounting to more than one third of the whole.

After breaking many retorts by explosions, without gaining any accurate results, I employed a porcelain tube, curved so as to be capable of introduction into the pneumatic apparatus, and closed at one end.

The closed end was heated red, nitrate of ammoniac introduced into it, and all the latter

portions of gas produced in the explosion, received in the pneumatic apparatus, filled with warm water.

Three explosions were required to fill a jar of the capacity of 20 cubic inches. The gas produced in the first, when it came over, was transparent and dark orange, similar in its appearance to the nitrous acid gas produced in the first experiment; but it speedily became white and clouded, whilst a slight diminution of volume took place.

When the second portion was generated and mingled with the clouded gas, it again became transparent and yellow for a short time, and then assumed the same appearance as before.

The water in the trough, after this experiment, had an acid taste, and quickly reddened cabbage juice rendered green by an alkali

6 cubic inches of the gas produced were exposed to boiled water, but little or no absorption took place. Hence, evidently, it contained no nitrous oxide.

They were then exposed to solution of sulphate of iron: the solution quickly became dark colored, and an absorption of 1,6 took place on agitation.*

The gas remaining instantly extinguished the taper, and was consequently nitrogene.

This experiment was repeated, with nearly the same results.

We may then conclude, that at high temperatures, nitrate of ammoniac is wholly resolved into water, nitrous acid, nitrous gas, and nitrogene; whilst a vivid luminous appearance is produced.

The transparency and orange color produced in the gas that had been clouded, by new portions of it, doubtless arose from the solution of the nitric acid and water forming the cloud, in the heated nitrous vapor produced, so as to constitute an aëriform triple compound; whilst the cloudiness and absorption subsequent were pro-

* The absorption of nitrous gas by sulphate of iron, &c. will be treated of in the next division.

duced by the diminished temperature, which destroyed the ternary combination, and separated the nitrous acid and water from the nitrous gas,

From the rapidity with which the deflagration of nitrate of ammoniac proceeds, and from the immense quantity of light produced, it is reasonable to suppose that a very great increase of temperature takes place. The tube in which the decomposition has been effected, is always ignited after the process.

IX. *Speculations on the decompositions of Nitrate of Ammoniac.*

All the phænomena of chemistry concur in proving, that the affinity of one body, A, for another, B, is not destroyed by its combination with a third, C, but only modified; either by condensation, or expansion, or by the attraction of C for B.

On this principle, the attraction of compound bodies for each other must be revolved into the

reciprocal attractions of their constituents, and consequently the changes produced in them by variations of temperature explained, from the alterations produced in the attractions of those constituents.

Thus in nitrate of ammoniac, four affinities may be supposed to exist :

1. That of hydrogene for nitrogene, producing ammoniac.

2. That of oxygene for nitrous gas, producing nitric acid.

3. That of the hydrogene of ammoniac for the oxygene of nitric acid.

4. That of the nitrogene of ammoniac for the nitrous gas of nitric acid.

At temperatures below 300°, the salt, from the equilibrium between these affinities, preserves its existence.

Now when its temperature is raised to 400°, the attractions of hydrogene for nitrogene,* and

* As is evident from the decomposition of ammoniac by heat.

of nitrous gas for oxygene, † are diminished; whilst the attraction of hydrogene for oxygene † is increased; and perhaps that of nitrogene for nitrous gas.

Hence the former equilibrium of affinity is destroyed, and a new one produced.

The hydrogene of the ammoniac combines with the oxygene of the nitric acid to generate water; and the nitrogene of the ammoniac enters into combination with the nitrous gas to form nitrous oxide: and the water and nitrous oxide produced, most probably exist in binary combination in the aëriform state, at the temperature of the decomposition.

But when a heat above 800° is applied to nitrate of ammoniac, the attractions of nitrogene and hydrogene for each other, and of

• † Nitric acid is phlogificated by heat, as appears from Dr. Priestley's experiments. Vol. 3, p. 26.

† As is evident from the increase of temperature required for the formation of water.

oxygen for nitrous gas,* are still more diminished; whilst that of nitrogen for nitrous gas is destroyed, and that of hydrogen for oxygen increased to a great extent: likewise a new attraction takes place; that of nitrous gas for nitric acid, to form nitrous vapor.† Hence a new arrangement of principles is rapidly produced; the nitrogen of ammoniac

* For ammoniac and nitrous oxide are both decomposed at the red heat, and oxygen given out from nitric acid when it is passed through a heated tube.

† Whenever nitrous acid is produced at high temperatures, it is always highly phlogisticated, provided it has not been long in contact with oxygen. When Dr. Priestley passed nitric acid through a tube heated red, he procured much oxygen, and phlogisticated acid; and the water in the apparatus employed was fully impregnated with nitrous air. Hence it would appear, that heat diminishes the attraction between oxygen and nitrous gas, and increases the affinity of nitrous gas for nitrous acid. Mr. JAMES THOMSON, whose theory of the Nitrous Acid I have already mentioned, from some experiments on the phlogistication of Nitric Acid by heat, which he has communicated to me, concludes with great justice, that a portion of the acid is always completely decomposed in this process: the oxygen liberated, and the nitrous gas combined with the remaining acid.

having no affinity for any of the single principles at this temperature, enters into no binary compound: the oxygene of the nitric acid forms water with the hydrogene, and the nitrous gas combines with the nitric acid to form nitrous vapor. All these substances most probably exist in combination at the temperature of their production; and at a lower temperature, assume the forms of nitrous acid, nitrous gas, nitrogene, and water.

I have avoided entering into any discussions concerning the light and heat produced in this process; because these phænomena cannot be reasoned upon as isolated facts, and their relation to general theory will be treated of hereafter.

X. *On the preparation of Nitrous Oxide for experiments on Respiration.*

When compact nitrate of ammoniac is slowly decomposed, the nitrous oxide produced is almost immediately fit for respiration; but as one part of the salt begins to decompose before

the other is rendered fluid, a considerable loss is produced by sublimation.

For the production of large quantities of nitrous oxide, fibrous nitrate of ammoniac should be employed. This salt undergoes no decomposition till the greater part of its water is evaporated, and in consequence at the commencement of that process, is uniformly heated.

The gas produced from fibrous nitrate, must be suffered to rest at least for an hour after its generation. At the end of this time it is generally fit for respiration. If examined before, it will be found to contain more or less of a white vapor, which has a disagreeable acidulous taste, and strongly irritates the fauces and lungs. This vapor, most probably, consists of acid nitrate of ammoniac and water, which were dissolved by the gas at the temperature of its production, and afterwards slowly precipitated.

It is found in less quantity when compact nitrate is employed, because more salt is sublimed in this process, which being rapidly precipitated, carries with it the acid and water.

Whatever salt is employed, the last portions of gas produced, generally contain less vapor, and may in consequence be respired sooner than the first.

The nitrate of ammoniac should never be decomposed in a metallic vessel,* nor the gas produced suffered to come in contact with any metallic surface; for in this case the free nitric acid will be decomposed, and in consequence, a certain quantity of nitrous gas produced.

The apparatus that has been generally employed in the medical pneumatic institution, for the production of nitrous oxide, consists

1. Of a glass retort, of the capacity of two or three quarts, orificed at the top, and furnished with a ground stopper.

2. Of a glass tube, conical for the purpose of receiving the neck of the retort; about 4 inches wide in the narrowest part, 4 feet long, curved at the extremity, so as to be capable of

* Except it be gold or platina.

introduction into an airholder, and inclosed by tin plate to preserve it from injury.

3. Of airholders of Mr. Watt's invention, filled with water saturated with nitrous oxide.

4. Of a common air-furnace, provided with dampers for the regulation of the heat.

The retort, after the insertion of the salt, is connected with the tube, carefully luted, and exposed to the heat of the furnace, on a convenient stand. The temperature is never suffered to be above 500° . After the decomposition has proceeded for about a minute, so that the gas evolved from the tube enlarges the flame of a taper, the curved end is inserted into the airholder, and the nitrous oxide preserved.

The water thrown out of the airholders in consequence of the introduction of the gas, is preserved in a vessel adapted for the purpose, and employed to fill them again; for if common water was to be employed in every experiment, a great loss of gas would be produced from absorption.

A pound of fibrous nitrate of ammoniac, decomposed at a heat not above 500°, produces nearly 5 cubic feet of gas; whilst from a pound of compact nitrate of ammoniac, rarely more than 4,25 cubic feet can be collected.

For the production of nitrous oxide in quantities not exceeding 20 quarts, a mode still more simple than that I have just described may be employed. The salt may be decomposed by the heat of an argands lamp, or a common fire, in a tubulated glass retort, of 20 or 30 cubic inches in capacity, furnished with a long neck, curved at the extremity; and the gas received in small airholders.

Thus, if the pleasurable effects, or medical properties of the nitrous oxide, should ever make it an article of general request, it may be procured with much less time, labor, and expence,* than most of the luxuries, or even necessaries, of life.

* A pound of nitrate of ammoniac costs about 5s. 10d. This pound, properly decomposed, produces rather more than 34 moderate doses of air; so that the expence of a dose is about 2d. What fluid stimulus can be procured at so cheap a rate?

DIVISION IV.

*EXPERIMENTS and OBSERVATIONS on the
COMPOSITION of NITROUS GAS, and on its
ABSORPTION by different bodies.*

I. *Preliminaries.*

IN my account of the composition of nitric acid, in Division I. I gave an estimation of the quantities of oxygene and nitrogene combined in nitrous gas: I shall now detail the experiments on which that estimation is founded.

At an early period of my researches relating to nitrous oxide, from the observation of the phenomena taking place during the production of this substance, I had concluded, that the common opinion with regard to the composition of nitrous gas, was very distant from the truth. I had indeed analysed nitrous gas, by converting it into nitrous oxide, before I at-

tempted to ascertain its composition by immediately separating the constituent principles from each other : and my first hopes of the possibility of effecting this, were derived from Dr. Priestley's experiments on the combustion of pyrophorus in nitrous gas, and on the changes effected in it, by heated iron and charcoal.

This great philosopher found, that pyrophorus placed in contact with nitrous gas, burnt with great vividness, whilst the gas was diminished in volume to about one half, which generally consisted of nitrogene and nitrous oxide.* He likewise found, iron heated by a lens in nitrous gas, increased in weight, whilst the gas was diminished about $\frac{1}{2}$, and converted into nitrogene.*

He heated common charcoal, and charcoal of copper, † in nitrous gas by a lens. When

* Experiments and Observations, vol. ii. pag. 50. Last Edition.

† That is, charcoal produced by the decomposition of spirits of wine. Vol. 11. pag. 39.

common charcoal was employed, the gas was neither increased or diminished in bulk, but wholly converted into nitrogene; when charcoal of copper was used, the volume was a little increased, and the gas remaining consisted of $\frac{5}{7}$ nitrogene, and $\frac{2}{7}$ carbonic acid.

In his experiments on the iron and pyrophyrus, the nitrous gas was evidently decomposed. From the great quantity of nitrogene produced in those on the charcoal, it seems likely that both the common charcoal,* and the charcoal of copper employed contained atmospherical air, which being dispelled by the heat of the lens,

* Dr. Priestley says, "having heated iron in nitrous air, I proceeded to heat in the same air, a piece of charcoal not long after it had been subjected to a strong heat covered with sand. The sun not shining immediately, after the charcoal was introduced into the vessel of air, through the mercury by which it was confined, part of the air was absorbed; but on heating the charcoal, the quantity was increased. Having continued the progress as long as I thought necessary, I examined the air and found it to be about as much as the original quantity of nitrous air; but it was all phlogificated air extinguishing a candle and having no mixture of fixed air in it."—Experiments and Observations, Vol. II, page 39.

was decomposed by the nitrous gas: indeed, till I made the following experiment, I suspected that the carbonic acid produced, when the charcoal of copper was employed, arose from a decomposition of the nitrous acid, formed in this way.

I introduced a piece of well-burnt charcoal, which could hardly have weighed the eighth of a grain, whilst red hot, under a cylinder filled with mercury, and admitted to it half a cubic inch of nitrous gas. A slight absorption took place.

The sun being very bright, I kept the charcoal in the focus of a small lens for near a quarter of an hour. At the end of this time the gas occupied a space nearly as before the experiment, and a very minute portion of the charcoal had been consumed. On introducing into the cylinder a small quantity of solution of strontian, a white precipitation was perceived, and the gas slowly diminished to about three tenths of a cubic inch. To these

three tenths a little common air was admitted, when very slight red fumes were perceived.

This experiment convinced me, that the attraction of charcoal for the oxygene of nitrous gas, at high temperatures, was sufficiently strong to effect a slow decomposition of it.

To be more accurately acquainted with this decomposition, and to learn the quantities of carbonic acid and nitrogene produced from a known quantity of nitrous gas, I proceeded in the following manner.

II. *Analysis of Nitrous Gas by Charcoal.*

A quantity of nitrous gas was procured in a water apparatus, from the decomposition of nitrous acid by mercury. A portion of it was transferred to the mercurial trough. After the mercury and the jar had been dried by bibulous paper, 40 measures of this portion were agitated in a solution of sulphate of iron. The gas remaining after the absorption was complete,

filled about a measure and half; so that the nitrous gas contained nearly $\frac{1}{20}$ nitrogene.

Thermometer being 53° , a small piece of well burnt charcoal, the weight of which could hardly have equalled a quarter of a grain, was introduced ignited, into a small cylinder filled with mercury, graduated to ,10 grain measures; to this, 16 measures, equal to 160 grain m. of nitrous gas, were admitted. An absorption of about one measure and half took place. When the focus of a lens was thrown on the charcoal, a slight increase of the gas was produced, from the emission of that which had been absorbed.

After the process had been carried on for about a half an hour, the charcoal evidently began to fume, and to consume very slowly, though no alteration in the volume of the gas was observed.

The sun not constantly shining, the progress of the experiment was now and then stopped; but taking the whole time, the focus could not have been applied to it for less than four hours. When the process was finished, the gas was

increased in bulk nearly three quarters of a measure.

A drop of water was introduced into the cylinder, by means of a small glass tube, on the supposition that the carbonic acid, and nitrogene, might be capable of holding in solution, more water than that contained in the nitrous gas decomposed; but no alteration of volume took place.

When 20 grain measures of solution of pale green* sulphate of iron were introduced into the cylinder, they became rather yellower than before, but not dark at the edges, as is always the case when nitrous gas is present. On agitation, a diminution of nearly half a measure was produced, doubtless from the absorption of some of the carbonic acid by the solution.

A small quantity of caustic potash, much more than was sufficient to decompose the sulphate of iron, was now introduced. A rapid diminution took place, and the gas remaining

* That is, sulphate of iron containing oxide of iron, in the first degree of oxygenation.

filled about 8 measures. This gas was agitated for some time over water, but no absorption took place. Two measures of it were then transferred into a detonating cylinder with two measures of oxygen. The electric spark was passed through them, but no diminution was produced. Hence it was nitrogen, mingled with no ascertainable quantity of hydrogen: consequently little or no water could have been decomposed in the process.

Now supposing, for the greater ease of calculation, each of the measures employed, cubic inches.

16 of nitrous gas — $\frac{1}{26} = 15,4$ were decomposed, and these weigh, making the necessary corrections, 5,2; but 7,4 nitrogen were produced, and these weigh about 2,2. So that reasoning from the relative specific gravities of nitrous gas and nitrogen, 5,2 grains of nitrous gas will be composed of 3 oxygen, and 2,2 nitrogen.

But 8,7 of carbonic acid were produced, which weigh 41 grains, and consist of 2,9 oxy-

gene, and 1,2 charcoal.* Consequently, drawing conclusions from the quantity of carbonic acid formed, 5,2 grains of nitrous gas will consist of 2,9 oxygene, and 2,3 nitrogene.

The difference in these estimations is much less than could have been expected; and taking the mean proportions, it would be inferred from them, that 100 grains of nitrous gas, contain 56,5 oxygene, and 43,5 nitrogene.

I repeated this experiment with results not very different, except that the increase of volume was rather greater, and that more unaborbable gas remained; which probably depended on the decomposition of a minute quantity of water, that had adhered to the charcoal in passing through the mercury.

As nitrous gas is decomposable into nitrous acid, and nitrogene, by the electric spark; it occurred to me, that a certain quantity of nitrous acid might have been possibly produced, in the experiments on the decomposition of nitrous gas, by the intensely ignited charcoal.

* That is, carbon, or oxide of diamond.

To ascertain this circumstance, I introduced into 12 measures of nitrous gas, a small piece of charcoal which had been just reddened. The sun being very bright, the focus of the lens was kept on it for rather more than an hour and quarter. In the middle of the process it began to fume and to sparkle, as if in combustion. In three quarters of an hour, the gas was increased rather more than half a measure; but no alteration of volume took place afterwards.

The mercury was not white on the top as is usually the case when nitrous acid is produced. On introducing into the cylinder a little pale green sulphate of iron, and then adding prussiate of potash, a white precipitate only was produced. Now, if the minutest quantity of nitric acid had been formed, it would have been decomposed by the pale green oxide of iron, and hence, a visible quantity of prussian blue* produced, as will be fully explained hereafter.

* That is, blue prussiate of iron.

III. *Analysis of Nitrous Gas by Pyrophorus.*

I placed some newly made pyrophorus, about as much as would fill a quarter of a cubic inch, into a jar filled with dry mercury, and introduced to it, four cubic inches of nitrous gas, procured from mercury and nitric acid.

It instantly took fire and burnt with great vividness for some moments.

After the combustion had ceased, the gas was diminished about three quarters of a cubic inch. The remainder was not examined; for the diminution appeared to go on for some time, after; in an half hour, when it was complete, it was to 2 cubic inches. A taper, introduced into these, burnt with an enlarged flame, blue at the edges; from whence it appeared, that they were composed of nitrogene and nitrous oxide.

I now introduced about half a cubic inch of pyrophorus to two cubic inches of nitrous gas; the combustion took place, and the gas was

rapidly diminished to one half ; and on suffering it to remain five minutes to one-third nearly ; which extinguished flame.

Suspecting that this great diminution was owing to the absorption of some of the nitrogene formed, by the charcoal of the pyrophorus, I carefully made a quantity of pyrophorus ; employing more than two-thirds of alumn, to one-third of sugar.

To rather more than half of a cubic inch of this, two cubic inches of nitrous gas, which contained about $\frac{1}{40}$ nitrogene, were admitted. After the combustion, the gas remaining, *apparently* filled a space equal to 1,2 cubic inches ; but, as on account of the burnt pyrophyrus in the jar, it was impossible to ascertain the volume with nicety, it was carefully and wholly transferred into another jar. It filled a space equal to 1,15 cubic inches nearly.

When water was admitted to this gas no absorption took place. It underwent no diminution with nitrous gas, and a taper plunged into it was instantly extinguished. We may consequently conclude that it was nitrogene.

Now 2 cubic inches of nitrous gas weigh ,686 grains, and 1,1 of nitrogene — ,05, the quantity previously contained in the gas = to 1,05, 3,19. Hence ,686 of nitrous gas would be composed of ,367 oxygene, and ,319 nitrogene; and 100 grains would contain 53,4 oxygene, and 46,6 nitrogene.

IV. *Additional observations on the combustion of bodies in Nitrous Gas, and on its Composition.*

Though phosphorus may be fused, and even sublimed, in nitrous gas, without producing the flightest luminous appearance,* yet when

* No luminous appearance is produced when phosphorus is introduced into *pure* nitrous gas. It has been often observed, that phosphorus is luminous in nitrous gas, that has not been long in contact with water after its production. This phænomenon, I suspect, depends either on the decomposition of the nitric acid held in solution by the nitrous gas; or on the combination of the phosphorus with oxygene loosely adhering to the binary æriform compound of nitric acid and nitrous gas. I have not yet examined if nitrous gas can be converted into nitrous oxide by long exposure to heated phosphorus: it appears, however, very probable.

it is introduced into it in a state of active inflammation, it burns with almost as much vividness as in oxygen.* Hence it is evident, that at the heat of ignition, phosphorus is capable of attracting the oxygen from the nitrogen of nitrous gas.

I attempted to analyse nitrous gas, by introducing into a known quantity of it, confined by mercury, phosphorus, in a vessel containing a minute quantity of oxygen.† The phosphorus was inflamed with an ignited iron wire, by which, at the moment of the combustion, the vessel containing it was raised from the mercury into the nitrous gas. But after making in this way, five of six unsuccessful experiments, I desisted. When the communication between the vessels was made before the oxygen was nearly combined with the phosphorus, nitrous

* Perhaps this fact has been noticed before; I have not, however, met with it in any chemical work.

† This mode of inflaming bodies in gases, not capable of supporting combustion at low temperatures, will be particularly described hereafter.

acid was formed, which instantly destroyed the combustion ; when, on the contrary, the phosphorus was suffered to consume almost the whole of the oxygene, it was not sufficiently ignited when introduced, to decompose the nitrous gas.

In one experiment, indeed, the phosphorus burnt for a moment in the nitrous gas ; the diminution however was slight, and not more than $\frac{1}{4}$ of it was decomposed.

Sulphur, introduced in a state of vivid inflammation, into nitrous gas, was instantly extinguished.

I passed a strong electric shock through equal parts of hydrogen and nitrous gas, confined by mercury in a detonating tube ; but no inflammation, or perceptible diminution, was produced.

19,2 grain measures of hydrogen were fired by the electric shock, with 10 of nitrous oxide, and 6 of nitrous gas ; the diminution was to 17 ; and pale green sulphate of iron admitted to the residuum, was not discolored. Consequently the

nitrous gas was decomposed by the hydrogen, and as will be hereafter more clearly understood, nearly as much nitrogen furnished by it, as would have been produced from half the quantity of nitrous oxide.

Suspecting that phosphorated hydrogen might inflame with nitrous gas, I passed the electric spark through 1 measure of phosphorated hydrogen, and 4 of nitrous gas; but no diminution was perceptible. I likewise passed the electric spark through 1 of nitrous gas, with 2 of phosphorated hydrogen, without inflammation.

Perhaps if I had tried many other different proportions of the gases, I should have at last discovered one, in which they would have inflamed; for, as will be seen hereafter, nitrous oxide cannot be decomposed by the compound combustible gases, except definite quantities are employed.

From Dr. Priestley's experiments on iron and pyrophorus, and from the experiments I have detailed, on charcoal, phosphorus, and hydro-

gene, it appears that at certain temperatures, nitrous gas is decomposable by most of the combustible bodies : even the extinction of sulphur, when introduced into it in a state of inflammation, depends perhaps, on the smaller quantity of heat produced by the combustion of this body, than that of most others.

The analysis of nitrous gas by charcoal, as affording data for determining immediately the quantities of oxygene and nitrogene, ought to be considered as most accurate ; and correcting it by mean calculations derived from the decomposition of nitrous gas by pyrophorus and hydrogen, and its conversion into nitrous oxide, a process to be described hereafter, we may conclude, that 100 grains of nitrous gas are composed of 55,95 oxygene, and 44,05 nitrogene ; or taking away decimals, of 56 oxygene, and 44 nitrogene.

This estimation will agree very well with the mean proportions that would be given from Dr. Priestley's experiments on the decomposition of nitrous gas by iron ; but as he never ascer-

tained the purity of his nitrous gas,* and probably employed different kinds in different experiments, it is impossible to fix on any one, from which accurate conclusions can be drawn.

Lavoisier's estimation of the quantities of oxygen and nitrogen entering into the composition of nitrous gas, has been generally adopted. He supposes 64 parts of nitrous gas to be composed of $43\frac{1}{2}$ of oxygen, and $20\frac{1}{2}$ of nitrogen. †

The difference between this account and mine is very great indeed; but I have already, in Division 1st, pointed out sources of error in the experiments of this great man, on the decomposition of nitre by charcoal; which experiments were fundamental, both to his accounts of the constitution of nitrous acid, and nitrous gas.

* Elements English Transf. edit. i. pag. 216.

† Experiments and Observations, Vol. II. pag. 40, 2d. Ed.

V. *Of the absorption of Nitrous Gas by Water.*

Amongst the properties of nitrous gas noticed by its great discoverer, is that of absorbability by water.

In exposing nitrous air to distilled water, Dr. Priestley found a diminution of the volume of gas, nearly equal to one tenth of the bulk of the water; and by boiling the water thus impregnated, he procured again a certain portion of the nitrous gas.

Humbolt, in his paper on eudiometry, mentions the diminution of nitrous gas by water. This diminution, he supposes to arise from the decomposition of a portion of the nitrous gas, by the water, and the consequent formation of nitrate of ammoniac.*

* He says, " On a observé, (depuis qu'on travaille sur le
 " pureté de l'air) que le gaz nitreux, secoué avec l'eau, en
 " souffre une diminution de volume. Quelques physiciens
 " attribuent ce changement à une vraie absorption, à une
 " dissolution du gaz nitreux dans l'eau; d'autres à l'air con-
 " tenu dans les interstices de tous les fluides. Le cit.
 " Vanbreda, à Delft, a fait des recherches très-exactes sur
 " l'influence des eaux de pluie et de puit, sur les nombres
 " eudiométriques; et les belles expériences du cit. Hassen-

I confess, that even before the following experiments were made, I was but little inclined to adopt this opinion : the small diminution of nitrous gas by water, and the uniform limits of this diminution, rendered it extremely improbable.

a. To ascertain the quantity of nitrous gas

“ fratz, sur l'abondance d'oxygène, contenue dans les eaux
 “ de neige et de pluie, font supposer que l'air des interstices
 “ de l'eau joue un rôle important dans l'absorption du gaz
 “ nitreux. En comparant ces effets avec les phénomènes
 “ observé dans la decomposition du sulfate de fer, nous sup-
 “ posâmes, le cit. Tassaert et moi, que le simple contact du
 “ gaz nitreux avec l'eau distillée pourroit bien causer une
 “ décomposition de ce dernier. Nous examinâmes soign-
 “ eusement une petite quantité d'eau distillée, secouée avec
 “ beaucoup de gas nitreux très-pur, et nous trouvâmes,
 “ au moyen de la terre calcaire, et l'acide muriatique, qu'il
 “ s'y forme du *nitrate d'ammoniaque*. L'eau se décompose
 “ en cette opération, par un double affinité de l'oxygene
 “ pour le gaz nitreux, et de l'hydrogène pour l'azote ; il se
 “ forme de l'acide nitrique et de l'*ammoniaque* ; et, quoique
 “ la quantité du dernier paroisse trop petite pour en évaluer
 “ exactement la quantité, son existence cependant se mani-
 “ feste, (à ne pas sans douter) par le dégagement des va-
 “ peurs, qui blanchissent dans la proximité de l'acide mu-
 “ riatique. Voilà un fait bien frappant que la composition
 “ d'une substance alcaline par le contact d'une acide, et de
 “ l'eau.

Annales de Chimie, t. xxviii. pag. 153.

absorbable by pure water, and the limits of absorption, I introduced into a glass retort about 5 ounces of water, which had been previously boiled for some hours. The neck of the retort was inverted in mercury, and the water made to boil. After a third of it had been distilled, so that no air could possibly remain in the retort, the remainder was driven over, and condensed in an inverted jar filled with mercury. To three cubic inches of this water,* confined in a cylinder graduated to ,05 cubic inches, 5 cubic inches of nitrous gas, containing nearly one thirtieth nitrogene, were introduced.

After agitation for near an hour, rather more than $\frac{4}{20}$ of a cubic inch appeared to be absorbed; but though the process was continued for near two hours longer, no further diminution took place.

The remaining gas was introduced into a tube graduated to ,02 cubic inches. It measured $\frac{14}{50}$; hence $\frac{11}{50}$ had been absorbed.

* Which was certainly as free from air as it ever can be obtained.

Consequently, 100 cubic inches of pure water are capable of absorbing 11,8 of nitrous gas. In the water thus impregnated with nitrous gas I could distinguish no peculiar taste;* it did not at all alter the color of blue cabbage juice.

b. To determine if the absorption of nitrous gas was owing to a decomposition of it by the water, as Humbolt has supposed, or to a simple solution; I procured some nitrous gas from nitrous acid and mercury, containing about one seventieth nitrogen. .5 cubic inches of it, mingled with 25, of oxygen, from sulphuric acid and manganese left a residuum of .03. 5 cubic inches more were introduced to 3 of water, procured in the same manner as in the last experiment, in the same cylinder.

* Dr. Priestley found distilled water, saturated with nitrous air, to acquire an astringent taste and pungent smell. In some unboiled impregnated pump water, I once thought that I perceived a subacid taste; but it was extremely slight, and probably owing to nitrous acid formed by the union of the oxygen of the common air in the water, with some of the nitrous gas.

After the distillation was complete, the cylinder was transferred in a small vessel containing mercury, into a water bath, and nearly covered by the water.

As the bath was heated, small globules of gas were given out from the impregnated water, and when it began to boil, the production of gas was still more rapid. After an hour's ebullition, the volume of treated gas was equal to 1.4 cubic inches nearly.

The cylinder was now taken out of the bath, and quietly rendered cool by being placed in a water apparatus. At the common temperature the gas occupied, as nearly as possible, the space of .5 cubic inches: these .5 mingled with .25 of oxygen, of the same kind as that employed before, left a residuum nearly equal to .03.

From this experiment, which was repeated with nearly the same result, it is evident,

1. That nitrous gas is not decomposable by pure water.
2. That the diminution of volume of nitrous gas placed in contact with water, is owing to a simple solution of it in that fluid.

3, That at the temperature of 212° , nitrous gas is incapable of remaining in combination with water.

Humbolt's opinion relating to the decomposition of nitrous gas by water, is founded upon the disengagement of vapor from distilled water impregnated with nitrous gas, by means of lime, which became white in the proximity of the muriatic acid. But this is a very imperfect, and fallacious test, of the presence of ammoniac. I have this day, April 2, 1800, heated 4 cubic inches of distilled water, impregnated with nitrous gas, with caustic lime; the vapor certainly became a little whiter when held over a vessel containing muriatic acid; but the vapor of distilled water produced precisely the same appearance,* which was owing, most likely, to

* As carbonic acid and ammoniac are both products of animalification, is it not probable that our common waters particularly those in, and near towns and cities, contain carbonate of ammoniac? If so, this salt will always exist in them after distillation. In the experiments on carbonate of ammoniac, to which I have often alluded, I found, in distilling a solution of this salt in water, that before half of

the combination of the acid with the aqueous vapor. Indeed, when I added a particle of nitrate of ammoniac, which might have equalled one twentieth of a grain, to the lime and impregnated water, the increased whiteness of the vapor was but barely perceptible, though this quantity of nitrate of ammoniac is much more considerable than that which could have been formed, even supposing the nitrous gas decomposed.

VI. *Of the absorption of Nitrous Gas by Water of different kinds.*

In agitating nitrous gas over spring water, the diminution rarely amounts to more than one thirtieth, the volume of water being taken as unity. I at first suspected that this great dif-

the water had passed into the recipient, the carbonate of ammoniac had sublimed; so that the distilled solution was much stronger than before, whilst the water remaining in the retort was tasteless. Will this supposition at all explain Humbolt's mistake?

ference in the quantity of gas absorbed by spring water, and pure water, depended on carbonic acid contained in the last, diminishing the attraction of it for nitrous gas : but by long boiling a quantity of spring water confined by mercury, I obtained from it about one twentieth of its bulk of air, which gave nearly the same diminution with nitrous gas, as atmospheric air.

This fact induced me to refer the difference of diminution to the decomposition of the atmospheric air held in solution by the water, the oxygene of which I supposed to be converted into nitric acid, by the nitrous gas, whilst the nitrogene was liberated ; and hence the increased residuum.

a. I exposed to pure water, that is, water procured by distillation under mercury, nitrous gas, containing a known quantity of nitrogene. After the absorption was complete, I found the same quantity of nitrogene in the residuum, as was contained in a volume of gas equal to the whole quantity employed.

b. Spring water boiled for some hours, and suffered to cool under mercury, absorbed a quantity of nitrous gas equal to one thirteenth of its bulk; which is not much less than that absorbed by pure water.

c. I exposed to spring water, 10 measures of nitrous gas; the composition of which had been accurately ascertained; the diminution was one twenty-eighth, the volume of water being taken as unity. On placing the residuum in contact with solution of sulphate of iron, the nitrogene remaining was nearly one-twentieth more than had been contained by the gas before its exposure to water.

d. Distilled water was saturated with common air, by being agitated for some time in the atmosphere. Nitrous gas placed in contact with this water, underwent a diminution of $\frac{1}{18}$; the volume of water being unity. The gas remaining after the absorption contained about one twenty-seventh nitrogene more than before.

e. Nitrous gas exposed to water combined

with about one fourth of its volume of carbonic acid, diminished to $\frac{1}{32}$ * nearly. The remainder contained little or no superabundant nitrogene.

From these observations it appears, that the different degrees of diminution of nitrous gas by different kinds of water, may depend upon various causes.

1. Less nitrous gas will be absorbed by water holding in solution earthy salts, than by pure water; and in this case the diminution of the attraction of water for nitrous gas will probably be in the ratio of the quantities of salt combined with it. *a. b.*

2. The apparent diminution of nitrous gas in water, holding in solution atmospheric air, will be less than in pure water, though the absolute diminution will be greater; for the same portion will be absorbed, whilst another portion is combined with the oxygene of the atmospheric air contained in the water; and from the disengagement of the

* The water still being unity.

nitrogene of this air, arises an increased residuum. *c. d.*

3. Probably in waters containing nitrogene, hydrogene, and other gases, absorbable only to a slight extent, the apparent diminution will be less, on account of the disengagement of those gases from the water, by the stronger affinity of nitrous gas for that fluid.

4. In water containing carbonic acid, and probably some other acid gases, the diminution will be small in proportion to the quantity of gas contained in the water: the affinity of this fluid for nitrous gas being diminished by its greater affinity for the substance combined with it. *e.*

The different diminution of nitrous gas when agitated in different kinds of water, has been long observed by experimenters on the constituent parts of the atmosphere, and various solutions have been given of the phænomenon; the most singular is that of Humbolt.* He supposes

* He says " 100 parties de gaz nitreux, (à 0.14 d'azote) se couées avec l'eau distillée, récemment cuite, diminuent en

that the apparent diminution of nitrous gas is less in spring water than distilled water, on account of the decomposition of the carbonate of lime contained in the spring water, by the nitrous acid formed from the contact of nitrous gas with the water ; the carbonic acid disengaged from this decomposition increasing the residuum.

This opinion may be confuted without even reference to my observations. It is, indeed,

“ volume de 0.11, ou 0.12. Ce même gaz, en contact avec
“ l'eau de puits, ne perd que 0.02. La cause de cette dif-
“ férence de 0.9, ou 0.10, ne doit pas être attribuée ni à
“ l'impurité de l'air atmosphérique, contenu dans les inter-
“ stices de l'eau, ni à la décomposition de cette eau même.
“ Elle n'est qu'apparente ; car l'acide nitrique, qui se forme
“ par le contact du gaz nitreux avec l'eau de puits, en dé-
“ compose le carbonate de chaux. Il se dégage de l'acide
“ carbonique, qui, en augmentant le volume du residu, rend
“ l'absorption du gaz nitreux moins sensible. Pour déter-
“ miner la quantité de cet acide carbonique, je lavai le
“ résidu avec de l'eau de chaux. Dans un grand nombre
“ d'expériences, le volume diminua de 0.09, ou 0.07. Il
“ faut en conclure que l'eau de puits absorbe réellement
“ 9 + 2, ou 7 + 2 parties de gaz nitreux, c'est-à-dire, à
“ peu-près la même quantité que l'eau distillée.”

altogether unworthy of a philosopher, generally acute and ingenious. He seems to have forgotten that carbonic acid is absorbable by water.

VII. *Of the absorption of Nitrous Gas, by solution of pale green Sulphate of Iron.*

a. The discovery of the exact difference between the sulphates of iron, is owing to Proust.* According to the ingenious researches of this chemist, there exist two varieties of sulphate of iron, the green and the red. The oxide in the green sulphate contains $\frac{27}{100}$ oxygene. This salt, when pure, is insoluble in spirit of wine; its solution in water is of a pale green color; it is not altered by the gallic acid, and affords a white precipitate with alkaline prussiates.

The red sulphate of iron is soluble in alcohol and uncrystalizable; its oxide contains $\frac{48}{100}$ oxygene. It forms a black precipitate with the gallic acid, and with the alkaline prussiates, a blue one.

* Nicholson's Phil. Jour. No. 1, p. 453.

The common sulphates of iron generally consist of combinations of these two varieties in different proportions.

The green sulphate may be converted into the red by oxygenated muriatic acid or nitric acid. The common sulphate may be converted into green sulphate, by agitation in contact with sulphurated hydrogen.

The green sulphate has a strong affinity for oxygen, it attracts it from the atmosphere, from oxygenated marine acid, and nitric acid. The alkalis precipitate from it a pale green oxide, which if exposed to the atmosphere, rapidly becomes yellow red.

The red sulphate of iron has no affinity for oxygen, and when decomposed by the alkalis, gives a red precipitate, which undergoes no alteration when exposed to the atmosphere.*

b. The absorption of nitrous gas by a solution of sulphate of iron, was long ago discovered by

* I have been able to make these observations on the sulphates of iron, most of them after Proust.

Priestley. During this absorption, he remarked a change of color in the solution, analogous to that produced by the mixture of it with nitric acid.

This chemical fact has been lately applied by Humbolt, to the discovery of the nitrogene generally mingled with nitrous gas.

Vauquelin and Humbolt have published a memoir, on the causes of the absorption* of nitrous gas by solution of sulphate of iron. They saturated an ounce and half of sulphate of iron in solution, with 180 cubic inches of nitrous gas.

Thus impregnated it strongly reddened tincture of turnsoyle; when mingled with sulphuric acid, gave nitric acid vapor; and saturated with potash, ammoniacal vapor.

By analysis, it produced as much ammoniac as that contained in 4 grains of ammoniacal muriate, and a quantity of nitric acid equal to that existing in 17 grains of nitre. Hence they

* Annales de chimie, vol. xxviii. pag. 182.

concluded, that the nitrous gas and a portion of the water of the solution, had mutually decomposed each other; the oxygene of the water combining with the oxygene and a portion of the nitrogene of nitrous gas to form nitric acid; and its hydrogene uniting with the remaining nitrogene, to generate ammoniac.

They have taken no notice of the nature of the sulphate of iron employed, which was most probably the common or mixed sulphate; nor of the attraction of the oxide of iron in this substance for oxygene.

c. Before I was acquainted with the observations of Proust, the common facts relating to the oxygenation of vitriol of iron induced me to suppose, that the attraction of this substance for oxygene was in some way connected with the process of absorption. The comparison of the experiments of Humbolt and Vauquelin, with the observations of Proust, enabled me to discover the true nature of the process.

I procured a solution of red sulphate of iron, by passing oxygenated muriatic acid

through a solution of common sulphate of iron, till it gave only a red precipitate, when mingled with caustic potash. To nitrous gas confined by mercury, a small quantity of this solution was introduced. On agitation, its color altered to muddy green; but the absorption that took place was extremely trifling: in half an hour it did not amount to $\frac{1}{2}$, the volume of the solution being unity, when it had nearly regained the yellow color.

I now obtained a solution of green sulphate of iron, by dissolving iron filings in diluted sulphuric acid. The solution was agitated in contact with sulphurated hydrogen, and afterwards boiled; when it gave a white precipitate with prussiate of potash.

A small quantity of this solution agitated in nitrous gas, quickly became of an olive brown, and the gas was diminished with great rapidity; in two minutes, a quantity equal to four times the volume of the solution, had been absorbed.

These facts convinced me that the solubility of nitrous gas in common sulphate of iron,

chiefly depended upon the pale green sulphate contained by it ; and that the attraction of one of the constituents of this substance, the green oxide of iron, for oxygen, was one of the causes of the phenomenon.

d. Green sulphate of iron rapidly decomposes nitric acid. It was consequently difficult to conceive how any affinities existing between nitrous gas, water, and green sulphate of iron, could produce the nitric acid found in the experiments of Vauquelin and Humbolt.

To ascertain if the presence of a great quantity of water destroyed the power of green sulphate of iron to decompose nitric acid, I introduced into a cubic inch of solution of green sulphate of iron, two drops of concentrated nitric acid.

The solution assumed a very light olive color ; prussiate of potash mingled with a little of it, gave a dark green precipitate. Hence the nitric acid had been evidently decomposed. As no nitrous gas was given out, which is always the case when nitric acid is poured on

crystalised sulphate of iron, I suspected that a compleat decomposition of the acid had taken place; but when the solution was heated, a few minute globules of gas were liberated, and it gradually became slightly clouded.

Having often remarked that no precipitation is ever produced during the conversion of green sulphate of iron into red, by oxygenated muriatic acid, or concentrated nitric acid, I could refer the cloudiness to no other cause than to the formation of ammoniac.

To ascertain if this substance had been produced, a quantity of slacked caustic lime was thrown into the solution. On the application of heat, the ammoniacal smell was distinctly perceptible, and the vapor held over orange nitrous acid, gave dense white fumes.

e. When I considered this fact of the decomposition of nitric acid and water by the solution of green sulphate of iron, and the change of color effected in it by the absorption of nitrous gas, exactly analogous to that produced by the decomposition of nitric acid; I was induced to

believe that the nitric acid found in the analysis of Vauquelin and Humbolt, had been formed by the combination of some of the nitrous gas thrown into the solution with the oxygen of the atmosphere: and that the absorbability of nitrous gas, by solution of green sulphate of iron, was owing to a decomposition produced by the combination of its oxygen with the green oxide of iron, and of its nitrogen with the hydrogen disengaged from water, decomposed at the same time.

To ascertain this, I procured a quantity of nitrous gas: it was suffered to remain in contact with water for some hours after its production. Transferred to the mercurial apparatus, it gave no white vapor when placed in contact with solution of ammoniac; and consequently held no nitric acid in solution.

Into a graduated jar filled with mercury, a cubic inch of concentrated solution of pure green sulphate of iron was introduced, and 7 cubic inches of nitrous gas admitted to it. The solution immediately became dark olive at

the edges, and on agitation this color was diffused through it. In 3 minutes, when near $5\frac{3}{4}$ cubic inches had been absorbed, the diminution ceased. The solution was now of a bright olive brown, and transparent at the edges. After it had rested for a quarter of an hour, no farther absorption was observed; the color was the same, and no precipitation could be perceived. A little of it was thrown into a small glass tube, under the mercury, and examined in the atmosphere. Its taste was rather more astringent than that of solution of green sulphate; it did not at all alter the color of red cabbage juice. When a little of it was poured on the mercury, it soon lost its color, its taste became acid, and it quickly reddened cabbage juice, even rendered green by an alkali.

To the solution remaining in the mercurial jar, a small quantity of prussiate of potash was introduced, to ascertain if any red sulphate of iron had been formed; but instead of the production of either a blue, or a white precipitate, the whole of the solution became opaque, and chocolate colored.

Surprised at this appearance, I was at first induced to suppose, that the ammoniac formed by the nitrogene of the nitrous gas and the hydrogene of the water, had been sufficient to precipitate from the sulphuric acid, the red oxide of iron produced, and that the color of the mixture was owing to this precipitation. To dissolve any uncombined oxide that might exist in the solution, I added a very minute quantity of diluted sulphuric acid; but little alteration of color was produced. Hence, evidently, no red oxide had been formed.

This unexpected result obliged me to theorise a second time, by supposing that nitrate of ammoniac had been produced, which by combining with the white prussiate of iron, generated a new combination. But on mingling together green sulphate of iron, prussiate of potash, and nitrate of ammoniac in the atmosphere, the mixture remained perfectly white.

To ascertain if any nitric acid existed, combined with any of the bases, in the impregnated solution, I introduced into it an equal bulk

of diluted sulphuric acid : it became rather paler ; but no green or blue tinge was produced.

That the pruffic acid had not been decomposed, was evident from the bright green produced, when less than a grain of dilute nitric acid was admitted into the solution.

f. From these experiments it was evident, that no red sulphate of iron, or nitric acid, and consequently no ammoniac, had been produced after the absorption of nitrous gas by green sulphate of iron. And when I compared them with the observations of Priestley, who had expelled by heat a minute quantity of nitrous gas from an impregnated solution of common sulphate of iron, and who found common air phlogificated by standing in contact with it, I began to suspect that nitrous gas was simply dissolved in the solution, without undergoing decomposition.

g. To determine more accurately the nature of the process, I introduced into a mercurial cylinder 410 grains of solution of green sulphate of iron, occupying a space nearly equal to a

cubic inch and quarter ; it was saturated with nitrous gas, by absorbing 8 cubic inches. This saturated solution exhibited the same appearance as the last ; and after remaining near an hour untouched, had evidently deposited no oxide of iron, nor gained any acid properties.

Into a small matrafs filled with mercury, having a tight stopper with a curved tube adapted to it, the greater part of this solution was introduced ; judging from the capacity of the matrafs, about 50 grains of it might have been lost. To prevent common air from coming in contact with the solution, the stopper was introduced into the matrafs under the mercury ; the curved tube connected with a graduated cylinder filled with that substance ; and the matrafs brought over the side of the mercurial trough. But in spite of these precautions a large globule of common air got into the top of the matrafs, from the curvature of the tube. When the heat of a spirit lamp was applied to the solution, it gave out gas with great rapidity, and gradually lost its color. When 5 cubic

inches were collected it became perfectly pale green, whilst a yellow red precipitate was deposited on the bottom of the matras.

On pouring a little of the clear solution into prussiate of potash, it gave only white prussiate of iron.

But on introducing a particle of sulphuric acid into the solution, sufficient to dissolve some of the red precipitate, and then pouring a little of it into a solution of prussiate of potash, it gave a fine blue prussiate of iron.

Hence the red precipitate was evidently red yellow oxide of iron.

I now examined the gas, suspecting that it was nitrous oxide. On mingling a little of it with atmospheric air, it gave red vapor, and diminished. Solution of sulphate of iron introduced to the remainder, almost wholly absorbed it: the small residual globule of nitrogen could not equal one thirtieth of a cubic inch.

Consequently it was nitrous gas, nearly pure.

Caustic potash was now introduced into the solution, till all the oxide of iron was precipitated. The solution, when heated, gave a

strong smell of ammoniac, and dense white fumes when held over muriatic acid. It was kept at the heat of ebullition till the evaporation had been nearly compleated. Sulphuric acid poured upon the residuum gave no yellow fumes, or nitric acid vapor in any way perceptible; even when heated and made to boil, there was no indication of the production of any vapor, except that of the sulphuric acid.

b. This experiment, compared with the others, seemed almost to prove, that nitrous gas combined with solution of pale green sulphate of iron, at the common temperature, without decomposition; and that when the impregnated solution was heated, the greater portion of gas was disengaged, whilst the remainder was decomposed by the green oxide of iron; which attracted at the same time oxygene from the water and the nitrous gas; whilst their other constituent principles, hydrogen and nitrogen, entered into union as ammoniac.

Whilst, however, I was reasoning upon this singular chemical change, as affording pre-

sumplive proofs in favor of the exertion of simple affinities by the constituent parts of compound substances, a doubt concerning the decomposition of the nitrous gas occurred to me. As near as I could guess at the quantity of nitrous gas contained by the impregnated solution, at least $\frac{3}{4}$ of it must have been expelled undecomposed.

More than a quarter of a cubic inch of common air had been present in the matrafs: the oxygene of this common air must have combined with the nitrous gas, to form nitric acid. Might not this nitric acid have been decomposed, and furnished oxygene to the red oxide of iron, and nitrogene to the small quantity of ammoniac found in the solution, as in *d*?

i. I now introduced to a solution of green sulphate confined by mercury, nitrous gas, perfectly free from nitric acid. When the solution was saturated, a portion of it was introduced into a small matrafs filled with dry mercury, in the mercurial trough. The curved tube was closed by a small cork at the top, and filled

with nitrous gas ; it was then adapted to the mattrafs, which was raised from the trough, and the solution thus effectually preserved from the contact of the atmosphere.

When the heat of a spirit lamp was applied to the mattrafs, it began to give out gas with great rapidity. After some time the solution lost its dark color, and became turbid. When the production of nitrous gas had ceased, it was suffered to cool. A copious red precipitate had fallen down ; which, examined by the same tests as in the last experiment, proved to be red oxide of iron.

The solution treated with lime, as before, gave ammoniac ; but with sulphuric acid, not the slightest indications of nitric acid.

k. Having thus procured full evidence of the decomposition of nitrous gas in the heated solution, in order to gain a more accurate acquaintance with the affinities exerted, I endeavoured to ascertain the quantity of nitrous gas decomposed by a given solution, under known circumstances.

Into a cylinder of the capacity of 20 cubic inches, inverted in mercury, 1150 grains of solution of green sulphate of iron, of specific gravity 1.4, were introduced. Nitrous gas was admitted to it, and after some time 21 cubic inches were absorbed.

The impregnated solution was thrown into a matrafs, in the same manner as in the last experiment, and the same precautions taken to preserve it from the contact of atmospheric air. A quantity was lost during the process of transferring, which, reasoning from the space occupied in the matrafs by the remaining portion, as determined by experiment afterwards, must have amounted nearly to 240 grains.

The curved tube from the matrafs was now made to communicate with the mercurial air-holder. By the application of heat 12,5 cubic inches of nitrous gas were collected, after the common temperature had been restored to the matrafs; which was suffered to remain in communication with the conducting tube.

The solution was now pale green, that is, of its

natural color, and a considerable quantity of red oxide of iron had been deposited.

Solid caustic potash was introduced into it, till all the green oxide of iron had been precipitated, and till the solution rendered green, red cabbage juice.

A tube was now accurately connected with the matrafs, bent, and introduced into a small quantity of diluted sulphuric acid. Nearly half of the fluid in it was slowly distilled into the sulphuric acid, by the heat of a spirit lamp. The impregnated acid evaporated at a heat above 212° , and gave a small quantity of crystallised salt, which barely amounted to two grains and quarter : it had every property of sulphate of ammoniac. Sulphuric acid in excess was poured on the residuum, and the whole distilled by a heat not exceeding 300° , into a small quantity of water. This water, after the process, tasted strongly of sulphuric acid ; it had no peculiar odor. Tin thrown into it when heated, was not perceptibly oxydated ; mingled with stontitic lime water, it gave a copious white

precipitate, and after the precipitation became almost tasteless. Hence it evidently contained no nitric acid.

The 12,5 cubic inches of undecomposed gas that came over were examined; and accounting for the small quantity of common air previously contained in the airholder, must have been almost pure.

7. Now supposing 927 grains of the impregnated solution (including the weight of the nitrous gas), to have been operated upon, this must have contained about 16,7 cubic inches of nitrous gas. But 12,5 cubic inches escaped undecomposed: hence 4,2 were decomposed; and these weigh 1,44 grains, and are composed of ,8 oxygene, and ,64 nitrogene.*

Consequently, the nitrous gas must have furnished ,8 of oxygene to the green oxide of iron.

But ,64 of nitrogene require ,15 of hydrogene to form ,79 of ammoniac:† consequently 1 of

* Division IV. Section 5.

† Division II. Section 1.

water was decomposed, and this furnished ,85 of oxygen to the green oxide of iron.

The green oxide of iron contains $\frac{27}{100}$ oxygen; the red $\frac{48}{100}$. But the whole quantity of oxygen supplied from the water and nitrous gas is $8 + 85 = 1,65$; and calculating on the difference of the composition of the red and green oxide of iron, 5,7 grains of red oxide must have been deposited, and consequently these would saturate as much acid as ,79 grains of ammoniac, or 4,1 grains of green oxide of iron.*

And supposing the ammoniac in sulphate of ammoniac to be to the acid as 1 is to 3,† 3.2 grains of sulphate of ammoniac must have been formed, containing about 2,4 grains acid; and then 6,5 grains of green sulphate of iron must have been decomposed.

Hence we gain the following equation :

* No precipitation takes place during the conversion of solution of green sulphate into red; and the acid appears saturated.

† Division II, Section 6

The conclusions that may be drawn from this experiment, afford a striking instance of the importance of the application of the science of quantity to the chemical changes: for the data being one chemical fact, the decomposition of a given quantity of nitrous gas by known agents; the composition of nitrous gas, of water, ammoniac, the oxides of iron, and sulphate of ammoniac; we are able not only to determine the quantities of the simple constituents that have entered into new arrangements, but likewise the composition of two compound bodies, the green and red sulphates of iron.*

m. Though from the experiments in *e* it appeared that no decomposition of nitrous gas had been produced during or even after its absorption by solution of sulphate of iron at the common temperature; yet a suspicion that it might take place slowly, and that

* According to the estimation in the equation, 6.5 of dry green sulphate of iron contain 4.1 green oxide of iron, and 2.4 of Kirwan's real sulphuric acid; and 8.1 red sulphate of iron, contain 2.4 acid, and 5.7 red oxide of iron.

indications of it might be given by deposition, induced me to examine minutely two impregnated solutions, one of which had been at rest, confined by mercury, for 19 hours, and the other for 27. In neither of them could I discover any deposition, or alteration of color, which might denote a change.

Two cubic inches of oxygene were admitted to half a cubic inch of one of these solutions. The oxygene was slowly absorbed, and the solution gradually lost its color.

To ascertain if during the conversion of the nitrous gas held in solution by sulphate of iron, into nitric acid, by the oxygene of the atmosphere at the common temperature, any water was decomposed; I suffered an impregnated solution, weighing nearly two ounces, to remain in contact with the atmosphere at 57° — 62° , till it was become perfectly pale. It then had a strong acid taste, effervesced with carbonate of potash, and gave a blue precipitate with prussiate of potash.—It was saturated with quicklime, and heated: slight indications

of the presence of ammoniac were perceived.

As in this experiment the nitric acid had been most probably decomposed by the green oxide of iron, as in *f*, I sent oxygenated muriatic acid through an impregnated solution, till all the green oxide of iron was converted into red, and all the nitrous gas into nitric acid.

This solution saturated with potash, and heated, gave no ammoniacal smell.

From these experiments we may conclude,

1st. That solution of red sulphate of iron has little or no affinity for nitrous gas*; and that solution of common sulphate absorbs nitrous gas only in proportion as it contains green sulphate.

2dly. That solutions of green sulphate of iron dissolve nitrous gas in quantities proportionable to their concentration, without effecting

* The muddy green color produced in a solution of red sulphate of iron agitated in nitrous gas, depended upon impurities in the mercury. I have since found, that when the solution is completely oxygenated, the diminution is barely perceptible.

any decomposition of it at common temperatures. And the solubility of nitrous gas in solution of green sulphate, may be supposed to depend on an equilibrium of affinity, produced by the following simple attractions :

1. That of green oxide of iron for the oxygen of nitrous gas and water.

2. That of the hydrogen of the water for the nitrogen of the nitrous gas.

3. That of the principles of the sulphuric acid, for nitrogen and hydrogen.

3dly. That at high temperatures, that is, from 200° to 300° , the equilibrium of affinity producing the binary combination between nitrous gas and solution of green sulphate of iron is destroyed ; the attraction of the green oxide of iron for oxygen being increased ; whilst probably that of nitrogen for hydrogen is diminished.

Hence the nitrous gas is either liberated,* in

* Perhaps the liberation of nitrous gas from the solution

consequence of the affinity between oxygen and hydrogen, and oxygen and nitrogen not following the same ratio of alteration on increased temperature; or decomposed, because at a certain temperature the green oxide exerts such affinities upon water and nitrous gas, as to attract oxygen from both of them to form red oxide; whilst the still existing affinity between the hydrogen of the one, and the nitrogen of the other, disposes them to combine to form ammoniac.

4thly. That the change of color produced by introducing nitric acid to solution of common sulphate of iron, exactly analogous to that occasioned in it by impregnation with nitrous gas, is owing to the decomposition of the acid, by the combination of its oxygen with the green

takes place at a lower temperature than its decomposition. I have always observed that the quantity of yellow precipitate is greater when the solution is rapidly made to boil. Were it possible to heat it to a certain temperature at once, probably a complete decomposition would take place.

oxide of iron, and of its nitrous gas with the solution.

5thly. That nitrous gas in combination with solution of green sulphate of iron, is capable of exerting a strong affinity upon free or loosely combined oxygen, and of uniting with it to form nitric acid.

n. The products obtained from a solution of sulphate of iron saturated with nitrous gas, by Vauquelin and Humbolt, and their consequent mistake with regard to the nature of the process of absorption,* must have arisen from exposure of their impregnated solution to the atmosphere.

Indeed, from the acidity of it, on examination, from the small portion of ammoniac, and the large quantity of nitric acid obtained, it appears most probable that the whole of the nitrous gas employed was converted into nitric acid, by combining with atmospheric oxygen; for no nitric acid could have been obtained in

* Annales de Chimie. T. 38, pag. 187.

the mode in which they operated, unless the green oxide of iron in the solution had been previously converted into red.

VIII. *On the absorption of Nitrous Gas by solution of green Muriate of Iron.*

a. The analogy between the affinities of the constituents of the muriate and sulphate of iron, induced me to conjecture that they possessed similar powers of absorbing nitrous gas; and I soon found that this was actually the case; for on agitating half a cubic inch of solution of muriated iron, procured by dissolving iron filings in muriatic acid, in nitrous gas, the gas was absorbed with great rapidity, whilst the solution assumed a deep and bright brown tinge:

b. Proust,* who as I have before mentioned, supposes the existence of two oxides of iron only,

* Annales de Chimie, xxiii. pag. 85; or Nicholson's Phil. Journal vol. i. pag. 45.

one containing $\frac{27}{100}$ oxygen, the other $\frac{48}{100}$, has assumed, that the muriatic acid, and most other acids as well as the sulphuric, are capable of combining with these oxides, and of forming with each of them a distinct salt. He has, however, detailed no experiments on the muriates of iron.

As these salts are still more distinct from each other in their properties than the sulphates, and as these properties are connected with the phenomenon of the absorption and decomposition of nitrous gas, I shall detail the observations I have been able to make upon them.

c. When iron filings have been dissolved in pure muriatic acid, and the solution preserved from the contact of air, it is of a pale green color, and gives a white precipitate with alkaline prussiates. The alkalies throw down from it a light green oxide of iron.

When evaporated, it gives crystals almost white, which are extremely soluble in water; but insoluble in alcohol.

The solution of green muriate of iron has a

great affinity for oxygen, and attracts it from the atmosphere, from nitric acid, and probably from oxygenated muriatic acid.

When red oxide of iron is dissolved in muriatic acid, or when nitric acid is decomposed by solution of green muriate of iron; the red muriate of iron is produced. The solution of this salt is of a deep brown red, its odor is peculiar, and its taste, even in a very diluted state, highly astringent. It acts upon animal and vegetable matters in a manner somewhat analogous to the oxygenated muriatic acid, rendering them yellowish white, or yellow.*

Sulphuric acid poured upon it, produces a smell resembling that of oxygenated muriatic acid. Evaporated at a low temperature, it gives an uncrystallisable dark orange colored salt, which is soluble in alcohol, and when decomposed by the alkalies, gives a red precipitate. With prussiate of potash it gives prussian blue.

* Probably by giving them oxygen; whereas the green muriate and sulphate blacken animal substances; most likely by abstracting from them oxygen.

The common muriate of iron consists of different proportions of these two salts. It may be converted into red muriate by concentrated nitric acid, or into green by sulphurated hydrogen.

d. To ascertain if solution of red muriate of iron was capable of absorbing nitrous gas, I introduced into a jar filled with mercury, a cubic inch of nitrous gas, and admitted to it nearly half a cubic inch of solution of red muriate of iron. No discoloration took place. By much agitation, however, an absorption of nearly $\frac{2}{3}$ was produced, and the solution became of a muddy green. But this change of color, and probably the absorption, was in consequence of the oxydation of either the mercury, or some imperfect metals combined with it, by the oxygen of the red muriate. For I afterwards found, that precisely the same change of color was produced when a solution was agitated over mercury.

e I introduced to a cubic inch of concentrated solution of green muriate of iron, 7 cubic

inches of nitrous gas, free from nitric acid ; the solution instantly became colored at the edges, and on agitation absorbed the gas with much greater rapidity than even sulphate of iron ; in a minute, only a quarter of a cubic inch remained.

The solution appeared of a very dark brown, but evidently no precipitation had taken place in it, and the edges, when viewed against the light, were transparent and puce colored.

Five cubic inches more of nitrous gas were now dissolved in the solution. The intensity of the color increased, and after an hour no deposition had taken place. A little of it was then examined in the atmosphere ; it had a much more astringent taste than the unimpregnated solution, and effected no change in red cabbage juice. When prussiate of potash was introduced into it, its color changed to olive brown. A few drops of the solution, that had accidentally fallen on the mercury, soon became colorless, and then effervesced with carbonate of potash, and tasted strongly acid.

The remainder of the impregnated solution, which must have nearly equalled .75 cubic inches, was introduced into a matrafs, having a stopper and curved tube, as in the experiments on the solution of sulphate of iron; great care being taken to preserve it from the contact of air.

The matrafs was heated by a spirit lamp, the curved tube being in communication with a mercurial cylinder. Near 8 cubic inches of nitrous gas were collected, when the solution became of a muddy yellow. It was suffered to cool, and examined. A small quantity of yellow precipitate covered the bottom of the matrafs; the fluid was pellucid, and light green. A little of it thrown on prussiate of potash, gave a white precipitate, colored by streaks of light blue. When the yellow precipitate was partly dissolved by sulphuric acid, a drop of the solution, mingled with prussiate of potash, gave a deep blue green.

Hence, evidently, the precipitate was red oxide of iron.

Caustic potash in excess was introduced into the remainder of the solution, and it was heated. It gave an evident smell of ammoniac, and dense white fumes, when held over strong phlogisticated nitrous acid.

When half of it was evaporated, sulphuric acid in excess was poured on the remainder; muriatic acid was liberated, not perceptibly combined with any nitric acid.

f. In an experiment that I made to ascertain the quantity of nitrous gas capable of combining with solution of green muriate of iron; I found that ,75 cubic inches of saturated solution absorbed about 18 of nitrous gas, which is nearly double the quantity combinable with an equal portion of the strongest solution of sulphate of iron. A part of this impregnated solution, heated slowly, gave out more gas in proportion to the quantity it contained, than the last, and consequently produced less precipitate; so that I am inclined to suppose it probable, that at a certain temperature, all the dissolved nitrous gas may be dispelled from a solution.

From these experiments we may conclude,

1st. That the solution of green muriate of iron absorbs nitrous gas in consequence of nearly the same affinities as solution of green sulphate of iron ; its capability of absorbing larger quantities depending most probably on its greater concentration (that is, on the greater solubility of the muriate of iron), and perhaps, in some measure, on a new combining affinity, that of muriatic acid for oxygen.

2dly. That at certain temperatures nitrous gas is either liberated from solution of green muriate, or decomposed, by the combination of its oxygen with green oxide of iron, and of its nitrogen with hydrogen, produced by water decomposed by the oxide at the same time.

IX. Absorption of Nitrous Gas by Solution of Nitrate of Iron.

a. As well as two sulphates and two muriates

of iron, there exist two nitrates.* When concentrated nitric acid is made to act upon iron, nitrous gas is disengaged with great rapidity, and with great increase of temperature: the solution assumes a yellowish tinge, and as the process goes on, a yellow red oxide is precipitated.

Nitrate of iron made in this way, gives a bright blue mingled with prussiate of potash, and decomposed by the alkalies, a red precipitate. Its solution has little or no affinity for nitrous gas.

b. When very dilute nitric acid, that is, such as of specific gravity 1,16, is made to oxydate iron, without the assistance of heat, the solution gives out no gas for some time, and becomes dark olive brown: when neutralised it gives, decomposed by the alkalies, a light green precipitate; and mingled with prussiate of potash, pale green prussiate of iron.

* The existence of green nitrate was not suspected by Proust.

It owes its color to the nitrous gas it holds in solution. By exposure to the atmosphere it becomes pale, the nitrous gas combined with it being converted into nitric acid.

It is then capable of absorbing nitrous gas, and consists of pale nitrate of iron, mingled with red nitrate.

I have not yet obtained a nitrate of iron giving only a white precipitate with prussiate of potash, that is, such as contains *only* oxide of iron at its minimum of oxydation; for when pure green oxide of iron is dissolved by very dilute nitric acid, a small quantity of the acid is generally decomposed, which is likewise the case in the decomposition of nitre by green sulphate of iron. The solutions of nitrate of iron, however, procured in both of these modes, absorb nitrous gas with rapidity, and by sulphurated hydrogen might probably be converted into pale nitrate.

As it is impossible to obtain concentrated solutions of pale nitrate of iron, chiefly containing green oxide, its powers of absorbing

nitrous gas cannot be compared with the muriatic and sulphuric solutions, unless they are made of nearly the same specific gravity.

Nitrous gas is disengaged by heat from the impregnated solution of nitrate of iron, at the same time that much red oxide of iron is precipitated. Whether any nitrous gas is decomposed, I have not yet ascertained; for when unimpregnated pale nitrate of iron is heated, a part of the acid, and of the water of the solution, is decomposed by the green oxide of iron;* and in consequence ammoniac, and red nitrate of iron formed, whilst red oxide is precipitated.

X. Absorption of Nitrous Gas by other Metallic Solutions.

a. White prussiate of iron in contact with water absorbs nitrous gas to a great extent, and

* In this process nitrous oxide is sometimes given out; as will be seen hereafter.

becomes dark chocolate.*

b. Concentrated solution of sulphate of tin, probably at its minimum of oxydation, absorbs one eighth of its bulk of nitrous gas, and becomes brown, without deposition.

c. Solution of sulphate of zinc † absorbs about one tenth of its volume of nitrous gas, and becomes green.

d. Solution of muriate of zinc † absorbs nearly the same quantity, and becomes orange brown.

e. These are all the metallic substances on which I have experimented. It is more than probable that there exist others possessing similar powers of absorbing nitrous gas.

Whenever the metals capable of decomposing water exist in solutions at their minimum of oxydation, the affinities exerted by them on

* Hence we learn why no nitrous gas is disengaged when impregnated solution of sulphate of iron is decomposed by prussiate of potash, as in Div. IV. Sec. vii.

† In both of these solutions the metal is at its minimum of oxydation. The absorption of a small quantity of nitrous gas by white vitriol was observed by Priestley.

nitrous gas and water, will be such as to produce combination. The powers of metallic solutions to combine with nitrous gas at common temperatures, as well as to decompose it at higher temperatures, will probably be in the ratio of the affinity of the metallic oxides they contain, for oxygene.

XI. *The action of Sulphurated Hydrogene on solution of Green Sulphate of Iron, impregnated with Nitrous Gas.*

a. In an experiment on the absorption of nitrous gas by solution of green sulphate of iron, I introduced an unboiled solution of common sulphate, deprived of red oxide of iron by sulphurated hydrogene, into a jar filled with nitrous gas; the absorption took place as usual, and nearly six of gas entered into combination, the volume of the solution being unity. On applying heat to a part of this impregnated solution, the whole of the nitrous gas it contained (as nearly as I could guess), was expelled

undecomposed, and no yellow precipitate produced. Prussiate of potash poured into it gave only white prussiate of iron; and when it was heated with lime, no ammoniacal smell was perceptible.

I could refer this phenomenon to no other cause than to the existence of a small quantity of sulphurated hydrogen in the solution. That this was the real cause I found from the following experiment.

b. One part of a solution of green sulphate of iron, formed by the agitation of common sulphate of iron in contact with sulphurated hydrogen, was boiled for some minutes to expel the small quantity of gas retained by it undecomposed. It had then no peculiar smell, and gave a white prussiate of iron with prussiate of potash; the other part had a faint odor of sulphurated hydrogen, and gave a dirty white precipitate with prussiate of potash. Nearly equal quantities of each were saturated with nitrous gas, and heated. The unboiled impregnated solution gave out all its nitrous

gas undecomposed ; whilst in the boiled solution it was partly decomposed, yellow precipitate and ammoniac being formed.

c. This singular phænomenon of the power of a minute quantity of sulphurated hydrogen, in preventing the decomposition of nitrous gas and water, by green oxide of iron, will most probably take place in other impregnated solutions. It seems to depend on the strong affinity of the hydrogen of sulphurated hydrogen for oxygen.

XII. *Additional Observations.*

a. For separating nitrous gas from gases absorbable to no great extent by water ; a well boiled solution of green muriate of iron should be employed. Nitrous gas agitated in this is rapidly absorbed, and it has no affinity for, or action on, nitrogen, hydrogen, or hydrocarbonate.

b. Nitrous gas carefully obtained from mercury and nitric acid, when received under mer-

cury, or boiled water, and absorbed by solution of green muriate, or sulphate of iron, rarely leaves a residuum of $\frac{1}{200}$ of its volume: preserved over common water, and absorbed, the remainder is generally from $\frac{1}{40}$ to $\frac{1}{90}$, from the nitrogene disengaged by the decomposition of the common air contained in the water.

c. The nitrous gas carefully obtained from the decomposition of nitric acid of 1.26, by copper, I have hardly ever found to contain more than from $\frac{1}{30}$ to $\frac{1}{50}$ nitrogene, when received through common water: when boiled water is employed, the residuum is nearly the same as that of nitrous gas obtained from mercury.

d. Consequently the gas from those two solutions may be used in common. It is more than probable, that the small quantities of nitrogene generally mingled with nitrous gas from copper and mercury, arise either from the common air of the vessels in which it was produced, or that of the water over which it was received. There is no reason for supposing that it is generated by a complete decomposition of

a portion of the acid.*

e. Whenever nitrous oxide is mingled with nitrous gas and nitrogene, it must be separated by well boiled water ; and after the corrections are made for the quantity of air disengaged from the water, the nitrous gas absorbed by the muriatic solution.

* Humbolt, who is the first philosopher that has applied the solution of sulphate of iron to ascertain the purity of nitrous gas, asserts that he uniformly found nitrous gas obtained from solution of copper in nitrous acid, to contain from six tenths to one tenth nitrogene.

Annales de Chimie, vol. xxviii. pag. 147.

DIVISION V.

EXPERIMENTS and OBSERVATIONS on the production of NITROUS OXIDE from NITROUS GAS and NITRIC ACID, in different modes.

I. *Preliminaries.*

a. **T**he opinions of Priestley* and Kirwan,† relating to the causes of the conversion of nitrous gas into nitrous oxide, were founded on the theory of phlogiston. The first of these philosophers obtained nitrous oxide by placing nitrous gas in contact with moistened iron filings, or the alkaline sulphures. The last by exposing it to sulphurated hydrogen.

The Dutch chemists,‡ the latest experi-

* Vol. ii. pag. 55. † Phil. Transf. vol. lxxvi. pag. 133.

‡ Journal de Physique, tom. xliii. 323.

mentalist on nitrous oxide, have supposed that the production of this substance depends upon the simple abstraction of a portion of the oxygene of nitrous gas. They obtained nitrous oxide by exposing nitrous gas to muriate of tin, to copper in solution of ammoniac, and likewise by passing it over heated sulphur.

The diminution of volume sustained by nitrous gas during its conversion into nitrous oxide, has never been accurately ascertained; it has generally been supposed to be from two thirds to eight tenths.

b. Nitrous gas may be converted into nitrous oxide in two modes.

First, by the simple abstraction of a portion of its oxygene, by bodies possessing a strong affinity for that principle, such as alkaline sulphites, muriate of tin, and dry sulphures.

Second, by the combination of a body with a portion both of its oxygene and nitrogene, such as hydrogene, when either in a nascent form, or a peculiar state of combination.

c. Each of these modes will be distinctly treated of; and to prevent unnecessary repetitions, I shall give an account of the general manner in which the following experiments on the conversion of nitrous gas into nitrous oxide, have been conducted.

Nitrous gas, the purity of which has been accurately ascertained by solution of muriate of iron, is introduced into a graduated jar filled with dry mercury. If a fluid substance is designed for the conversion of the gas into nitrous oxide, it is heated, to expel any loosely combined air which might be liberated during the process; and then carefully introduced into the jar, by means of a small phial. After the process is finished, and the diminution accurately noted, the nitrous oxide formed is absorbed by pure water. If any nitrous gas remains, it is condensed by solution of muriate of iron; other residual gases are examined by the common tests. The quantity of nitrous oxide dissolved by the fluid is determined by a comparative experiment; and the corrections for tempera-

ture and pressure being guessed at, the conclusions drawn.

If a solid substance is used, rather more nitrous gas than that designed for the conversion, is introduced into the jar. The substance is brought in contact with the gas, by being carried under the mercury; and as a little common air generally adheres to it, a small portion of the nitrous gas is transferred into a graduated tube, after the insertion, and its purity ascertained. In other respects the process is conducted as mentioned above.

II. *Of the conversion of Nitrous gas into Nitrous Oxide, by Alkaline Sulphites.*

The alkaline sulphites, particularly the sulphite of potash, convert nitrous gas into nitrous oxide, with much greater rapidity than any other bodies.

At temperature 46° , 16 cubic inches of nitrous gas were converted, in less than an hour, into 7,8 of nitrous oxide, by about 100

grains of pulverised sulphite of potash, containing its water of crystallisation. No sensible increase of temperature was produced during the process, no water was decomposed, and the quantity of nitrogen remaining after the experiment, was exactly equal to that previously contained in the nitrous gas.

The nitrous oxide produced from nitrous gas by sulphite of potash, has all the properties of that generated from the decomposition of nitrate of ammoniac. It gives, as will be seen hereafter, the same products by analysis. Phosphorus, the taper, sulphur, and charcoal, burn in it with vivid light. It is absorbable by water, and capable of expulsion from it unaltered, by heat.

Nitrous gas is converted into nitrous oxide by the alkaline sulphites with the same readiness, whether exposed to the light, or deprived of its influence.

The solid sulphites act upon nitrous gas much more readily than their concentrated solutions; they should however always be suffered to

retain their water of crystallisation, or otherwise they attract moisture from the gas, and render it drier, and in consequence more condensed than it would otherwise be. In case perfectly dry sulphites are employed, the gas should be always saturated with moisture after the experiment, by introducing into the cylinder a drop of water.

The sulphites, after exposure to nitrous gas, are either found wholly, or partially, converted into sulphates. Consequently the conversion of nitrous gas into nitrous oxide by these bodies, simply depends on the abstraction of a portion of its oxygen; the nitrogen and remaining oxygen assuming a more condensed state of existence.

If we reason from the different specific gravities of nitrous oxide and nitrous gas, as compared with the diminution of volume of nitrous gas, during its conversion into nitrous oxide, 100 parts of nitrous gas, supposing the former estimation of the composition of nitrous oxide given in Division III, accurate, would consist

of 54 oxygene, and 46 nitrogene; which is not far from the true estimation. Or assuming the composition of nitrous gas, as given in Division IV, it would appear from the diminution, that 100 parts of nitrous oxide consisted of 38 oxygene, and 62 nitrogene.

III. *Conversion of Nitrous Gas into Nitrous Oxide, by Muriate of Tin, and dry Sulphures.*

a. Nitrous gas exposed to dry muriate of tin, is slowly converted into nitrous oxide; during this process the apparent diminution is to about one half; but if the products are nicely examined, and the necessary corrections made, the real diminution of nitrous gas by muriate of tin, will be the same as by the sulphites; that is, 100 parts of it will be converted into 48 of nitrous oxide.

During this conversion, no water is decomposed, and no nitrogene evolved. Solution of muriate of tin converts nitrous gas into nitrous oxide; but with much less rapidity than the solid salt.

b. Nitrous gas exposed to dry and perfectly well made sulphures, particularly such as are produced from crystalised alunⁿ* and charcoal not sufficiently inflammable to burn in the atmosphere, is converted into nitrous oxide by the simple abstraction of a portion of its oxygene, and consequently undergoes a diminution of $\frac{52}{100}$.

It is probable, that all the bodies having strong affinity for oxygene will, at certain temperatures, convert nitrous gas into nitrous oxide. Priestley, and the Dutch chemists, effected the change by heated sulphur. Perhaps nitrous gas sent through a tube heated, but not ignited, with phosphorus, would be converted into nitrous oxide.

IV. *Decomposition of Nitrous Gas, by Sulphurated Hydrogene.*

a. When nitrous gas and sulphurated hy-

* That is, alun containing sulphate of potash.

drogene are mingled together, a decomposition of them slowly takes place. The gases are diminished, sulphur deposited, nitrous oxide formed, and signs of the production of ammoniac* and water perceived.

In this process no sulphuric, or sulphureous acid is produced; consequently none of the sulphur is oxydated, and of course the changes depend upon the combination of the hydrogene of the sulphurated hydrogene, with different portions of the oxygene and nitrogene of the nitrous gas, to form water and ammoniac, the remaining oxygene and nitrogene assuming the form of nitrous oxide.

This singular exertion of attractions by a simple body, appears highly improbable a priori, nor did I admit it, till the formation of ammoniac, and the non-oxygenation of the sulphur, were made evident by many experiments.

In those experiments, the diminution of the nitrous gas was not uniformly the same. It

* The production of ammoniac in this process was observed by Kirwan and Austin.

varied from $\frac{11}{20}$ to $\frac{14}{20}$. In the most accurate of them, 5 cubic inches of nitrous gas were converted into 2.2 of nitrous oxide. Consequently the quantity of ammoniac formed was .047 grains.

In experiments on the conversion of nitrous gas into nitrous oxide, by sulphurated hydrogen, the gases should be rendered as dry as possible. The presence of water considerably retards the decomposition.

b. The sulphures* dissolved in water convert nitrous gas into nitrous oxide. This decomposition is not, however, produced by the simple abstraction of oxygen from the nitrous gas to form sulphuric acid. It depends as well on the de-

* Solution of sulphure of strontian, or barytes, should be used. During the conversion of nitrous gas into nitrous oxide by those bodies, a thin film is deposited on the surface of the solution. This film examined, is found to consist of sulphur and sulphate. Possibly the nitrous gas is wholly decomposed by the hydrogen of the sulphurated hydrogen in the solution, whilst the sulphate is produced from water decomposed by the sulphur to form more gas for the saturation of the hydro-sulphure.

composition of the sulphurated hydrogen dissolved in the solution, or liberated from it. In this process sulphur is deposited on the surface of the fluid, sulphuric acid is formed, and the diminution, making the necessary corrections, is nearly the same as when free sulphurated hydrogen is employed.

It is extremely probable that sulphurated hydrogen, in combination with the alkalies, as well as with water, is capable of being slowly decomposed by nitrous gas.

V. *Decomposition of Nitrous Gas by Nascent Hydrogene.*

a. When nitrous gas, is exposed to wetted iron filings, a diminution of its volume slowly takes place; and after a certain time, it is found converted into nitrous oxide.

In this process ammoniac* is formed, and the iron partially oxydated.

* As was first observed by Priestley and Austin, and as I have proved by many experiments.

The water in contact with the iron is decomposed by the combination of its oxygene with that substance, and of its hydrogene with a portion of the oxygene and nitrogene of the nitrous gas, to form water and ammoniac.

That the iron is not oxydated at the expence of the oxygene of the nitrous gas, appears very probable from the analogy between this process, and the mutual decomposition of nitrous gas and sulphurated hydrogene. Besides, dry iron filings effect no change whatever in nitrous gas, at common temperatures.

I have generally found about 12 of nitrous gas converted into 5 of nitrous oxide in this process; which is not very different from the diminution by sulphurated hydrogene. It takes place equally well in light and darkness; but more rapidly in warm weather than in cold.

b. Nitrous gas exposed to a large surface of zinc, in contact with water, is slowly converted into nitrous oxide; at the same time that ammoniac is generated, and white oxide of zinc formed. This process appears to depend, like

the last, upon the decomposition of water by the affinities of part of the oxygene and nitrogene of nitrous gas, for its hydrogene, to form ammoniac and water; and by that of zinc for its oxygene. Zinc placed in contact with water, and confined by mercury,* decomposes it at the common temperature. Zinc, when perfectly dry, does not in the slightest degree act upon nitrous gas.

I have not been able to determine exactly the diminution of volume of nitrous gas, during its conversion into nitrous oxide by zinc. In one experiment 20 measures of nitrous gas, containing about ,03 nitrogene, were diminished to 9, after an exposure of eight days to wetted zinc; but from an accident, I was not able to ascertain the exact quantity of nitrous oxide formed.

c. It is probable that most of the imperfect metals will be found capable of oxydation, by the decomposition of water, when its hydrogene is abstracted by the oxygene and nitrogene of

* As I have found by experiment.

nitrous gas. I have this day (April 14, 1800), examined two portions of nitrous gas, one of which had been exposed to copper filings, and the other to powder of tin, for twenty-three days.

The gas that had been exposed to copper was diminished nearly two fifths. The taper burnt in it with an enlarged flame, blue at the edges. Hence it evidently contained nitrous oxide.

The nitrous gas in contact with tin had undergone a diminution of one fourth only, and did not support flame.

VI. *Miscellaneous Observations on the conversion of Nitrous Gas into Nitrous Oxide.*

a. Dr. Priestley found nitrous gas exposed to a mixture of iron filings and sulphur, with water, converted after a certain time, into nitrous oxide. Sulphurated hydrogen is always produced during the combination of iron and sulphur, when they are in contact with water; and by the hydrogen of this in the nascent

state, the nitrous gas is most probably decomposed.

b. Green oxide of iron moistened with water, exposed to nitrous gas, slowly gains an orange tinge, whilst the gas is diminished. Most likely it is converted into nitrous oxide; but this I have not ascertained.

c I exposed nitrous gas, to the following bodies over mercury for many days, without any diminution, or apparent change in its properties. Alcohol, saccharine matter, hydro-carbonate, sulphureous acid, and phosphorus.

d. Crystallised sulphate, and muriate of iron, absorb a small quantity of nitrous gas, and become dark colored on the outside; but after this absorption, (which probably depends on their water of crystallisation,) has taken place, no change is effected in the gas remaining.

e The power of iron to decompose water being much increased by increase of temperature, nitrous gas is converted into nitrous oxide much more rapidly when placed in contact with a surface of heated iron, than when exposed to it at

common temperatures. During the decomposition of nitrous gas in this way, ammoniac * is formed.

f. The curious experiments of Rouppe,† on the absorption of gases by charcoal, compared with the phænomena noticed in this Division, render it probable that hydrogen in a state of loose combination with charcoal, will be found to convert nitrous gas into nitrous oxide.

VII. *Recapitulation of conclusions concerning the conversion of Nitrous Gas into Nitrous Oxide.*

a. Certain bodies having a strong affinity for oxygen, as the sulphites, dry sulphures, muriate of tin, &c. convert nitrous gas into nitrous oxide, by simply attracting a portion of its oxygen; whilst the remaining oxygen

* As was observed by Milner. Nitrous gas passed over heated zinc, or tin, I doubt not will be found converted into nitrous oxide.

† Annales de Chimie. xxxii, p. 3.

enters into combination with the nitrogene, and they assume a more condensed state of existence.

b. Nitrous gas is converted into nitrous oxide by hydrogene, in a peculiar state of existence, as in sulphurated hydrogene; and that by a series of very complex affinities. Both oxygen and nitrogene are attracted from the nitrous gas by the hydrogene, in such proportions as to form water and ammoniac, whilst the remaining oxygen and nitrogene * assume the form of nitrous oxide.

c. Nitrous gas placed in contact with bodies, such as iron and zinc decomposing water, is converted into nitrous oxide, at the same time that ammoniac is formed. It is difficult to ascertain the exact rationale of this process. For either the nascent hydrogene produced by the decomposition of the water by the metallic substance may combine with portions of both the

* The decomposition and recomposition of water, in this process, are analogous to some of the phenomena observed by the ingenious Mrs. Fulhame.

oxygene and nitrogene of the nitrous gas ; and thus by forming water and ammoniac, convert it into nitrous oxide. Or the metallic substance may attract at the same time oxygene from the water and nitrous gas, whilst the nascent hydrogene of the water seizes upon a portion of the nitrogene of the nitrous gas to form ammoniac.

The degree of diminution, and the analogy between this process and the decomposition of nitrous gas by sulphurated hydrogene, render the first opinion most probable.

VIII. *The production of Nitrous Oxide during the oxydation of Tin, Zinc, and Iron, in Nitric Acid.*

a. Dr. Priestley discovered, that during the solution of tin, zinc, and iron, in nitric acid, certain portions of nitrous oxide were produced, mingled with quantities of nitrous gas, and nitrogene, varying in proportion as the acid employed was more or less concentrated.

It has long been known that ammoniac is formed during the solution of tin, zinc, and iron, in diluted nitric acid. Consequently, in these processes water is decomposed.

I had designed to investigate minutely these phenomena, so as to ascertain the quantities of water and acid decomposed, and of the new products generated. But after going through some experiments on the oxydation of tin without gaining conclusive results, the labor, and sacrifice of time they demanded, obliged me to desist from pursuing the subject, till I had completed more important investigations.

I shall detail the few observations which have occurred to me, relating to the production of nitrous oxide from metallic solutions.

b. When tin is dissolved in concentrated nitric acid, such as of 1.4, nitrous oxide is produced, mingled with generally more than twice its bulk of nitrous gas. In this process but little free nitrogen is evolved, and the tin is chiefly precipitated in the form of a white powder. If the solution, after the generation of these pro-

ducts, is saturated with lime, and heated, the ammoniacal smell is distinct.

When nitric acid of specific gravity 1.24, is made to act upon tin; in the beginning of the process, nearly equal parts of nitrous gas and nitrous oxide are produced; as it advances, the proportion of nitrous oxide to the nitrous gas increases: the largest quantity of nitrous oxide that I have found in the gas procured from tin is $\frac{3}{4}$, the remainder being nitrous gas and nitrogene.

When tin is oxydated in an acid of less specific gravity than 1.09, the quantities of gas disengaged are very small, and consist of nitrogene, mingled with minute portions of nitrous oxide, and nitrous gas.

Whenever I have saturated solutions of tin in nitric acid of different specific gravities, with lime, and afterwards heated them, the ammoniacal smell has been uniformly perceptible, and generally most distinct when diluted acids have been employed.

c. When zinc is dissolved in nitric acid,

whatever is its specific gravity, certain quantities of nitrous oxide are produced.

Nitric acids of greater specific gravity than 1.2, act upon zinc with great rapidity, and great increase of temperature. The gases disengaged from these solutions consist of nitrous gas, nitrous oxide, and nitrogen; the nitrous oxide rarely equals one third of the whole.

When nitric acid of 1,104 is made to dissolve zinc, the gas obtained in the middle of the process consists chiefly of nitrous oxide. From such a solution I obtained gas which gave a residuum of one sixth only when absorbed by water. The taper burnt in it with a brilliant flame, and sulphur with a vivid rose-colored light.

100 grains of granulated zinc, during their solution in 300 grains of nitric acid, of 1,43, diluted with 14 times its weight of water, produced 26 cubic inches of gas. Of this gas $\frac{7}{36}$ were nitrous, $\frac{17}{36}$ nitrous oxide, and the remainder nitrogen. The solution saturated with lime and heated, gave a distinct smell of ammoniac.

d. During the solution of iron in concentrated nitric acid, the gas given out is chiefly nitrous; it is however generally mingled with minute quantities of nitrous oxide. When very dilute nitric acids are made to act upon iron, by the assistance of heat, nitrous oxide is produced in considerable quantities, mingled with nitrous gas and nitrogen; the proportions of which are smaller as the process advances.* The fluid remaining after the oxydation and solution of iron in nitric acid, always contains ammoniac.

e. As during the solution of tin, zinc, and iron, in nitric acid, the quantity of acid is diminished in proportion as the process advances, it is reasonable to suppose that the relative quantities of the gases evolved are perpetually varying. In the beginning of a dissolution, the nitrous gas

* From one of Dr. Priestley's experiments, it appears that hydrogen gas is sometimes disengaged during the solution of iron in very dilute nitric acid by heat. This phenomenon has never occurred to me.

generally predominates, in the middle nitrous oxide, and at the end nitrogen.

f. During the generation of nitrous gas, nitrous oxide, and ammoniac, from the decomposition of solution of nitric acid in water, by tin, zinc, and iron, very complex attractions must exist between the constituents of the substances employed. The acid and the water are decomposed at the same time, and in proportions different as the solution is more concentrated, by the combination of their oxygen with the metallic body.

The nitrous gas is produced by the combination of the metal with $\frac{32}{100}$ of the oxygen of the acid. The nitrous oxide is most probably generated by the decomposition of a portion of the nitrous gas disengaged, by the nascent hydrogen of the water decomposed; some of it may be possibly formed from a more complete decomposition of the acid.

The production of ammoniac may arise, probably from two causes; from the decomposition of the nitrous gas by the combi-

nation of the nascent hydrogen of the water, with portions of its oxygen and nitrogen at the same time ; and from the union of hydrogen with nascent nitrogen liberated in consequence of a complete decomposition of part of the acid.

IX. *Additional Observations on the production of Nitrous Oxide.*

a. When nitric acid is combined with muriatic acid, or sulphuric acid,* the quantities of nitrous oxide produced from its decomposition by tin, zinc, and iron, are rather increased than diminished. The nitrous oxide obtained from these solutions is, however, never sufficiently pure for physiological experiments. It is always mingled with either nitrous gas, nitrogen, or hydrogen, and sometimes with all of them.

b. From the solutions of bismuth, nickel,

* As was discovered by Priestley, and the Dutch Chemists.

lead, and copper, in diluted nitric acid, I have never obtained any perceptible quantity of nitrous oxide: the gas produced is nitrous, mingled with different portions of nitrogene. Antimony and mercury, during their solution in aqua regia, give out only nitrous gas.

Probably none of the metallic bodies, except those that decompose water at temperatures below ignition, will generate nitrous oxide from nitric acid. On cobalt and manganese I have never had an opportunity of experimenting: manganese will probably produce nitrous oxide.

c. During the solution of vegetable matters* in nitric acid, by heat, very minute portions of nitrous oxide are sometimes produced, always however mingled with large quantities of nitrous gas, and carbonic acid.

When nitric acid is decomposed by ether, fixed oils, volatile oils, or alcohol, towards the end of the process small quantities of nitrous oxide are produced, and

* Such as the leaves, bark, and wood, of trees.

sometimes sufficiently pure to support the flame of the taper. †

d. When green oxide of iron is dissolved in nitric acid, nitrous oxide is produced, mingled with nitrogene and nitrous gas.

e During the conversion of green sulphate, or green muriate of iron into red, by the decomposition of dilute nitric acid, nitrous oxide is formed, mingled with different proportions of nitrous gas and nitrogene.

f. When solution of green nitrate of iron is heated, a part of the acid is decomposed, red oxide is precipitated, red nitrate formed, and impure nitrous oxide evolved.

g. When iron is introduced into a solution of nitrate of copper, the copper is precipitated in its metallic state, whilst nitrous oxide, mingled with small portions of nitrogene, is produced.*

Both zinc and tin precipitate copper in its metallic form from solution in the nitric acid.

† As I have observed after Priestley.

* As was discovered by Priestley.

During these precipitations, certain quantities of nitrous oxide are generated, mingled however with larger quantities of nitrogene than that produced from decomposition by iron. In all these processes ammoniac is formed, and water consequently decomposed.

The decomposition of water and nitric acid, during the precipitation of copper from solution of nitrate of copper, by tin, zinc, and iron, depends upon the strong affinity of those metals for oxygene, and their powers of combining with a larger quantity of it than copper.

X. *Decomposition of Aqua Regia by Platina, and evolution of a Gas analogous to Oxygenated Muriatic Acid, and Nitrogene:*

a. De la Metherie, in his essay on different airs, has asserted that the gas produced by the solution of platina in nitro-muriatic acid, is identical with the dephlogisticated nitrous gas of Priestley. He calls it nitrous gas with excess

of pure air, and affirms that it diminishes, both with nitrous gas and common air.

b. I introduced into a vessel containing 30 grains of platina, 2050 grains of aqua regia, composed of equal parts, by weight, of concentrated nitric acid of 1,43, and muriatic acid of 1,16. At the common temperature, that is, 49°, no action between the acid and platina appeared to take place. On the application of the heat of a spirit lamp, the solution gradually became yellow red, and gas was given out with rapidity. Some of this gas received in a jar filled with warm water, appeared of a bright yellow color. On agitation, the greater part of it was absorbed by the water, and the remainder extinguished flame. When it was received over mercury, it acted upon it with great rapidity, and formed on the surface a white crust.

As the process of solution advanced, the color of the acid changed to dark red, at the same time that the production of gas was much increased; more than 40 cubic inches were soon collected in the water apparatus.

Different portions of the gas were examined, it exhibited the following properties :

1. Its color was orange red,* and its smell exactly resembled that of oxygenated muriatic acid.

2. When agitated in boiled water, it was rapidly absorbed, leaving a residuum of rather more than one twelfth.

3. The taper burnt in it with increased brilliancy, the flame being long, and deep red at the edges.

4. Iron introduced into it ignited, burnt with a dull red light.

5. Green vegetables exposed to it were instantly rendered white.

6. It underwent no diminution, mingled with atmospheric air.

7. When mingled with nitrous gas, it gave dense red vapor, and rapid diminution.

* This deep color depended, in some measure, upon the nitro-muriatic vapor suspended in it. I have since observed that it is more intense in proportion as the heat employed for the production of the gas has been stronger. The natural color of the peculiar gas is deep yellow.

c. From the exhibition of these properties, it was evident that the gas produced during the solution of platina in aqua regia, chiefly consisted of oxygenated muriatic acid, or of a gas highly analogous to it. It was, however, difficult to conceive how a body, by combining with a portion of the oxygene of nitro-muriatic acid, could produce from it oxygenated muriatic acid, apparently mingled with very small portions of any other gas.

d. To ascertain whether any permanent gas was produced during the ebullition of aqua regia, of the same composition as that used for the solution of the platina; I kept a large quantity of it boiling for some time, in communication with the water apparatus; the gas generated appeared to be wholly nitro-muriatic, and was absorbed as fast as produced, by the water.

e. To determine whether any nitrous oxide was mingled with the peculiar gas, as well as the nature and quantity of the unaborbable gas, nitrous gas was gradually added to 21 cubic inches of the gas produced from a new solution,

till the diminution was complete : the gas remaining equalled 2,3 cubic inches ; it was unabsorbable by water, and extinguished flame.

In another experiment, when the the last portions of gas from a solution were carefully received in water previously boiled, 12 cubic inches agitated in water left a residuum of 1.3 ; whilst the same quantity decomposed by nitrous gas, containing ,02 nitrogene, left about 1.5

Hence it appeared that the aëriform products of the solution consisted of the peculiar gas analogous to oxygenated muriatic acid, and of a small quantity of nitrogene.

f. Consequently a portion of the nitric acid of the aqua regia had been decomposed ; but if it had given oxygene both to the platina and muriatic acid, the quantity of nitrogene evolved ought to have been much more considerable.

g. To ascertain if any water had been decomposed, and the nitrogene condensed in the solution by its hydrogene, to form ammoniac, I saturated a solution with lime, and heated it, but no ammoniacal smell was perceived.

b. To determine if any nitrogene had entered into chemical combination with muriatic acid and oxygene, so as to form an aëriform triple compound, analogous in its properties to oxygenated muriatic acid, I exposed some of the gas to mercury, expecting that this substance, by combining with its oxygene, would effect a complete decomposition; and this was actually the case: for the gas was at first rapidly diminished, and the mercury became oxydated; its volume, however, soon increased; and the residual gas appeared to be nitrous, mingled with much nitrogene. The exact proportions of each, from an accident, I could not determine.

This experiment was inconclusive, because the nitro-muriatic acid suspended in the peculiar gas, from which it can probably be never perfectly freed, acted in common with it upon the mercury, and produced nitrous gas: and this nitrous gas, at the moment of its production, formed nitrous acid by combining with the oxygene of the peculiar gas; and the nitrous

acid generated * was again decomposed by the mercury ; and hence nitrous gas evolved, and possibly some nitrogene.

i. Peculiar circumstances prevented me at this time from completely investigating the subject. It remains doubtful whether the gas consists simply of highly oxygenated muriatic acid and nitrogene, † produced by the decom-

* The decomposition of æriform nitrous acid by mercury, was first noted by Priestley ; vol. iii. pag. 101. This decomposition I have often had occasion to observe. In reading Humbolt's paper on eudiometry, *Annales de Chimie*, xxviii, pag. 150, I was not a little surprised to find that he takes no notice of this fact. He seems to suppose that nitrous acid can remain æriform, and even be condensed, in contact with mercury, without alteration. He says, " In mingling 100 parts of atmospheric air with 100 of nitrous air, the air immediately became red, but all the acid produced remained æriform ; and after eighteen hours some *drops* only of acid were formed, which *swam* upon the mercury."

† Lavoisier has said concerning aqua regia, " In solutions of metals in this acid, as in all other acids, the metals are first oxydated, by attracting a part of the oxygene from the compound radical. This occasions the disengagement of a particular species of gas not hitherto described, which may be called nitro-muriatic gas. It

position of nitric acid from the coalescing affinities of platina and muriatic acid for oxygene ; or whether it is composed of a *peculiar* gas, analogous to oxygenated muriatic acid, and nitrogene, generated from some unknown affinities. †

XI. *On the action of the Electric Spark on a mixture of Nitrogene and Nitrous Gas.*

Thinking it possible that nitrous gas and

“ has a very disagreeable smell, and is fatal to animal life
“ when respired ; it attacks iron, and causes it to rust ; it
“ is absorbed in considerable quantities by water.” Elem.
Eng. 237.

† I have no doubt but that the gas procured from the solution of gold in aqua regia, is analogous to that produced from platina.

Some very uncommon circumstances are attendant on the solution of platina :

1st. The immense quantity of acid required for the solution of a minute quantity of platina.

2d. The great quantity of gas produced during the solution of this minute quantity.

3d. The intense red color of the solution, and its perfectly acid properties after it ceases to act upon the metal.

nitrogene might be made to combine by the action of the electric spark, so as to form nitrous oxide, I introduced 20 grain measures of each of them into a small detonating tube, graduated to grains, standing over mercury, and containing a very small quantity of cabbage juice rendered green by an alkali. After electric sparks had been passed through the gases for an hour and half, they were diminished to about 32, and the cabbage juice was slightly reddened. On introducing about 10 measures of hydrogen, and passing the electric spark through the whole, no inflammation or diminution was perceptible. Hence the condensation most probably arose wholly from the formation of nitrous acid,* by the more intimate union of the oxygen of nitrous gas with some of its nitrogen, as in the experiments of Priestley.

As the nascent nitrogen, in the decompo-

* For if nitrous oxide had been formed, it would have been decomposed by the hydrogen.

fition of nitrate of ammoniac, combines with a portion of oxygene and nitrogene, to form nitrous oxide; it is probable that nitrous oxide may be produced during the passage of nitrous gas and ammoniac through a heated tube.

XII. *General Remarks.*

There are no reasons for supposing that nitrous oxide is formed in any of the processes of nature; and the nice equilibrium of affinity by which it is constituted, forbids us to hope for the power of composing it from its simple principles. We must be content to produce it, either directly or indirectly, from the decomposition of nitric acid. And as in the decomposition of nitrate of ammoniac, not only all the nitrogene of the nitric acid enters into the composition of the nitrous oxide produced, but likewise that of the ammoniac, this process is by far the cheapest, as well as the most expeditious. A mode of producing ammoniac at

little expence, has been proposed by Mr. Watt. Condensed in the sulphuric acid, it can be easily made to combine with nitric acid, from the decomposition of nitre by double affinity. And thus, if the hopes which the experiments at the end of those researches induce us to indulge, do not prove fallacious, a substance which has been heretofore almost exclusively appropriated to the destruction of mankind, may become, in the hands of philosophy, a means of producing health and pleasurable sensation.

RESEARCH II.
INTO THE COMBINATIONS OF
NITROUS OXIDE,
AND ITS
DECOMPOSITION
BY
COMBUSTIBLE BODIES.

RESEARCH II.

DIVISION I.

EXPERIMENTS and OBSERVATIONS on the COMBINATIONS of NITROUS OXIDE.

1. Combination of Water with Nitrous Oxide.

a. **T**HE discoverer of nitrous oxide first observed its solubility in water; and it has since been noticed by different experimentalists.

Dr. Priestley found that water dissolved about one half of its bulk of nitrous oxide, and that at the temperature of ebullition, this substance was incapable of remaining in combination with it.*

* Experiments and observations, vol. ii. pag. 81.

b. I introduced to 9 cubic inches of pure water, i. e. water distilled under mercury, 7 cubic inches of nitrous oxide, which had been obtained over mercury, from the decomposition of nitrate of ammoniac, and in consequence was perfectly pure. After they had remained together for 11 hours, temperature being 46° , during which time they were frequently agitated, the gas remaining was 2,3; consequently 4,7 cubic inches had been absorbed. And then, 100 cubic inches, = 25300 grains of water, will absorb 54 cubic inches, = 27 grains, of nitrous oxide.

c. The taste of water impregnated with nitrous oxide, is distinctly sweetish; it is softer than common water, and, in my opinion, much more agreeable to the palate. It produces no alteration in vegetable blues, and effects no change of color in metallic solutions.

d. Thinking that water impregnated with nitrous oxide might probably produce some effects when taken into the stomach, by giving out its gas, I drank, in June, 1799, about

3 ounces of it, but without perceiving any effects.

A few days ago, considering this quantity as inadequate, I took at two draughts nearly a pint, fully saturated; and at this time Mr. Joseph Priestley drank the same quantity.

We neither of us perceived any remarkable effects.

Since that time I have drank near three pints of it in the course of a day. In this instance it appeared to act as a diuretic, and I imagined that it expedited digestion. As a matter of taste, I should always prefer it to common water.

e. Two cubic inches of pure water, that had been made to absorb about 1,1 cubic inches of nitrous oxide; when kept for some time in ebullition, and then rapidly cooled, produced nearly 1 of gas. Sulphur burnt in this gas with a vivid rose-colored flame.

In another experiment, in which the gas was expelled by heat from impregnated water, and absorbed again after much agitation on

cooling ; the residuum was hardly perceptible, and most likely depended upon some gas which had adhered to the mercury, and was liberated during the ebullition. Hence it appears that nitrous gas is expelled unaltered from its aqueous solution by heat.

f. I have before mentioned, Division III, that nitrous oxide, during its combination with spring water, expels the common air dissolved in it. This common air generally amounts to one sixteenth, the volume of the water being unity. A correction on account of this circumstance must be made for the apparent deficiency of diminution, and for the common air mingled in consequence, with nitrous oxide during its absorption by common water.

g. Water impregnated with nitrous gas absorbed nitrous oxide ; but the residual gas was much greater than that of common water, and gave red fumes with atmospheric air. Nitrous gas agitated for a long while over water highly impregnated with nitrous oxide, was not in the slightest degree diminished, in one experiment indeed it was rather increased ; doubtless from

the liberation of some nitrous oxide from the water by the agitation.

b. Nitrous oxide kept in contact with aqueous solution of sulphurated hydrogen and often agitated, was not in the slightest degree diminished.

Sulphurated hydrogen, introduced into a solution of nitrous oxide, was rapidly absorbed, and as the process advanced, the nitrous oxide was given out.

i. Water impregnated with carbonic acid, possessed no action upon nitrous oxide, and did not in the slightest degree absorb it. When carbonic acid was introduced to an aqueous solution of nitrous oxide; the æriform acid was absorbed, and the nitrous oxide liberated.

k. From these observations it appears that nitrous oxide has less affinity for water, than even the weaker acids, sulphurated hydrogen and carbonic acid; as indeed one might have conjectured a priori from its degree of solubility: likewise that it has a stronger attraction for water than the gases not possessed of acid or

alkaline properties ; it expelling from water nitrous gas, oxygene, and common air ; probably hydro-carbonate, hydrogene, and nitrogene.

II. *Combinations of Nitrous Oxide with Fluid Inflammable Bodies.*

a. Vitriolic ether absorbs nitrous oxide in much larger quantities than water.

A cubic inch of ether, at temperature 52°, combined with a cubic inch and seven tenths of nitrous oxide.

Ether thus impregnated was not at all altered in its appearance ; its smell was precisely the same, but the taste appeared less pungent, and more agreeable. Nitrous oxide is liberated unaltered from ether at a very low temperature, that is, at about the boiling point of this fluid.

For expelling nitrous oxide from impregnated ether, and for ascertaining in general the quantity of gases combined with fluids, I have lately made use of a very simple method, which it may not be amiss to describe.

The impregnated fluid is introduced into a small thin tube, graduated to ,05 cubic inches, through mercury. The quantity of fluid should never equal more than a fifth or sixth of the capacity of the tube.

The lower part of the tube is adapted to an orifice in the shelf of the mercurial apparatus, so as to make an angle of about 40° with the surface of the mercury.

The flame of a small spirit lamp is then applied to that part of the tube containing the fluid; and after the expulsion of the gas from it, the heat is raised so as to drive out the fluid through the orifice of the tube. Thus the liberated gas is preserved in a state proper for accurate examination.

Impregnated ether, during its combination with water, gives out the greater part of its nitrous oxide. During the liberation of nitrous oxide from ether, by its combination with water, a very curious phænomenon takes place.

If the water employed is colored, so that it may be seen in a stratum distinct from the im-

pregnated ether, at the point of contact a number of small spherules of fluid will be perceived, apparently repulsive both to water and ether; these spherules become gradually covered with minute globules of gas, and as this gas is liberated from their surfaces, they gradually disappear.

b. Alcohol dissolves considerable quantities of nitrous oxide.

2 cubic inches of alcohol, at 52° , combined with 2,4 cubic inches of nitrous oxide. The alcohol thus impregnated had a taste rather sweeter than before, but in other physical properties was not perceptibly altered.

Nitrous oxide is incapable of remaining in combination with this fluid at the temperature of ebullition; it is liberated from it unaltered by heat.

Impregnated alcohol, during its combination with water, gives out the greater part of its combined nitrous oxide: on mingling the two fluids together, at the point of contact the alcohol becomes covered with an infinite number of small globules of gas, which continue to be

generated during the whole of the combination, and in passing through the fluid render it almost opaque.

c. The essential oils absorb nitrous oxide to a greater extent than either alcohol or ether.

,5 cubic inches of oil of carui combined with 1,2 cubic inches of nitrous oxide at 51°. The color of the oil thus impregnated was rather paler than before.

Nitrous oxide is expelled unaltered from impregnated oil of carui, by heat.

1 of oil of turpentine absorbed nearly 2 of nitrous oxide, at 57°. Its properties were not sensibly altered from this combination, and the gas was expelled from it undecomposed, by heat.

d. As well as the essential oils, the fixed oils dissolve nitrous oxide at low temperatures, whilst at high temperatures they do not remain in combination.

1 of olive oil absorbed, at 61°, 1,2 of nitrous oxide, but without undergoing any apparent physical change.

III. *Action of Fluid Acids on Nitrous Oxide.*

a. Nitrous oxide exposed to concentrated sulphuric acid, undergoes no change, and suffers no diminution, that may not be accounted for from the abstraction of a portion of its water by the acid.

b. Nitrous oxide is scarcely at all soluble in nitrous acid, and exposed to that substance, undergoes no alteration.

c. Muriatic acid, of specific gravity 1,14 absorbs about a third of its bulk of nitrous oxide. It suffers no apparent change in its properties from being thus impregnated, and the gas is again given out from it on the application of heat.

d. Acetic acid absorbs nearly one third of its bulk of nitrous oxide.

e. Aqua regia, that is, the nitro-muriatic acid, absorbs a very minute portion of nitrous oxide.

f. Nitrous oxide was exposed to a new compound acid, consisting of oxygenated muriatic acid, and sulphuric acid, which I discovered in

July, 1799, and of which an account will be shortly published; but it was neither absorbed or altered.

I have before mentioned that the aqueous solutions of sulphurated hydrogen and carbonic acid, neither dissolve or alter nitrous oxide.

IV. *Action of Saline Solutions, and other Substances, on Nitrous Oxide.*

a. Nitrous oxide exposed to concentrated solution of green sulphate of iron, at 58° , underwent no perceptible diminution; not even after it had been suffered to remain in contact with it for half an hour.

b. It underwent diminution of nearly $\frac{2}{3}$ when agitated in contact with a solution of red sulphate of iron, the volume of the solution being unity.

c. Solution of green sulphate of iron, fully impregnated with nitrous gas, did not in the slightest degree absorb nitrous oxide, and appeared to have no action upon it.

d. Solution of green muriate of iron, whether impregnated with nitrous gas, or unimpregnated, has no affinity for, or action upon, nitrous oxide.

e. Solution of red muriate of iron in alcohol, absorbed nearly one fifth of its bulk, of nitrous oxide.

f. Solution of prussiate of potash absorbed nearly one third of its volume, of nitrous oxide, which was again expelled from it by heat.

g. Solution of nitrate of copper appeared to have no affinity for nitrous oxide.

h. Concentrated solution of nitrate of ammoniac, at 58°, absorbed one eighth of its bulk of nitrous oxide.

i. Solutions of alkaline sulphures absorb nitrous oxide in quantities proportionable to the water they contain; it is expelled from them unaltered by heat. None of the hydro-sulphures dissolve more than half their bulk of nitrous oxide.

k. Concentrated solutions of the sulphites possess little or no action on nitrous oxide:

diluted solutions absorb it in small quantities.

7. Concentrated solution of muriate of tin absorbs about one eighth of nitrous oxide; more dilute solutions absorb larger quantities.

From these observations we learn, that neutro-faline solutions in general, have very feeble attractions for nitrous oxide; and as solutions of green muriate, and sulphate of iron, whether free from nitrous gas, or impregnated with it, possess no action upon nitrous oxide, nitrous gas may be separated from this substance by those solutions with greater facility than nitrous oxide can be separated from nitrous gas, by water or alcohol.

Charcoal absorbs nitrous oxide as well as all other gases; and it is disengaged from it by heat.

I have as yet found no other solid body, not possessed of alkaline properties, capable of absorbing nitrous oxide in any state of existence.

The bodies possessing the strongest affinity for oxygene, the dry sulphites, muriate of tin, the common sulphures, white prussiate of potash, and green oxide of iron, do not in the slightest

degree act on nitrous oxide at common temperatures.

V. *Action of different Gases on Nitrous Oxide.*

a. 12 measures of muriatic acid gas were mingled with 7 measures of nitrous oxide at 56°. After remaining together for a minute, they filled a space equal to $19\frac{1}{2}$ measures. When water was introduced to them, the muriatic acid was absorbed much more slowly than if it had been unmingled.

In another experiment, when the gases were saturated with water, 9 measures of each of them, when mingled and suffered to remain in contact for a quarter of an hour, filled a space nearly equal to 19; and after the muriatic acid had been absorbed by potash, the nitrous oxide remained unaltered in its properties.

From the expansion, it appears most probable that aëriform muriatic acid, and nitrous oxide, have a certain affinity for each other, and

that they combine when mingled together ; for in the last experiment, the increase of volume cannot be accounted for by supposing that nitrous oxide undergoes less change of volume than muriatic acid, by æriform combination with water, and that the expansion depended upon the solution of some of its combined water by the muriatic acid. That muriatic acid and nitrous oxide have a slight affinity for each other, likewise appears from the absorption of nitrous oxide by aqueous solution of muriatic acid.

Thinking that nitrous oxide might attract muriatic acid from its solution in water, I exposed a minute quantity of fluid muriatic acid to nitrous oxide ; but no alteration of volume took place in the gas.

b. 6 measures of nitrous oxide were mingled with 11 measures of sulphureous acid, saturated with water ; after remaining at rest for six minutes, they filled a space nearly equal to 18 measures. Exposed to water, the sulphureous acid was absorbed, but not nearly so rapidly as

when in a free state. Sulphur burnt with a vivid flame in the residual nitrous oxide. 7 measures of sulphureous acid were now mingled with 8 of nitrous oxide. They filled a space nearly equal to $15\frac{3}{4}$, and no farther expansion took place afterwards.

From these experiments it appears probable that sulphureous acid, and nitrous oxide, have some affinity for each other.

c. 11 measures of carbonic acid were mingled with 8 of nitrous oxide; they filled a space nearly equal to 19 measures. On exposing the mixture to caustic potash, the carbonic acid was absorbed, and the nitrous oxide remained pure. Hence it appears that carbonic acid and nitrous oxide do not combine with each other.

d Oxygenated muriatic acid, and nitrous oxide, were mingled in a water apparatus: there was a slight appearance of condensation; but this was most probably owing to absorption by the water; on agitation, the oxygenated muriatic acid was absorbed, and the greater part of the nitrous oxide remained unaltered.

e. Sulphurated hydrogen and nitrous oxide, mingled together, neither expanded or contracted; exposed to solution of potash, the acid* only was absorbed.

f. 10 measures of nitrous gas were admitted to 12 of nitrous oxide at 59° . They filled a space equal to 22, and after remaining together for an hour, had undergone no change. Solution of muriate of iron absorbed the nitrous gas without affecting the nitrous oxide.

g. Nitrous oxide was successively mingled with oxygen, atmospheric air, hydro-carbonate, phosphorated hydrogen, hydrogen, and nitrogen, at 57° ; it appeared to possess no action on any of them, and was separated by water, the gases remaining unaltered.

h. As nitrous oxide was soluble in ether, alcohol, and the other inflammable fluids, it was reasonable to suppose that its affinity for those bodies would enable them to unite with

* The experiments of Berthollet have clearly proved the perfect acidity of this substance.

it in the aëriform state. At the suggestion of Dr. Beddoes I made the following experiment:

To 12 measures of nitrous oxide, at 54° , I introduced a single drop of ether; the gas immediately began to expand, and in four minutes filled a space equal to sixteen measures and a quarter. When an inflamed taper was plunged into the gas thus holding ether in solution, a light blue flame slowly passed through it.

A considerable diminution of temperature is most probably produced, from the great expansion of nitrous oxide during its combination with ether.

A drop of alcohol was admitted to 14 measures of nitrous oxide. In five minutes, the gas filled a space equal to fifteen and a third; but no farther diminution took place afterwards.

A minute quantity of oil of turpentine was introduced to 14 measures of nitrous oxide; it filled, in 4 minutes, a space rather less than 14; and no farther change took place afterwards. Most likely this contraction arose from the precipitation of the water dissolved in the gas by

the stronger affinity of the oil for nitrous oxide. To ascertain with certainty if any oil had been dissolved by the gas, I introduced into it a small quantity of ammoniac. It immediately became slightly clouded, most probably from the formation of soap, by the combination of the dissolved oil with the ammoniac.

From these experiments we learn, that when nitrous oxide is mingled with either carbonic acid, oxygene, common air, hydro-carbonate, sulphurated hydrogen, hydrogen, or nitrogen, they may be separated from each other without making any allowance for contraction or expansion : but if a mixture of either muriatic acid, or sulphureous acid gas, with nitrous oxide, is experimented upon ; in the absorption of the acid by alkalies, the apparent volume of gas condensed will be less than the real one, by a quantity equal to the sum of expansion from combination. Consequently a correction must be made on account of this circumstance.

Though alcohol, ether, essential oils, and the fluid inflammable bodies in general, dissolve

nitrous oxide with much greater rapidity than water, yet as we are not perfectly acquainted with their action on unabsorbable gases, it is better to employ water for separating nitrous oxide from these substances; particularly as that fluid is more or less combined with all gases, and as we are acquainted with the extent of its action upon them.

By pursuing the subject of the solution of essential oils in gases, we may probably discover a mode of obtaining them in a state of absolute dryness. For if other gases as well as nitrous oxide, have a stronger affinity for oils than for water, water most probably will be precipitated from them during their solution of oils; and after their saturation with oil, it is likely that they are capable of being deprived of that substance by ammoniac.

VI. *Action of aëriform Nitrous Oxide on the Alkalies. History of the discovery of the combinations of Nitrous Oxide with the Alkalies.*

a. When nitrous oxide in a free state is

exposed to the solid caustic alkalies and alkaline earths, at common temperatures, it is neither absorbed nor acted upon; when it is placed in contact with solutions of them in water, a small quantity is dissolved; but this combination appears to depend on the water of the solution, for the gas can be expelled unaltered, at the temperature of ebullition.

b. Caustic potash was exposed to nitrous oxide for 13 hours: the diminution was not to one fiftieth, and this slight condensation most probably depended upon its combination with the water of the gas.

Concentrated solution of potash absorbed a fourth of its bulk of nitrous oxide. When the impregnated solution was heated, globules of gas were given out from it rapidly; but the quantity collected was too small to examine.

Soda, whether solid or in solution, exhibited exactly the same phenomena with nitrous oxide. The solution of soda absorbed near a quarter of its bulk of gas.

c. 11 measures of ammoniacal gas were

mingled with 8 measures of nitrous oxide over dry mercury, both of the gases being saturated with water. No change of appearance was produced by the mixture, and they filled, after two minutes, a space equal to 19. On the introduction of a little water, the ammoniac was absorbed, and the nitrous oxide remained unaltered, for it was dissolved by water as rapidly as if it had never been mingled with ammoniac.*

7 measures of nitrous oxide, exposed to 6 measures of solution of ammoniac in water, was in an hour diminished to $4\frac{1}{2}$ nearly. When the solution was heated over mercury, permanent gas was produced, which was unabsorbable by a minute quantity of water, and soluble in a large quantity; consequently it was nitrous oxide.

* The Dutch chemists have asserted, that mixture with ammoniac prevents the absorption of nitrous oxide by water, either wholly or partially. *Journal de Physique*, t. xliii. part ii. pag. 327. It is difficult to account for their mistake.

d. Nitrous oxide was exposed to dry caustic strontian; it underwent a diminution of nearly one fortieth, which most likely was owing to the combination of the strontian with its water.

11 measures of nitrous oxide were agitated in contact with 8 of strontian lime water: nearly 4 measures were absorbed. The impregnated solution exposed to heat, rapidly gave out its gas; 3 measures were soon collected, which mingled with a small quantity of hydrogen, and inflamed by the taper, gave a smart detonation.

e. Nitrous oxide exposed to lime and argil, both wet and dry, was not in the slightest degree acted upon.

From these experiments it is evident that nitrous oxide in the aëriform state cannot be combined either with the alkalies, or the alkaline earths. That a combination may be effected between nitrous oxide and these substances, it must be presented to them, in the *nascent state*.

The salts composed of the alkalies and nitrous oxide, are not analogous to any other compound

substances, being possessed of very singular properties. Before these properties are detailed, it may not be amiss to give an account of the accidental way in which I discovered the mode of combination.

In December, 1799, designing to make a very delicate experiment, with a view to ascertain if any water was decomposed during the conversion of nitrous gas into nitrous oxide, by sulphite of potash, I exposed 200 grains of crystalised sulphite of potash, containing great superabundance of alkali, to 14 cubic inches of nitrous gas, containing one eighteenth nitrogen^e. The alkali was employed to preserve any ammoniac that might be formed, in the free state, as it would otherwise combine with sulphureous acid.*

The volume of gas diminished with great rapidity; in two hours and ten minutes it was

* Sulphureous acid saturates more potash than sulphuric acid, so that most probably during the conversion of sulphite of potash into sulphate, portions of sulphureous acid are disengaged.

reduced to $6\frac{4}{5}$, which I considered as the limit of diminution. Accidentally, however, suffering it to remain for three hours longer, I was much surprised by finding that not quite 12 cubic inches remained, which consisted of nitrous oxide, mingled with the nitrogen that existed before the experiment.

In accounting theoretically for this phænomenon, different suppositions necessarily presented themselves.

1st, It was possible, that though sulphite of potash, and potash, separately possessed no action on free nitrous oxide, yet in combination they might exert such affinities upon it as either to absorb it, or make it enter into new combinations.

2dly. It was more probable that the caustic potash, though incapable of condensing æriform nitrous oxide, was yet possessed of a strong affinity for it when in the *nascent state*, and that the nitrous oxide condensed in the experiment had been combined in this state with the free alkali.

To ascertain if the compound of potash and

fulphite of potash with fulphate, was capable of acting upon nitrous oxide, I suffered a quantity of this substance to remain in contact with the gas for near a day : no change whatever took place.

To determine whether the diminution of nitrous oxide depended upon its absorption in the nascent state, by the peculiar compound of potash and fulphite of potash, or if it was simply owing to the alkali.

I mingled a solution of fulphite of potash with caustic soda ; the salt, after being evaporated at a low temperature, was exposed to nitrous gas. The nitrous oxide formed was absorbed, but in rather less quantities than when alkaline fulphite of potash was employed.

Hence it was evident that the alkali was the agent that had condensed the nitrous oxide in those experiments, for soda is incapable of combining either with fulphate, or fulphite of potash.

To ascertain whether any change in the constitution of the nitrous oxide had been produced

by the condensation, I introduced a small quantity of sulphite of potash, with excess of alkali, that had absorbed nitrous oxide, into a long and thin cylindrical tube filled with mercury; and inclining it at an angle of 35° with the plane of the mercury, applied the heat of a spirit lamp to that part of the tube containing the salts; when the glass became very hot, gas was given out with rapidity; in less than a minute the tube was full. This gas was transferred into another tube, and examined; it proved to be nitrous oxide in its highest state of purity;* for a portion of it absorbed by common water, left no more than a residuum of $\frac{1}{15}$, and sulphur burnt in it with a vivid rose-colored flame.

Being now satisfied that the alkalies were capable of combining with nitrous oxide; to investigate with precision the nature of these new compounds, I proceeded in the following manner.

* Hence we learn that sulphite of potash, when strongly heated, does not decompose nitrous oxide, even in the *nascent state*.

VII. *Combination of Nitrous Oxide with Potash.*

a. Into a solution of sulphite of potash, which had been made by passing sulphureous acid gas from a mercurial airholder into caustic potash dissolved in water, I introduced 17 grains of dry potash. The whole evaporated at a low temperature, gave 143 grains of salt. This salt was not *wholly* composed of sulphite of potash and potash; it contained as well, a minute quantity of carbonate, and sulphate of potash, formed during the evaporation.*

120 grains of it finely pulverised, and retaining the water of crystallisation, were exposed to 15 cubic inches of nitrous gas, over mercury. The nitrous gas diminished with great rapidity, and in three hours a cubic inch and nine tenths

* See the excellent memoir of Fourcroy and Vauquelin on the sulphureous acid, and its combinations. *Annales de Chimie*, ii, 54. Or Nicholson's *Phil. Journal*, vol. i, pag. 313.

only remained, which consisted of nearly one third nitrous oxide, and two thirds nitrogene that had pre-existed in the nitrous gas. The increase of weight of the salt could not be determined, as some of it was lost by adhering to the vessel in which the combination was effected, and to the mercury. It presented no distinct series of crystallisations, even when examined by the magnifier; rendered green vegetable blues, and its taste was very different from that of the remaining quantity of salt that had been exposed to the atmosphere. A portion of it strongly heated over mercury, gave out gas with great rapidity, which had all the properties of the purest nitrous oxide.

When water was poured upon some of it, no gas was given out, and the whole was equably and gradually dissolved. Alcohol, as well as ether, appeared incapable of dissolving any part of it.

When muriatic acid was introduced into it, confined by mercury, a rapid effervescence took place. Part of the gas disengaged was sulphu-

reous acid, and carbonic acid; the remainder was nitrous oxide.

b. I made a number of experiments upon salts procured in the manner I have just described, with a view to obtain the compound of nitrous oxide and potash, free from admixture of other salts.

When the mixed salt was boiled in alcohol or ether, no part of it appeared to be dissolved. Finding that little or no gas was given out during the ebullition of concentrated solutions of the mixed salts, I attempted to separate the sulphate, sulphite, and carbonate of potash, from the combination of nitrous oxide and potash, by successive evaporations and crystallisations. But though in this way it was nearly freed from sulphate of potash, yet the extreme and nearly equal solubility of the other salts, prevented me from completely separating them from each other.

By exposing, however, very finely pulverised sulphite of potash, mingled with alkali, for a great length of time to nitrous gas, it was almost

wholly converted into sulphate; and after the separation of this by solution, evaporation, and crystallisation, at a low temperature, I obtained the new combination, mingled with very little carbonate of potash, and still less of sulphite.

The minute quantity of sulphite chiefly appeared in very small crystals; distinct from the mass of salt, which possessed no regular crystallisation, and was almost wholly composed of the new compound, intimately mingled with a little carbonate. The new compound, as nearly as I could estimate from the quantity of nitrous oxide absorbed, consisted of about 3 alkali, to 1 of nitrous oxide, by weight.

It exhibited the following properties:

1. Its taste was caustic, and possessed of a pungency different from either potash or carbonate of potash.

2. It rendered vegetable blues green, which might possibly depend upon the carbonate of potash mixed with it.

3. Pulverised charcoal mingled with a few grains of it, and inflamed, burnt with slight

scintillations. Projected into zinc in a state of fusion, a slight inflammation was produced.

4. When either sulphuric, muriatic, or nitric acid was introduced to it under mercury, it gave out nitrous oxide, mingled with a little carbonic acid.

5. Thrown into a solution of sulphurated hydrogen, gas was disengaged from it, but in quantities too minute to be examined.

6. When carbonic acid was thrown into a solution of it in water, gas was disengaged; on examination it proved to be nitrous oxide.

7. A concentrated solution of it kept in ebullition in a cylinder, confined by mercury, gave out a few globules of gas, which were too minute to be examined, and probably consisted of common air previously contained in the water.

c. In the experiments made to ascertain these properties all the salt was expended, otherwise I should have endeavoured to ascertain what quantity of gas would have been liberated by heat from a given weight; and likewise what would have

been the effects of admixture of it with oil. When some of the mixed salt was mingled with oil of turpentine, part of it was dissolved, and the fluid became white; but no gas was given out. On this coarse experiment, however, I cannot place much dependance. If the combination of nitrous oxide and potash is capable of combining with oil without decomposition, barytes and strontian* will probably separate the oil from it, and thus it may possibly be obtained in a state of purity.

In a rough experiment made on the conversion of nitrous gas into nitrous oxide, by concentrated solution of sulphite of potash with excess of alkali, very little of the nitrous oxide was absorbed. Hence it is probable that water lessens the affinity of potash for nascent nitrous oxide.

* Unless the sum of affinity of the potash, oil, nitrous oxide, and earths, should be such as to enable the nitrous oxide to combine with the earth, whilst the oil and alkali remained in combination, &c.

VIII. *Combination of Nitrous Oxide with Soda.*

The union of nitrous oxide with soda is effected in the same manner as with potash. The alkali, mingled by solution and evaporation, with either sulphite of soda, or of potash, is exposed to nitrous gas; the nitrous oxide is condensed by it at the moment of generation, and the combination effected.

As far as I have been able to observe, nitrous oxide is not absorbed to so great an extent by soda, as potash.

I have not yet been able to obtain the combination of nitrous oxide with soda in its pure state. To the attainment of this end, difficulties identical with those noticed in the last section present themselves. It is extremely difficult to procure the soda perfectly free from carbonic acid, and though by using sulphite of potash the sulphate formed is easily separated, yet still evaporation and crystallisation will not disengage the

fulphite and carbonate from the new compound.

The compound of soda and nitrous oxide, mingled with a little fulphite and carbonate of soda, was rapidly soluble, both in warm and cold water, without effervescence. Its solution, heated to ebullition, gave out no gas. The taste of the solid salt was caustic, and more acrid than that of the mixture of carbonate and fulphite of soda. When cast upon zinc in fusion, it burnt with a white flame. When heated to 400° or 500°, it gave out nitrous oxide with rapidity. Nitrous oxide was expelled from it by the sulphuric, muriatic, and carbonic acids, *I believe*, by fulphurated hydrogen.*

IX. *Combination of Nitrous Oxide with Ammoniac.*

I attempted to effect this combination by

* For when a little of the mixed salt was introduced into a solution of fulphurated hydrogen, globules of gas were given out during the solution.

converting nitrous gas into nitrous oxide, by sulphite of ammoniac, wetted with strong solution of caustic ammoniac; but without success; for the whole of the nitrous oxide produced remained in a free state.

When I exposed sulphite of potash, mingled by solution and evaporation with highly alkaline carbonate of ammoniac, † to nitrous gas, the diminution was nearly one fourth more than if pure sulphite of potash had been employed. Hence it appears most likely that ammoniac is capable of combination with nitrous oxide in the nascent state.

In the experiments on the conversion of nitrous gas into nitrous oxide, by nascent hydrogen, and by sulphurated hydrogen, Ref. I. Divif. V. probably the water formed at the same

† Carbonate of ammoniac formed at a high temperature, containing near 60 per cent alkali, and capable of combining with small quantities of acids without giving out its carbonic acid. Of this salt a particular account will be given in the experiments on the ammoniacal salts, which I have often mentioned in the course of this work.

time with the ammoniac and nitrous oxide, prevented them from entering into combination; *possibly* the peculiar compound was formed, but in quantities so minute as not to be distinguished from simple ammoniac;* for even the existence of ammoniac in these processes, is but barely perceptible.

If it should be proved by future experiments, that in the decomposition of nitrous gas by nascent hydrogen, a peculiar compound of nitrous oxide, water and ammoniac, is formed, it will afford proofs in favor of the doctrine of predisposing affinity;† for then this decom-

* It may not be amiss to mention some appearances taking place in the decomposition of nitrous gas by sulphurated hydrogen, though it is useless to theorise concerning them. The sulphur deposited is at first yellow; as the process proceeds, it becomes white, and in some instances I have suspected a diminution of it.

† Predisposing affinity, the existence of which at first consideration it is difficult to admit, may be easily accounted for by *supposing* the attractions of the simple principles of compound substances. And this doctrine will apply in all

position might be supposed to depend upon the disposition of oxygene, hydrogene and nitro-gene to assume the states of combination in which they might form a triple compound, of water, nitrous oxide, and ammoniac.

Nitrous oxide might probably be made to combine with ammoniac by exposing a mixture of nitrous gas and aëriform ammoniac, to the sulphites.

It is probable that nitrous oxide may be combined with ammoniac, by means of double affinity. Perhaps sulphate of ammoniac and the combination of potash with nitrous oxide mingled together in solution, would be converted into sulphate of potash and the compound of nitrous oxide, and ammoniac.

instances where the constitution of bodies is known. Pre-disposing affinity ought not to be considered as the affinity of *non-existing* bodies for each other; but as the mutual affinity of their simple principles, disposing them to assume new arrangements.

X. *Probability of forming Compounds of Nitrous Oxide and the Alkaline Earths.*

I attempted to combine nitrous oxide with lime and strontian, by exposing sulphites of lime and strontian with excess of earth, to nitrous gas; but this process did not succeed: the diminution took place so slowly as to destroy all hopes of gaining any results in a definite time. Sulphite of potash is decomposable by barytes, strontian, and lime;* consequently it was impossible to employ this substance to effect the combination.

As the dry sulphures, when well made, convert nitrous gas into nitrous oxide, it is probable that the union of the earths with nascent nitrous oxide may be effected by exposing nitrous gas to their sulphures, containing an excess of earth.

Perhaps the combination of nitrous oxide with

* See the above-mentioned elaborate memoir of Fourcroy and Vauquelin.

frontian may be effected by introducing the combination of potash and nitrous oxide into frontian lime water.

It is probable that nitrous oxide may be combined with clay and magnesia, by exposing these bodies, mingled with sulphite of potash or soda, to nitrous gas.

XI. *Additional Observations on the combinations of Nitrous Oxide with the Alkalies.*

A desire to complete physiological investigations relating to nitrous oxide, has hitherto prevented me from pursuing to a greater extent, the experiments on the combination of this substance with the alkalies, &c. As soon as an opportunity occurs, I purpose to resume the subject.

The observations detailed in the foregoing sections are sufficient to show that nitrous oxide is capable of entering into intimate union with the fixed alkalies: and as the compounds formed by this union are insoluble in alcohol,

decomposable by the acids, and heat, and possessed of peculiar properties, they ought to be considered as a new class of saline substances.

If it is thought proper, on a farther investigation of their properties, to signify them by specific names, they may, according to the usually adopted fashion of nomenclature, be called *nitroxis*: thus the *nitroxi of potash* would signify the salt formed by the combination of nitrous oxide with potash.

Future experiments must determine the different affinities of nitrous oxide for the alkalis, and alkaline earths.

With regard to the uses of these new compounds it is difficult to form a guess. When they are obtained pure, and fully saturated with nitrous oxide, on account of the low temperature at which their gas is liberated, they will probably constitute detonating compounds. From their facility of decomposition by the weaker acids, they may possibly be used medicinally, if ever the evolution of nitrous oxide in the stomach should be found beneficial in diseases.

XII. *The properties of Nitrous Oxide resemble those of Acids.*

If we were inclined to generalise, and to place nitrous oxide among a known class of bodies, its properties would certainly induce us to consider it as more analogous to the acids than to any other substances; for it is capable of uniting with water and the alkalies, and is insoluble in most of the acids. It differs, however, from the stronger acids, in not possessing the sour taste,* and the power of reddening vegetable blues: and from both the stronger and weaker acids, in not being combinable when in a perfectly free state, at common tempera-

* The different persons who have respired nitrous oxide have, as will be seen hereafter, given different accounts of the taste; the greater number have called it sweet, some metallic. One of my friends, in a letter to me dated Nov. 13, 1799, containing a detail of some experiments made on the respiration of nitrous oxide, at Birmingham, denotes the taste of it by the term "sweetish faintly acidulous." To me the taste both of the gas and of its solution in water, has always appeared faintly sweetish.

tures, with the alkalies. If it should be proved by future experiments, that condensation by cold gave it the capability of immediately forming neutro-saline compounds with the alkalies; it ought to be considered as the weakest of the acids. Till those experiments are made, its extraordinary chemical and physiological properties are sufficient to induce us to consider it as a body *sui generis*.

It is a singular fact that nitrous gas, which contains in its composition a quantity of oxygene so much greater than nitrous oxide, should nevertheless possess no acid properties. It is uncombinable with alkalies, very little soluble in water, and absorbable by the acids.

DIVISION II.

*On the DECOMPOSITION of NITROUS OXIDE
by COMBUSTIBLE BODIES. Its ANALYSIS.
OBSERVATIONS on the different combinations of
OXYGENE and NITROGENE.*

I. Preliminaries.

FROM the phænomena mentioned in Ref. I. Divif. III.* it appears that the combustible bodies burn in nitrous oxide at certain temperatures. The experiments in this Division were instituted for the purpose of investigating the precise nature of these combustions, with a view of ascertaining exactly the composition of nitrous oxide.

It will be seen hereafter that very high temperatures are required for the decomposition of

* Section 2.

nitrous oxide, by most of the combustible bodies, and that in this process heat and light are produced to a very great extent. These agents alone are possessed of a considerable power of action on nitrous oxide; of which it is necessary to give an account, that we may be able to understand the phænomena in the following sections.

II. Conversion of Nitrous Oxide into Nitrous Acid, and a Gas analogous to Atmospheric Air, by Ignition.

a. Dr. Priestley asserts, that nitrous oxide exposed for a certain time to the action of the electric spark, is rendered immiscible with water, and capable of diminution with nitrous gas, without suffering any alteration of volume; and likewise that the same changes are effected in it by exposure to ignited incombustible bodies.*

The Dutch chemists state, that the electric

* Vol. ii. pag. 91.

spark passed through nitrous oxide, occasions a small diminution of its volume, and that the gas remaining is analogous to common air.† They conclude that this change depends on the separation of its constituent parts, oxygene and nitrogene, from each other.

None of these chemists have suspected the production of nitrous acid in this process.

b. Nitrous oxide undergoes no change whatever from the simple action of light. I exposed some of it, confined by mercury, for many days to this agent, often passing through it concentrated rays by means of a small lens. When examined it appeared, as well as I could estimate, of the same degree of purity as at the beginning of the experiment.

c. A temperature below that of ignition effects no alteration in the constitution of nitrous oxide. I passed nitrous oxide from a

† Journal de Physique, tom. xliii, part ii. pag. 330. They effected the same change by passing it through a heated tube. Dr. Priestley had published an account of similar experiments more than two years before.

retort containing decomposing nitrate of ammoniac, through a green glass tube, strongly heated in an air-furnace, but not suffered to undergo ignition. The gas, received in a water apparatus exhibited the same properties as the purest nitrous oxide; some of it absorbed by water, left a residuum of not quite one thirteenth.

d. The action of the electric spark for a long while continued, converts nitrous oxide into a gas analogous to atmospheric air, and nitrous acid.

I passed about 150 strong shocks from a small Leyden phial, through 7 ten grain measures of pure nitrous oxide. After this it filled a space rather less than six measures: the mercury was rendered white on the top, as if it had been acted on by nitric acid. Six measures of nitrous gas mingled with the residual gas of the experiment, over mercury covered by a little water, gave red fumes, and rapid diminution. In five minutes the volume of the gases nearly equalled ten. Thermometer in this experiment was 58°.

Electric sparks were passed for an hour and half through 7 ten grain measures of nitrous oxide over mercury covered with a little red cabbage juice, previously saturated with nitrous oxide, and rendered green by an alkali. After the process the gas filled a space equal to rather more than six measures and half, and the juice was become of a pale red. The gas was introduced into a small tube filled with pure water, and agitated; no absorption was perceptible: 7 measures of nitrous gas added to it gave red fumes, and after six minutes a diminution to $9\frac{1}{4}$ nearly. $6\frac{1}{2}$ measures of common air from the garden, with 7 of nitrous gas, gave exactly 9.

In this experiment it was evident that nitrous oxide was converted into a gas analogous to atmospheric air, at the same time that an acid was formed. There could be little doubt but that this was the nitrous acid. To ascertain it, however, with greater certainty, the electric spark was passed through 6 measures of nitrous oxide, over a little solution of green sulphate of

iron, confined by mercury. As the process went on, the color of the solution became rather darker. When the diminution was complete, a little prussiate of potash was added to the solution. A precipitate of pale blue prussiate of potash was produced.

c. Nitrous oxide was passed from decomposing nitrate of ammoniac, through a porcelain tube well glazed inside and outside, strongly ignited in an air-furnace, and communicating with the water apparatus. The gas collected was rendered opaque by dense red vapor. It appeared wholly unabsorbable by water. After the precipitation of its vapor, a candle burnt in it with nearly the same brilliancy as in atmospheric air. 20 measures of it that had been agitated in water immediately after its production, mingled with 40 measures of nitrous gas, diminished to about 47.5; whereas 20 measures that had remained unagitated for some time after their generation, introduced to the same quantity of nitrous gas, gave nearly 49. 20 measures of atmospheric air, with 40 of the same nitrous gas, were condensed to 46.

The water with which the gas had been in contact, was strongly acid. A little of it poured into a solution of green sulphate of iron, and then mingled with prussian alkali, produced a green precipitate. Hence the acid it contained was evidently nitrous.

That no source of error could have existed in this experiment from fissure in the tube, I proved, by sending water through it whilst ignited, after the process, from the same retort in which the nitrate of ammoniac had been decomposed; a few globules of air only were produced, not equal to one tenth of the volume of the water boiled, and which were doubtless previously contained in it.

I have repeated this experiment two or three times, with similar results; whenever the air was agitated in water immediately after its production, it gave *almost* the same diminution with nitrous gas as common air; when, on the contrary, it has been suffered to remain for some time in contact with the phlogificated nitrous acid suspended in it, the condensation has been less

with nitrous gas by five or six hundred parts. Hence I am inclined to believe, that if it were possible to condense all the nitrous acid formed, immediately after its generation, so as to prevent it from absorbing oxygene from the permanent gas, this gas would be found identical with the air of the atmosphere.

The changes effected by fire on nitrous oxide are not analogous to those produced by it in other bodies; for the power of this agent seems generally *uniform*, either in wholly separating the constituent principles of bodies from each other, or in making them enter into more intimate union.*

It is a singular phænomenon, that whilst it condenses one part of the oxygene and nitrogene of nitrous oxide, in the form of nitrous acid;

* On the one hand, it decomposes ammoniac into hydrogene and nitrogene, whilst on the other, it converts free oxygene and nitrogene into nitrous acid. It likewise converts nitrous gas into nitrous acid and nitrogene. Till we are more accurately acquainted with the nature of heat, light, and electricity, we shall probably be unable to explain these phænomena.

it should cause the remainder to expand, in the state of atmospheric air. Does not this fact afford an inference in favor of the *chemical* composition of atmospheric air ?

III. *Decomposition of Nitrous Oxide by Hydrogene, at the temperature of Ignition,*

In the following experiments on the decomposition of nitrous oxide by hydrogen, the gases were carefully generated in the mercurial apparatus, and their purity ascertained by the tests mentioned in Research I. They were measured in small tubes graduated to grains, and then transferred into the detonating tube, which was eight tenths of an inch in diameter, and graduated to ten grain measures.

The space occupied by the gases being noted after the inflammation by the electric shock, green muriate of iron, and prussiate of potash, were successively introduced, to ascertain if any nitrous acid had been formed. The absorption, if any took place, was marked, and the gases

transferred into a narrow grain measure tube, and their bulk and composition accurately ascertained.

b. The hydrogen employed was procured from water by means of zinc and sulphuric acid. 50 grain measures of it fired by the electric spark, with 30 grain measures of oxygen containing one eleventh nitrogen, gave a residuum of about 4. Nitrous gas mingled with those 4, indicated the presence of rather less than 1 of unconsumed oxygen. In another experiment 23 of it, with 20 of the same oxygen left rather more than 6 residuum.

The nitrous oxide was apparently pure, for it left a remainder of about ,05 only, when absorbed by common water.

c. 50 of hydrogen were fired with 40 of nitrous oxide; the concussion was very great, and the light given out bright red; no perceptible quantity of nitrous acid was formed; the residual gas filled a space equal to 52. No part of it was absorbable by water, it gave no diminution with nitrous gas, when it was mingled with a little oxygen, and again acted on by the

electric spark, an inflammation and slight diminution was produced.

d. 33 of hydrogene were fired with 35 of nitrous oxide: nitrous acid was produced in very minute quantity; the gas that remained was not absorbable by water, and filled a space equal to 37 grains. Nitrous gas mingled with these, underwent a very slight diminution.

e. 46 hydrogene were fired with 46 nitrous oxide. The quantity of nitrous acid formed was just sufficient to tinge the white prussiate of potash. The gases filled a space equal to 49, gave no perceptible diminution with nitrous gas, and did not inflame with oxygene.

f. 40 hydrogene were fired with 39 nitrous oxide; no perceptible quantity of nitrous acid was formed. The residual gas filled a space equal to 41; was unabsorbable by water, underwent no diminution when mingled with nitrous gas; or when acted on by the electric spark in contact with oxygene.

g. 20 hydrogene were fired with 64 nitrous oxide; after detonation the expansion of the

gases was greater in this experiment than any of the preceding ones; dense white fumes were observed in the cylinder, and a flow contraction of volume took place. After a little green muriate of iron had been admitted, the gases filled a space equal to 73: pruffiate of potash mingled with the muriate, gave a deeper blue than in any of the preceding experiments. The residual gas was unaborbable by water: 65 of it, mingled with 65 of nitrous gas, diminished to 93; whilst 65 of common air, with 65 of nitrous gas, gave 84.

b. 8 of hydrogene were fired with 54 of nitrous oxide; the same phænomena as were observed in the last experiment took place; nitrous acid was formed; after the absorption of which the residual gas filled a space equal to 55. 50 of this, with an equal quantity of nitrous gas, diminished to 76. In these processes the temperatures were from 56° to 61° .

These experiments are selected as the most accurate of nearly fifty, made on the inflamma-

tion of different quantities of nitrous oxide and hydrogene.

As Mr. Keir found muriatic acid in the fluid, produced by the inflammation of oxygene and hydrogene in closed vessels, in Dr. Priestley's experiments, I preserved the residual gas of about 3 cubic inches of nitrous oxide, that had been detonated at different times with less than a cubic inch and half of hydrogene ; but solution of nitrate of silver was not clouded when agitated in this gas, nor when introduced into the detonating tube in which the inflammation had been made.

From these experiments we learn that nitrous oxide is decomposable at the heat of ignition, by hydrogene, in a variety of proportions.

When the quantity of hydrogene very little exceeds that of the nitrous oxide, both of the gases disappear, water is produced, no nitrous acid is formed, and the volume of nitrogen evolved is rather greater than that of the nitrous oxide decomposed.

When the quantity of hydrogene is less than

that of the nitrous oxide, water, nitrous acid, oxygene and nitrogene, are generated in different proportions; one part of the nitrous oxide is most probably wholly decomposed by the hydrogene, and the other part converted into nitrous acid and atmospheric air, in consequence of the ignition.

From experiments *c*, *d*, and *e*, the composition of nitrous oxide may be deduced. In experiment *d*, 39 of nitrous oxide were decomposed by 40 of hydrogene, and converted into 41 of nitrogene.

Now from *b* it appears that 40 of hydrogene require for their condensation about 20.8 of oxygene in volume; so that founding the estimation upon the quantity of hydrogene consumed, 100 parts of nitrous oxide would consist nearly of 63.1 of nitrogene, and 36.9 of oxygene. But 41 of nitrogene weigh 12.4, Ref. I. Div. I. Consequently, deducing the composition of nitrous oxide from the quantity of nitrogene evolved, 100 parts of it would consist of 63.5 nitrogene, and 36.5 oxygene.

These estimations are very little different from those which may be deduced from the other experiments, and the coincidence is in favor of their accuracy.

From the following experiment it appears that the temperature required for the decomposition of nitrous oxide by hydrogen must be higher than that which is necessary to produce the inflammation of hydrogen with oxygen. I introduced into small tubes filled with equal parts of nitrous oxide and hydrogen, standing on a surface of mercury, iron wires ignited to different degrees, from the dull red to the vivid white heat. The gases were always inflamed by the white and vivid red heats; but never by the dull red heat, though the last uniformly inflamed mixtures of oxygen and hydrogen, and atmospheric air and hydrogen.

Dr. Priestley* first detonated together nitrous oxide and hydrogen; his experiment was repeated by the Dutch chemists, who found that when a small quantity of hydrogen was

* Vol. ii. pag. 83.

employed, the nitrous oxide was partially converted into a gas analogous to common air. Their estimation of its composition, which is not far removed from the truth, was founded on this phænomenon.*

IV. *Decomposition of Nitrous Oxide by Phosphorus.*

a. Phosphorus introduced into pure nitrous oxide at common temperatures, is not at all luminous. It is capable of being fused, and even sublimed in it, without undergoing acidification, and without effecting any alteration in its composition.

About 2 grains of phosphorus were fused, and gradually sublimed, in 2 cubic inches of pure nitrous oxide, over mercury, by the heat of a

* Journal de Physique, tom. xliii. part 2, pag. 331. They supposed it to consist of about 37,5 oxygene, and 62,5 nitrogene. The nearness of this account to the truth is singular, when we consider that they were neither acquainted with the specific gravity of nitrous oxide, nor with the production of nitrous acid in this experiment.

burning lens. No alteration was produced in the volume of gas, and a portion of it absorbed by water, left a residuum of one twelfth only.

Phosphorus was sublimed in pure nitrous oxide over mercury, in a dark room, by an iron heated *nearly* to ignition; but no luminous appearance was perceptible, nor was any gas decomposed.

b. Phosphorus decomposes nitrous oxide at the temperature of ignition, with greater or less rapidity, according to the degree of heat. We have already seen, that when phosphorus in active inflammation is introduced into nitrous oxide, it burns with intensely vivid light.

Phosphorus was sublimed by a heated wire in a jar filled with nitrous oxide, standing over warm mercury. In this state of sublimation an iron heated dull red was introduced to it by being rapidly passed through the mercury; a light blue flame surrounded the wire, and disappeared as soon as it ceased to be red.

To phosphorus sublimed as before, in nitrous oxide, over warm mercury, a thick wire ignited

to whiteness was introduced; a terrible detonation took place, and the jar was shattered in pieces.

By employing thick conical jars,* containing only a small quantity of nitrous oxide, I effected the detonation several times with safety; but on account of the great expansion of the elastic products, the jar was generally either raised from the mercury, or portions of gas were thrown out of it. Hence I was unable to ascertain the exact changes produced by this mode of decomposition.

c. As my first attempts to ascertain the constitution of nitrous oxide were made on its decomposition by phosphorus, I employed many dif-

* Experiments on the detonation of nitrous oxide with phosphorus in this way require great attention. The detonating jar should be very conical; the nitrous oxide employed should never equal more than one eighth of the capacity of the jar. The wire for the inflammation must be very thick, and curved so as to be easily introduced into the jar. When ignited, it must be instantaneously passed through the heated mercury into the jar.

Perhaps the electric spark might be advantageously applied for detonating phosphoric vapor with nitrous oxide.

ferent modes of partially igniting this substance in it over mercury, so as to produce a combustion without explosion.

The first method adopted was inflammation by means of oxygenated muriate of potash. A small particle of oxygenated muriate of potash was inserted into the phosphorus to be burnt. On the application of a wire, moderately hot, to the point of insertion, the salt was decomposed by the phosphorus, and sufficient fire generated and partially applied by the slight explosion, to produce the combustion of the phosphorus, without the previous sublimation of any part of it.

The second way employed was the ignition of a part of the phosphorus, by means of the combustion of a small portion of tinder of cotton,* or paper, in contact with it, by the burning glass.

The third, and most successful mode, was by introducing into the graduated jar containing

* It will be seen hereafter that these bodies are easily inflamed in nitrous oxide.

the nitrous oxide, the phosphorus in a small tube containing oxygen, so balanced as to swim on the surface of the mercury, without communicating with the nitrous oxide. The phosphorus was fired in the oxygen with an ignited iron wire, by which at the moment of combustion, the tube containing it was raised into the nitrous oxide, and thus the inflammation continued.

d. In different experiments, made with accuracy, I found that the whole of a quantity of nitrous oxide was never decomposable by ignited phosphorus; the combustion always stopped when the nitrous oxide remaining was to the nitrogen evolved as about 1 to 5; likewise that the volume of nitrogen produced was rather less than that of the nitrous oxide decomposed, and that this deficiency arose from the formation of nitrous acid by the intense ignition produced during the process.

Of one experiment I shall give a detail.

Temperature being 48° , two cubic inches of pure nitrous oxide, which had been generated

over mercury, were introduced into a jar of the capacity of 9 cubic inches, graduated to, 1 cubic inches, and much enlarged at the base. A grain of phosphorus was inserted into a small vessel about one third of an inch long, and half an inch in diameter, containing about 15 grain measures of very pure oxygene; this vessel, which swam on the surface of the mercury, was carefully introduced into the jar containing the nitrous oxide. The phosphorus was fired by means of a heated wire, and before the oxygene was wholly consumed, the vessel containing it elevated into the nitrous oxide. The combustion was extremely vivid and rapid. After the atmospheric temperature was restored, the gas was rendered opaque by dense white vapor. When this had been precipitated, and the small vessel removed from the jar, the gas filled a space nearly equal to 1.9 cubic inches. On introducing to it a little solution of green muriate of iron, and prussiate of potash, green prussiate of iron was produced: hence, evidently, nitrous acid had been formed.

On the admiffion of pure water, an abforption of rather more than ,3 took place.

The 16 meafures remaining underwent no perceptible diminution with nitrous gas; the taper plunged into them was instantly extinguifhed.

To afcertain if the phofphoric acid produced in the experiments made under mercury did not in fome meafure prevent the decomposition of the whole of the nitrous oxide by the phofphorus, I introduced into a mixture of 5 nitrogene and 1 nitrous oxide, ignited phofphorus: but it was immediately extinguifhed.*

The Dutch Chemiffts found that phofphorus might be fufed in nitrous oxide without being luminous. They affert that phofphorus in a ftate of inflammation, introduced into this gas, was immediately extinguifhed; though when taken out into the atmofphere, it again burnt of its own accord.† It is difficult to account for their miftake.

* Phofphorus burnt feebly with a white flame in a mixture of 4 nitrogene and 1 nitrous oxide.

† Journal de Phyfique, xliii. 328.

V. *Decomposition of Nitrous Oxide by Phosphorated Hydrogene.*

a. It has been mentioned in Ref. II. Div. I. that phosphorated hydrogen and nitrous oxide possess no action on each other, at atmospheric temperatures.

Phosphorated hydrogen mingled with nitrous oxide, is capable of being inflamed by the electric spark, or by ignition.

b. E. 1. 10 grain measures of phosphorated hydrogen, carefully produced by means of phosphorus and solution of caustic alkali, were mingled with 52 measures of nitrous oxide. The electric spark passed through them, produced a vivid inflammation. The elastic products were clouded with dense white vapor, and after some minutes filled a space nearly equal to 60. On the introduction of water, no absorption took place. When 43 of nitrous gas were admitted, the whole diminished to 70.

E. 2. 25 of nitrous oxide were fired with 10

of phosphorated hydrogene, by the electric spark. After detonation* they filled a space exactly equal to 25. On the admiffion of folution of green sulphate of iron, and pruffiate of potafh, no blue or green precipitate was produced. On the introduction of water, no diminution was perceived. 25 of nitrous gas mingled with them, gave exactly 50.

E. 3. 10 of nitrous oxide, mingled with 20 of phosphorated hydrogene, could not be inflamed.

25 of nitrous oxide, with 20 phosphorated hydrogene, inflamed. The gas after detonation, was rendered opaque by dense white vapor, and filled a space nearly equal to 45. No abforption took place when water was introduced. On admitting a little oxygene no white fumes, or diminution, was perceived. The electric spark paffed through the mixture, produced an explosion, with great diminution.

c. From *E. 1* it appears, that when a small quantity of phosphorated hydrogene is inflamed with

* In this experiment, as in the last, dense white vapor was produced.

nitrous oxide, both the phosphorus and hydrogen are consumed; whilst the superabundant nitrous oxide, is converted into nitrous acid and atmospheric air, by the ignition; or a certain quantity is partially decomposed into atmospheric air by the combination of a portion of its oxygen with the combustible gas.

From *E. 2* we learn, that when the phosphorated hydrogen and nitrous oxide are to each other as 25 to 10 nearly, they both disappear, whilst nitrogen is evolved, and water and phosphoric acid produced. Reasoning concerning the composition of nitrous oxide from this experiment, we should conclude that it was composed of about 38 oxygen, and 62 nitrogen.

The result of *E. 3* is interesting; we are taught from it that the affinity of phosphorus for the oxygen of nitrous oxide is stronger than that of hydrogen, at the temperature of ignition; so that when phosphorated hydrogen is mingled with a quantity of nitrous oxide, not containing sufficient oxygen to burn both its constituent parts, the phosphorus only is consumed, whilst the hydrogen is liberated.

In repeating the experiments with phosphorated hydrogene that had remained for some hours in the mercurial apparatus, I did not gain exactly the same results; for a larger quantity of it was required to decompose the nitrous oxide, than in the former experiments; doubtless from its having deposited a portion of its phosphorus. They confirm, however, the above mentioned conclusions.

In the course of experimenting, I passed the electric spark, for a quarter of an hour, through about 60 measures of phosphorated hydrogene. It underwent no alteration of volume. Phosphorus was apparently precipitated from it, and it had wholly lost its power of inflaming, in contact with common air.

VI. *Decomposition of Nitrous Oxide by Sulphur.*

From the phænomena before mentioned,*

* Ref. I. Div. III. S. II.

relating to the combustion of sulphur in nitrous oxide, it was evident that this gas was only decomposable by it, at a much higher temperature than common air.

I introduced into sulphur in contact with nitrous oxide, over mercury heated to 112° — 114° , a wire intensely ignited. It lost much of its heat in passing through the mercury, but still appeared red in the vessel. The sulphur rapidly fused, and sublimed without being at all luminous. This experiment was repeated five or six times, but in no instance could the combustion of sulphur, by means of the ignited wire, be effected.

I inflamed sulphur in nitrous oxide in the same manner as phosphorus; namely, by introducing it into the small vessel filled with oxygen, and igniting it by means of the heated wire. In these experiments the sulphur burnt with a vivid rose-colored light, and much sulphuric, with a little sulphureous acid, was formed.

Experimenting in this way I was never, however, able to decompose more than one third

of the quantity of nitrous oxide employed; not only the nitrogene evolved, but likewise the sulphuric and sulphureous acids produced, stopping the combustion.

I found that sulphur in a state of vivid inflammation, when introduced into a mixture of one fourth nitrogene, and three fourths nitrous oxide, burnt with a flame very much enlarged, and of a vivid rose color. In one third nitrogene, and two thirds nitrous oxide, it burnt feebly with a yellow flame. In equal parts of nitrous oxide and nitrogene, it was instantly extinguished.

Sulphur burnt feebly, with a light yellow flame, when introduced ignited into a mixture of 5 nitrous gas, and 6 nitrous oxide. In one third nitrous oxide, and two thirds nitrous gas, it was instantly extinguished. From many circumstances, I am inclined to believe that sulphur is incapable, at any temperature, of slowly decomposing nitrous oxide, so as to burn in it with a blue flame, forming sulphureous acid alone. It appears to attract oxygene from it

only when intensely ignited, so as to form chiefly sulphuric acid, and that with great rapidity, and vivid inflammation.

VII. *Decomposition of Nitrous Oxide by Sulphurated Hydrogene.*

a. Though nitrous oxide and sulphurated hydrogen do not act upon each other at common temperatures, yet they undergo a mutual decomposition when mingled together in certain proportions, and ignited by the electric spark.

From more than twenty experiments made on the inflammation of sulphurated hydrogen in nitrous oxide, I select the following as the most conclusive and accurate. The temperature at which they were made was from 41° to 49°.

b. E. 1. About 35 measures of nitrous oxide were fired with 10 of sulphurated hydrogen; the expansion during inflammation was very great, and the flame sky-blue. Immediately after, the gases filled a space equal to 48 nearly. White fumes were then formed, and they gradually contracted to 40. On the

admission of a little frontian lime water, a slight absorption took place, with white precipitation; and the volume occupied by the residual gas nearly equalled 37. On admitting nitrous gas to these, no perceptible diminution took place.

E. 2. 20 sulphurated hydrogen, with 25 nitrous oxide, could not be inflamed.

30 nitrous oxide, with 22 sulphurated hydrogen, could not be inflamed.

35 nitrous oxide, with 20 sulphurated hydrogen, inflamed with vivid blue light, and great expansion. After the explosion, the gases filled exactly the same space as before the experiment; no white fumes were perceived, and no farther contraction occurred. On the addition of frontian lime water, a copious precipitation, with diminution, took place; and the residual gas filled a space nearly equal to $35\frac{1}{2}$.

E. 3. 47 nitrous oxide, and 14 sulphurated hydrogen, inflamed. After the explosion, the gases filled a space nearly equal to 65; then white fumes formed, and they gradually diminished to 52. On the introduction of muriate of stron-

fian, a copious white precipitate was produced; and on the addition of water, no further absorption took place. To the residual 52, about 20 of nitrous gas were added; they filled together a space equal to about 67.

c. In none of the experiments made on the inflammation of sulphurated hydrogen and nitrous oxide, could I ascertain with certainty the precipitation of sulphur. In one or two processes the detonating tube was rendered a little white at the points of contact with the mercury; but this was most probably owing to the oxydation of the mercury, either by the heated sulphuric acid formed, or from nitrous acid produced by the ignition. The presence of nitrous acid I could not ascertain in these processes by my usual tests, because the combustion of sulphur over white prussiate of iron, converts it into light green.

When I introduced an inflamed taper into about 3 parts of sulphurated hydrogen, and 2 parts of nitrous oxide, in which proportions they could not have been fired by the

electric spark, a blue flame passed through them, and much sulphur was deposited on the sides of the vessel. But this sulphur most probably owed its formation to the decomposition of a portion of sulphurated hydrogene not burnt, by the sulphureous acid formed from the combustion of the other portion.

We may then conclude with probability, that sulphurated hydrogene and nitrous oxide will not decompose each other, when acted on by the electric spark, unless their proportions are such as to enable the whole of the sulphurated hydrogene to be decomposed, so that both of its constituents may become oxygenated, by attracting oxygene from the nitrous oxide: likewise, that when the sulphurated hydrogene is at its *maximum* of inflammation, the hydrogene and sulphur form with the whole of the oxygene of nitrous oxide, water and sulphureous acid; *E. 2*: whereas at its *minimum* they produce water, and chiefly, *perhaps* wholly, sulphuric acid; at the same time that the nitrous oxide partially decomposed, is converted into nitrogene, and a

gas analogous to atmospheric air, or into nitrogene, nitrous acid, and atmospheric air. *E. 1.*
E. 3.

By pursuing those experiments, and using larger quantities of gas, we may probably be able to ascertain from them with accuracy, the composition of sulphuric and sulphureous acids.

I own I was disappointed in the results, for I expected to have been able to ascertain from them, the relative affinities of sulphur, and hydrogene for the oxygene of nitrous oxide, at the temperature of ignition. I conjectured that nitrous oxide, mingled with excess of sulphurated hydrogene, would have been decomposed, and one of the principles of it evolved unaltered, as was the case with phosphorated hydrogene.

If we estimate the composition of nitrous oxide from the quantity of nitrogene produced in *E. 2*, it is composed of about 61 nitrogene, and 39 oxygene.

VIII. *Decomposition of Nitrous Oxide by Charcoal.*

An account of the analysis of nitrous oxide by charcoal is given in Ref. I. Div. III. I have lately made two experiments on the combustion of charcoal in nitrous oxide, in which every precaution was taken to prevent the existence of sources of error. Of one of these I shall give a detail.

E. Temperature being 51° , about a grain of charcoal, which had been exposed for some hours to a red heat, was introduced whilst ignited, under mercury, and transferred into a graduated jar, containing 3 cubic inches of pure nitrous oxide, standing over dry mercury.

The focus of a burning lens was thrown on the charcoal; it instantly inflamed, and burnt with great vividness for near a minute, the gas being much expanded. The focus was continually applied to it for ten minutes, when the process appeared at an end. The gases, when the common temperature and pressure were

restored, filled a space equal to 4,2 cubic inches.

On introducing into them a few grain measures of solution of green muriate of iron, for the double purpose of saturating them with moisture, and ascertaining if any nitrous acid had been formed, no change of volume took place; and prussiate of potash gave with the muriate a white precipitate only.

On the admiffion of a small quantity of concentrated solution of caustic potash, a diminution of the gas slowly took place; when it was complete the volume equalled about 3.05 cubic inches. By agitation in well boiled water, about ,9 of these were absorbed; the remainder appeared to be pure nitrogene.

The difference between the estimation founded upon the nitrogene evolved, and that deduced from the carbonic acid generated in this experiment, is not nearly so great as in that Ref. I. Div. III. Taking about the mean proportions, we should conclude that nitrous oxide was composed of about 38 oxygene, and 62 nitrogene.

Charcoal burnt with greater vividness than in common air, in a mixture of one third nitrogen and two thirds nitrous oxide. In equal parts of nitrous oxide and nitrogen, its light was barely perceptible. In one third nitrous oxide, and two thirds nitrogen, it was almost immediately extinguished.

As charcoal burns vividly in nitrous gas, when it has been previously ignited to whiteness, I introduced it into a mixture of equal parts of nitrous oxide and nitrous gas; it burnt with a deep and bright red.

IX. *Decomposition of Nitrous Oxide by Hydro-carbonate.*

Nitrous oxide, and hydro-carbonate, possess no action on each other, except at high temperatures. When mingled in certain proportions, and exposed to the electric shock, a new arrangement of their principles takes place.

E. 1. Temperature being 53°, 35 of nitrous oxide, mingled with 15 of hydro-

carbonate, were fired by the electric spark; the inflammation was very vivid, and the light produced, bright red. After the explosion, the space occupied by the gases equalled about 60. On the admission of solution of strontian, a copious white precipitate was produced, and the gas diminished by agitation, to rather more than 35. When 36 of nitrous gas were added to these, white fumes appeared and the whole diminished to 62. When a little muriatic acid was poured on the white precipitate from the solution of strontian, gas was evolved from it, and it was gradually dissolved.

E. 2. 22 nitrous oxide were inflamed with 20 hydro-carbonate; after the explosion, they filled a space equal to 45; when strontian lime water was introduced, white precipitation took place, and the diminution was to 31.

To these 31, 14 of nitrous oxide were admitted, and the electric spark passed through them; an inflammation took place: carbonic acid was formed, after the absorption of which,

the gas remaining filled a space equal to 43, and did not diminish with nitrous gas.

The hydro-carbonate employed in these experiments, was procured from alcohol by means of sulphuric acid. In another set of experiments made with less accuracy, the same general results were obtained. Whenever hydro-carbonate inflamed with nitrous oxide, both its constituents were oxygenated; in all cases carbonic acid was formed, and in no instance free hydrogen evolved, or charcoal precipitated.

In the decomposition of nitrous oxide by hydro-carbonate, the residual nitrogen is less than in other combustions. This circumstance I am unable to explain.

Reasoning from analogy, there can be little doubt, but that when hydro-carbonate is inflamed with excess of nitrous oxide, it will be only partially decomposed, or converted into nitrogen, nitrous acid, and atmospheric air.

The Dutch Chemists have asserted, that charcoal does not burn in nitrous oxide, except in consequence of the previous decomposition of

the gas by the hydrogen always contained in this substance; and likewise, that when hydro-carbonate and nitrous oxide were mingled together, and fired by the electric spark, the hydrogen only was burnt, whilst the charcoal was precipitated.

It is difficult to account for these numerous mistakes. Their theory of the *non-respirability* of nitrous oxide was founded upon them. They supposed that the chief use of respiration was to deprive the blood of its superabundant carbon, by the combination of atmospheric oxygen with that principle; and that nitrous oxide was highly fatal to life, because it was incapable of de-carbonating the blood* !!

X. *Combustion of Iron in Nitrous Oxide.*

I introduced into a jar of the capacity of 20 cubic inches, containing 11 cubic inches of nitrous oxide, over mercury, a small quantity of fine iron wire twisted together, and having

* Journal de Physique, xliii. 334.

affixed to it a particle of cork. On throwing the focus of a burning glass on the cork, it instantly inflamed, and the fire was communicated to the wire, which burnt with great vividness for some moments, projecting brilliant white sparks. After it had ceased to burn the gas was increased in volume rather more than three tenths of an inch. The nitrous acid tests were introduced, but no acid appeared to have been formed. On exposing the gas to water, near 4,2 cubic inches were absorbed: the 7,1 remaining appeared to be pure nitrogene.

From this experiment it is evident that iron at the temperature of ignition, is capable of decomposing nitrous oxide; likewise that it is incapable of burning in it when it contains more than three fifths nitrogene.

I attempted to inflame zinc in nitrous oxide, in the same way as iron; but without success. By keeping the focus of a burning glass upon some zinc filings, in a small quantity of nitrous oxide, I converted a little of the zinc into white oxide, and consequently decomposed a portion of the gas.

XI. *Combustion of Pyrophorus in Nitrous Oxide.*

Pyrophorus, which inflames in nitrous gas, and atmospheric air, at or even below 40° , requires for its combustion in nitrous oxide a much higher temperature. It will not burn in it, or alter it, even at 212° .

I have often inflamed pyrophorus in nitrous oxide over mercury, by means of a wire strongly heated, but not ignited. The light produced by the ignition of pyrophorus in nitrous oxide is white, like that produced by it in oxygen: in nitrous gas it is red.

When pyrophorus burns out in nitrous oxide, a little increase of the volume of gas is produced. Strontian lime water agitated in this gas becomes clouded; but the quantity of carbonic acid formed is extremely minute. I have never made any delicate experiments on the combustion of pyrophorus in nitrous oxide.

XII. *Combustion of the Taper in Nitrous Oxide.*

It has been noticed by different experimentalists, that the taper burns with a flame considerably enlarged in nitrous oxide: sometimes with a vivid light and crackling noise, as in oxygene; at other times with a white central flame, surrounded by a feeble blue one.

My experiments on the combustion of the taper in nitrous oxide, were chiefly made with a view to ascertain the cause of the double flame.

When the inflamed taper is introduced into pure nitrous oxide, it burns at first with a brilliant white light, and sparkles as in oxygene. As the combustion goes on, the brilliancy of the flame diminishes; it gradually lengthens, and becomes surrounded with a pale blue cone of light, from the apex of which much unburnt charcoal is thrown off, in the form of smoke. The flame continues double to the end of the process.

When the residual gases are examined after combustion, much nitrous acid is found suspended in them ; and they are composed of carbonic acid, nitrogene, and about one fourth of undecomposed nitrous oxide.

The double flame depends upon the nitrous acid formed by the ignition ; for it can be produced by plunging the taper into common air containing nitrous acid vapor, or into a mixture of nitrous oxide and nitrogene, through which nitrous acid has been diffused. It is never perceived in the combustion of the taper, till much nitrous acid is formed.

In attempting to respire some residual gas of nitrous oxide, in which a taper had burnt out, I found it so highly impregnated with nitrous acid, as to disable me from even taking it into my mouth.

The taper burns in a mixture of equal parts nitrous oxide and nitrogene, at first with a flame nearly the same as that of a candle in common air ; white. Before its extinction the interior white flame, and exterior blue flame, are perceived.

The taper is instantly extinguished in a mixture of one fourth nitrous oxide, and three fourths nitrogene.

In a mixture of equal parts nitrous oxide and nitrous gas, the taper burns at first with nearly as much brilliancy as in pure nitrous oxide; gradually the double and feeble flame is produced.

XIII. *On the Combustion of different Compound Bodies in Nitrous Oxide.*

All the solid and fluid compound inflammable bodies on which I have experimented, burn in nitrous oxide, at high temperatures. Wood, cotton, and paper, are easily inflamed in it by the burning glass. During their combustion, nitrous acid is always formed, carbonic acid, and water produced, and nitrogene evolved, rather less in bulk than the nitrous oxide decomposed.

I have already mentioned that alcohol and ether are soluble in nitrous oxide. When an ignited body is introduced into the solution of

alcohol, or ether in nitrous oxide, a slight explosion takes place.

XIV. *General Conclusions relating to the Decomposition of Nitrous Oxide, and to its Analysis.*

From what has been said in the preceding sections, it appears that the inflammable bodies, in general, require for their combustion in nitrous oxide, much higher temperatures than those at which they burn in atmospheric air, or oxygene.

When intensely heated they decompose it, with the production of much heat and light, and become oxygenated.

During the combustion of solid or fluid bodies, producing flame, in nitrous oxide, nitrous acid is generated, most probably from a new arrangement of principles, analogous to those observed in Sect. II, by the ignition of that part of the gas not in contact with the burning substance. Likewise when nitrous oxide in excess is decom-

posed by inflammable gases, nitrous acid, and sometimes a gas analogous to common air, is produced, doubtless from the same cause.

Pyrophorus is the only body that inflames in nitrous oxide, below the temperature of ignition.

Phosphorus burns in it with the blue flame, probably forming with its oxygene only phosphoreous acid at the dull red heat, and with the intensely vivid flame, producing phosphoric acid at the white heat.

Hydrogene, charcoal, sulphur, iron, and the compound inflammable bodies, decompose it only at heats equal to, or above, that of ignition: *probably* each a different temperature.

From the phænomena in Sect. V. it appears, that at the temperature of intense ignition, phosphorus has a stronger affinity for the oxygene of nitrous oxide than hydrogene; and reasoning from the different degrees of combustibility of the inflammable bodies, in mixtures of nitrous oxide and nitrogene, and from other phæno-

mena, we may conclude with probability, that at about the white heat, the affinity of the combustible bodies for oxygen takes place in the following order. Phosphorus, hydrogen, charcoal,* iron, sulphur, &c.

This order of attraction is very different from that obtaining at the red heat; in which temperature charcoal and iron have a much stronger affinity for oxygen than either phosphorus or hydrogen.†

The smallest quantity of oxygen given in the different analyses of nitrous oxide just detailed, is thirty five hundred parts; the greatest proportion is thirty-nine.

Taking the mean estimations from the most accurate experiments, we may conclude that 100 grains of the known ponderable matter of

* As is proved by the decomposition of oxide of iron and sulphuric acid by charcoal, at that temperature.

† Hydrogen at or about the red heat, appears to attract oxygen stronger than phosphorus. See Dr. Priestley's experiments, vol. i. page 262.

nitrous oxide, consist of about 36,7 oxygene, and 63,3 nitrogene ; or taking away decimals, of 37 oxygene to 63 nitrogene ; which is identical with the estimation given in Research I.

XV. *Observations on the combinations of Oxygene and Nitrogene.*

During the decompositions of the combinations of oxygene and nitrogene by combustible bodies, a considerable momentary expansion of the acting substances, and the bodies in contact with them is generally produced, connected with increased temperature ; whilst light is often generated to a great extent.

Of the causes of these phænomena we are at present ignorant. Our knowledge of them must depend upon the discovery of the precise nature of heat and light, and of the laws by which they are governed. The application of general hypotheses to isolated facts can be of little utility ; for this reason I shall at present forbear to enter into any discussions concerning

those agents, which are imperceptible to the senses, and known only by solitary effects.

Analysis and synthesis clearly prove that oxygen and nitrogen constitute the known ponderable matter of atmospheric air, nitrous oxide, nitrous gas, and nitric acid.

That the oxygen and nitrogen of atmospheric air exist in chemical union, appears almost demonstrable from the following evidences.

1st. The equable diffusion of oxygen and nitrogen through every part of the atmosphere, which can hardly be supposed to depend on any other cause than an affinity between these principles.*

2dly. The difference between the specific

* That attraction must be called chemical, which enables bodies of different specific gravities to unite in such a manner as to produce a compound, in every part of which the constituents are found in the same proportions to each other. Atmospheric air, examined after having been at perfect rest in closed vessels, for a great length of time, contains in every part the same proportions of oxygen and nitrogen; whereas if no affinity existed between these principles, following the laws of specific gravity, they ought to sepa-

gravity of atmospheric air, and a mixture of 27 parts oxygene and 73 nitrogene, as found by calculation ; a difference apparently owing to expansion in consequence of combination.

3dly. The conversion of nitrous oxide into nitrous acid, and a gas analogous to common air, by ignition.

4thly. The solubility of atmospheric air undecomposed in water.

ATMOSPHERIC AIR, then, may be considered as the least intimate of the combinations of nitrogene and oxygene.

It is an elastic fluid, permanent at all known temperatures, consisting of ,73 nitrogene, and ,27 oxygene. It is decomposable at certain temperatures, by most of the bodies possessing affinity for oxygene. It is soluble in about thirty times its bulk of water, and as far as we are acquainted with its affinities, incapable of

rate ; the oxygene forming the inferior, the nitrogene the superior stratum.

The supposition of the *chemical* composition of atmospheric air, has been advanced by many philosophers. The two first evidences have been often noticed.

combining with most of the simple and compound substances. 100 cubic inches of it weigh about 31 grains at 55° temperature, and 30 atmospheric pressure.

NITROUS OXIDE is a gas unalterable in its constitution, at temperatures below ignition. It is composed of oxygene and nitrogene, existing *perhaps* in the most intimate union which those substances are capable of assuming.* Its properties approach to those of acids. It is decomposable by the combustible bodies at very high temperatures, is soluble in double its volume of water, and in half its bulk of most of the inflammable fluids. It is combinable with the alkalies, and capable of forming with them peculiar salts. 100 grains of it are composed of about 63 nitrogene, and 37 oxygene. 100 cubic inches of it weigh 50 grains, at 55° temperature, and 30 atmospheric pressure.

* For it is unalterable by those bodies which are capable of attracting oxygene from nitrous gas and nitrous acid, at common temperatures.

NITROUS GAS is composed of about ,56 oxygene, and ,44 nitrogene, in intimate union. It is soluble in twelve times its bulk of water, and is combinable with the acids, and certain metallic solutions; it is possessed of no acid properties, and is decomposable by most of the bodies that attract oxygene strongly, at high temperatures. 100 cubic inches of it weigh about 34 grains, at the mean temperature and pressure.

NITRIC ACID is a substance permanently aëriform at common temperatures, composed of about 1 nitrogene, to 2,3 oxygene. It is soluble to a great extent in water, and combinable with the alkalies, and nitrous gas. It is decomposable by most of the combustible bodies, at certain temperatures. 100 cubic inches of it weigh, at the mean temperature and pressure, nearly 76 grains.

RESEARCH III.

RELATING TO THE RESPIRATION OF

NITROUS OXIDE,

AND OTHER

G A S E S.

RESEARCH III.

DIVISION I.

EXPERIMENTS and OBSERVATIONS on the EFFECTS produced upon ANIMALS by the RESPIRATION of NITROUS OXIDE.

I. *Preliminaries.*

THE term *respirable*, in its physiological application, has been differently employed. Some times by the respirability of a gas has been meant, its power of supporting life for a great length of time, when repeatedly applied to the blood in the lungs. At other times all gases have been considered as respirable, which were capable of introduction into the lungs by voluntary efforts, without any relation to their vitality.

In the last sense the word respirable is most properly employed. In this sense it is used in the following sections.

Non-respirable gases are those, which when applied to the external organs of respiration, stimulate the muscles of the epiglottis in such a way as to keep it perfectly close on the glottis; thus preventing the smallest particle of gas from entering into the bronchia, in spite of voluntary exertions; such are carbonic acid, and acid gases in general.*

Of respirable gases, or those which are capable of being taken into the lungs by voluntary efforts.

One only has the power of uniformly supporting life;—atmospheric air. Other gases, when respired, sooner or later produce death; but in different modes.

Some, as nitrogene and hydrogene, effect no positive change in the venous blood. Animals

* See the curious experiments of Rosier, *Journal de Physique*, 1786, vol. 1, pag. 419.

immersed in these gases die of a disease produced by privation of atmospheric air, analogous to that occasioned by their submerſion in water, or non-reſpirable gases.

Others, as the different varieties of hydro-carbonate, deſtroy life by producing ſome poſitive change* in the blood, which probably immediately renders it incapable of ſupplying the nervous and muſcular fibres with principles eſſential to ſenſibility and irritability.

Oxygene, which is capable of being reſpired for a much greater length of time than any other gas, except common air, finally deſtroys life; firſt producing changes in the blood, connected with new living action.†

After experiments, to be detailed hereafter, made upon myſelf and others, had proved that nitrous oxide was reſpirable, and capable of

* As appears from the experiments of Dr. Beddoes; likewise thoſe of Mr. Watt.

† As appears from the experiments of Lavoifier and Dr. Beddoes; and as will be ſeen hereafter.

supporting life for a longer time than any of the gases, except atmospheric air and oxygen, I was anxious to ascertain the effects of it upon animals, in cases where its action could be carried to a full extent; and to compare the changes occasioned by it in their organs, with those produced by other powers.

II. *On the respiration of Nitrous Oxide by warm-blooded Animals.*

The nitrous oxide employed in the following experiments, was procured from nitrate of ammoniac, and received in large jars, filled with water previously saturated with the gas. The animal was introduced into the jar, by being carried under the water; after its introduction, the jar was made to rest on a shelf, about half an inch below the surface of the water; and the animal carefully supported, so as to prevent his mouth from resting in the water.

This mode of experimenting, either under water or mercury, is absolutely necessary, to

ascertain with accuracy the effects of pure gases on living beings. In some experiments that I made on the respiration of nitrous oxide, by animals that were plunged into jars of it opened in the atmosphere, and immediately closed after their introduction, the unknown quantities of common air carried in, were always sufficient to render the results perfectly inaccurate.

Animals suffer little or nothing by being passed through water.

That the phænomena in these experiments might be more accurately observed, two or three persons were always present at the time of their execution, and an account of them was noted down immediately after.

a. A stout and healthy young cat, of four or five months old, was introduced into a large jar of nitrous oxide. For ten or twelve moments he remained perfectly quiet, and then began to make violent motions, throwing himself round the jar in every direction. In two minutes he appeared quite exhausted, and sunk quietly to the bottom of the jar. On applying my hand

to the thorax, I found that the heart beat with extreme violence ; on feeling about the neck, I could distinctly perceive a strong and quick pulsation of the carotids. In about three minutes the animal revived, and panted very much ; but still continued to lie on his side. His inspirations then became longer and deeper, and he sometimes uttered very feeble cries. In four minutes the pulsations of the heart appeared quicker and feebler. His inspirations were at long intervals, and very irregular ; in five minutes the pulse was hardly perceptible ; he made no motions, and appeared wholly senseless. After five minutes and quarter he was taken out, and exposed to the atmosphere before a warm fire. In a few seconds he began to move, and to take deep inspirations. In five minutes he attempted to rise on his legs ; but soon fell again, the extremities being slightly convulsed. In eight or nine minutes he was able to walk, but his motions were staggering and unequal, the right leg being convulsed, whilst the other was apparently stiff and immoveable ; in about

half an hour he was almost completely recovered.

b. A healthy kitten, of about six weeks old, was introduced into nitrous oxide. She very soon began to make violent exertions, and in less than a minute fell to the bottom of the receiver, as if apoplectic. At this moment, applying my hand to her side, I felt the heart beating with great violence. She continued gasping, with long inspirations, for three minutes and half; at the end of five minutes and half she was taken out completely dead.

c. Another kitten of the same breed was introduced into nitrous oxide, the day after. She exhibited the same phænomena, and died in it in about five minutes and half.

d. A small dog that had accidentally met with a dislocation of the vertebræ of the loins, and was in great pain, as manifested by his moaning and whining, was introduced into a large jar of nitrous oxide. He immediately became quiet, and lay on his side in the jar, breathing very deeply. In four minutes his respiration became noisy, and his eyes sparkled

very much. I was not able to apply my hand to the thorax. In five minutes he appeared senseless, and in seven minutes was perfectly dead.

e. A strong rabbit, of ten or twelve months old, was introduced into nitrous oxide. He immediately began to struggle very much, and in a minute fell down senseless: in two minutes the legs became convulsed, and his inspirations were deep and noisy: in less than five minutes he appeared perfectly dead.

f. A rabbit of a month old introduced into nitrous oxide, became senseless in less than a minute; the pulsations of the heart were very strong at this moment: they gradually became weaker, and in three minutes and half the animal was dead.

g. Another rabbit of the same breed, after being rendered senseless in nitrous oxide in a minute and half, was taken out. He soon became convulsed; in a minute began to breathe quickly; in two minutes attempted to rise, but staggered, and fell again on his side. His hinder

legs were paralytic for near five minutes. In twenty he had almost recovered.

g. A middle sized guinea-pig was much convulsed, after being in nitrous oxide for a minute. In two minutes and half he was senseless. Taken out at this period, he remained for some minutes by the side of a warm fire, without moving; his fore legs then became convulsed; his hind legs were perfectly paralytic. In this state he continued, without attempting to rise or move, for near an hour, when he died.

b. A large and old guinea-pig died in nitrous oxide, exhibiting the same phænomena as the other animals, in about five minutes and quarter. A young one was killed in three minutes and half.

i. A small guinea-pig, after breathing nitrous oxide for a minute and half, was taken out, and placed before a warm fire. He was for a few minutes a little convulsed; but in a quarter of an hour got quite well, and did not relapse.

k. A large mouse introduced into nitrous oxide, was for a few seconds very active. In

half a minute he fell down senseless ; in a minute and quarter he appeared perfectly dead.

l. A mouse taken out of nitrous oxide, after being in it for half a minute, continued convulsed for some minutes, but finally recovered.

m. A young hen was introduced into a vessel filled with nitrous oxide. She immediately began to struggle very much ; fell on her breast in less than half a minute, and in two minutes was quite dead.

n. A goldfinch died in nitrous oxide in less than a minute.

In each of these experiments a certain absorption of the gas was always perceived, the water rising in the jar during the respiration of the animal. From them we learn

1st. That nitrous oxide is destructive when respired for a certain time to the warm blooded animals, apparently previously exciting them to a great extent.

2dly. That when its operation is stopped before compleat exhaustion is brought on, the healthy living action is capable of being gradually reproduced, by enabling the animal to respire atmospheric air.

3dly. That exhaustion and death is produced in the small animals by nitrous oxide sooner than in the larger ones, and in young animals of the same species, in a shorter time than in old ones, as indeed Dr. Beddoes had conjectured a priori would be the case.

Most of the animals destroyed in these experiments were examined after death; the appearances in their organs were peculiar. To prevent unnecessary repetitions, an account of them will be given in the fourth section.

III. *Effects of the respiration of Nitrous Oxide upon animals, as compared with those produced by their immersion in Hydrogene and Water.*

Before the following experiments were made, a number of circumstances had convinced me that nitrous oxide acted on animals by producing some positive change in their blood, connected with new living action of the irritable and sensitive organs, and terminating in their death.

To ascertain however, the difference between the effects of this gas and those of hydrogen and non-respirable gases, I proceeded in the following way.

a. Of two healthy rabbits of about two months old, of the same breed, and nearly of the same size.

One was introduced into nitrous oxide. In a half a minute, it had fallen down apparently senseless. On applying my hand to the thorax, the action of the heart appeared at first, very quick and strong, it gradually became weaker, and in two minutes and half, the animal was taken out quite dead.

The other was introduced into a jar of pure hydrogen through water. He immediately began to struggle very much, and in a quarter of a minute fell on his side. On feeling the thorax, the pulsations of the heart appeared very quick and feeble, they gradually diminished; his breathing became momentarily shorter, and in rather more than three quarters of a minute, he was taken out dead. Dr. Kinglake was

present at this experiment, and afterwards dissected both of the animals.

b. Of two similar rabbits of the same breed, nearly three months old. One was introduced into nitrous oxide, and after being rendered senseless by the respiration of it for nearly a minute and half, was exposed to the atmosphere, before a warm fire. He recovered gradually, but was occasionally convulsed, and had a paralysis of one of his hinder legs for some minutes : in an hour he was able to walk. The other, after being immersed in hydrogen for near half a minute, was restored to the atmosphere apparently inanimate. In less than a minute he began to breathe, and to utter a feeble noise ; in two minutes was able to walk, and in less than three minutes appeared perfectly recovered.

b. A kitten of about two months old, was introduced into a jar of nitrous oxide, at the same time that another of the same breed was plunged under a jar of water. They both struggled very much. The animal in the nitrous

oxide fell senseless before that under water had ceased to struggle, and to throw out air from its lungs. In two minutes and three quarters, the animal under water was quite dead: it was taken out and exposed to heat and air, but did not shew the slightest signs of life. At the end of three minutes and half, the animal in nitrous oxide began to gasp, breathing very slowly; at four minutes and three quarters it was yet alive; at the end of five minutes and quarter it appeared perfectly dead. It was taken out, and did not recover.

From these experiments it was evident, that animals lived at least twice as long in nitrous oxide as in hydrogen or water. Consequently from this circumstance alone, there was every reason to suppose that their death in nitrous oxide could not depend on the simple privation of atmospheric air; but that it was owing to some peculiar changes effected in the blood by the gas.

IV. *Of the changes effected in the Organisation of warm-blooded Animals, by the respiration of Nitrous Oxide.*

The external appearance of animals that have been destroyed in nitrous oxide, is very little different from that of those killed by privation of atmospheric air. The fauces and tongue appear of a dark red, and the eyes are dull, and a little protruded. Their internal organs, however, exhibit a very peculiar change. The lungs are pale brown red, and covered here and there with purple spots; the liver is of a very bright red, and the muscular fibre in general dark. Both the auricles and ventricles of the heart are filled with blood. The auricles contract for minutes after the death of the animal. The blood in the left ventricle, and the aorta, is of a tinge between purple and red, whilst that in the right ventricle is of a dark color, rather more purple than the venous blood. But these appearances, and their causes, will be better understood after the following comparative observations are read.

a. Of two similar rabbits, about eight months old, one A, was killed by exposure for near six minutes to nitrous oxide, the other, B, was destroyed by a blow on the head.

They were both opened as speedily as possible. The lungs of B were pale, and uniform in their appearance; this organ in A was redder, and every where marked with purple spots. The liver of A was of a dark and bright red, that of B of a pale red brown. The diaphragm of B, when cut, was strongly irritable; that of A rather darker, and scarce at all contractile. All the cavities of the heart contracted for more than 50 minutes in B. The auricles contracted for near 25 minutes with force and velocity in A: but the ventricles were almost inactive. The vena cava, and the right auricle, in A, were filled with blood, apparently a shade darker than in B. The blood in the left auricle, and the aorta, appeared in A of a purple, a shade brighter than that of the venous blood. In the left auricle of B it was red.

I opened the head of each, but not without injuring the brains, so that I was unable to

make any accurate comparison. The color of the brain in A appeared rather darker than in B.

b. Two rabbits, C and D, were destroyed, C by immersion in nitrous oxide, D in hydrogen: they were both dissected by Dr. Kinglake. The blood in the pulmonary vein and the left auricle of C was of a different tinge, from that in D more inclined to purple red: The membrane of the lungs in C was covered with purple spots, that of D was pale and uniform in its appearance. The brain in C was rather darker than in D; but there was no perceptible effusion of blood into the ventricles either in D or C. The liver in C was of a brighter red than in health, that in D rather paler.

c. In the last experiment, the comparative irritability of the ventricles and auricles of the heart and the muscular fibre in the two animals, had not been examined. That these circumstances might be noticed, two rabbits, E and F were killed; E under water in about

a minute, and F in nitrous oxide in three minutes. They were immediately opened, and after a minute, the appearance of the heart, and organs of respiration observed.

Both the right and left ventricles of the heart in F contracted but very feebly; the auricles regularly and quickly contracted; the aorta appeared perfectly full of blood. In E, a feeble contraction of the left finus venosus and auricle was observed; the left ventricle did not contract: the right contracted, but more slowly than in F. In a few minutes, the contractions of the ventricles in F had ceased, whilst the auricles contracted as strongly and quickly as before. The blood in the pulmonary veins of F was rather of a redder purple than in E; the difference of the blood in the vena cava was hardly perceptible, perhaps it was a little more purple in F. The membranous substance of the lungs in F was spotted with purple as from extravasated blood, whilst that in E was pale. The brain in F was darker than in E. On opening the ventricles no extravasation of blood was perceptible.

The auricles of the heart in F contracted strongly for near twenty minutes, and then gradually their motion became less frequent; in twenty-eight minutes it had wholly ceased. The right auricle and ventricle in E, occasionally contracted for half an hour. The livers of both animals were similar when they were first opened, of a dark red; that of F preserved its color for some time when exposed to the atmosphere; whilst that of E almost immediately became paler under the same circumstances.

The peristaltic motion continued for nearly an equal time in both animals.

d. The sternum of a young rabbit was removed so that the heart and lungs could be perceived, and he was introduced into a vessel filled with nitrous oxide; the blood in the pulmonary veins gradually became more purple, and the heart appeared to beat quicker than before, all the muscles contracting with great force. After he had been in about a minute, spots began to appear on the lungs,

though the contractions of the heart became quicker and weaker; in three minutes and half he was quite dead; after death the ventricles contracted very feebly, though the contractions of the auricles were as strong almost after the end of five minutes as at first. This animal was passed through water saturated with nitrous oxide; possibly this fluid had some effect on his organs.

Besides these animals, many others, as guinea-pigs, mice and birds, were dissected after being destroyed in nitrous oxide; in all of them the same general appearance was observed. Their muscular fibre almost always appeared less irritable than that of animals destroyed, by organic læsion of part of the nervous system, in the atmosphere. The ventricles of the heart in general, contracted feebly and for a very short time; whilst the auricles continued to act for a great length of time. The lungs were dark in their appearance, and always suffused here and there with purple; the blood in the pulmonary veins when slightly

observed, appeared dark, like venous blood, but when minutely examined, was evidently much more purple. The blood in the vena cava, was darker than that in the pulmonary veins. The cerebrum was dark.

In a late experiment, I thought I perceived a slight extravasation of blood in one of the ventricles of the brain in a rabbit destroyed in nitrous oxide ; but as this appearance had not occurred in the animals I had examined before, or in those dissected by Dr. Kinglake, and Mr. King, Surgeon, I am inclined to refer it to an accidental cause. At my request, Mr. Smith, Surgeon, examined the brain of a young rabbit that had been killed in his presence in nitrous oxide ; he was of opinion that no effusion of blood into the ventricles had taken place.

In comparing the external appearance of the crural nerves in two rabbits that had been dissected by Dr. Kinglake, having been destroyed one in hydrogen, the other in nitrous oxide, we could perceive no perceptible difference.

It deserves to be noticed, that whenever the

gall bladder and the urinary bladder have been examined in animals destroyed in nitrous oxide, they have been always distended with fluid; which is hardly ever the case in animals killed by privation of atmospheric air.

In the infancy of my experiments on the action of nitrous oxide upon animals, I thought that it rendered the venous blood less coagulable; but this I now find to be a mistake. The blood from the pulmonary veins of animals killed in nitrous oxide, does not sensibly differ in this respect from the arterial blood of those destroyed in hydrogen, and both become vermilion nearly in the same time when exposed to the atmosphere.

In describing the various shades of color of the blood in the preceding observations on the different dissected animals, the poverty of the language of color, has obliged me to adopt terms, which I fear will hardly convey to the mind of the reader, distinct notions of the differences observable by minute examination in the venous and arterial blood of

animals that die of privation of atmospheric air, and of those destroyed by the action of nitrous oxide. This difference can only be observed in the vessels by means of a strong light; it may however be easily noticed in the fluid blood by the introduction of it from the arteries or veins at the moment of their incision, between two polished surfaces of white glass,* so closely adapted to each other, as to prevent the blood from coming in contact with the atmosphere.

Having four or five times had an opportunity of bleeding people in the arm for trifling complaints, I have always received the blood in phials, filled with various gases, in a mode to be described hereafter. Venous blood agitated in nitrous oxide, compared with similar blood in common air, hydrogene, and nitrogene, was always darker and more purple

* The colour of common venous blood, examined in this way, resembles that of the paint called by colour-men red ochre; that of blood saturated with nitrous oxide, approaches to the tinge of lake.

than the first, and much brighter and more florid than the two last, which were not different in their color from venous blood, received between two surfaces of glafs. It will be seen hereafter, that the coagulum of venous blood is rendered more purple when exposed to nitrous oxide, whilst the gas is absorbed; likewise that blood altered by nitrous oxide, is capable of being again rendered vermilion, by exposure to the air.

The appearances noticed in the above mentioned experiments, in the lungs of animals destroyed in nitrous oxide, are similar to those observed by Dr. Beddoes, in animals that had been made to breathe oxygene for a great length of time.

There were many reasons for supposing that the large purple spots in the lungs of animals destroyed in nitrous oxide, were owing to extravasation of venous blood from the capillary vessels; their coats being broken by the highly increased arterial action. To ascertain whether these phænomena existed at a period of the

action of nitrous oxide, when the animal was recoverable by exposure to the atmosphere,

I introduced a rabbit of six months old, into a vessel of nitrous oxide, and after a minute, when it had fallen down apparently apoplectic, plunged him wholly under water; he immediately began to struggle, and what surprised me very much, died in less than a minute after submersion. On opening the thorax, the blood in the pulmonary veins was nearly of the color of that in animals that have been simply drowned. The lungs were here and there, marked with a few points; but there were no large purple spots, as in animals that have been wholly destroyed in nitrous oxide: the right side of the heart only contracted. In this experiment, the excitement from the action of the gas was probably carried to such an extent, as to produce indirect debility. There are reasons for supposing, that animals after having been excited to but a small extent by the respiration of nitrous oxide, will live under water for a greater length of time, than animals previously made to breathe common air.

V. *Of the respiration of mixtures of Nitrous Oxide, and other gases, by warm-blooded Animals.*

a. A rabbit of near two months old, was introduced into a mixture of equal parts hydrogene and nitrous oxide through water. He immediately began to struggle; in a minute fell on his side; in three minutes gasped, and made long inspirations; and in four minutes and half, was dead. On dissection, he exhibited the same appearances as animals destroyed in nitrous oxide.

b. A large and strong mouse was introduced into a mixture of three parts hydrogene to one part nitrous oxide. He immediately began to struggle very much, in half a minute, became convulsed, and in about a minute, was quite dead.

c. Into a mixture of one oxygene, and three nitrous oxide, a small guinea-pig was introduced. He immediately began to struggle, and in two minutes reposed on his side, breathing very deeply. He made afterwards no violent

muscular motion ; but lived quietly for near fourteen minutes : at the end of which time, his legs were much convulsed. He was taken out, and recovered.

d. A mouse lived apparently without suffering, for near ten minutes, in a mixture of 1 atmospheric air, and 3 nitrous oxide, at the end of eleven minutes he began to struggle, and in thirteen minutes became much convulsed.

e. A cat of three months old, lived for seventeen minutes, in a very large quantity of a mixture of 1 atmospheric air, and 12 nitrous oxide. On her first introduction she was very much agitated and convulsed, in a minute and half she fell down as if apoplectic, and continued breathing very deeply during the remainder of the time, sometimes uttering very feeble cries. When taken out, she appeared almost inanimate, but on being laid before the fire, gradually began to breathe and move ; being for some time, like most of the animals that have recovered after breathing nitrous oxide, convulsed on one side, and paralytic the other.

- f. A goldfinch lived for near five minutes in a mixture of equal parts nitrous oxide and oxygen, without apparently suffering. Taken out, he appeared faint and languid, but finally recovered.*

VI. *Recapitulation of facts relating to the respiration of Nitrous Oxide, by warm-blooded Animals.*

1. Warm-blooded animals die in nitrous oxide infinitely sooner than in common air or oxygen; but not nearly in so short a time as in gases incapable of effecting positive changes in the venous blood, or in non-respirable gases.

2. The larger animals live longer in nitrous oxide than the smaller ones, and young animals

* Small birds suffer much from cold when introduced into gases through water. In this experiment, the goldfinch was immediately inserted into a large mouthed phial, filled with the gases, and opened in the atmosphere.

die in it sooner than old ones of the same species.

3. When animals, after breathing nitrous oxide, are removed from it before complete exhaustion has taken place, they are capable of being restored to health under the action of atmospheric air.

4. Peculiar changes are effected in the organs of animals by the respiration of nitrous oxide. In animals destroyed by it, the arterial blood is purple red, the lungs are covered with purple spots, both the hollow and compact muscles are *apparently* very irritable, and the brain is dark colored.

5. Animals are destroyed by the respiration of mixtures of nitrous oxide and hydrogen nearly in the same time as by pure nitrous oxide; they are capable of living for a great length of time in nitrous oxide mingled with very minute quantities of oxygen or common air.

These facts will be reasoned upon in the next division.

VII. *Of the respiration of Nitrous Oxide by amphibious Animals.*

As from the foregoing experiments, it appeared that the nitrous oxide destroyed warm-blooded animals by increasing the living action of their organs to such an extent, as finally to exhaust their irritability and sensibility ; it was reasonable to conjecture that the cold-blooded animals, possessed of voluntary power over respiration, would so regulate the quantity of nitrous oxide applied to the blood in their lungs as to bear its action for a great length of time. This conjecture was put to the test of experiment ; the following facts will prove its error.

a. Of two middle-sized water-lizards, one was introduced into a small jar filled with nitrous oxide, over moist mercury, by being passed through the mercury ; the other was made to breathe hydrogen, by being carried into it in the same manner.

The lizard in nitrous oxide, in two or three minutes, began to make violent motions, ap-

peared very uneasy, and rolled about the jar in every direction, sometimes attempting to climb to the top of it. The animal in hydrogen was all this time very quiet, and crawled about the vessel without being apparently much affected. At the end of twelve minutes, the lizard in nitrous oxide was lying on his back seemingly dead; but on agitating the jar he moved a little; at the end of fifteen minutes he did not move on agitation, and his paws were resting on his belly. He was now taken out stiff and apparently lifeless, but after being exposed to the atmosphere for three or four minutes, took an inspiration, and moved his head a little; he then raised the end of his tail, though the middle of it was still stiff and did not bend when touched. His four legs remained close to his side, and were apparently useless; but on pricking them with the point of a lancet, they became convulsed. After being introduced into shallow water, he was able to crawl in a quarter of an hour, though his motions were very irregular. In an hour he was quite well. The

animal in hydrogene appeared to have suffered very little in three quarters of an hour, and had raised himself against the side of the jar. At the end of an hour he was taken out, and very soon recovered.

b. Some hours after, the same lizards were again experimented upon. That which had been inserted into hydrogene in the last experiment, being now inserted into nitrous oxide.

This lizard was apparently lifeless in fourteen minutes, having tumbled and writhed himself very much during the first ten minutes. Taken out after being in twenty-five minutes, he did not recover. The other lizard lived in hydrogene for near an hour and quarter, taken out after an hour and twenty minutes, he was dead.

These animals were both opened, but the viscera of the nitrous oxide lizard were so much injured by the knife, that no accurate comparison of them with those of the other could be made, I thought that the lungs appeared rather redder.

c. Of two similar large water-lizards, one was introduced into a vessel standing over mercury, wholly filled with water that had been long boiled and suffered to cool under mercury.

The animal very often rose to the top of the jar as, if in search of air, during the first half hour ; but shewed no other signs of uneasiness. At the end of three quarters of an hour, he became very weak, and appeared scarcely able to swim in the water. Taken out at the end of fifty minutes, he recovered.

The other was inserted into nitrous oxide. After much struggling, he became senseless in about fifteen minutes, and lay on his back. Taken out at the end of twenty minutes, he remained for a long time motionless and stiff, but in a quarter of an hour, began to move some of his limbs.

From these experiments, we may conclude, that water-lizards, and most probably the other amphibious animals, die in nitrous oxide in a much shorter time than in hydrogene or pure water ; consequently their death in it cannot

depend on the simple privation of atmospheric air.

At the season of the year in which this investigation was carried on, I was unable to procure frogs or toads. This I regret very much.

Supposing that cold-blooded animals die in nitrous oxide from positive changes effected in their blood by the gas, it would be extremely interesting to notice the apparent alterations taking place in their organs of respiration and circulation during its action, which could easily be done, the membranous substance of their lungs being transparent. The increase or diminution of the irritability of their muscular fibre, might be determined by comparative galvanic experiments.

VIII. *Effects of solution of nitrous oxide in water on Fishes.*

a. A small flounder was introduced into a vessel filled with solution of nitrous oxide in water over mercury. He remained at rest for ten minutes and then began to move about the

jar in different directions. In a half an hour he was apparently dying, lying on his side in the water. He was now taken out, and introduced into a vessel filled with water saturated with common air, he very soon recovered.

b. Of two large thornbacks,* equally brisk and lively. One, A, was introduced into a jar containing nearly 3 cubic inches of water, saturated with nitrous oxide, and which previous to its impregnation had been long boiled; the other, B, was introduced into an equal quantity of water which had been deprived of air by distillation through mercury.

A, appeared very quiet for two or three minutes, and then began to move up and down in the jar, as if agitated. In eight minutes his motions became very irregular, and he darted obliquely from one side of the jar to the other.

* I use the popular name. This fish is very common in every part of England; it is nearly of the same size and color as the minnow, and is distinguished from it by two small bony excrescences at the origin of the belly. It is extremely susceptible.

In twelve minutes, he became still, and moved his gills very slowly. In fifteen minutes he appeared dead. After sixteen minutes he was taken out, but shewed no signs of life.

B was very quiet for four minutes and half. He then began to move about the jar. In seven minutes he had fallen on his back, but still continued to move his gills. In eleven minutes he was motionless; taken out after thirteen minutes, he did not recover.

c. Of two thornbacks, one, C was introduced into about an ounce of boiled water in contact with hydrogen, standing over mercury. The other, D, was introduced into well boiled water saturated with nitrous oxide, and standing in contact with it over mercury. C lived near thirteen minutes, and died without being previously much agitated. D was apparently motionless, after having the same affections as A in the last experiment, in sixteen minutes. At the end of this time he was taken out and introduced into common water. He soon began to move his gills, and in less than a quarter of

an hour was so far recovered as to be able to swim.

The last experiment was repeated on two smaller thornbacks ; that in the aqueous solution of nitrous oxide lived near seventeen minutes, that in the water in contact with hydrogen, about fifteen and half.

The experiments in Ref. I. Div. 3, prove the difficulty, and indeed almost impossibility of driving from water by boiling, the whole of the atmospheric air held in solution by it ; they likewise show that nitrous oxide by its strong affinity for water, is capable of expelling air from that fluid after no more can be procured from it by ebullition.

Hence, if water saturated with nitrous oxide had no positive effects upon fishes ; they ought to die in it much sooner than in water deprived of air by ebullition. From their living in it rather longer ;* we may conclude, that they are destroyed not by privation of atmospheric air, but

* A priori I expected that fishes, like amphibious animals would have been very quickly destroyed by the action of nitrous oxide.

from some positive change effected in their blood by the gas.

A long while ago, from observing that the gills of fish became rather of a lighter red during their death, in the atmosphere; I conjectured that the disease of which they died, was probably hyperoxygenation of the blood connected with highly increased animal heat. For not only is oxygene presented to their blood in much larger quantities in atmospheric air than in its aqueous solution; but likewise, to use common language, in a state in which it contains much more *latent heat*. Without however laying any stress on this supposition, I had the curiosity to try whether thornbacks would live longest in atmospheric air or nitrous oxide. In one experiment, they appeared to die in them nearly in the same time. In another, the fish in nitrous oxide lived nearly half as long again as that in atmospheric air.

XI. *Effects of Nitrous Oxide on Insects.*

The winged insects furnished with breathing

holes, become motionless in nitrous oxide very speedily ; being however possessed of a certain voluntary power over respiration, they sometimes recover, after having been exposed to it for some minutes, under the action of atmospheric air.

A butterfly was introduced into a small jar, filled with pure nitrous oxide, over mercury. He struggled a little during the first two or three seconds ; in about seven seconds, his legs became convulsed, and his wings were wrapt round his body ; in about half a minute he was senseless ; taken out after six minutes, he did not recover.

Another butterfly introduced into hydrogen, became convulsed in about a quarter of a minute, was senseless in twenty seconds, and taken out after five minutes, did not revive.

A large drone, after being in nitrous oxide for a minute and a quarter, was taken out senseless. After being for some time exposed to the atmosphere, he began to move, and at last rose on his wings. For some time, however, he was unable to fly in a straight line ; and often after

describing circles in the air, fell to the ground as if giddy.

A large fly, became motionless in nitrous oxide after being convulsed, in about half a minute. Another was rendered senseless in hydrogen, in less than a quarter of a minute.

A fly introduced into hydrocarbonate, dropt immediately senseless; taken out after about a quarter of a minute, he recovered; but like the fly that had lived after exposure to nitrous oxide, was for some time vertiginous.

Flies live much longer under water, alcohol, or oil, than in non-respirable gases, or gases incapable of supporting life. A certain quantity of air always continues attached in the fluid to the fine hairs surrounding their breathing holes, sufficient to support life for a short time.

Snails and earth-worms, live in nitrous oxide a long while, they die in it however, much sooner than in water or hydrogen; probably from the same causes as the amphibious animals.

DIVISION II.

*Of the CHANGES effected in NITROUS OXIDE,
and other GASES, by the RESPIRATION of
ANIMALS.*

I. *Preliminaries.*

AS soon as I had discovered that nitrous oxide was respirable, and possessed of extraordinary powers of action on living beings, I was anxious to be acquainted with the changes effected in it by the venous blood. To investigate these changes, appeared at first a simple problem; I soon however found that it involved much preliminary knowledge of the chemical properties and affinities of nitrous oxide. After I had ascertained by experiments detailed in the preceding Researches, the composition of this gas

its combinations, and the physical changes effected by it in living beings, I began my enquiry relating to the mode of its operation.

Finding that the residual gas of nitrous oxide after it had been breathed for some time in silk bags, was chiefly nitrogene, I at first conjectured that nitrous oxide was decomposed in respiration in the same manner as atmospheric air, and its oxygene only combined with the venous blood; the following experiments soon however convinced me of my error.

II. *Absorption of Nitrous Oxide by venous blood. Changes effected in the blood by different Gases.*

a. Though the laws of the coagulability of the blood are unknown, yet we are certain that at the moment of coagulation, a perfectly new arrangement of its principles takes place; consequently, their powers of combination must be newly modified. The affinities of

living blood can only be ascertained during its circulation in the vessels of animals. At the moment of effusion from those vessels, it begins to pass through a series of changes, which first produce coagulation, and finally its complete decomposition.

Consequently, the action of fluid blood upon gases out of the vessels, will be more analogous to that of circulating blood in proportion as it is more speedily placed in contact with them.

b. To ascertain the changes effected in nitrous oxide by fluid venous blood.

A jar, six inches long and half an inch wide, graduated to .05 cubic inches, having a tight stopper adapted to it, was filled with nitrogene, which is a gas incapable of combining with, and possessing no power of action upon venous blood. A large orifice was made in the vein of a tolerably healthy man, and the stopper removed from the jar, which was brought in contact with the arm so as to receive the blood, and pressed close against the skin, in such a way as to leave an orifice just sufficient for the escape of the nitro-

gene, as the blood flowed in. When the jar was full, it was closed, and carried to the pneumatic apparatus, the mercury of which had been previously a little warmed. A small quantity of the blood was transferred into another jar to make room for the gas. The remaining quantity equalled exactly two cubic inches; to this was introduced as speedily as possible, eleven measures equal to ,55 cubic inches of nitrous oxide, which left a residuum of $\frac{1}{32}$ only, when absorbed by boiled water, and was consequently, perfectly pure. On agitation, a rapid diminution of the gas took place.

In the mass of blood which was opaque, but little change of color could be perceived; but that portion of it diffused over the sides of the jar, was evidently of a brighter purple than the venous blood.

It was agitated for two or three minutes, and then suffered to rest; in eight minutes it had wholly coagulated; a small quantity of ferum had separated, and was diffused over the coagulum. This coagulum was dark; but

evidently of a more purple tinge than that of venous blood ; no gas had apparently been liberated during its formation.

The nitrous oxide remaining, was not quite equal to seven measures ; hence, at least four measures of it had been absorbed.

To ascertain the nature of the residuum, it was necessary to transfer it into another vessel, but this I found very difficult to accomplish, on account of the coagulated blood. By piercing through the coagulum and removing part of it by means of curved iron forceps, I at last contrived to introduce about $4\frac{1}{2}$ measures of the gas into a small cylinder, graduated to ,25 cubic inches, in which it occupied of course, nearly 9 measures ; when a little solution of strontian was admitted to these, it became very slightly clouded ; but the absorption that took place did not more than equal half its bulk. Consequently, the quantity of carbonic acid evolved from the blood, or formed, must have been extremely minute.

On the introduction of pure water, a rapid

absorption of the gas took place, and after agitation, not quite 3 measures remained. These did not *perceptibly* diminish with nitrous gas; their quantity was too small to be examined by any other test; but there is reason to suppose that they were chiefly composed of nitrogene.

From this experiment, it appeared that nitrous oxide is absorbed when placed in contact with venous blood; at the same time, that a very minute quantity of carbonic acid and probably nitrogene is produced.

c. In another similar experiment when nearly half a cubic inch of nitrous oxide was absorbed by about a cubic inch and three quarters of fluid blood, the residual gas did not equal more than $\frac{1}{8}$, the quantity absorbed being taken as unity. This fact induced me to suppose that the absorption of nitrous oxide by venous blood, was owing to a simple solution of the gas in that fluid, analogous to its solution in water or alcohol.

To ascertain if nitrous oxide could be expelled from blood impregnated with it, by heat; I introduced to 2 cubic inches of fluid

blood taken from the medial vein, about ,6 cubic inches of nitrous oxide. After agitation, in seven minutes nearly ,4, were absorbed. In ten minutes, after the blood had completely coagulated, the cylinder containing it, was transferred in contact with mercury, into a vessel of solution of salt in water; this solution was heated and made to boil. During its ebullition, the whole of the blood became either white or pale brown, and formed a solid coherent mass; whilst small globules of gas were given out from it. In a few minutes, about ,25 of gas had collected. After the vessel had cooled, I attempted to transfer this gas into a small graduated jar in the mercurial apparatus, but in vain; the mass in the jar was so solid and tough, that I could not remove it. By transferring it to the water apparatus, I succeeded in displacing enough of the coagulum to suffer the water to come in contact with the gas; an absorption of nearly half of it took place; hence, *I conjecture*, that nitrous oxide had been given out by the impregnated blood.

d. Some fresh dark coagulum of venous blood, was exposed to nitrous oxide. A very slight alteration of color took place at the surface of the blood, perceptible only in a strong light, and a minute quantity of gas was absorbed. A taper burnt in the remaining gas as brilliantly as before, hence, it had apparently suffered no alteration.

e. To compare the physical changes effected in the venous blood by nitrous oxide, with those produced by other gases, I made the following experiments.—I filled a large phial, containing near 14 cubic inches, with blood from the vein of the arm of a man, and immediately transferred it to the mercurial apparatus. Different portions of it were thrown into small graduated cylinders, filled with the following gases: nitrogene, nitrous gas, common air, oxygene, nitrous oxide, carbonic acid, and hydrocarbonate.

The blood in each of them was successively agitated till it began to coagulate; and making allowances for the different periods of agitation,

there was no marked difference in the times of coagulation.

The color of the coagulum in every part of the cylinder, containing nitrogene, was the same very dark red. When it was agitated so as to tinge the sides of the jar, it appeared exactly of the color of venous blood received between two surfaces of glass; no perceptible absorption of the gas had taken place.

The blood in nitrous gas was dark, and much more purple on the top than that in nitrogene. When agitated so as to adhere to the jar as a thin surface, this purple was evidently deep and bright. An absorption of rather more than $\frac{1}{8}$ of the volume of gas had taken place.

The blood in oxygene and atmospheric air, were of a much brighter tinge than that in any of the other gases. On the top, the color was vermilion, but no perceptible absorption had taken place.

The coagulum in nitrous oxide, when examined in the mass was dark, and hardly distinguishable in its color from venous blood; but when minutely noticed at the surface where it was

covered with serum, and in its diffusion over the sides of the jar, it appeared of a fine purplered, a tinge brighter than the blood in nitrous gas. An absorption had taken place in this cylinder, more considerable than in any of the others.

In carbonic acid, the coagulum was of a brown red, much darker than the venous blood, and a slight diminution of gas had taken place.

In the hydrocarbonate,* the blood was red, a shade darker than the oxygenated blood, and a very slight diminution of the gas† was perceptible.

f. To human blood that had been saturated with nitrous oxide whilst warm and constantly agitated for four or five minutes, to prevent its uniform coagulation, oxygene was introduced; the red purple on the surface of it,

* The hydrocarbonate employed, was procured from alcohol, by means of sulphuric acid. This gas contains more carbon, than hydrocarbonate from water and charcoal.

† The curious fact of the reddening of venous blood by hydrocarbonate, was discovered by Dr. Beddoes.

immediately changed to vermilion; and on agitation, this color was diffused through it. On comparing the tinge with that of oxygenated blood, no perceptible difference could be observed. No change of volume of the oxygene introduced, had taken place; and consequently, no nitrous oxide had been evolved from the blood.

g. Blood, impregnated with nitrous gas, was exposed to oxygene; but after agitation in it for many minutes, no change of its dark purple tinge could be observed, though a slight diminution of the oxygene appeared to take place.

h. Blood that had been rendered vermilion in every part by long agitation in atmospheric air, the coagulum of which was broken and diffused with the coagulable lymph through the serum, was exposed to nitrous oxide; for some minutes no perceptible change of color took place; but by agitation for two or three hours, it evidently assumed a purple tinge, whilst a slight absorption of gas took place. It never

however, became nearly so dark as venous blood that had been exposed to nitrous oxide.

i. Blood, oxygenated in the same manner as in the last experiment, the coagulum of which had been broken, was exposed to nitrous gas. The surface of it immediately became purple, and by agitation for a few minutes, this color was diffused through it. A slight diminution of the gas was observed. On comparing the tinge with that of venous blood that had been previously exposed to nitrous gas, there was no perceptible difference.

k. Blood exposed to oxygenated muriatic acid is wholly altered in its constitution and physical properties, as has been often noticed; the coagulum becomes black in some parts, and brown and white in others. Venous blood, after agitation in hydrogene or nitrogene, oxygenates when exposed to the atmosphere in the same manner as simple venous blood. I had the curiosity to try whether venous blood exposed to hydrogene, would retain its power of being oxygenated longer than blood

saturated with nitrous oxide : for this purpose some similar black coagulum was agitated for sometime in two phials, one filled with hydrogene, the other with nitrous oxide. They were then suffered to rest for three days at a temperature from about 56° to 63° . After being opened, no offensive smell was perceived in either of them, the blood in hydrogene was rather darker than at the time of their exposure, whilst that in nitrous oxide was of a brighter purple. On being agitated for some time in the atmosphere, the blood in nitrous oxide became red, but not of so bright a tinge as oxygenated venous blood. The color of the blood in hydrogene did not at all alter.

7. To ascertain whether impregnation with nitrous oxide accelerated or retarded the putrefaction of the blood ; I exposed venous blood in four phials, the first filled with hydrocarbonate, the second with hydrogene ; the third with atmospheric air, and the fourth with nitrous oxide. Examined after a fortnight, the blood in hydrogene and common air were both black, and stunk

very much ; that in hydrocarbonate was red, and perfectly sweet ; that in nitrous oxide appeared purple and had no disagreeable smell.

In a second experiment, when blood was exposed for three weeks to hydrocarbonate and nitrous oxide, that in nitrous oxide was darker than before and stunk a little ; that in hydrocarbonate was still perfectly sweet. The power of hydrocarbonate to prevent the putrefaction of animal matters, was long ago noticed by Mr. Watt.

m. Having accidentally cut one of my fingers so as to lay bare a little muscular fibre, I introduced it whilst bleeding into a bottle of nitrous oxide ; the blood that trickled from the wound evidently became much more purple ; but the pain was neither alleviated or increased. When however, the finger was taken out of the nitrous oxide and exposed to the atmosphere, the wound smarted more than it had done before. After it had ceased to bleed, I inserted it through water into a vessel of nitrous gas ; but it did not become more painful than before.

From all these observations, we may conclude,

1st. That when nitrous oxide is agitated in fluid venous blood, a certain portion of the gas is absorbed; whilst the color of the blood changes from dark red to red purple.

2dly. That during the absorption of nitrous oxide by the venous blood, minute portions of nitrogene and carbonic acid are produced, either by evolution from the blood, or from a decomposition of part of the nitrous oxide.

3dly. That venous blood impregnated with nitrous oxide is capable of oxygenation; and vice versa; that oxygenated blood may be combined with nitrous oxide.

When blood separated into coagulum and serum, is exposed to nitrous oxide, it is most probable that the gas is chiefly absorbed by the serum. That nitrous oxide however is capable of acting upon the coagulum, is evident from *d*. In the fluid blood, as we shall see hereafter, nitrous oxide is absorbed by the attractions of the whole compound.

III. *Of the changes effected in Nitrous Oxide by Respiration.*

To ascertain whether the changes effected in nitrous oxide by the circulating blood acting through the moist coats of the pulmonary veins of living animals, were highly analogous to those produced in it by fluid venous blood removed from the vessels, I found extremely difficult.

I have before observed, that when animals are made to respire nitrous oxide, a certain absorption of the gas always takes place; but the smaller animals, the only ones that can be experimented upon in the mercurial apparatus, die in nitrous oxide so speedily and occasion so slight a diminution of gas, that I judged it useless to attempt to analyse the residuum of their respiration, which supports flame as well as pure nitrous oxide, and is chiefly absorbable by water.

In the infancy of my researches, I often respired nitrous oxide in a large glass bell, fur-

nished with a breathing tube and stopcock, and poised in water saturated with the gas.

In two or three experiments in which the nostrils being closed after the exhaustion of the lungs, the gas was inspired from the bell and respired into it, a considerable diminution was perceived, and by the test of lime water some carbonic acid appeared to have been formed; but on account of the absorption of this carbonic acid by the impregnated water, and the liberation of nitrous oxide from it, it was impossible to determine with the least accuracy, the quantities of products after respiration.

About this time likewise, I often examined the residuum of nitrous oxide, after it had been respired in silk bags. In these experiments when the gas had been breathed for a long time, a considerable diminution of it was observed, and the remainder extinguished flame and gave a very slight diminution with nitrous gas. But the great quantity of this remainder as well as other phenomena, convinced me that though the oiled silk was apparently air tight when

dry, under flight pressure, yet during the action of respiration, the moist and warm gas expired, penetrated through it, whilst common air entered through the wetted surface.

To ascertain accurately, the changes effected in nitrous oxide by respiration, I was obliged to make use of the large mercurial airholder mentioned in Research I. of the capacity of 200 cubic inches. The upper cylinder of it was accurately balanced so as to be constantly under the pressure of the atmosphere. To an aperture in it, a stop cock having a very large orifice was adapted, curved and flattened at its upper extremity, so as to form an air-tight mouth-piece.

By accurately closing the nose, and bringing the lips tight on the mouth-piece, after a few trials I was able to breathe oxygen or common air in this machine for two minutes or two minutes and half, without any other uneasy feeling than that produced by the inclination of the neck and chest towards the cylinder. The power of uniformly exhausting the lungs and

fauces to the same extent, I did not acquire till after many experiments. At last, by preserving exactly the same posture after exhaustion of the lungs before the inspiration of the gas to be experimented upon, and during its compleat expiration, I found that I could always retain nearly the same quantity of gas in the bronchial vessels and fauces; the difference in the volume expired at different times, never amounting to a cubic inch and half.

By connecting the conducting pipe of the mercurial airholder, during the respiration of the gas, with a small trough of mercury by means of a curved tube, it became a perfect and excellent breathing machine. For by exerting a certain pressure on the airholding cylinder, it was easy to throw a quantity of gas after every inspiration or expiration, into tubes filled with mercury standing in the trough. In these tubes it could be accurately analysed, and thus the changes taking place at different periods of the process ascertained.

Whenever I breathed pure nitrous oxide in the mercurial airholder, after a compleat voluntary ex-

haustion of my lungs, the pleasurable delirium was very rapidly produced, and being obliged to stoop on the cylinder, the determination of blood to my head from the increased arterial action in less than a minute became so great, as often to deprive me of voluntary power over the muscles of the mouth. Hence, I could never rely on the accuracy of any experiment, in which the gas had been respired for more than three quarters of a minute.

I was able to respire the gas with great accuracy for more than half a minute; it at first, rather increasing than diminishing the power of volition; but even in this short time, very strong sensations were always produced, with sense of fulness about the head, somewhat alarming; a feeling which hardly ever occurs to me when the gas is breathed in the natural posture.

In all the numerous experiments that I made on the respiration of nitrous oxide in this way, a very considerable diminution of gas always took place; and the diminution was generally apparently greater to the eye during the first four or five inspirations.

The residual gas of an experiment was always examined in the following manner. After being transferred through mercury into a graduated cylinder, a small quantity of concentrated solution of caustic potash was introduced to it, and suffered to remain in contact with it for some hours; the diminution was then noted, and the quantity of gas absorbed by the potash, judged to be carbonic acid. To the remainder, twice its bulk of pure water was admitted. After agitation and rest for four or five hours, the absorption by this was noticed, and the gas absorbed considered as nitrous oxide. The residual unabsorbable gas was mingled over water with twice its bulk of nitrous gas; and by this means, its composition, whether it consisted wholly of nitrogen, or of nitrogen mingled with small quantities of oxygen, ascertained.

From a number of experiments made at different times on the respiration of nitrous oxide, I select the following as the most accurate.

E. 1. At temperature 54°, I breathed 102 cubic inches of nitrous oxide, which contained near $\frac{1}{50}$ common air, for about half a minute, seven inspirations and seven expirations being made. After every expiration, an evident diminution of gas was perceived ; and when the last full expiration was made, it filled a space equal to 62 cubic inches.

These 62 cubic inches analysed, were found to consist of

Carbonic acid	3,2
Nitrous oxide	29,0
Oxygene	4,1
Nitrogene	25,7
	<hr/>
	62,0
	<hr/>

Hence, accounting for the two cubic inches of common air previously mingled with the nitrous oxide, 71 cubic inches had disappeared in this experiment.

In the last respirations, the quantity of gas was so much diminished, as to prevent the full expansion of the lungs ; and hence the appa-

rent diminution was very much less after the first four inspirations.

E. 2. At temperature 47° , I breathed 182 cubic inches of nitrous oxide, mingled with $2\frac{1}{2}$ cubic inches of atmospheric air, which previously existed in the airholder, for near 40 seconds; having in this time made 8 respirations. The diminution after the first full inspiration, appeared to a by-stander nearly uniform. When the last complet expiration was made, the gas filled a space equal to 128 cubic inches, the common temperature being restored. These 128 cubic inches analysed, were found to consist of

Carbonic acid	5,25
Nitrous oxide	88,75
Oxygene	5,00
Nitrogene	29,00

Consequently, in this experiment, 93,25 cubic inches of nitrous oxide had disappeared.

In each of these experiments, the cylinder was covered with condensed watry vapor ex-

actly in the same manner as if common air had been breathed in it. It ought to be observed that, E. 1. was made in the morning, four hours and half after a moderate breakfast ; whereas, E. 2. was made but an hour and quarter after a plentiful dinner ; at which near three-fourths of a pint of table-beer had been drank.

From these experiments we learn, that nitrous oxide is rapidly absorbed by the venous blood, through the moist coats of the pulmonary veins. But as after a complete voluntary exhaustion of the lungs, much residual air must remain in the bronchial vessels and fauces, as appears from their incapability of completely collapsing, it is evident that the gas expired after every inspiration of nitrous oxide must be mingled with different quantities of the residual gas of the lungs ;* whilst after a complete expiration, much of the unabsorbed nitrous oxide must remain as residual gas in the lungs. Now when a complete expi-

* By lungs, I mean in this place, all the internal organs of respiration.

ration is made after the breathing of atmospheric air, it is evident that the residual gas of the lungs consists of nitrogene,* mingled with small portions of oxygene and carbonic acid. And these are the only products found after the respiration of nitrous oxide.

To ascertain whether these products were partially produced, during the process of respiration, as I was inclined to believe from the experiments in the last section, or whether they were wholly the residual gases of the lungs, I found extremely difficult.

I at first thought of breathing nitrous oxide immediately after my lungs had been filled with oxygene; and to compare the products remaining after the full expiration, with those produced after a full expiration of pure oxygene; but on the supposition that oxygene and nitrous oxide, when applied together to the venous blood, must effect changes in it different from

* Because these products are formed during the respiration of common air.

either of them separately, the idea was relinquished.

I attempted to inspire nitrous oxide, after having made two inspirations and a complete expiration of hydrogen; but in this experiment the effects of the hydrogen were so debilitating, and the consequent stimulation by the nitrous oxide so great, as to deprive me of sense. After the first three inspirations, I lost all power of standing, and fell on my back, carrying in my lips the mouth-piece separated from the cylinder, to the great alarm of Mr. Patrick Dwyer, who was noting the periods of inspiration.

Though experiments on successive inspirations of pure nitrous oxide might go far to determine whether or no any nitrogen, carbonic acid and oxygen were products of respiration, yet I distinctly saw that it was impossible in this way to ascertain their quantities, supposing them produced, unless I could first determine the capacity of my lungs; and the different proportions of the gases remaining in the bronchial vessels after a

complete expiration, when atmospheric air had been respired.

In some experiments (that I made on the respiration of hydrogen, with a view to determine whether carbonic acid was *produced* by the combination of carbon loosely combined in the venous blood, with the oxygen respired, or whether it was simply *given out* as excrementitious by this blood) I found, without however being able to solve the problem I had proposed to myself, that in the respiration of pure hydrogen, little or no alteration of volume took place; and that the residual gas was mingled with some nitrogen, and a little oxygen and carbonic acid.

From the comparison of these facts with those noticed in the last section and in R. III. Div. I. there was every reason to suppose that hydrogen was not absorbed or altered when respired; but only mingled with the residual gases of the lungs. Hence, by making a full expiration of atmospheric air, and afterwards taking six or seven respirations of hydrogen in the mercurial

airholder, and then making a compleat expiration, I conjectured that the residual gas and the hydrogene would be so mingled, as that nearly the same proportions should remain in the bronchial vessels, as in the airholder. By ascertaining these proportions and calculating from them, I hoped to be able to ascertain with tolerable exactness, the capacity of my fauces and bronchia, as well as the composition of the gas remaining in them, after a complete expiration of common air.

IV. *Respiration of Hydrogene.*

The hydrogene that I employed, was procured from the decomposition of water by means of clean iron filings and diluted sulphuric and muriatic acids. It was breathed in the same manner as nitrous oxide, in the large mercurial airholder.

After a compleat voluntary exhaustion of my lungs in the usual posture, I found great difficulty in breathing hydrogene for so long

as half a minute, so as to make a compleat expiration of it. It produced uneasy feelings in the chest, momentary loss of muscular power, and sometimes a transient giddiness.

In some of the experiments that I made ; on account of the giddiness, the results were rendered inconclusive, by my removing my mouth from the mouth-piece after expiration, before the assistant could turn the stopcock.

The purity of the hydrogene was ascertained immediately before the experiment by the test of nitrous gas, and by detonation with oxygene or atmospheric air ; generally 12 measures of atmospheric air were fired with 4 of the hydrogene, and if the diminution was to ten or a little more, the gas was judged to be pure.

After the experiment, when the compleat expiration had been made and the common temperature restored ; the volume of the gas was noticed, and then a small quantity of it thrown into the mercurial apparatus by means of the conducting tube, to be examined. The carbonic acid was separated by from it by means

of solution of potash or strontian; the quantity of oxygene it contained, was ascertained by means of nitrous gas of known composition; the superabundant nitrous gas was absorbed by solution of muriate of iron; and the proportions of hydrogen and nitrogen in the remaining gas, discovered by inflammation with atmospheric air or oxygene in the detonating tube by the electric spark.

a. The two following experiments made upon quantities of hydrogen, equal to those of the nitrous oxide respired in the experiments in the last section, are given as the most accurate of five.

E. 1. I respired at 59° 102 cubic inches of hydrogen apparently pure, for rather less than half a minute, making in this time seven quick respirations.

After the complete expiration, when the common temperature was restored, the gas occupied a space equal to 103 cubic inches nearly. These analyses were found to consist of

Carbonic acid ..	4,0
Oxygene	3,7
Nitrogene	17,3
Hydrogene	78,0
	<hr/>
	103,0

Now as in this experiment, the gas was increased in bulk only a cubic inch ; supposing that after the compleat expiration the gas in the lungs, bronchia and fauces was of nearly similar composition with that in the airholder, and that no hydrogene had been absorbed by the blood, it would follow that 24 cubic inches of hydrogene remained in the internal organs of respiration, and consequently, by the rule of proportion, about 7,8 of the mixed residual gas of the common air. And then the whole quantity of residual gas of the lungs, supposing the temperature 59°, would have been 31,8 cubic inches ; but as its temperature was nearly that of the internal parts of the body, 98°, it must have filled a greater space ; calculating from the experiments

of Guyton and Vernois,* about 37,5† cubic inches.

From the increase of volume, it would appear that a minute quantity of gas had been generated during the respiration, and this was, as we shall see hereafter, most probably carbonic acid.‡ Likewise there is reason to suppose, that a little of the residual oxygene must have been absorbed. Making allowances for those circumstances, it would follow, that the 37,5 cubic inches of gas remaining in my lungs, after a compleat expiration of atmospheric air at animal heat 98°, equal to 31,8 cubic inches at 59°, were composed of

Nitrogene	21,9
Carbonic acid	4,9
Oxygene	5,0
	<hr/>
	31,8

* Annales de Chimie, vol. 1, page 279.

† This is only an imperfect approximation; the ratio of the increase of expansibility of gases to the increase of temperature, has not yet been ascertained. It is probable that the expansibility of gases is altered by their mixture.

‡ For there is no reason to suppose the production of nitrogene.

E. 2. I respired for near a half a minute in the mercurial airholder at 61°, 182 cubic inches of hydrogen; having made during this time, six long inspirations. After the last expiration, the gas filled a space nearly equal to 184 cubic inches, and analysed, was found to consist of

Carbonic acid	24,8
Oxygene	4,6
Nitrogene	21,0
Hydrogene	153,6
	<hr/>
	184.

Now in this experiment, reasoning in the same manner as before, 28,4 cubic inches of hydrogen must have remained in the lungs, and likewise 5,5 of the atmospheric residual gas. Consequently, the whole residual gas was nearly equal to 34 cubic inches at 61°, which at 98° would become about 40,4 cubic inches. And reasoning as before, it would appear from this experiment, that the quantity of gas remaining in my lungs after a complete voluntary respira-

tion, equalled at 98, about 40 cubic inches, and at 61°, 34 nearly : making the necessary corrections ; that after common air had been breathed, these 34 cubic inches consisted of

Carbonic acid	4,1
Oxygene	5,5
Nitrogene	24,4

b. It would have been possible to prove the truth of the postulate on which the experiments were founded, by respiring common air or oxygene after the compleat expiration of the hydrogene, for the same time as the hydrogene was respired and in equal quantities.

For if portions of hydrogene were found in the airholder equal to those of the residual gases in the two experiments, it would prove that a *uniform* mixture of residual gas with the gas inspired, was produced by the respiration. That this mixture must have taken place, appeared, however, so evident from analogous facts, that I judged the experimental proof unnecessary.

Indeed, as most gases, though of different specific gravities, when brought in contact with each

other, assume some sort of union, it is more than probable, that gas inspired into the lungs, from being placed in contact with the residual gas on such an extensive surface, must instantly mingle with it. Hence, possibly one deep inspiration and complete expiration of the whole of a quantity of hydrogene, will be sufficient to determine the capacity of the lungs after complete voluntary exhaustion, and the nature of the residual air.

That two inspirations are sufficient, appears probable from the following experiment.

E. 3. After a complete voluntary expiration of common air, I made two deep inspirations of 141 cubic inches of hydrogene. After the complete expiration, they filled a space equal to rather more than 142 cubic inches, and analysed, were found to consist of

Carbonic acid	3,1
Oxygene	4,5
Nitrogene	18,8
Hydrogene	115,6
	<hr/>
	142.

Now calculating on the exhausted capacity of my lungs from this experiment, supposing uniform mixture, they would contain after expiration of common air, about 30,7 cubic inches at 58°, equal to 36 at 98°, composed of about

Nitrogene	20,9
Oxygene	5,8
Carbonic acid . .	4,0
	30,7

One should suppose a priori that in this experiment much less of the residual oxygene of the lungs must have been absorbed, than in Expts. 1 and 2 ; yet there is no very marked difference in the portions evolved. That a tolerably accurate mixture took place, appears from the quantity of nitrogene. The smaller quantity of carbonic acid is an evidence in favour of its evolution from the venous blood.

c. It is reasonable to suppose that the pressure upon the residual gas of the exhausted lungs, must be nearly equal to that of the atmosphere. But as aqueous vapour is perpetually given out

by the exhalents, and perhaps evolved from the moist coats of the pulmonary vessels, it is likely that the residual gas is not only fully saturated with moisture at 98°, but likewise impregnated with uncombined vapor ; and hence its volume enlarged beyond the increment of expansion of temperature.

Considering all these circumstances, and calculating from the mean of the three experiments on the composition of the residual gas, I concluded,

1st. That the exhausted capacity of my lungs was equal to about 41 cubic inches.

2dly. That the gas contained in my bronchial vessels and fauces, after a complete respiration of atmospheric air, was equal to about 32 cubic inches, its temperature being reduced to 55°.

3dly. That these 32 cubic inches were composed of about

Nitrogene . . .	23,0
Carbonic acid . . .	4,1
Oxygene . . .	4,9

d. In many experiments made in the mercurial airholder on the capacity of my lungs under different circumstances, I found that I threw out of my lungs by a full forced expiration at temperatures from 58° to 62°

	cub.in.	cub.in.
After a full voluntary inspiration, from	189	191
After a natural inspiration, from ..	78	79
After a natural expiration, from ..	67	68

So that making the corrections for temperature, it would appear, that my lungs in a state of voluntary inspiration, contained about 254 cubic inches; in a state of natural inspiration about 135; in a state of natural expiration, about 118; and in a state of forced expiration 41.*

As the exhausted capacity as well as impleted capacity of the internal organs of respiration must be different in different individuals, according as the forms and size of their thorax,

* This capacity is most probably below the medium, my chest is narrow, measuring in circumference, but 29 inches, and my neck rather long and slender.

fauces, and bronchia are different, it would be almost useless to endeavour to ascertain a standard capacity. It is however probable, that a ratio exists between the quantities of air inspired in the natural and forced inspiration, those expired in the natural and forced expiration, and the whole capacity of the lungs. If this ratio were ascertained, a single experiment on the natural inspiration and expiration of common air, would enable us to ascertain the quantity of residual gas in the lungs of any individual after a complete forced expiration.*

V. *Additional observations and experiments on the Respiration of Nitrous Oxide.*

a. Having thus ascertained the capacity of my lungs, and the composition of the residual gas of expiration, I proceeded to reason concerning

* Dr. Goodwyn in his excellent work on the connexion of life with respiration, has detailed some experiments on the capacity of the lungs after natural expiration. He makes the medium capacity about 109 cubic inches, which agrees very well with my estimation.—page 27.

the experiments in section III, on the respiration of nitrous oxide.

In Exp. I. nearly 100 cubic inches of nitrous oxide, making the corrections on account of the common air, were respired for half a minute. In this time, they were reduced to 62 cubic inches, which consisted of 3,2 carbonic acid, 29 nitrous oxide, 4,1 oxygene, and 25,7 nitrogene.

But, as appears from the last section, there existed in the lungs before the inspiration of the nitrous oxide, about 32 cubic inches of gas, consisting of 23 nitrogene, 4,1 carbonic acid, and 4,9 oxygene, temperature being reduced to 59°. This gas must have been perfectly mingled with the nitrous oxide during the experiment; and consequently, the residual gas in the lungs after the experiment, was of the same composition as that in the airholder.

Supposing it as before, to be about 32 cubic inches: from the rule of proportion, they will be composed of

Nitrous oxide . . .	14,7
Nitrogene	13,3

Carbonic acid . . .	1,9
Oxygene	2,1

And the whole quantity of gas in the lungs and the airholder, supposing the temperature 59°, will equal 94 cubic inches, which are composed of

Nitrous oxide	43,7
Nitrogene	39,0
Carbonic acid	5,2
Oxygene	6,1
	<hr/>
	94

But before the experiment, the gas in the lungs and airholder equalled 134 cubic inches, and these, reckoning for the common air, were composed of

Nitrous oxide	100
Nitrogene,	24,3
Carbonic acid	4,1
Oxygene	5,6

Hence, it appears, that 56,3 cubic inches of nitrous oxide were absorbed in this experiment, and 13,7 of nitrogene produced, either by evolution from the blood, or decomposition of the

nitrous oxide. The quantities of carbonic acid and oxygene approach so near to those existing after the respiration of hydrogene, that there is every reason to believe that no portion of them was produced in consequence of the absorption, or decomposition of the nitrous oxide.

b. In Exp. 2, calculating in the same manner, before the first inspiration, a quantity of gas equal to 216,5 cubic inches at 47°, existed in the lungs and airholder, and these 216,5 cubic inches were composed of

Nitrous oxide,	182,0
Nitrogene	24,9
Carbonic acid	4,1
Oxygene	5,5
	<hr/>
	216,5

After the compleat expiration, 160 cubic inches remained in the lungs and airholder, which was composed of

Nitrous oxide	110,6
Nitrogene	36,3
Carbonic acid	6,8
Oxygene	6,3

Hence, it appears, that 71,4 cubic inches of nitrous oxide were absorbed in this experiment, and about 12 of nitrogen produced. The quantity of carbonic acid and oxygen is rather greater than that which existed in the experiments on hydrogen.

c. From these estimations, I learned that a small quantity of nitrogen was produced during the absorption of nitrous oxide in respiration. It remained to determine, whether this nitrogen owed its production to evolution from the blood, or to the decomposition of a portion of the nitrous oxide.

Analogical evidences were not in favour of the hypothesis of decomposition. It was difficult to suppose that a body requiring the temperature of ignition for its decomposition by the most inflammable bodies, should be partially absorbed and partially decomposed at 98°, by a fluid apparently possessed of uniform attractions.

It was more easy to believe, that from the immense quantity of nitrogen taken into the blood in nitrous oxide; the system soon became

overcharged with this principle, which not being wholly expended in new combinations during living action, was liberated in the aëriform state by the exhalents, or through the moist coats of the veins.

Now if the last rationale were true, it would follow, that the quantity of nitrogene produced in respiration, ought to be increased in proportion as a greater quantity of nitrous oxide entered into combination with the blood.

d. To ascertain whether this was the case, I made after full voluntary exhaustion of my lungs, one full voluntary inspiration and expiration of 108 cubic inches of nitrous oxide. After this, it filled a space nearly equal to 99 cubic inches. The quantities of carbonic acid and oxygene in these were not determined; but by the test of absorption by water, they appeared to contain only 18 nitrogene; which is very little more than should have been given from the residual gas of the lungs.

In a second experiment, I made two respirations of 108 cubic inches of nitrous oxide

nearly pure. The diminution was to 95. On analysing these 95, I found to my great surprize; that they contained only 17 nitrogene. Hence, I could not but suspect some source of error in the process.

I now introduced into a strong new silk bag, the sides of which were in perfect contact, about 8 quarts of nitrous oxide. From the mode of introduction, this nitrous oxide must have been mingled with a little common air, not however sufficient to disturb the results.

I then adapted a cork cemented to a long curved tube to my right nostril; the tube was made to communicate with the water apparatus; and the left nostril being accurately closed, and the mouth-piece of the silk bag tightly adapted to the lips, I made a full expiration of the common air of my lungs, inspired nitrous oxide from the bag, and by carefully closing the mouth-piece with my tongue, expired it through the curved tube into the water apparatus. In this way, I made nine respirations of nitrous oxide. The expired gas of the first respiration

C c.

was not preserved ; but part of the gas of the second, third, fifth, seventh and ninth, were caught in separate graduated cylinders. The second, analysed by absorption, consisted of about 29 absorbable gas, which must have been chiefly nitrous oxide ; and 17 unabsorbable gas, which must have been chiefly nitrogen ; and the third of 22 absorbable gas, and 8 unabsorbable. The fifth was composed of 27 to 6 ; the seventh of 23 to 7, and the ninth of 26 to 11.

e. Though the results of these experiments were not so conclusive as could be wished ; yet, comparing them with those of the experiments in section III. it seemed reasonable to conclude, that the production of nitrogen was increased, in proportion as the blood became more fully impregnated with nitrous oxide.

From this conclusion, compared with the phenomenon noticed in section 2, and in Div. I. section 4, I am induced to believe that the production of nitrogen during the respiration of nitrous oxide, is not owing to the decomposition of part of the nitrous oxide, in the

aëriform state *immediately* by the attraction of the red particles of venous blood for its oxygene ; but that it is rather owing to a new arrangement produced in the principles of the impregnated blood, during circulation ; from which, becoming supersaturated with nitrogene, it gives it out through the moist coats of the vessels.

For if any portion of nitrous oxide were decomposed immediately by the red particles of the blood, one should conjecture, that the quantity of nitrogene produced, ought to be greater during the first inspirations, before these particles became fully combined with condensed oxygene. If on the contrary, the whole of the nitrogene and oxygene of the nitrous oxide were both combined with the blood, and carried through the pulmonary veins and left chamber of the heart to the arteries ; then, supposing the oxygene chiefly expended in living action, whilst the nitrogene was only partially consumed in new combinations, it would follow, that the venous blood of animals made to breathe nitrous oxide, hyper-saturated with nitrogene, must be different from

common venous blood ; and this we have reason to believe from the phænomena in Div. I. section 4, is actually the case.

f. Besides the nitrogene generated during the respiration of nitrous oxide, we have noticed the evolution of other products, carbonic acid,* and water.

Now as nearly equal quantities of carbonic acid are produced, whether hydrogene or nitrous oxide is respired, provided the process is carried on for the same time ; there is every reason to believe, as we have said before, that no part of the carbonic acid produced, is generated from the immediate decomposition of nitrous oxide by carbon existing in the blood.

Consequently, in these experiments, it must be either evolved from the venous blood ; or formed, by the slow combination of the oxygene of the residual air of respiration with the charcoal of the blood.

* The oxygene as we have before noticed, most probably wholly existed in the residual gas.

But if it was produced by the decomposition of residual atmospheric air, it would follow, that its volume must be much less than that of the oxygen of the residual air, which had disappeared ; for some of this oxygen must have been *absorbed* by the blood, and during the conversion of oxygen into carbonic acid by charcoal, a slight diminution of volume is produced.

In the experiments when nitrous oxide and hydrogen were respired for about half a minute, the medium quantity of carbonic acid produced, was 5,6 cubic inches nearly.

Now we will assume, that the quantity of carbonic acid produced, is in the ratio of the oxygen diminished ; and there is every reason to believe, that in the expiration of atmospheric air, the expired air and the residual air are nearly of the same composition.

Hence, no more carbonic acid can remain in the lungs or be produced from the residual gas after the complete expiration of common air, than that which can be generated from a

volume of atmospheric air equal to the residual gas of the lungs.

The residual gas of the lungs, after complete expiration, equals at 55°, 32 cubic inches, and 32 cubic inches of common air contain 8.6 cubic inches of oxygen.

But in the experiments on the respiration of hydrogen, not only 5.6 cubic inches of carbonic acid were produced, but more than 4 of residual oxygen remained unabsorbed.

Hence it appears impossible that all the carbonic acid evolved from the lungs during the respiration of nitrous oxide or hydrogen could have been produced by the combination of charcoal in the venous blood with residual atmospheric oxygen: there is consequently every reason to believe that it is wholly or partially liberated from the venous blood through the moist coats of the vessels.

g. The water carried out of the lungs in solution by the expired gas of nitrous oxide, could neither have been wholly or partially formed by the decomposition of nitrous oxide. The

coats of the vessels in the lungs, and indeed in the whole internal surface of the body, are always covered with moisture, and the solution of part of this moisture by the inspired heated gas, and its deposition by the expired gas, are sufficient causes for the appearance of the phenomenon.

There are no reasons for supposing that any of the residual atmospheric oxygen is immediately combined with fixed or nascent hydrogen, or hydrocarbonate, in the venous blood at 98°, by slow combustion, and consequently none for supposing that water is immediately formed in respiration.

The evolution of water from the vessels in the lungs, is almost certain from numerous analogies.

b. As from the experiments in section II. it appeared that nitrous oxide was capable of being combined with oxygenated blood, and vice versa, blood impregnated with nitrous oxide capable of oxygenation; I was curious to ascertain what changes would be effected in nitrous oxide when

it was respired, mingled with atmospheric air or oxygene. For this purpose, without making a very delicate experiment, I breathed in the large mercurial airholder about 112 cubic inches of nitrous oxide, mingled with 44 of common air, for near half a minute, in the usual mode. The gas, after expiration, filled a space nearly equal to 119. I did not exactly ascertain the composition of the residual gas; it supported flame rather better than common air, and after the nitrous oxide was absorbed, gave much less diminution with nitrous gas than atmospheric air.

i. I breathed a mixture of four quarts of nitrous oxide with three quarts of hydrogen, in a dry silk bag, for near a minute; an evident diminution was produced; but on account of the mode of experimenting it was impossible to determine the quantity of nitrous oxide absorbed, or the exact nature of the products. When a taper was introduced into a little of the residual gas, it inflamed with a very feeble explosion. Now a mixture of 4 parts nitrous ox-

ide and 3 hydrogene, detonates when inflamed with very great violence.

k. Nitrous oxide can be respired without danger by the human animal for a much longer time than that required for the death of the smaller quadrupeds in it.

I have breathed it two or three times in a considerable state of purity, in a dry silk bag, for four minutes and quarter and four minutes and half: some diseased individuals have respired it for upwards of five minutes.

In the infancy of my experiments, from general appearances, I thought that the proportion of nitrous oxide absorbed in respiration was greater in the first inspirations than the last; but this I have since found to be a mistake. In the last respirations the apparent absorption is indeed less; but this is on account of the increased evolution of nitrogene from the blood. When nitrous oxide is respired for a long time, the last inspirations are always fuller and quicker than the first; but the consumption by the same individual is nearly in the ratio of the time of respiration. Three

quarts i. e. about 174 cubic inches, are consumed so as to be unfit for respiration, by an healthy individual with lungs of moderate capacity, in about a minute and quarter; six quarts, or 348 cubic inches, last generally for two minutes and half or two minutes and three quarters; eight quarts, or 464 cubic inches, for more than three minutes and half; and twelve, or 696 cubic inches, for nearly five.

The quantities of nitrous oxide absorbed by the same individual, will, as there is every reason to suppose, be different under different circumstances, and will probably be governed in some measure by the state of the health. It is reasonable to suppose, that the velocity of the circulation must have a considerable influence on the absorption of nitrous oxide; probably in proportion as it is greater a larger quantity of gas will be consumed in equal times.

I am inclined from two or three experiments, to believe that nitrous oxide is absorbed more rapidly after hearty meals or during stimulation from wine or spirits, than at other times. As

its absorption appears to depend on a simple solution in the venous blood ; probably diminution of temperature will increase its capability of being absorbed.

l. The quantities of nitrous oxide absorbed by different individuals, will probably be governed in some measure by the size of their lungs and the surface of the blood vessels, all other circumstances being the same.

From the observations that I have been able to make on the absorption of nitrous oxide, as compared with the capacity of the lungs, the range of the consumption of different individuals does not extend to more than a pint, or 30 cubic inches at the maximum dose.

We may therefore conclude, that the medium consumption of nitrous oxide by the respiration of different individuals, is not far from two cubic inches, or about a grain every second, or 120 cubic inches, or 60 grains every minute.

m. When nitrous oxide is breathed in tight silk bags, towards the end of the experiment as the internal surface becomes moist, as I have

before mentioned, a certain quantity of common air penetrates through it and becomes mixed with the residual gas of the experiment; but this quantity is always too small to destroy any of the effects of the nitrous oxide. The residual gas of the common air, the nitrogene and carbonic acid produced in the process, and the residuum of the admitted atmospheric air, hardly ever amount after the experiment, to one half of the volume of the nitrous oxide absorbed. There is consequently, a perfect propriety in successively inspiring and expiring the whole of a given quantity of nitrous oxide, till it is nearly consumed. In the respiration of nitrous oxide as the gas is absorbed and not decomposed, little will be gained in effect, by perpetually inspiring and expiring new portions, whilst an immense quantity of gas will be idly wasted, and this circumstance, considering the expence of the substance, is of importance.

VI. *On the respiration of Atmospheric Air.*

Having thus ascertained the absorption of nitrous oxide in respiration, and the evolution of nitrogene and carbonic acid from the lungs during its absorption : considering atmospheric air as a compound in which principles identical with those in nitrous oxide existed, though in different quantities and looser combination, I was anxious to compare the changes effected in this gas by respiration, with those produced in nitrous oxide and oxygene ; particularly as they are connected with the health and life of animals.

The ingenious experiments of Lavoisier and Goodwyn, prove the consumption of oxygene in respiration, and the production of carbonic acid. From many experiments on the respiration of common air, Dr. Priestley suspected that a certain portion of nitrogene, as well as oxygene, was absorbed by the venous blood.

b. In the following experiments on the respiration of atmospheric air in the mercurial air-holder ; the composition of the gas before inspiration and after expiration, was ascertained in the following manner.

Forty measures of it were agitated over mercury in solution of caustic potash, and suffered to remain in contact with it for two or three hours. The diminution was noted, and the gas absorbed judged to be carbonic acid. Twenty measures of the gas, freed from carbonic acid, were mingled with thirty of nitrous gas, in a tube of ,5 inches diameter ; they were not agitated,* but suffered to rest for an hour or an hour and half, when the volume occupied by them was noticed : and $50 - m$ the volume occupied, divided by 3 considered as the oxygene x , and $20 - x$ considered as the nitrogene.

* When they are agitated, a greater proportion of nitrous gas is absorbed, condensed in the nitric acid by the water ; and to find the oxygene,

$$x = \frac{50 - m}{3,4} \text{ or } \frac{50 - m}{3,5}$$

c. To ascertain the changes effected in atmospheric air by single inspirations,

I made, after a complete voluntary exhaustion of my lungs, at temperature 61° , one inspiration and expiration of 141 cubic inches of atmospheric air. After expiration, they filled a space equal to 139 cubic inches nearly. These 139 cubic inches analysed were found to consist of

Nitrogene	101
Oxygene.	32
Carbonic acid . .	6

The 141 cubic inches before inspiration, were composed of 103 nitrogene, 1 carbonic acid and 37 oxygene. The time taken to perform the inspiration and full expiration, was nearly a quarter of a minute.

I repeated this experiment seven or eight times, and the quantity of oxygene absorbed was generally from 5 to 6 cubic inches, the carbonic acid formed from 5 to 5,5, and the quantity of nitrogene apparently diminished by from 1 to 3 cubic inches.

E. 2. I made, after a voluntary expiration of common air, one inspiration and full expiration of 100 cubic inches of atmospheric air. It was diminished nearly to $98\frac{3}{4}$ or 99 cubic inches, and analysed, was found to consist of

Nitrogene ..	71,7
Oxygene	22,5
Carbonic acid ..	4,5

This experiment I likewise repeated four or five times, with very little difference of result, and there always seemed to be a small diminution of nitrogene. I made no corrections on account of the residual air of the lungs in these processes, because there was every reason to suppose that it was always of similar composition.

c. Before I could ascertain whether similar changes were effected in atmospheric air, by natural inspirations as by forced ones, I was obliged to practise respiration in the mercurial airholder, by suffering the conducting tube to communicate with the atmosphere till I had attained the power of breathing in it naturally, without labor or attention; I then found by a

IX. *Observations on the respiration of Nitrous Oxide.*

The experiments in the first Division of this Research, prove that nitrous oxide when respired by animals, produces peculiar changes in their blood and in their organs, first connected with increased living action; but terminating in death.

From the experiments in this Division, it appears, that nitrous oxide is rapidly absorbed by the circulating venous blood, and of course its condensed oxygene and nitrogene distributed in the blood over the whole of the system.

Concerning the changes effected in the principles of the impregnated blood during circulation and its action upon the nervous and muscular fibre; it is useless to reason in the present state of our knowledge.

It would be easy to form theories referring the action of blood impregnated with nitrous oxide, to its power of supplying the nervous and muscular fibre with such proportions of conden-

fed nitrogene, oxygene and light or ethereal fluid, as enabled them more rapidly to pass through those changes which constitute their life: but such theories would be only collections of terms derived from known phænomena and applied by loose analogies of language to unknown things.

We are unacquainted with the composition of dead organised matter; and new instruments of experiment and new modes of research must be found, before we can ascertain even our capabilities of discovering the laws of life.

RESEARCH IV.

RELATING TO THE

EFFECTS PRODUCED BY THE RESPIRATION

OF

NITROUS OXIDE

UPON DIFFERENT

INDIVIDUALS.

THE HISTORY

OF THE

REIGN

RESEARCH IV.

RELATING TO
THE EFFECTS
PRODUCED BY THE
RESPIRATION OF NITROUS OXIDE.

DIVISION I.

*HISTORY of the DISCOVERY.—Effects produced by
the RESPIRATION of different GASES.*

A SHORT time after I began the study of Chemistry, in March 1798, my attention was directed to the dephlogisticated nitrous gas of Priestley, by Dr. Mitchill's Theory of Contagion.*

The fallacy of this Theory was soon demonstrated, by a few coarse experiments made on small quantities of the gas procured from zinc

* Dr. Mitchill attempted to prove from some phænomena connected with contagious diseases, that dephlogisticated nitrous gas which he called oxide of septon, was the principle of contagion, and capable of producing the most terrible effects when respired by animals in the minutest quantities or even when applied to the skin or muscular fibre.

and diluted nitrous acid. Wounds were exposed to its action, the bodies of animals were immersed in it without injury ; and I breathed it mingled in small quantities with common air, without remarkable effects. An inability to procure it in sufficient quantities, prevented me at this time, from pursuing the experiments to any greater extent. I communicated an account of them to Dr. Beddoes.

In 1799, my situation in the Medical Pneumatic Institution, made it my duty to investigate the physiological effects of the aëriform fluids, the properties of which presented a chance of useful agency. At this period I recommenced the investigation.

A considerable time elapsed before I was able to procure the gas in a state of purity, and my first experiments were made on the mixtures of nitrous oxide, nitrogene and nitrous gas, which are produced during metallic solutions.

In the beginning of March, I prepared a large quantity of impure nitrous oxide from the nitrous solution of zinc. Of this I often breathed

the quantities of a quart and two quarts generally mingled with more than equal parts of oxygene or common air. In the most decisive of those trials, its effects appeared to be depressing, and I imagined that it produced a tendency to fainting: the pulse was certainly rendered slower under its operation.

At this time, Mr. Southey respired it in an highly diluted state; it occasioned a slight degree of giddiness, and considerably diminished the quickness of his pulse.

Mr. C. Coates likewise respired it highly diluted, with similar effects.

In April, I obtained nitrous oxide in a state of purity, and ascertained many of its chemical properties. Reflections upon these properties and upon the former trials, made me resolve to endeavour to inspire it in its pure form, for I saw no other way in which its respirability, or powers could be determined.*

* I did not attempt to experiment upon animals, because they die nearly in equal times in non-respirable gases, and gases incapable of supporting life and possessed of no action on the venous blood.

I was aware of the danger of this experiment. It certainly would never have been made if the hypothesis of Dr. Mitchill had in the least influenced my mind. I thought that the effects might be possibly depressing and painful, but there were many reasons which induced me to believe that a single inspiration of a gas apparently possessing no immediate action on the irritable fibre, could neither destroy or materially injure the powers of life.

On April 11th, I made the first inspiration of pure nitrous oxide; it passed through the bronchia without stimulating the glottis, and produced no uneasy feeling in the lungs.

The result of this experiment, proved that the gas was respirable, and induced me to believe that a farther trial of its effects might be made without danger.

On April 16th, Dr. Kinglake being accidentally present, I breathed three quarts of nitrous oxide from and into a silk bag for more than half a minute, without previously closing my nose or exhausting my lungs.

The first inspirations occasioned a slight degree of giddiness. This was succeeded by an uncommon sense of fulness of the head, accompanied with loss of distinct sensation and voluntary power, a feeling analogous to that produced in the first stage of intoxication ; but unattended by pleasurable sensation. Dr. Kinglake, who felt my pulse, informed me that it was rendered quicker and fuller.

This trial did not satisfy me with regard to its powers ; comparing it with the former ones I was unable to determine whether the operation was stimulant or depressing.

I communicated the result to Dr. Beddoes, and on April the 17th, he was present, when the following experiment was made.

Having previously closed my nostrils and exhausted my lungs, I breathed four quarts of nitrous oxide from and into a silk bag. The first feelings were similar to those produced in the last experiment ; but in less than half a minute, the respiration being continued, they diminished gradually, and were succeeded by a

sensation analogous to gentle pressure on all the muscles, attended by an highly pleasurable thrilling, particularly in the chest and the extremities. The objects around me became dazzling and my hearing more acute. Towards the last inspirations, the thrilling increased, the sense of muscular power became greater, and at last an irresistible propensity to action was indulged in; I recollect but indistinctly what followed; I know that my motions were various and violent.

These effects very soon ceased after respiration. In ten minutes, I had recovered my natural state of mind. The thrilling in the extremities, continued longer than the other sensations.*

This experiment was made in the morning; no languor or exhaustion was consequent, my feelings throughout the day were as usual, and I passed the night in undisturbed repose.

* Dr. Beddoes has given some account of this experiment, in his Notice of some observations made at the Medical Pneumatic Institution. It was noticed in Mr. Nicholson's Phil. Journal for May 1799.

The next morning the recollections of the effects of the gas were very indistinct, and had not remarks written immediately after the experiment recalled them to my mind, I should have even doubted of their reality. I was willing indeed to attribute some of the strong emotion to the enthusiasm, which I supposed must have been necessarily connected with the perception of agreeable feelings, when I was prepared to experience painful sensations. Two experiments however, made in the course of this day, with scepticism, convinced me that the effects were solely owing to the specific operation of the gas.

In each of them I breathed five quarts of nitrous oxide for rather a longer time than before. The sensations produced were similar, perhaps not quite so pleasurable; the muscular motions were much less violent.

Having thus ascertained the powers of the gas, I made many experiments to ascertain the length of time for which it might be breathed with safety, its effects on the pulse, and its

general effects on the health when often respired.

I found that I could breathe nine quarts of nitrous oxide for three minutes, and twelve quarts for rather more than four. I could never breathe it in any quantity, so long as five minutes. Whenever its operation was carried to the highest extent, the pleasurable thrilling at its height about the middle of the experiment, gradually diminished, the sense of pressure on the muscles was lost; impressions ceased to be perceived; vivid ideas passed rapidly through the mind, and voluntary power was altogether destroyed, so that the mouth-piece generally dropt from my unclosed lips.

Whenever the gas was in a high state of purity, it tasted distinctly sweet to the tongue and palate, and had an agreeable odor. I often thought that it produced a feeling somewhat analogous to taste, in its application to my lungs. In one or two experiments, I perceived a distinct sense of warmth in my chest.

I never felt from it any thing like oppressive

respiration : my inspirations became deep in proportion as I breathed it longer ; but this phænomenon arose from increased energy of the muscles of respiration, and from a desire of increasing the pleasurable feelings.

Generally when I breathed from six to seven quarts, muscular motions were produced to a certain extent ; sometimes I manifested my pleasure by stamping or laughing only ; at other times, by dancing round the room and vociferating.

After the respiration of small doses, the exhilaration generally lasted for five or six minutes only. In one or two experiments when ten quarts had been breathed for near four minutes, an exhilaration and a sense of slight intoxication lasted for two or three hours.

On May 3d. To ascertain whether the gas would accelerate or retard the progress of sleep, I breathed at about 8 o'clock in the evening, 25 quarts of nitrous oxide, in quantities of six at a time, allowing but short intervals between each dose. The feelings were much less pleasu-

nable than usual, and during the consumption of the two last doses, almost indifferent ; indeed the gas was breathed rather too soon after its production and contained some suspended acid vapour which stimulated the lungs so as to induce coughing.

After the experiments, for the first time I was somewhat depressed and debilitated ; my propensity to sleep however, came on at the usual hour, and as usual was indulged in, my repose was found and unbroken.

Between May and July, I habitually breathed the gas, occasionally three or four times a day for a week together ; at other periods, four or five times a week only.

The doses were generally from six to nine quarts ; their effects appeared undiminished by habit, and were hardly ever exactly similar. Sometimes I had the feelings of intense intoxication, attended with but little pleasure ; at other times, sublime emotions connected with highly vivid ideas ; my pulse was generally increased in fulness, but rarely in velocity.

The general effects of its operation upon my health and state of mind, are extremely difficult of description; nor can I well discriminate between its agency and that of other physical and moral causes.

I slept much less than usual, and previous to sleep, my mind was long occupied by visible imagery. I had a constant desire of action, a restlessness, and an uneasy feeling about the præcordia analogous to the sickness of hope.

But perhaps these phenomena in some measure depended on the interest and labour connected with the experimental investigation relating to the production of nitrous oxide, by which I was at this time incessantly occupied.

My appetite was as usual, and my pulse not materially altered. Sometimes for an hour after the inspiration of the gas, I experienced a species of mental indolence* pleasing rather than

* Mild physical pleasure is perhaps always destructive to action. Almost all our powerful voluntary actions, arise either from hope, fear, or desire; and the most powerful from desire, which is an emotion produced by the coalescence of hope or ideal pleasure with physical pain.

otherwise, and never ending in listlessness.

During the last week in which I breathed it uniformly, I imagined that I had increased sensibility of touch : my fingers were pained by any thing rough, and the tooth edge produced from slighter causes than usual. I was certainly more irritable, and felt more acutely from trifling circumstances. My bodily strength was rather diminished than increased.

At the latter end of July, I left off my habitual course of respiration ; but I continued occasionally to breathe the gas, either for the sake of enjoyment, or with a view of ascertaining its operation under particular circumstances.

In one instance, when I had head-ache from indigestion, it was immediately removed by the effects of a large dose of gas ; though it afterwards returned, but with much less violence. In a second instance, a slighter degree of head-ache was wholly removed by two doses of gas.

The power of the immediate operation of the gas in removing intense physical pain, I had a very good opportunity of ascertaining,

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1295
-165
1294

number of experiments, that I took into my lungs at every natural inspiration, about 13 cubic inches of air, and that I threw out of my lungs at every expiration,* rather less than this quantity; about $12\frac{3}{4}$ cubic inches.

The mean composition of the 13 cubic inches of air inspired, was

	cub. in.
Nitrogene ..	9,5
Oxygene . . .	3,4
Carbonic acid . .	0,1

That of the 12,7 of air expired

Nitrogene ..	9,3
Oxygene ..	2,2
Carbonic acid	1,2

These results I gained from more than 20 experiments, so that I could not possibly entertain any doubt of this accuracy.

I found, by making a person observe my respirations when I was inattentive to the process,

* The diminution of air by single inspirations, was particularly noticed by Dr. Goodwyn.

that I made about 26 or 27 natural inspirations in a minute. So that calculating from the above estimations, it would follow, that 31,6 cubic inches of oxygene were consumed, and 5,2 inches of nitrogene lost in respiration every minute, whilst 26,6 cubic inches of carbonic acid were produced.

To collect the products of a great number of natural expirations so as to ascertain whether their composition corresponded with the above accounts, I proceeded in the following manner.

I fastened my lips tight on the mouth-piece of the exhausted airholder, and suffering my nostrils to remain open, inspired naturally through them, throwing the expired air through my mouth into the airholder.

In many experiments, I found that in about a half a minute, I made in this way 14 or 15 expirations. The mean quantity of air collected was 171 cubic inches, and consisted of

	cub. in.
Nitrogene ..	128
Oxygene ..	29
Carbonic acid ..	14

Comparing these results with the former ones, we find the mean quantities of air respired in equal terms rather less; but the proportions of carbonic acid, nitrogen and oxygen in the respired air, nearly identical.

e. To ascertain the changes effected in a given quantity of atmospheric air by continued respirations, I breathed after a complete expiration, at temperature 63°, 161 cubic inches of air for near a minute, making in this time, 19 deep inspirations. After the complete expiration, which was very carefully made, the gas filled a space nearly equal to 152 cubic inches, so that 9 cubic inches of gas had disappeared.

The 152 cubic inches analysed, were found to consist of

	cub. in.
Nitrogen ..	111,6
Oxygen ..	23,
Carbonic acid,	17,4

The 161 cubic inches before inspiration, were composed of

	cub. in.
Nitrogene ..	117.0
Oxygene ..	42,4
Carbonic acid	1,6

But the residual gas in the lungs before the experiment, was of different composition from that remaining in the lungs after the experiment. Making corrections on account of this circumstance, as in section IV. it appears that about 5,1 of nitrogene were absorbed in respiration, 23,9 of oxygene consumed, and 12 of carbonic acid produced.

I repeated this experiment three times; in each experiment the diminution after respiration, was nearly the same; and the residual gas making the necessary allowances, of similar composition. So that supposing the existence of no source of error in the experiments from which the quantity and composition of the residual gas of the lungs were estimated in section IV. the absorption of nitrogene by the venous blood, appears almost demonstrated.

f. To compare the changes effected in atmospheric air by respiration of the smaller quadrupeds, with those in the experiments just detailed, I introduced into a jar of the capacity of 20 cubic inches filled with mercury in the mercurial trough, 15 cubic inches of atmospheric air which had been deprived of its carbonic acid by long exposure, to solution of potash.

Temperature being 64° , a healthy small mouse was quickly passed under the mercury into the jar, and suffered to rest on a very thin bit of cheese, which was admitted immediately after.

He continued for near 40 minutes without apparently suffering, occasionally raising himself on his hind legs. At the end of 50 minutes, he was lying on his side, and in 55 minutes was apparently dying. He was now carefully taken out through the mercury by the tail, and exposed before the fire, where he soon recovered. After the cheese had been carefully removed, the gas in the jar filled a space nearly equal to 14 cubic inches; so that a diminution of a

cubic inch had taken place. These 14 cubic inches analysed, were found to consist of

	cub. in.
Carbonic acid . .	2,0
Oxygene	1,4
Nitrogene . . .	10,6

The 15 cubic inches before the experiment, consisted of

	cub. in.
Oxygene	4
Nitrogene . . .	11

Hence it appeared, that 2,6 cubic inches of oxygene had been consumed, 2 cubic inches of carbonic acid produced, and about 0,4 of nitrogene left.

The relation between the quantities of oxygene consumed in this experiment, and the carbonic acid produced, are nearly the same as that of those in the experiments just detailed; but the quantity of nitrogene left is much smaller.

VII. *Respiration of Oxygene.*

The gases before and after respiration, were analysed in these experiments in the manner described in the last section, except that 3 of nitrous gas were always employed to one of oxygene.

E. I. At temperature 53°, after a full forced respiration, I respired in the mercurial airholder, for half a minute, 102 cubic inches of oxygene, making seven very long and deep inspirations. After the compleat expiration, the gases filled a space equal to 93 cubic inches; these 93 cubic inches analysed, were found to consist of

	cub. in.
Carbonic acid ..	5,9
Nitrogene	33,8
Oxygene	53,3

The 102 cubic inches before the experiment, were composed of

	cub. in.
Oxygene ..	78
Nitrogene ..	24

The residual gas in the lungs before the experiment, was 32 cubic inches, and composed of about 23 nitrogene, 4,1 carbonic acid, and 4,9 oxygene, Section IV. The residual gas after expiration, was composed of 18,2 oxygene, 2 carbonic acid, and 11,8 nitrogene.

Hence the whole of the gas in the lungs and airholder before inspiration, was 134 cubic inches, composed of

	cub. in.
Oxygene	82,9
Nitrogene	47,0
Carbonic acid	4,1

And after respiration, 125 cubic inches, consisting of

	cub. in.
Oxygene	71,5
Nitrogene	45,6
Carbonic acid	7,9

So that comparing the quantities, it appears, that 11,4 of oxygene and 1,4 of nitrogene, were consumed in this experiment, and 3,8 of carbonic acid produced.

I was much surpris'd at the small quantity of oxygene that had been consumed in this experiment. This quantity was less than that expended during the respiration of atmospheric air for half a minute : the portion of carbonic acid evolved was likewise smaller. I could detect no source of inaccuracy, and it was difficult to suppose that the greater depth and fulness of the inspirations could make any difference.

E. 2. I now respired at the same temperature, after a full expiration, 162 cubic inches of gas, composed of 133 oxygene and 29 nitrogene for two minutes, imitating as much as possible, the natural respiration. After the experiment, they filled a space equal to 123 cubic inches. And when the analysis and calculations had been made as in the last experiment, it appeared that 57 cubic inches of oxygene, and 2 of nitrogene had been absorbed, whilst 21 cubic inches of carbonic acid had been formed.

Now from the estimations in the last section,

it appears that 63 cubic inches of oxygene are consumed, and about 52 cubic inches of carbonic acid produced every two minutes during the natural respiration of common air. So that supposing the experiment accurate, 6 cubic inches of oxygene less are absorbed, and 30 cubic inches less of carbonic acid produced every minute, when oxygene nearly pure is respired, than when atmospheric air is respired.

Both these experiments were made in the morning, at a time when I was in perfect health; so that there could be apparently no source of error from accidental circumstances.

The uncommon and unexpected nature of the results, made me however, very sceptical concerning them; and before I would draw any inferences, I resolved to ascertain the comparative consumption of atmospheric air and oxygene by the smaller quadrupeds, for which purpose, I made the following experiment.

E. 3. Of two strong and healthy small mice, apparently of the same breed, and exactly similar.

One was introduced into a jar containing 10 cubic inches and half of oxygene, and 3 cubic inches of nitrogene, and made to rest on a bit of cheefe.

The other was introduced into a jar containing fifteen cubic inches and half of atmospheric air, and made to rest in the same manner on cheefe.

The mouse in oxygene began apparently to suffer in about half an hour, and occasionally panted very much; in about an hour he lay down on his side as if dying. The jars were often agitated, that the gases might be well mingled.

The mouse in atmospheric air became very feeble in 40 minutes, and at the end of 50 minutes was taken out through the mercury alive, but unable to stand.

The mouse in oxygene was taken out in the same manner after an hour and quarter, alive, but motionless, and breathing very deeply.

The gas in the jars was examined. That in the oxygene jar filled a space exactly equal to

12,7 cubic inches, and analysed, was found to consist of 1,7 carbonic acid, 2,6 of nitrogen, and 8,4 of oxygen. So that absolutely, 2,1 cubic inches of oxygen and ,4 of nitrogen had been consumed, and 1,7 of carbonic acid produced.

The gas in the atmospheric air jar was diminished nearly to 14,4, and consisted of 2,1 carbonic acid, 1,4 oxygen; and 10,9 nitrogen. So that 2,7 of oxygen and ,5 of nitrogen, had been consumed by the mouse; and 2,1 of carbonic acid produced.

Hence it appears, that the mouse in atmospheric air consumed nearly one-third more oxygen and produced nearly one-fourth more carbonic acid in respiration in 55 minutes, than the other in an hour and quarter in oxygen. And if we consider the perpetual diminution of the oxygen of the atmospheric air; from which at last it became almost incapable of supporting the life of the animal; we may conclude, that the quantity of oxygen consumed by it, had

the air been perpetually renovated, would have been much more considerable.

I design very shortly, to repeat these experiments, and to make others on the comparative consumption of oxygene and atmospheric air, by the larger quadrupeds. Whatever may be the results, I hope to be able to ascertain from them, why pure oxygene is incapable of supporting life.

VIII. *Observations on the changes effected in the blood, by atmospheric air and oxygene.*

From the experiments of Mr. Cigna and Dr. Priestley,* it appears that the coagulum of the venous blood becomes florid at its surface when exposed to the atmosphere, though covered and defended from the immediate contact of air by a very thick stratum of serum.

* Dr. Priestley found that it likewise became florid at the surface when covered by milk ; but that it underwent little or no alteration of color under water and most other fluids.—Vol. 3. p. 372.

Hence it is evident, that serum is capable of dissolving either the whole compound atmospheric air, or the oxygene of it.

Supposing what indeed is most probable from numerous analogies, that it dissolves the whole compound; it would follow, that the coloring of the coagulum of blood under serum, depended upon the decomposition of the atmospheric air condensed in the serum, the oxygene† of it combining with the red particles, and the nitrogen either remaining dissolved in the fluid, or being liberated through it into the atmosphere.

Now the circulating blood consists of red particles, floating in and diffused through serum and coagulable lymph.

† There are many analogous decompositions. Dr. Priestley noticed (and I have often made the observation) that green oxide of iron, or the precipitate from pale green sulphate of iron by caustic alkali, became red at the surface, when covered by a thick stratum of water. In my experiments on the green muriate and sulphate of iron, I observed that part of some dark oxide of iron which was at the bottom of a trough of water 9 inches deep, became red at the surface nearly in the same time as another portion of the same precipitation that was exposed to the atmosphere. This oxygenation must depend upon the decomposition of atmospheric air constantly dissolved by the water.

In natural respiration, the red particles are rendered of a brighter tinge during the passage of the blood through the pulmonary veins. And as we have seen in the last sections, during respiration atmospheric air is decomposed; all the oxygen of it consumed, *apparently* a small portion of the nitrogen lost, and a considerable quantity of carbonic acid produced.

It seems therefore reasonable to suppose, that the whole compound atmospheric air passing through the moist coats of the vessels is first dissolved by the serum of the venous blood, and in its condensed state, decomposed by the affinity of the red particles for its oxygen; the greater part of the nitrogen being liberated unaltered; but a minute portion of it possibly remaining condensed in the serum and coagulable lymph, and passing with them into the left chamber of the heart.

From the experiments on the respiration of nitrous oxide and hydrogen, it appears that a certain portion of the carbonic acid produced in respiration, is evolved from the venous blood;

but as a much greater quantity is generated during the respiration of common air and oxygene, than during that of hydrogen in equal times, it is not impossible but that some portion of it may be formed by the combination of charcoal in the red particles with the oxygene dissolved in the serum ; but this can only be determined by farther experiments.

Supposing that no part of the water evolved in solution by the expired gas of common air is formed immediately in respiration, it will follow that a very considerable quantity of oxygene must be constantly *combined* with the red particles, even allowing the consumption of a certain portion of it to form carbonic acid ; for the carbonic acid evolved, rarely amounts to more than three-fourths of the volume of the oxygene consumed.

Perhaps the serum of the blood is capable of dissolving a larger quantity of atmospheric air than of pure oxygene. On this supposition, it would be easy to explain the smaller consumption of oxygene in the experiments in the last section.

In cutting one of the unlucky teeth called *dentes sapientiæ*, I experienced an extensive inflammation of the gum, accompanied with great pain, which equally destroyed the power of repose, and of consistent action.

On the day when the inflammation was most troublesome, I breathed three large doses of nitrous oxide. The pain always diminished after the first four or five inspirations; the thrilling came on as usual, and uneasiness was for a few minutes, swallowed up in pleasure. As the former state of mind however returned, the state of organ returned with it; and I once imagined that the pain was more severe after the experiment than before.

In August, I made many experiments with a view of ascertaining whether any analogy existed between the sensible effects of the different gases which are sooner or later fatal to life when respired, and those of nitrous oxide.

I respired four quarts of Hydrogene* nearly

* Pure hydrogen has been often respired by different Philosophers, particularly by Scheele, Fontana, and the adventurous and unfortunate Rosier.

pure produced from zinc and muriatic acid, for near a minute, my lungs being previously exhausted and my nostrils carefully closed. The first six or seven inspirations produced no sensations whatever; in half a minute, I perceived a disagreeable oppression of the chest, which obliged me to respire very quickly; this oppression gradually increased, till at last the pain of suffocation compelled me to leave off breathing. I felt no giddiness during or after the experiment; my pulse was rendered feebler and quicker; and a by-stander informed me that towards the last, my cheeks became purple.

In a second experiment, when the hydrogen was procured from iron and diluted sulphuric acid, I was unable to respire it for so long as three quarters of a minute; a transient giddiness and muscular debility were produced, the pulse was rendered very feeble, and the pain of suffocation was greater than before.

I breathed three quarts of Nitrogene mingled with a very small portion of carbonic acid, for near a minute. It produced no alteration in

my sensations for the first twenty seconds ; then the painful sense of suffocation gradually came on, and increased rapidly in the last quarter of the minute, so as to oblige me to desist from the experiment. My pulse was rendered feebler and quicker. I felt no affection whatever in the head.

Mr. Watt's observations on the respiration of diluted Hydrocarbonate by men, and Dr. Beddoes's experiments on the destruction of animals by pure hydrocarbonate, proved that its effects were highly deleterious.

As it destroyed life apparently by rendering the muscular fibre inirritable without producing any previous excitement, I was anxious to compare its sensible effects with those of nitrous oxide, which at this time I believed to destroy life by producing the highest possible excitement, ending in læsion of organisation.

In the first experiment, I breathed for near a minute, three quarts of hydrocarbonate mingled with nearly two quarts of atmospheric air.*

* I believe it had never been breathed before by any individual, in a state so little diluted.

It produced a slight giddiness and pain in the head, and a momentary loss of voluntary power : my pulse was rendered much quicker and feebler. These effects however, went off in five minutes, and I had no return of giddiness.

Emboldened by this trial, in which the feelings were not unlike those I experienced in the first experiments on nitrous oxide, I resolved to breathe pure hydrocarbonate.

For this purpose, I introduced into a silk bag, four quarts of gas nearly pure, which was carefully produced from the decomposition of water by charcoal an hour before, and which had a very strong and disagreeable smell.

My friend, Mr. James Tobin, Junr. being present, after a forced exhaustion of my lungs, the nose being accurately closed, I made three inspirations and expirations of the hydrocarbonate. The first inspiration produced a sort of numbness and loss of feeling in the chest and about the pectoral muscles. After the second inspiration, I lost all power of perceiving external things, and had no distinct sensation except

a terrible oppression on the chest. During the third expiration, this feeling disappeared, I seemed sinking into annihilation, and had just power enough to drop the mouth-piece from my unclosed lips. A short interval must have passed during which I respired common air, before the objects about me were distinguishable. On recollecting myself, I faintly articulated, "*I do not think I shall die.*" Putting my finger on the wrist, I found my pulse thread-like and beating with excessive quickness.

In less than a minute, I was able to walk, and the painful oppression on the chest directed me to the open air.

After making a few steps which carried me to the garden, my head became giddy, my knees trembled, and I had just sufficient voluntary power to throw myself on the grass. Here the painful feeling of the chest increased with such violence as to threaten suffocation. At this moment, I asked for some nitrous oxide. Mr. Dwyer brought me a mixture of oxygene and nitrous oxide. I breathed this for a minute, and

believed myself relieved. In five minutes, the painful feelings began gradually to diminish. In an hour they had nearly disappeared, and I felt only excessive weakness and a slight swimming of the head. My voice was very feeble and indistinct. This was at two o'clock in the afternoon.

I afterwards walked slowly for about half an hour, with Mr. Tobin, Junr. and on my return, was so much stronger and better, as to believe that the effects of the gas had disappeared; though my pulse was 120 and very feeble. I continued without pain for near three quarters of an hour; when the giddiness returned with such violence as to oblige me to lie on the bed; it was accompanied with nausea, loss of memory, and deficient sensation. In about an hour and half, the giddiness went off, and was succeeded by an excruciating pain in the forehead and between the eyes, with transient pains in the chest and extremities.

Towards night these affections gradually dimi-

nished. At ten,† no disagreeable feeling except weakness remained. I slept sound, and awoke in the morning very feeble and very hungry. No recurrence of the symptoms took place, and I had nearly recovered my strength by the evening.

I have been minute in the account of this experiment because it proves, that hydrocarbonate acts as a sedative, i. e. that it produces diminution of vital action, and debility, without previously exciting. There is every reason to believe, that if I had taken four or five inspirations instead of three, they would have destroyed life immediately without producing any painful sensation. Perhaps most of the uneasy feelings after the experiment, were connected with the return of the healthy condition of organs.*

† I ought to observe, that between eight and ten, I took by the advice of Dr. Beddoes, two or three doses of diluted nitric acid.

* By whatever cause the exhaustion of organs is produced, pain is almost uniformly connected with their returning health. Pain is rarely ever perceived in limbs debilitated

About a week after this experiment, I attempted to respire Carbonic acid, not being at the time acquainted with the experiments of Rosier.

I introduced into a silk bag four quarts of well washed carbonic acid produced from carbonate of ammoniac* by heat, and after a compleat voluntary exhaustion of my lungs, attempted to inspire it. It tasted strongly acid in the mouth and fauces, and produced a sense of burning at the top of the uvula. In vain I made powerful voluntary efforts to draw it into the windpipe ; at the moment that the epiglottis was raised a little, a painful stimulation was induced, so as to close it spasmodically on the glottis ; and thus in repeated trials I was prevented from taking a single particle of carbonic acid into my lungs.

by fatigue till after they have been for some hours at rest. Pain is uniformly connected with the recovery from the debility induced by typhus, often with the recovery from that produced by the stimulation of opium and alcohol.

* Carbonic acid is produced in this way in a high state of purity, and with great readiness.

I tried to breathe a mixture of two quarts of common air and three of carbonic acid, without success; it stimulated the epiglottis nearly in the same manner as pure carbonic acid, and was perfectly non-respirable.

I found that a mixture of three quarts of carbonic acid with seven of common air was respirable, I breathed it for near a minute. At the time, it produced a slight degree of giddiness, and an inclination to sleep. These effects however, very rapidly disappeared after I had ceased to breathe,* and no other affections followed.

During the course of experiments on nitrous oxide, I several times breathed Oxygene procured from manganese by heat, for from three to five minutes.

In respiring eight or ten quarts; for the first

* Carbonic acid possesses no action on arterial blood. Hence perhaps, its slight effects when breathed mingled with large quantities of common air. Its effects are very marked upon venous blood! If it were thrown forcibly into the lungs of animals, the momentary application of it to the pulmonary venous blood would probably destroy life.

two or three minutes I could perceive no effects. Towards the end, even when I breathed very slowly, my respiration became oppressed, and I felt a sensation analogous to that produced by the want of fresh air; though but little of the oxygene had been consumed.

In one experiment when I breathed from and into a bag containing 20 quarts of oxygene for near six minutes; Dr. Kinglake felt my pulse, and found it not altered in velocity, but rather harder than before. I perceived no effects but those of oppression on the chest*.

* In a conversation with Mr. Watt, relating to the powers of gases, that excellent philosopher told me he had for some time entertained a suspicion, that the effects attributed to oxygene produced from manganese by heat, in some measure depended upon nitrous acid suspended in the gas, formed during ignition by the union of some of the oxygene of the manganese with nitrogene likewise condensed in it.

In the course of experiments on nitrous acid, detailed in Research I. made in September, October, and December, 1799, I several times experienced a severe oppression on the chest and difficulty of respiration, not unanalogous to that produced by oxygene, but much more violent, from breathing an atmosphere loaded with nitrous acid vapour. This fact seemed to confirm Mr. Watt's suspicion. I con-

Having observed in my experiments upon venous blood, that Nitrous gas rendered that fluid of a purple tinge, very like the color generated in it by nitrous oxide; and finding no painful effects produced by the application of nitrous gas to the bare muscular fibre, I began to imagine that this gas might be breathed with impunity, provided it were possible in any way to free the lungs of common air before inspiration, so as to prevent the formation of nitrous acid.

On this supposition, during a fit of enthusiasm produced by the respiration of nitrous oxide, I resolved to endeavour to breathe Nitrous gas.

114 cubic inches of nitrous gas were introduced into the large mercurial airholder; two

feels, however, that I have never been able to detect any smell of nitrous acid, either by means of my own organs or those of others, during the production of oxygen; when the gas is suffered to pass into the atmosphere. The oxygen breathed in the experiments detailed in the text, had been for some days in contact with water.

small silk bags of the capacity of seven quarts were filled with nitrous oxide.

After a forced exhaustion of my lungs, my nose being accurately closed, I made three inspirations and expirations of nitrous oxide in one of the bags, to free my lungs as much as possible from atmospheric oxygen; then, after a full expiration of the nitrous oxide, I transferred my mouth from the mouth-piece of the bag to that of the airholder, and turning the stop-cock, attempted to inspire the nitrous gas.— In passing through my mouth and fauces, it tasted astringent and highly disagreeable; it occasioned a sense of burning in the throat, and produced a spasm of the epiglottis so painful as to oblige me to desist instantly from attempts to inspire it. After moving my lips from the mouth-piece, when I opened them to inspire common air, æriform nitrous acid was instantly formed in my mouth, which burnt the tongue and palate, injured the teeth, and produced an inflammation of the mucous membrane which lasted for some hours.

As after the respiration of nitrous oxide in the experiments in the last Research, a small portion of the residual atmospheric air remained in the lungs, mingled with the gas, after forced expiration; it is most probable that a minute portion of nitrous acid was formed in this experiment, when the nitrous gas was taken into the mouth and fauces; which might produce its stimulating properties. If so, perhaps I owe my life to the circumstance; for supposing I had taken an inspiration of nitrous gas, and even that it had produced no positive effects, it is highly improbable, that by breathing nitrous oxide, I should have freed my lungs from it, so as to have prevented the formation of nitrous acid when I again inspired common air. I never design again to attempt so rash an experiment.

In the beginning of September I often respired nitrous oxide mingled with different proportions of common air or oxygene. The effects produced by the diluted gas were much less violent than those produced by pure nitrous

oxide. They were generally pleasant : the thrilling was not often perceived, but a sense of exhilaration was almost constant.

Between September and the end of October, I made but few experiments on respiration, almost the whole of my time being devoted to chemical experiments on the production and analysis of nitrous oxide.

At this period my health being somewhat injured by the constant labour of experimenting, and the perpetual inhalation of the acid vapours of the laboratory, I went into Cornwall ; where new associations of ideas and feelings, common exercise, a pure atmosphere, luxurious diet and moderate indulgence in wine, in a month restored me to health and vigor.

Nov. 27th. Immediately after my return, being fatigued by a long journey, I respired nine quarts of nitrous oxide, having been precisely thirty-three days without breathing any. The feelings were different from those I had experienced in former experiments. After the first six or seven inspirations, I gradually began

to lose the perception of external things, and a vivid and intense recollection of some former experiments passed through my mind, so that I called out "*what an amazing concatenation of ideas!*" I had no pleasurable feeling whatever, I used no muscular motion, nor did I feel any disposition to it; after a minute, when I made the note of the experiment, all the uncommon sensations had vanished; they were succeeded by a slight soreness in one of the arms and in the leg: in three minutes these affections likewise disappeared.

From this experiment I was inclined to suppose that my newly acquired health had diminished my susceptibility to the effects of the gas. About ten days after, however, I had an opportunity of proving the fallacy of this supposition.

Immediately after a journey of 126 miles, in which I had no sleep the preceding night, being much exhausted, I respired seven quarts of gas for near three minutes. It produced the usual pleasurable effects, and slight muscular motion.

I continued exhilarated for some minutes afterwards: but in half an hour found myself neither more or less exhausted than before the experiment. I had a great propensity to sleep.

I repeated the experiment four or five times in the following week, with similar effects. My susceptibility was certainly not diminished. I even thought that I was more affected than formerly by equal doses.

Though, except in one instance, when indeed the gas was impure, I had experienced no decisive exhaustion after the excitement from nitrous oxide, yet still I was far from being satisfied that it was unanalogous to stimulants in general.—No experiment had been made in which the excitement from nitrous oxide had been kept up for so great a length of time and carried to so great an extent as that in which it is uniformly succeeded by excessive debility under the agency of other powers.

It occurred to me, that supposing nitrous oxide to be a stimulant of the common class, it would follow that the debility produced in con-

sequence of excessive stimulation by a known agent, ought to be *increased* after excitement from nitrous oxide.*

To ascertain whether this was the case, I made on December 23d, at four P. M. the following experiment. I drank a bottle of wine in large draughts in less than eight minutes. Whilst I was drinking, I perceived a sense of fulness in the head, and throbbing of the arteries, not unanalogous to that produced in the first stage of nitrous oxide excitement. After I had finished the bottle, this fulness increased, the objects around me became dazzling, the power of distinct articulation was lost, and I was unable to walk steadily. At this moment the sensations were rather pleasurable than otherwise, the sense of fulness in the head soon however increased so as to become painful, and in

* In the same manner as the debility from intoxication by two bottles of wine is increased by a third.

less than an hour I sunk into a state of insensibility.*

In this situation I must have remained for two hours or two hours and half.

I was awakened by head-ache and painful nausea. The nausea continued even after the contents of the stomach had been ejected. The pain in the head every minute increased; I was neither feverish or thirsty; my bodily and mental debility were excessive, and the pulse feeble and quick.

In this state I breathed for near a minute and half five quarts of gas, which was brought to me by the operator for nitrous oxide; but as it produced no sensations whatever, and apparently rather increased my debility, I am almost convinced that it was from some accident, either common air, or very impure nitrous oxide.

Immediately after this trial, I respired 12 quarts

* I ought to observe that my usual drink is water, that I had been little accustomed to take wine or spirits, and had never been completely intoxicated but once before in the course of my life. This will account for the powerful effects of a single bottle of wine.

of oxygene for near four minutes. It produced no alteration in my sensations at the time ; but immediately after I imagined that I was a little exhilarated.

The head-ache and debility still however continuing with violence, I examined some nitrous oxide which had been prepared in the morning, and finding it very pure, respired seven quarts of it for two minutes and half.

I was unconscious of head-ache after the third inspiration ; the usual pleasurable thrilling was produced, voluntary power was destroyed, and vivid ideas rapidly passed through my mind ; I made strides across the room, and continued for some minutes much exhilarated. Immediately after the exhilaration had disappeared, I felt a slight return of the head-ache ; it was connected with transient nausea. After two minutes, when a small quantity of acidified wine had been thrown from the stomach, both the nausea and head-ache disappeared ; but languor and depression not very different in degree from those existing before the experiment, succeeded.

They however, gradually went off before bed time. I slept sound the whole of the night except for a few minutes, during which I was kept awake by a trifling head-ache. In the morning, I had no longer any debility. No head-ache or giddiness came on after I had arisen, and my appetite was very great.

This experiment proved, that debility from intoxication was not increased by excitement from nitrous oxide. The head-ache and depression, it is probable, would have continued longer if it had not been administered. Is it not likely that the slight nausea following the effects of the gas was produced by new excitability given to the stomach ?

To ascertain with certainty, whether the most extensive action of nitrous oxide compatible with life, was capable of producing debility, I resolved to breathe the gas for such a time and in such quantities, as to produce excitement equal in duration and superior in intensity to that occasioned by high intoxication from opium or alcohol.

To habituate myself to the excitement, and to carry it on gradually

On December 26th, I was inclosed in an air-tight breathing-box,* of the capacity of about 9 cubic feet and half, in the presence of Dr. Kinglake.

After I had taken a situation in which I could by means of a curved thermometer inserted under the arm, and a stop-watch, ascertain the alterations in my pulse and animal heat, 20 quarts of nitrous oxide were thrown into the box.

For three minutes I experienced no alteration in my sensations, though immediately after the introduction of the nitrous oxide the smell and taste of it were very evident.†

In four minutes I began to feel a slight glow

* The plan of this box was communicated by Mr. Watt. An account of it will be detailed in the *Researches*.

† The nitrous oxide was too diluted to act much; it was mingled with near 32 times its bulk of atmospheric air.

In the cheeks, and a generally diffused warmth over the chest, though the temperature of the box was not quite 50° . I had neglected to feel my pulse before I went in; at this time it was 104 and hard, the animal heat was 98° . In ten minutes the animal heat was near 99° , in a quarter of an hour 99.5° , when the pulse was 102, and fuller than before.

At this period 20 quarts more of nitrous oxide were thrown into the box, and well-mingled with the mass of air by agitation.

In 25 minutes the animal heat was 100° , pulse 124. In 30 minutes, 20 quarts more of gas were introduced.

My sensations were now pleasant; I had a generally diffused warmth without the slightest moisture of the skin, a sense of exhilaration similar to that produced by a small dose of wine, and a disposition to muscular motion and to merriment.

In three quarters of an hour the pulse was 104, and animal heat not 99.5° , the temperature of the chamber was 64° . The pleasurable

feelings continued to increase, the pulse became fuller and slower, till in about an hour it was 88°, when the animal heat was 99°.

20 quarts more of air were admitted. I had now a great disposition to laugh, luminous points seemed frequently to pass before my eyes, my hearing was certainly more acute and I felt a pleasant lightness and power of exertion in my muscles. In a short time the symptoms became stationary ; breathing was rather oppressed, and on account of the great desire of action, rest was painful.

I now came out of the box, having been in precisely an hour and quarter.

The moment after, I began to respire 20 quarts of unmingled nitrous oxide. A thrilling extending from the chest to the extremities was almost immediately produced. I felt a sense of tangible extension highly pleasurable in every limb ; my visible impressions were dazzling and apparently magnified, I heard distinctly every sound in the room and was perfectly aware

of my situation.* By degrees as the pleasurable sensations increased, I lost all connection with external things; trains of vivid visible images rapidly passed through my mind and were connected with words in such a manner, as to produce perceptions perfectly novel. I existed in a world of newly connected and newly modified ideas. I theorised; I imagined that I made discoveries. When I was awakened from this semi-delirious trance by Dr. Kinglake, who took the bag from my mouth, Indignation and pride were the first feelings produced by the sight of the persons about me. My emotions were enthusiastic and sublime; and for a minute I walked round the room perfectly regardless of what was said to me. As I recovered my former state of mind, I felt an inclination to communicate the discoveries I had made during the experiment. I endeavoured to recall the ideas, they were feeble and indistinct; one collection of terms, however, presented itself:

* In all these experiments after the first minute, my cheeks became purple.

and with the most intense belief and prophetic manner, I exclaimed to Dr. Kinglake, "*Nothing exists but thoughts!—the universe is composed of impressions, ideas, pleasures and pains!*"

About three minutes and half only, had elapsed during this experiment, though the time as measured by the relative vividness of the recollected ideas, appeared to me much longer.

Not more than half of the nitrous oxide was consumed. After a minute, before the thrilling of the extremities had disappeared, I breathed the remainder. Similar sensations were again produced; I was quickly thrown into the pleasurable trance, and continued in it longer than before. For many minutes after the experiment, I experienced the thrilling in the extremities, the exhilaration continued nearly two hours. For a much longer time I experienced the mild enjoyment before described connected with indolence; no depression or feebleness followed. I ate my dinner with great appetite and found myself lively and disposed to action immediately after. I passed the evening in executing expe-

riments. At night I found myself unusually cheerful and active; and the hours between eleven and two, were spent in copying the foregoing detail from the common-place book and in arranging the experiments. In bed I enjoyed profound repose. When I awoke in the morning, it was with consciousness of pleasurable existence, and this consciousness more or less, continued through the day.

Since December, I have very often breathed nitrous oxide. My susceptibility to its power is rather increased than diminished. I find six quarts a full dose, and I am rarely able to respire it in any quantity for more than two minutes and half.

The mode of its operation is somewhat altered. It is indeed very different at different times.

I am scarcely ever excited into violent muscular action, the emotions are generally much less intense and sublime than in the former experiments, and not often connected with thrilling in the extremities.

When troubled with indigestion, I have been two or three times unpleasantly affected after the excitement of the gas. Cardialgia, eructations and unpleasant fulness of the head were produced.

I have often felt very great pleasure when breathing it alone, in darkness and silence, occupied only by ideal existence. In two or three instances when I have breathed it amidst noise, the sense of hearing has been painfully affected even by moderate intensity of sound. The light of the sun has sometimes been disagreeably dazzling. I have once or twice felt an uneasy sense of tension in the cheeks and transient pains in the teeth.

Whenever I have breathed the gas after excitement from moral or physical causes, the delight has been often intense and sublime.

On May 5th, at night, after walking for an hour amidst the scenery of the Avon, at this period rendered exquisitely beautiful by bright moonshine; my mind being in a state of

agreeable feeling, I respired six quarts of newly prepared nitrous oxide.

The thrilling was very rapidly produced. The objects around me were perfectly distinct, and the light of the candle not as usual dazzling. The pleasurable sensation was at first local and perceived in the lips and about the cheeks. It gradually however, diffused itself over the whole body, and in the middle of the experiment was for a moment so intense and pure as to absorb existence. At this moment, and not before, I lost consciousness; it was however, quickly restored, and I endeavoured to make a by-stander acquainted with the pleasure I experienced by laughing and stamping. I had no vivid ideas. The thrilling and the pleasurable feeling continued for many minutes; I felt two hours afterwards, a slight recurrence of them, in the intermediate state between sleeping and waking; and I had during the whole of the night, vivid and agreeable dreams. I awoke in the morning with the feeling of restless energy, or that desire of action connected with no definite object, which I had

often experienced in the course of experiments in 1799.

I have two or three times since respired nitrous oxide under similar circumstances; but never with equal pleasure.

During the last fortnight, I have breathed it very often; the effects have been powerful and the sensations uncommon; but pleasurable only in a slight degree.

I ought to have observed that a desire to breathe the gas is always awakened in me by the sight of a person breathing, or even by that of an air-bag or an air-holder.

I have this day, June 5th, respired four large doses of gas. The first two taken in the morning acted very powerfully; but produced no thrilling or other pleasurable feelings. The effects of the third breathed immediately after a hearty dinner were pleasant, but neither intense or intoxicating. The fourth was respired at night in darkness and silence after the occurrence of a circumstance which had produced some anxiety. This dose affected me power-

fully and pleasantly ; a slight thrilling in the extremities was produced ; an exhilaration continued for some time, and I have had but little return of uneasiness. 11 P. M.

From the nature of the language of feeling, the preceding detail contains many imperfections ; I have endeavoured to give as accurate an account as possible of the strange effects of nitrous oxide, by making use of terms standing for the most similar common feelings.

We are incapable of recollecting pleasures and pains of sense.* It is impossible to reason concerning them, except by means of terms which have been associated with them at the moment of their existence, and which are afterwards called up amidst trains of concomitant ideas.

* Physical pleasure and pain generally occur connected with a compound impression, i. e. an organ and some object. When the idea left by the compound impression, is called up by being linked accidentally to some other idea or impression, no recurrence, or the slightest possible, of the pleasure or pain in any form will take place. But when the compound impression itself exists *without* the physical pleasure or pain, it will awaken ideal or intellectual

When pleasures and pains are new or connected with new ideas, they can never be intelligibly detailed unless associated during their existence with terms standing for analogous feelings.

I have sometimes experienced from nitrous oxide, sensations similar to no others, and they have consequently been indescribable. This has been likewise often the case with other persons. Of two paralytic patients who were asked what they felt after breathing nitrous

pleasure or pain, i. e. hope or fear. So that physical pleasure and pain are to hope and fear, what impressions are to ideas. For instance, assuming no accidental association, the child does not fear the fire before he is burnt. When he puts his finger to the fire he feels the physical pain of burning, which is connected with a visible compound impression, the fire and his finger. Now when the compound idea of the fire and his finger, left by the compound impression are called up by his mother, saying, "*You have burnt your finger,*" nothing like fear or the pain of burning is connected with it. But when the finger is brought near the fire, i. e. when the compound impression again exists, the ideal pain of burning or the passion of fear is awakened, and it becomes connected with those very actions which removed the finger from the fire.

oxide, the first answered, "*I do not know how, but very queer.*" The second said, "*I felt like the sound of a harp.*" Probably in the one case, no analogous feelings had ever occurred. In the other, the pleasurable thrillings were similar to the sensations produced by music; and hence, they were connected with terms formerly applied to music.

DIVISION II.

*DETAILS of the EFFECTS produced by the RES-
PIRATION of NITROUS OXIDE upon different
INDIVIDUALS furnished by THEMSELVES.*

THE experiments related in the following details, were made in the Medical Pneumatic Institution.

Abstracts from many of them have been published by Dr. Beddoes.*

I. *Detail of Mr. J. W. TOBIN.*

Having seen the remarkable effects produced on Mr. Davy, by breathing nitrous oxide, the 18th of April; I became desirous of taking some.

A day or two after I breathed 2 quarts of this

* Notice of some Observations made at the Medical Pneumatic Institution.

gas, returning it back again into the same bag, after two or three inspirations, breathing became difficult, and I occasionally admitted common air into my lungs. While the respiration was continued, my sensations became more pleasant. On taking the bag from my mouth, I staggered a little, but felt no other effect.

On the second time of making the experiment, I took nearly four quarts, but still found it difficult to continue breathing long, though the air which was left in the bag was far from being impure.

The effects however, in this case, were more striking than in the former. Increased muscular action was accompanied by very pleasurable feelings, and a strong desire to continue the inspiration. On removing the bag from my mouth, I laughed, staggered, and attempted to speak, but stammered exceedingly, and was utterly unable to pronounce some words. My usual state of mind, however, soon returned.

On the 29th, I again breathed four quarts. The pleasant feelings produced at first, urged

me to continue the inspiration with great eagerness. These feelings however, went off towards the end of the experiment, and no other effects followed. The gas had probably been breathed too long, as it would not support flame. I then proposed to Mr. Davy, to inhale the air by the mouth from one bag, and to expire it from the nose into another. This method was pursued with less than three quarts, but the effects were so powerful as to oblige me to take in a little common air occasionally. I soon found my nervous system agitated by the highest sensations of pleasure, which are difficult of description; my muscular powers were very much increased, and I went on breathing with great vehemence, not from a difficulty of inspiration, but from an eager avidity for more air. When the bags were exhausted and taken from me, I continued breathing with the same violence, then suddenly starting from the chair, and vociferating with pleasure, I made towards those that were present, as I wished they should participate in my feelings. I struck gently at

Mr. Davy and a stranger entering the room at the moment, I made towards him, and gave him several blows, but more in the spirit of good humour than of anger. I then ran through different rooms in the house, and at last returned to the laboratory somewhat more composed; my spirits continued much elevated for some hours after the experiment, and I felt no consequent depression either in the evening or the day following, but slept as soundly as usual.

On the 5th of May, I again attempted to breathe nitrous oxide, but it happened to contain suspended nitrous vapour which rendered it non-respirable.

On the 7th, I inspired 7 quarts of pure gas mingled with an equal quantity of common air, the sensations were pleasant, and my muscular power much increased.

On the 8th, I inspired five quarts without any mixture of common air, but the effects were not equal to those produced the day before; Indeed there were reasons for supposing that the gas was impure.

On the 18th, I breathed nearly six quarts of the pure nitrous oxide. It is not easy to describe my sensations; they were superior to any thing I ever before experienced. My step was firm, and all my muscular powers increased. My senses were more alive to every surrounding impression; I threw myself into several theatrical attitudes, and traversed the laboratory with a quick step; my mind was elevated to a most sublime height. It is giving but a faint idea of the feelings to say, that they resembled those produced by a representation of an heroic scene on the stage, or by reading a sublime passage in poetry when circumstances contribute to awaken the finest sympathies of the soul. In a few minutes the usual state of mind returned. I continued in good spirits for the rest of the day, and slept soundly.

Since the 18th of May, I have very often breathed nitrous oxide. In the first experiments when pure, its effects were generally similar to those just described.

Lately I have seldom experienced vivid sen-

sations. The pleasure produced by it is flight and tranquil, I rarely feel sublime emotions or increased muscular power.

J. W. TOBIN.

October, 1799.

II. *Detail of MR. WM. CLAYFIELD.*

The first time that I breathed the nitrous oxide, it produced feelings analogous to those of intoxication. I was for some time unconscious of existence, but at no period of the experiment experienced agreeable sensations, a momentary nausea followed it; but unconnected with languor or head-ache.

After this I several times respired the gas, but on account of the fulness in the head and apparent throbbing of the arteries in the brain,*always desisted to breathe before the full effects were produced. In two experiments however, when by powerful voluntary efforts I succeeded in breathing a large quantity of gas for some mi-

* In some of these experiments, heating was rendered more acute.

nutes, I had highly pleasurable thrillings in the extremities, and such increase of muscular power, as to be obliged to exert my limbs with violence. After these experiments, no languor or depression followed.

WILLIAM CLAYFIELD.

III. *Letter from* DR. KINGLAKE.

In compliance with your desire, I will endeavour to give you a faithful detail of the effects produced on my sensations by the inhalation of nitrous oxide.

My first inspiration of it was limited to four quarts, diluted with an equal quantity of atmospheric air. After a few inspirations, a sense of additional freedom and power (call it energy if you please) agreeably pervaded the region of the lungs; this was quickly succeeded by an almost delirious but highly pleasurable sensation in the brain, which was soon diffused over the whole frame, imparting to the muscular power at once an increased disposition and tone for action; but the mental effect of the excitement

was such as to absorb in a sort of intoxicating placidity, and delight, volition, or rather the power of voluntary motion. These effects were in a greater or less degree protracted during about five minutes, when the former state returned, with the difference however of feeling more cheerful and alert, for several hours after.

It seemed also to have had the further effect of reviving rheumatic irritations in the shoulder and knee-joints, which had not been previously felt for many months. No perceptible change was induced in the pulse either at or subsequent to the time of inhaling the gas.

The effects produced by a second trial of its powers, were more extensive, and concentrated on the brain. In this instance, nearly six quarts undiluted, were accurately and fully inhaled. As on the former occasion, it immediately proved agreeably respirable, but before the whole quantity was quite exhausted, its agency was exerted so strongly on the brain, as progressively to suspend the senses of seeing, hearing, feeling, and ultimately the power of volition itself. At this

period, the pulse was much augmented both in force and frequency ; slight convulsive twitches of the muscles of the arms were also induced ; no painful sensation, nausea, or languor, however, either preceded, accompanied, or followed this state, nor did a minute elapse before the brain rallied, and resumed its wonted faculties, when a sense of glowing warmth extending over the system, was speedily succeeded by a re-instatement of the equilibrium of health.

The more permanent effects were (as in the first experiment) an invigorated feel of vital power, improved spirits, transient irritations in different parts, but not so characteristically rheumatic as in the former instance.

Among the circumstances most worthy of regard in considering the properties and administration of this powerful aerial agent, may be ranked, the fact of its being (contrary to the prevailing opinion*) both highly respirable, and

* Dr. Mitchill (an American Chemist) has erroneously supposed its full admission to the lungs, in its concentrated state, to be incompatible with animal life, and that in a more diluted form it operates as a principal agent in the

salutary, that it impresses the brain and system at large with a more or less strong and durable degree of pleasurable sensation, that unlike the effect of other violently exciting agents, no sensible exhaustion or diminution of vital power accrues from the exertions of its stimulant property, that its most excessive operation even, is neither permanently nor transiently debilitating; and finally, that it fairly promises under judicious application, to prove an extremely efficient remedy, as well in the vast tribe of diseases originating from deficient irritability and sensibility, as in those proceeding from morbid associations, and modifications, of those vital principles.

production of contagious diseases, &c. This gratuitous position is thus unqualifiedly affirmed. "If a full inspiration of gaseous oxyd be made, there will be a sudden extinction of life; and this accordingly accounts for the fact related by Ruffel (History of Aleppo, p. 232.) and confirmed by other observers, of many persons falling down dead suddenly, when struck with the contagion of the plague."

Vide Remarks on the Gaseous Oxyd of Azote, by Sathuel Latham Mitchill, M. D.

If you should deem any thing contained in this cursory narrative capable of subserving in any degree the practical advantages likely to result from your scientific and valuable investigation of the genuine properties of the nitrous oxide, it is perfectly at your disposal.

I am

Your sincere friend,

ROBERT KINGLAKE.

Bristol, June 14th, 1799.

TO MR. DAVY.

IV. *Detail of MR. SOUTHEY.*

In breathing the nitrous oxide, I could not distinguish between the first feelings it occasioned and an apprehension of which I was unable to divest myself. My first definite sensation was a dizziness, a fulness in the head, such as to induce a fear of falling. This was momentary. When I took the bag from my mouth, I immediately laughed. The laugh was involuntary

but highly pleasurable, accompanied by a thrill all through me ; and a tingling in my toes and fingers, a sensation perfectly new and delightful. I felt a fulness in my chest afterwards ; and during the remainder of the day, imagined that my taste and hearing were more than commonly quick. Certain I am that I felt myself more than usually strong and chearful.

In a second trial, by continuing the inhalation longer, I felt a thrill in my teeth ; and breathing still longer the third time, became so full of firength as to be compelled to exercise my arms and feet.

Now after an interval of some months, during which my health has been materially impaired, the nitrous oxide produces an effect upon me totally different. Half the quantity affects me, and its operation is more violent ; a slight laughter is first induced,* and a desire to continue the

* In the former experiments, Mr. Southey generally respired six quarts, now he is unable to consume two.

In an experiment made since this paper was drawn up, the effect was rather pleasurable.

inhalation, which is counteracted by fear from the rapidity of respiration ; indeed my breath becomes so short and quick, that I have no doubt but the quantity which I formerly breathed, would now destroy me. The sensation is not painful, neither is it in the slightest degree pleasurable.

ROBERT SOUTHEY.

V. *Letter from* DR. ROGET.

The effect of the first inspirations of the nitrous oxide was that of making me vertiginous, and producing a tingling sensation in my hands and feet : as these feelings increased, I seemed to lose the sense of my own weight, and imagined I was sinking into the ground. I then felt a drowsiness gradually steal upon me, and a disinclination to motion ; even the actions of inspiring and expiring were not performed without effort : and it also required some attention of mind to keep my nostrils closed with my fingers. I was gradually roused from this tor-

por by a kind of delirium, which came on so rapidly that the air-bag dropt from my hands. This sensation increased for about a minute after I had ceased to breathe, to a much greater degree than before, and I suddenly lost sight of all the objects around me, they being apparently obscured by clouds, in which were many luminous points, similar to what is often experienced on rising suddenly and stretching out the arms, after sitting long in one position.

I felt myself totally incapable of speaking, and for some time lost all consciousness of where I was, or who was near me. My whole frame felt as if violently agitated : I thought I panted violently : my heart seemed to palpitate, and every artery to throb with violence ; I felt a ringing in my ears ; all the vital motions seemed to be irresistibly hurried on, as if their equilibrium had been destroyed, and every thing was running headlong into confusion. My ideas succeeded one another with extreme rapidity, thoughts rushed like a torrent through my mind, as if their velocity had been suddenly

accelerated by the bursting of a barrier which had before retained them in their natural and equable course. This state of extreme hurry, agitation, and tumult, was but transient. Every unnatural sensation gradually subsided; and in about a quarter of an hour after I had ceased to breathe the gas, I was nearly in the same state in which I had been at the commencement of the experiment.

I cannot remember that I experienced the least pleasure from any of these sensations. I can however, easily conceive, that by frequent repetition I might reconcile myself to them, and possibly even receive pleasure from the same sensations which were then unpleasant.

I am sensible that the account I have been able to give of my feelings is very imperfect. For however calculated their violence and novelty were to leave a lasting impression on the memory, these circumstances were for that very reason unfavourable to accuracy of comparison with sensations already familiar.

The nature of the sensations themselves,

which bore greater resemblance to a half delirious dream than to any distinct state of mind capable of being accurately remembered, contributes very much to increase the difficulty. And as it is above two months since I made the experiment, many of the minuter circumstances have probably escaped me.

I remain

Yours, &c.

P. ROGET.

To MR. DAVY.

VI. *Letter from* MR. JAMES THOMSON.

The first time I respired nitrous oxide, the experiment was made under a strong impression of fear, and the quantity I breathed not sufficient, as you informed me, to produce the usual effect. I did not note very accurately my sensations. I remember I experienced a slight degree of vertigo after the third or fourth inspiration; and breathed with increased vigor, my inspirations being much deeper and more

vehement than ordinary. I was enabled the next time I made the experiment, to attend more accurately to my sensations, and you have the observations I made on them at the time.

After the fourth inspiration, I experienced the same increased action of the lungs, as in the former case. My inspirations became uncommonly full and strong, attended with a thrilling sensation about the chest, highly pleasurable, which increased to such a degree as to induce a fit of involuntary laughter, which I in vain endeavoured to repress. I felt a slight giddiness which lasted for a few moments only. My inspirations now became more vehement and frequent; and I inhaled the air with an avidity strongly indicative of the pleasure I received. That peculiar thrill which I had at first experienced at the chest, now pervaded my whole frame; and during the two or three last inspirations, was attended with a remarkable tingling in my fingers and toes. My feelings at this moment are not to be described: I felt a high, an extraordinary degree of pleasure, different

from that produced by wine, being divested of all its gross accompaniments, and yet approaching nearer to it than to any other sensation I am acquainted with.

I am certain that my muscular strength was for a time much increased. My disposition to exert it was such as I could not repress, and the satisfaction I felt in any violent exertion of my legs and arms is hardly to be conceived. These vivid sensations were not of long duration ; they diminished insensibly, and in little more than a quarter of an hour I could perceive no difference between the state I was then in, and that previous to the respiration of the air.

The observations I made on repeating the experiment, do not differ from the preceding, except in the circumstance of the involuntary laughter, which I never afterwards experienced, though I breathed the air several times ; and in the following curious fact, which, as it was dependent on circumstances, did not always occur.

Having respired the same quantity of air as usual, and with precisely the same effects, I

was surpris'd to find myself affected a few minutes afterwards with the recurrence of a pain in my back and knees, which I had experienced the preceding day from fatigue in walking. I was rather inclined to deem this an accidental coincidence than an effect of the air; but the same thing constantly occurring whenever I breathed the air, shortly after suffering pain either from fatigue, or any other accidental cause, left no doubt on my mind as to the accuracy of the observation.

I have now given you the substance of the notes I made whilst the impressions were strong on my mind. I cannot add any thing from recollection that will at all add to the accuracy of this account, or assist those who have not respired this air, in forming a clearer idea of its extraordinary effects. It is extremely difficult to convey to others by means of words, any idea of particular sensations, of which they have had no experience. It can only be done by making use of such terms as are expressive of sensations that resemble them, and in these our

vocabulary is very defective. To be able at all to comprehend the effects of nitrous oxide, it is necessary to respire it, and after that, we must either invent new terms to express these new and particular sensations, or attach new ideas to old ones, before we can communicate intelligibly with each other on the operation of this extraordinary gas.

I am &c.

JAMES THOMSON.

London, Sept. 21, 1799.

TO MR. DAVY.

VII. *Detail of MR. COLERIDGE.*

The first time I inspired the nitrous oxide, I felt an highly pleasurable sensation of warmth over my whole frame, resembling that which I remember once to have experienced after returning from a walk in the snow into a warm room. The only motion which I felt inclined to make, was that of laughing at those who were looking at me. My eyes felt distended,

and towards the last, my heart beat as if it were leaping up and down. On removing the mouth-piece the whole sensation went off almost instantly.

The second time, I felt the same pleasurable sensation of warmth, but not I think, in quite so great a degree. I wished to know what effect it would have on my impressions; I fixed my eye on some trees in the distance, but I did not find any other effect except that they became dimmer and dimmer, and looked at last as if I had seen them through tears. My heart beat more violently than the first time. This was after a hearty dinner.

The third time I was more violently acted on than in the two former. Towards the last, I could not avoid, nor indeed felt any wish to avoid, beating the ground with my feet; and after the mouth-piece was removed, I remained for a few seconds motionless, in great extacy.

The fourth time was immediately after breakfast. The few first inspirations affected me so little that I thought Mr. Davy had given me

atmospheric air : but soon felt the warmth beginning about my chest, and spreading upward and downward, so that I could feel its progress over my whole frame. My heart did not beat so violently ; my sensations were highly pleasurable, not so intense or apparently local, but of more unmingled pleasure than I had ever before experienced.*

S. T. COLERIDGE.

VIII. *Detail of MR. WEDGWOOD.*

July 23, I called on Mr. Davy at the Medical Institution, who asked me to breathe some of the nitrous oxide, to which I consented, being rather a sceptic as to its effects, never having seen any person affected. I first breathed about six quarts of air which proved to be only common atmospheric air, and which consequently produced no effect.

I then had 6 quarts of the oxide given me in

* The doses in these experiments were from five to seven quarts.

a bag undiluted, and as soon as I had breathed three or four respirations, I felt myself affected and my respiration hurried, which effect increased rapidly until I became as it were entranced, when I threw the bag from me and kept breathing on furiously with an open mouth and holding my nose with my left hand, having no power to take it away though aware of the ridiculousness of my situation. Though apparently deprived of all voluntary motion, I was sensible of all that passed, and heard every thing that was said; but the most singular sensation I had, I feel it impossible accurately to describe. It was as if all the muscles of the body were put into a violent vibratory motion; I had a very strong inclination to make odd antic motions with my hands and feet. When the first strong sensations went off, I felt as if I were lighter than the atmosphere, and as if I was going to mount to the top of the room. I had a metallic taste left in my mouth, which soon went off.

Before I breathed the air, I felt a good deal fatigued from a very long ride I had had the

day before, but after breathing, I lost all sense of fatigue.

IX. *Detail of MR. GEORGE BURNET.*

I had never heard of the effects of the nitrous oxide, when I breathed six quarts of it. I felt a delicious tremor of nerve, which was rapidly propagated over the whole nervous system. As the action of inhaling proceeds, an irresistible *appetite* to repeat it is excited. There is now a general swell of sensations, vivid, strong, and inconceivably pleasurable. They still become more vigorous and glowing till they are communicated to the brain, when an ardent flush overspreads the face. At this moment the tube inserted in the air-bag was taken from my mouth, or I must have fainted in extacy.

The operation being over, the strength and turbulence of my sensations subsided. To this succeeded a state of feeling uncommonly serene and tranquil. Every nerve being gently agita-

ted with a lively enjoyment. It was natural to expect that the effect of this experiment, would eventually prove debilitating. So far from this I continued in a state of high excitement the remainder of the day after two o'clock, the time of the experiment, and experienced a flow of spirits not merely chearful, but unusually joyous.

GEORGE BURNET.

X. *Detail of MR. T. POPLE.*

A disagreeable sensation as if breaking out into a profuse perspiration, tension of the tympanum, cheeks and forehead; almost total loss of muscular power; afterwards increased powers both of body and mind, very vivid sensations and highly pleasurable. Those pleasant feelings were not new, they were felt, but in a less degree, on ascending some high mountains in Glamorganshire.

On taking it the second time, there was a disagreeable feeling about the face. In a few

seconds, the feelings became pleasurable ; all the faculties absorbed by the fine pleasing feelings of existence without consciousness ; an involuntary burst of laughter.

THOMAS POPLE.

XI. *Detail of MR. HAMMICK.*

Having never heard any thing of the mode of operation of nitrous oxide, I breathed gas in a silk bag for some time, and found no effects, but oppression of respiration. Afterwards Mr. Davy told me that I had been breathing atmospheric air.

In a second experiment made without knowing what gas was in the bag, I had not breathed half a minute, when from the extreme pleasure I felt, I unconsciously removed the bag from my mouth ; but when Mr. Davy offered to take it from me, I refused to let him have it, and said eagerly, " let me breathe it again, it is highly pleasant ! it is the strongest stimulant I ever felt !" I was cold when I began to respire,

but had immediately a pleasant glow extending to my toes and fingers. I experienced from the air a pleasant taste which I can only call sweetly astringent; it continued for some time: the sense of exhilaration was lasting. This air Mr. Davy told me was nitrous oxide.

In another experiment, when I breathed a small dose of nitrous oxide, the effects were slight, and sometime afterwards I felt an unusual yawning and languor.

The last time that I breathed the gas, the feelings were the most pleasurable I ever experienced; my head appeared light, there was a great warmth in the back and a general unusual glow; the taste was distinguishable for some time as in the former experiment. My ideas were more vivid, and followed the natural order of association. I could not refrain from muscular action.

STEPHEN HAMMICK, Junr.

Sept. 15th.

XII. *Detail of Dr. BLAKE.*

Dr. Blake inhaled about six quarts of the air, was affected during the process of respiring it with a slight degree of vertigo, which was almost immediately succeeded by a thrilling sensation extending even to the extremities, accompanied by a most happy state of mind and highly pleasurable ideas. He felt a great propensity to laugh, and his behaviour in some measure appeared ludicrous to those around him. Muscular power seemed agreeably increased, the pulse acquired strength and firmness, but its frequency was somewhat diminished. He perceived rather an unpleasant taste in the mouth and about the fauces for some hours afterwards, but in every other respect, his feelings were comfortable during the remainder of the day.

December, 30th.

To Mr. DAVY.

XIII. *Detail of* MR. WANSEY.

I breathed the gas out of a silk bag, believing it to be nitrous oxide, and was much surpris'd to find that it produced no sensations. After the experiment, Mr. Davy told me it was common air.

I then breathed a mixture of common air and nitrous oxide. I felt a kind of intoxication in the middle of the experiment, and stopping to express this, destroy'd any farther effects.

I now breathed pure nitrous oxide; the effect was gradual, and I at first experienced fulness in the head, and afterwards sensations so delightful, that I can compare them to no others, except those which I felt (being a lover of music) about five years since in Westminster Abbey, in some of the grand chorusses in the Messiah, from the united powers of 700 instruments of music. I continued exhilarated throughout the day, slept at night remarkably sound, and ex-

perienced when I awoke in the morning, a recurrence of pleasing sensation.

In another experiment, the effect was still greater, the pulse was rendered fuller and quicker, I felt a sense of throbbing in the head with highly pleasurable thrillings all over the frame. The new feelings were at last so powerful as to absorb all perception. I distinguished during and after the experiment, a taste on the tongue, like that produced by the contact of zinc and silver.

HENRY WANSEY.

XIV. *Detail of MR. RICKMAN.*

On inhaling about six quarts, the first altered feeling was a tingling in the elbows not unlike the effect of a slight electric shock. Soon afterwards, an involuntary and provoking dizziness as in drunkenness. Towards the close of the inhalation, this symptom decreased; though the nose was still involuntarily held fast after the air-bag was removed. The dose was probably an

undercharge, as no extraordinary sensation was felt more than half a minute after the inhalation.

J. RICKMAN.

XV. *Detail of MR. LOVELL EDGORTH.*

My first sensation was an universal and considerable tremor. I then perceived some giddiness in my head, and a violent dizziness in my sight; those sensations by degrees subsided, and I felt a great propensity to bite through the wooden mouth-piece, or the tube of the bag through which I inspired the air. After I had breathed all the air that was in the bag, I eagerly wished for more. I then felt a strong propensity to laugh, and did burst into a violent fit of laughter, and capered about the room without having the power of restraining myself. By degrees these feelings subsided, except the tremor which lasted for an hour after I had breathed the air, and I felt a weakness in my knees. The principal feeling through the whole of the time, or what I should call the character-

iffical part of the effect, was a total difficulty of restraining my feelings, both corporeal and mental, or in other words, not having any command of one'sself.

XVI. *Detail of MR. G. BEDFORD.*

I inhaled 6 quarts. Experienced a sensation of fulness in the extremities and in the face, with a desire and power of expansion of the lungs very pleasurable. Feelings similar to intoxication were produced, without being disagreeable. When the bag was taken away, an involuntary though agreeable laughter took place, and the extremities were warm.

In about a quarter of an hour after the above experiment, I inhaled 8 quarts. The warmth and fulness of the face and extremities were sooner produced during the inspiration. The candle and the persons about me, assumed the same appearances as took place during the effect produced by wine, and I could perceive no

determinate outline. The desire and power to expand the lungs was increased beyond that in the former experiment, and the whole body and limbs seemed dilated without the sense of tension, it was as if the bulk was increased without any addition to the specific gravity of the body, which was highly pleasant. The provocation to laughter was not so great as in the former experiment, and when the bag was removed, the warmth almost suddenly gave place to a coldness of the extremities, particularly of the hands which were the first to become warm during the inspiration. A slight sensation of fulness not amounting to pain in the head, has continued for some minutes. After the first experiment, a sensation in the wrists and elbows took place, similar to that produced by the electric shock.

G. C. BEDFORD.

March 30th, 1800.

XVII. *Detail of* MISS RYLAND.

After having breathed five quarts of gas, I experienced for a short time a quickness and difficulty of breathing, which was succeeded by extreme languor, resembling fainting, without the very unpleasant sensation with which it is usually attended. It entirely deprived me of the power of speaking, but not of recollection, for I heard every thing that was said in the room during the time; and Mr. Davy's remark "that my pulse was very quick and full." When the languor began to subside, it was succeeded by restlessness, accompanied by involuntary muscular motions. I was warmer than usual, and very sleepy for several hours.

XVIII. *Letter from* Mr. M. M. COATES.

I will, as you request, endeavour to describe to you the effect produced on me last Sunday se'nnight by the nitrous oxide, and will at the

same time tell you what was the previous state of my mind on the subject.

When I sat down to breathe the gas, I believed that it owed much of its effect to the predisposing agency of the imagination, and had no expectation of its sensible influence on myself. Having ignorantly breathed a bag of common air without any effect, my doubts then arose to positive unbelief.

After a few inspirations of the nitrous oxide, I felt a fulness in my head, which increased with each inhalation, until, experiencing symptoms which I thought indicated approaching fainting, I ceased to breathe it, and was then confirmed in my belief of its inability to produce in me any pleasurable sensation.

But after a few seconds, I felt an immoderate flow of spirits, and an irresistible propensity to violent laughter and dancing, which, being fully conscious of the violence of my feelings, and of their irrational exhibition, I made great but ineffectual efforts to restrain; this was my state for several minutes. During the rest of the day,

I experienced a degree of hilarity altogether new to me. For six or seven days afterwards, I seemed to feel most exquisitely at every nerve, and was much indisposed to my sedentary pursuits; this acute sensibility has been gradually diminishing; but I still feel somewhat of the effects of this novel agent.

Your's truly,

To Mr. DAVY.

M. M. COATES.

June 11th, 1800.

DIVISION III.

*ABSTRACTS from ADDITIONAL DETAILS.—
OBSERVATIONS on the EFFECTS of NITROUS
OXIDE, by Dr. BEDDOES.—CONCLUSION.*

I. Abstracts from additional Details.

THE trials related in the following abstracts, have been chiefly made since the publication of Dr. Beddoes's Notice. Many of the individuals breathed the gas from pure curiosity. Others with a disbelief of its powers.

MR. WYNNE, M. P. breathed five quarts of diluted nitrous oxide, without any sensation. Six quarts produced fulness in the chest, heat in the hands and feet, and sense of tension in the fingers, slight but pleasant sensations. Seven quarts produced no new or different effects.

Mr. MACKINTOSH several times breathed nitrous oxide. He had sense of fulness in the head, thrillings, tingling in the fingers, and generally pleasurable feelings.

Mr. JOHN CAVE, Junr. from breathing four quarts of nitrous oxide, felt sensations as from superior wine, and general pleasant feelings.

Mr. MICHAEL CASTLE, from five quarts, experienced sensations of heat and thrilling, general spirits heightened considerably as from wine; afterwards, slight pain in the back of the head.

Mr. H. CARDWELL, from five quarts, had feelings so pleasurable as almost to destroy consciousness; almost convulsed with laughter; for a long time could not think of the feeling without laughing; sensation of lightness for some time after.

Mr. JARMAN, from five quarts, great pleasure, laughter, certainly better spirits, glow in the cheeks which continued long.

The gentleman who furnished the preceding detail, had heard of the effects of nitrous oxide, and was prepared to experience new sensations: I therefore gave him a bag of common air which he respired, believing it to be nitrous oxide; and was much surprised that no effects were produced. He then breathed five quarts of nitrous oxide, and after the experiment, gave this account of his sensations.

Rev. W. A. CANE, after inhaling the gas, felt the most delicious sensations accompanied by a thrill through every part of his body. He did not think it possible so charming an effect could have been produced. He had heard of the gas; but the result of the experiment far exceeded his expectations.

May 6th, 1800.

Mr. JOSEPH PRIESTLEY from breathing nitrous oxide, generally had unpleasant fulness of the head and throbbing of the arteries, which prevented him from continuing the respiration.

Dr. Beddoes mentioned in his Notice, that Mr. JOSIAH WEDGWOOD and Mr. THOMAS WEDGWOOD, experienced rather unpleasent feelings from the gas. Mr. JOSIAH WEDGWOOD has since repeated the trial, the effects were powerful, but not in the slightest degree pleasant.

Mr. R. BOULTON and Mr. G. WATT have been much less affected than any individuals.

Many other persons have respired the gas, but as their accounts contain nothing unnoticed in the details, it is usefess to particularise them.

The cases of all the males who have been unpleasently affected since we have learnt to prepare the gas with accuracy, are related in this Section and in the last Division. Those who have been pleasurablely affected after a fair trial and whose cases are not noticed, generally experienced fulness in the head, heat in the chest, pleasurable thrillings, and consequent exhilaration.

To persons who have been unaccustomed to breathe through a tube, we have usually given common air till they have learnt to respire with accu-

racy: and in cases where the form of the mouth has prevented the lips from being accurately closed on the breathing tube, by the advice of Mr. Watt, we have used a tin plate conical mouth-piece fixed to the cheeks, and accurately adapted to the lips; by means of which precautions, all our later trials have been perfectly conclusive.

II. Of the effects of Nitrous Oxide upon persons inclined to hysterical and nervous affections.

The case of Miss — N. and other cases, detailed by Dr. Beddoes in his Notice, seemed to prove that the action of nitrous oxide was capable of producing hysterical and nervous affections in delicate and irritable constitutions.

On this subject, we have lately acquired additional facts.

Miss E. a young lady who had been subject to hysteric fits, breathed three quarts of nitrous oxide mingled with much common air, and

felt no effects but a slight tendency to fainting. She then breathed four quarts of pure nitrous oxide : her first inspirations were deep, her last very feeble. At the end she dropt the bag from her lips, and continued for some moments motionless. Her pulse which at the beginning of the experiment was strong, appeared to me to be at this time, quicker and weaker. She soon began to move her hands and talked for some minutes incoherently, as if ignorant of what had passed. In less than a quarter of an hour, she had recovered, but could give no account of her sensations. A certain degree of languor continued through the day.

A young lady who never had hysterical attacks, wished to breathe the gas. I informed her of the disagreeable effects it had sometimes produced, and advised her if she had the slightest tendency to nervous affection, not to make the trial. She persisted in her resolution.

To ascertain the influence of imagination,

I first gave her a bag of common air, which she declared produced no effect. I then ordered for her a quart of nitrous oxide mingled with two quarts of common air; but from the mistake of the person who prepared it, three quarts of nitrous oxide were administered with one of common air. She breathed this for near a minute, and after the experiment, described her sensations as unpleasant, and said she felt at the moment as if she was dying. The unpleasant feelings quickly went off, and a few minutes after, she had apparently recovered her former state of mind. In the course of the day, however, a violent head-ache came on, and in the evening after she had taken a medicine which operated violently, hysterical affections were produced, followed by great debility. They occasionally returned for many days, and she continued weak and debilitated for a great length of time.

Mrs. S. a delicate lady, liable to nervous affections who had heard of the cases just de-

tailed, chose to breathe the gas. By three quarts she was thrown into a trance, which lasted for three or four minutes. On recovering, she could give no account of her feelings, and had some languor for half an hour afterwards,

These phænomena have rendered us cautious in administering the gas to delicate females. In a few instances however, it has been taken by persons of this class, and even by those inclined to hysterical and nervous complaints with pleasurable effects,

Miss L. a young lady who had formerly had hysterical fits, breathed a quart of nitrous oxide with three quarts of common air without effects. Two quarts of nitrous oxide with one of common air produced a slight giddiness; four quarts of nitrous oxide produced a fit of immoderate laughter, which was succeeded by slight exhilaration, her spirits were good throughout the day, and no depression followed.

the benefit it confers on some of the paralytic, and the injury it does or threatens to the hysterical and the exquisitely sensible. I find that five or six quarts operate as powerfully as ever. I seem to make a given quantity go farther by holding my breath so that the gas may be absorbed in a great degree without returning into the bag, and therefore, be as little heated before inspiration as possible.—This may be fancy.

After innumerable trials, I have never once felt lassitude or depression* Most commonly

* Of the facts on which Brown founded his law of indirect debility, no prudent man will lose sight either in practising or studying medicine. They are incontrovertible.—And our new facts may doubtless be conciliated to the Brunonian doctrine.

But to suppose that the expenditure of a quality or a substance or a spirit, and its renewal or accumulation are the general principles of animal phænomena, seems to me a grievous and baneful error. I believe it often happens that excitement and excitability increase, and that they oftener decrease together;—In short, without generalizing in a manner, of which Brown and similar theorists had no conception, our notions of the living world will in my opinion, continue to be as confused as the elements are said to have been in chaos. On some future occasion, I may presume to point

Miss B. Y—— and Miss S. Y—— both delicate but healthy young ladies, were affected very pleasantly ; each by three quarts of nitrous oxide, the first time of respiring it. Miss B Y—— continued exhilarated and in high spirits for some hours after the dose. Miss S. Y—— had a slight head-ache, which did not go off for some hours.

Mrs. F. inclined to be hysterical, breathed four quarts of nitrous oxide mingled with common air. She was giddy and described her feelings as odd ; but had not the slightest languor after the experiment.

III. *Observations on the effects of Nitrous Oxide, by DR. BEDDOES.*

Neither my notes nor my recollection supply much in addition to what I formerly stated in the *Notice of Observations at the Pneumatic Institution. Longman.* The gas maintains its first character as well in its effects on me, as in

I am sensible of a grateful glow *circum præcordia*. This has continued for hours.—In two or three instances only has exhalation failed to be followed by pleasurable feeling, it has never been followed by the contrary. On a few occasions before the gas was exhausted, I have found it impossible to continue breathing.

The pulse at first becomes fuller and stronger. Whenever, after exposure to a cold wind, the warmth of the room has created a glow in the cheeks, the gas has increased this to strong flushing—which common air breathed in the same way, failed to do.

Several times I have found that a cut which had ceased to be painful has smarted afresh, and on taking two doses in succession, the smarting ceased in the interval and returned during the second respiration. I had no previous expectation of the first smarting.

out the region through which I imagine the path to wind, that will lead the observers of some distant generation to a point, whence they may enjoy a view of the subtle, busy and intricate movements of the organic creation as clear as Newton obtained of the movements of the heavenly masses.

The only time I was near rendering myself insensible to present objects by very carefully breathing several doses in quick succession, I forcibly exclaimed, TONES !—In fact, besides a general thrilling, there seemed to be quick and strong alterations in the degree of illumination of all surrounding objects ; and I felt as if composed of finely vibrating strings. On this occasion, the skin seemed in a state of constriction and the lips glued to the mouth-piece, and the mucous membrane of the lungs contracted, but not painfully. However, no constriction or corrugation of the skin could be seen. I am conscious of having made a great number of observations while breathing, which I could never recover.

Immediately afterwards I have often caught myself walking with a hurried step and busy in soliloquy. The condition of general sensation being as while hearing cheerful music, or after good news, or a moderate quantity of wine.

Mr. John Cave, Junr. and his three friends, as well as others, compared the effects to Cham-

pagne. Most persons have had the idea of the effect of fermented liquors excited by the gas. It were to be wished that we had, for a standard of comparison, observations on the effect of these liquors as diversified and as accurate as we have obtained concerning the gas; nor would more uniformity in the action of these substances be observed if the enquiry were strictly pursued. Opium and spirits seem, in particular states to sicken and distress in the first instance; how differently does wine at an early hour and fasting act upon those who are accustomed to take it only after dinner!

I thought it might be an amusing spectacle to see the different tints of blood flowing from a wound by a leech in consequence of breathing different airs. The purple from the nitrous oxide was very evident. Oxygene, we thought, occasioned a quicker flow and brighter color in the blood. In another experiment, an inflamed area round the puncture from a leech applied the day before, was judged by several spectators to become much more crimson on the respiration of

about 20 quarts of oxygene gas, which possibly acts more powerfully on inflamed parts.* These and many similar experiments, require to be repeated on the blood of single arteries opened in warm and cold animals.

It has appeared to me that I could hold my breath uncommonly long when respiring oxygene gas mixed with nitrous oxide. While trying this to-day, (17th June), I thought the sense of smell much more acute after the nitrous oxide than before I began to respire at all ; and then I felt conscious that this increased acuteness had before repeatedly occurred—a

* After writing this, I was present when an invalid, in whose foot the gout, after much wandering, had at last fixed, breathed 12 quarts of oxygene gas. While breathing, he eagerly pointed to the inflamed leg ; and afterwards said he had felt in it a new sensation, somewhat like tension.—I never had seen oxygene respired where there was so much local inflammation.

June 18. After four quarts of oxygene with 6 of nitrous oxide and then 6 of nitrous oxide alone, violent itching of the wounds made by the leech ; and redness and tumour.—Both had healed, and I did not expect to feel any thing more from them.—I tried this again with two doses of nitrous oxide—The yellow halo round one wound changed to crimson, and there was so much stinging and swelling that I feared suppuration.—Absorption here was rapid.

fact very capable, I apprehend, of a pneumatological interpretation.

Time by my feelings has always appeared longer than by a watch.

I thought of trying to observe whether while I alternately breathed quantities of nitrous oxide and oxygene gas and common air, I could observe any difference in the operation of a blister beginning to bite the skin. It would be of consequence to ascertain the effect of regulating by compression the flow of blood, while stimulants of various kinds (and heated bodies among the rest) were applied to or near the extremities—because in erisipelas and various inflammatory affections, a ready and pleasant cure might be effected by partial compression of the arteries going to the diseased part; and a great improvement in practice thus obtained.

But I should run into an endless digression, were I to enumerate possible physiological experiments with artificial airs, or to speculate on the mechanical improvement of medicine, which at present as far as mechanical means of affect-

ing the living system are concerned, is with us in a state that would almost disgrace a nation of savages.

IV. CONCLUSION.

From the facts detailed in the preceding pages, it appears that the immediate effects of nitrous oxide upon the living system, are analogous to those of diffusible stimuli. Both increase the force of circulation, produce pleasurable feeling, alter the condition of the organs of sensation, and in their most extensive action destroy life.

In the mode of operation of nitrous oxide and diffusible stimuli, considerable differences however, exist.

Diffusible stimuli act immediately on the muscular and nervous fibre. Nitrous oxide operates upon them only by producing peculiar changes in the composition of the blood.

Diffusible stimuli affect that part of the system

most powerfully to which they are applied, and act on the whole only by means of its sympathy with that part. Nitrous oxide in combination with the blood, is universal in its application and action.

We know very little of the nature of excitement ; as however, life depends immediately on certain changes effected in the blood in respiration, and ultimately on the supply of certain nutritive matter by the lymphatics ; it is reasonable to conclude, that during the action of stimulating substances, from the increased force of circulation, not only more oxygene and perhaps nitrogene must be combined with the blood in respiration,* but likewise more fluid nutritive matter supplied to it in circulation.

* See Dr. Beddoes's *Considerations*, part 1. page 26. His observations in the note in the last section, will likewise apply here.—Is not healthy living action dependant upon a certain equilibrium between the principles supplied to the blood by the pulmonary veins from respiration and by the lymphatics from absorption ? Does not sensibility more immediately depend upon respiration ? Deprive an animal under stimulation, of air, and it instantly dies ; probably

By this oxygene and nutritive matter excitability may be kept up : and exhaustion consequent to excitement only produced, in consequence of a deficiency of some of the nutritive principles, which are supplied by absorption.

When nitrous oxide is breathed, nitrogene (a principle under common circumstances chiefly carried into the blood by the absorbents in fluid compounds) is supplied in respiration ; a greater quantity of oxygene is combined with the blood than in common respiration, whilst less carbonic acid and probably less water are evolved.

Hence a smaller quantity of nutritive matter is probably required from the absorbents during the excitement from nitrous oxide, than during the operation of stimulants ; and in consequence, exhaustion from the expenditure of nutritive matter more seldom occasioned.

if absorption could be prevented, it would likewise speedily die. It would be curious to try whether intoxication from fermented liquors cannot be prevented by breathing during their operation, an atmosphere deprived of part of its oxygene.

Since Research III. has been printed, I have endeavoured to ascertain the quantities of nitrogene produced when nitrous oxide is respired for a considerable time. In one experiment, when I breathed about four quarts of gas in a glass bell over impregnated water for near a minute, it was diminished to about two quarts; and the residuum extinguished flame.

Now the experiments in Research II. prove that when nitrous oxide is decomposed by combustible bodies, the quantity of nitrogene evolved is rather greater in volume than the pre-existing nitrous oxide. Hence much of the nitrogene taken into the system during the respiration of nitrous oxide, must be either carried into new combinations, or given out by the capillary vessels through the skin.

It would be curious to ascertain whether the quantity of ammoniac in the saline matters held in solution by the secreted fluids is increased after the respiration of nitrous oxide. Experiments made upon the consumption of nitrous oxide mingled with atmospheric air

by the smaller animals, would go far to determine whether any nitrogene is given out through the skin.

The various effects of nitrous oxide upon different individuals and upon the same individuals at different times, prove that its powers are capable of being modified both by the peculiar condition of organs, and by the state of general feeling.

Reasoning from common phænomena of sensation, particularly those relating to heat, it is probable that pleasurable feeling is uniformly connected with a moderate increase of nervous action ; and that this increase when carried to certain limits, produces mixed emotion or sublime pleasure ; and beyond those limits occasions absolute pain.

Comparing the facts in the last division, it is likely that individuals possessed of high health and little sensibility, will generally be less pleasurable affected by nitrous oxide than such as have more sensibility, in whom the emotions will sometimes so far enter the limits

of pain as to become sublime;* whilst the nervous action in such as have exquisite sensibility, will be so much increased as often to produce disagreeable feeling.

Modification of the powers of nitrous oxide by mixture of the gas with oxygene or common air, will probably enable the most delicately sensible to respire it without danger, and even with pleasurable effects: heretofore it has been administered to such only in its pure form or mingled with small quantities of atmospheric air, and in its pure form even the most robust are unable to respire it with safety for more than five minutes.

The muscular actions† sometimes connected

* Sublime emotion with regard to natural objects, is generally produced by the connection of the pleasure of beauty with the passion of fear.

† The immortal HARTLEY has demonstrated that all our motions are originally automatic, and generally produced by the action of tangible things on the muscular fibre.

The common actions of adults may be distinguished into two kinds; voluntary actions, and mixed automatic actions. The first are produced by ideas, or by ideas connected with passions. The second by impression, or by pleasure and pain.

with the feelings produced by nitrous oxide, seem to depend in a great measure upon the particular habits of the individual ; they will usually be of that kind which is produced either by common pleasurable feelings or strong emotions.

Hysterical affection is occasioned by nitrous oxide, probably only in consequence of the strong emotion produced, which destroys the power of the will, and calls up series of automatic motions formerly connected with a variety of less powerful but similar feelings.

The quickness of the operation of nitrous oxide, will probably render it useful in cases of extreme debility produced by deficiency of

In voluntary action, regular associations of ideas and muscular motions exist : as when a chemist performs a pre-conceived experiment.

In mixed automatic actions, the simple motions produced by impression are connected with series of motions formerly voluntary, but now produced without the intervention of ideas : as when a person accustomed to play on the harpsichord, from accidentally striking a key, is induced to perform the series of motions which produce a well-remembered tune.

Evidently the muscular actions produced by nitrous oxide are mixed automatic motions.

common exciting powers. Perhaps it may be advantageously applied mingled with oxygen or common air, to the recovery of persons apparently dead from suffocation by drowning or hanging.

The only diseases in which nitrous oxide has been hitherto employed, are those of deficient sensibility.—An account of its agency in paralytic affections, will be speedily published by Dr. Beddoes.

As by its immediate operation the tone of the irritable fibre is increased, and as exhaustion rarely follows the violent muscular motions sometimes produced by it, it is not unreasonable to expect advantages from it in cases of simple muscular debility.

The apparent general transiency of its operation in the pure form in single doses has been considered as offering arguments against its power of producing lasting changes in the constitution. It will, however, be easy to keep up excitement of different degrees of intensity for a great length of time, either by administering

the unmingled gas in rapid successive doses, or by preserving a permanent atmosphere, containing different proportions of nitrous oxide and common air, by means of a breathing chamber.* That single doses nevertheless, are capable of producing permanent effects in some constitutions, is evident, as well from the hysterical cases as from some of the details—particularly that of Mr. M. M. Coates.

As nitrous oxide in its extensive operation appears capable of destroying physical pain, it may probably be used with advantage during surgical operations in which no great effusion of blood takes place.

From the strong inclination of those who have been pleasantly affected by the gas to respire it again, it is evident, that the pleasure produced, is not lost, but that it mingles with the mass of feelings, and becomes intellectual pleasure, or hope. The desire of some individuals acquainted with the pleasures of nitrous oxide for the gas has been often so strong as to induce them to

* See R. IV. Div. I. page 478.

breathe with eagerness, the air remaining in the bags after the respiration of others.

As hydrocarbonate acts as a sedative,† and diminishes living action as rapidly as nitrous oxide increases it, on the common theory of excitability‡ it would follow, that by differently modifying the atmosphere by means of this gas and nitrous oxide, we should be in possession of a regular series of exciting and depressing* powers applicable to every deviation of the constitution from health : but the common theory

† R. IV. Div. I. page 467.

‡ That of Brown modified by his disciples.

* Supposing the increase or diminution of living action when produced by different agents, uniform, similar and differing only in degree; it would follow, that certain mixtures of hydrocarbonate and nitrous oxide, or hydrogen and nitrous oxide, ought to be capable of supporting the life of animals for a much longer time than pure nitrous oxide. From the experiments in Ref. III. Div. I. it appears however, that this is not the case.

It would seem, that in life, a variety of different corpuscular changes are capable of producing phenomena apparently similar; so that in the science of living action, we are incapable of reasoning concerning causes from effects.

of excitability is most probably founded on a false generalisation. The modifications of diseased action may be infinite and specific in different organs ; and hence out of the power of agents operating on the whole of the system.

Whenever we attempt to combine our scattered physiological facts, we are stopped by the want of numerous intermediate analogies ; and so loosely connected or so independant of each other, are the different series of phænomena, that we are rarely able to make probable conjectures, much less certain predictions concerning the results of new experiments.

An immense mass of pneumatological, chemical, and medical information must be collected, before we shall be able to operate with certainty, on the human constitution.

Pneumatic chemistry in its application to medicine, is an art in infancy, weak, almost useless, but apparently possessed of capabilities of improvement. To be rendered strong and mature, she must be nourished by facts,

strengthened by exercise, and cautiously directed in the application of her powers by rational scepticism.

THE UNIVERSITY OF CHICAGO

PHYSICS DEPARTMENT

PHYSICS 350

LECTURE 10

STATISTICAL MECHANICS

ENTROPY

AND THE SECOND LAW

OF THERMODYNAMICS

AND THE ARROW OF TIME

AND THE FUTURE

OF THE UNIVERSE

AND THE HUMAN CONDITION

AND THE MEANING OF LIFE

AND THE NATURE OF REALITY

AND THE FOUNDATIONS OF SCIENCE

AND THE LIMITS OF KNOWLEDGE

AND THE QUEST FOR WISDOM

AND THE SEARCH FOR TRUTH

AND THE Pursuit of Happiness

AND THE DREAM OF PERFECTION

AND THE IDEAL OF HARMONY

AND THE ASPIRE TO EXCELLENCE

AND THE STRIVING FOR GREATNESS

AND THE YEARNING FOR INFINITY

AND THE LONGING FOR ETERNITY

AND THE DESIRE FOR IMMORTALITY

AND THE HOPE OF RESURRECTION

AND THE FAITH IN DIVINITY

AND THE TRUST IN GOD

AND THE LOVE OF GOD

APPENDIX.

No. I.

Effects of Nitrous Oxide on Vegetation.

IN July 1799, I introduced two small plants of spurge into nitrous oxide, in contact with a little water over mercury; after remaining in it two days, they preserved their healthy appearance, and I could not perceive that any gas had been absorbed. I was prevented by an accident, from keeping them longer in the gas.

A small plant of mint introduced into nitrous oxide and exposed to light, in three days became dark olive and spotted with brown; and in about six days was quite dead.—Another similar plant, kept in the dark in nitrous oxide,

did not alter in color for five days, and at the end of seven days, was only a little yellower than before. I could not ascertain whether any gas had been absorbed.

I introduced into nitrous oxide through water, a healthy budding rose, thinking that its colors might be rendered brighter by the gas. I was disappointed, it very speedily faded and died; possibly injured by the solution of nitrous oxide in water.

Of two rows of peas just appearing above ground; I watered one with solution of nitrous oxide in water, and the other with common water daily, for a fortnight. At the end of this time, I could perceive no difference in their growth, and afterwards they continued to grow equally fast.

I introduced through water into six phials, one of which contained hydrogene, one oxygen, one common air, one hydrocarbonate, one carbonic acid, and one nitrous oxide, six similar plants of mint, their roots being in

contact with water and their leaves exposed to light.

The plant in carbonic acid began to fade in less than two days, and in four was dead. That in hydrogene died in less than five days; that in nitrous oxide did not fade much for the first two days, but on the third, drooped very much, and was dead at the same time as that in hydrogene. The plant in oxygene for the first four days, looked flourishing and was certainly of a finer green than before, gradually however, its leaves became spotted with black and dropped off one by one, till at the end of ten days they had all disappeared. At this time the plant in common air looked sickly and yellow, whilst that in hydrocarbonate was greener and more flourishing than ever.

I have detailed these experiments not on account of any important conclusions that may be drawn from them; but with a view of inducing others to repeat them, and to examine the changes effected in the gases. If it should be found by future experiments, that hydrocar-

bonate generally increased vegetation, it would throw some light upon the use of manures, containing putrefying animal and vegetable substances, from which this gas is perpetually evolved.

The chemistry of vegetation though immediately connected with agriculture, the art on which we depend for subsistence, has been but little investigated. The discoveries of Priestley and Ingenhoufz, seem to prove that it is within the reach of our instruments of experiment.

No. II.

APPROXIMATIONS

TO THE

Composition and Weight of the aërisform COMBINATIONS of NITROGENE.

At temperature 55°, and atmospheric pressure 30.

		100 Cubic In.	grains	Nitrogene Oxygene			
		Nitrogene	With Oxygene	Nitrogene	30.04	100 grains are composed of	
Oxygene	35.06						
Atmospher. air	31.10			73.00	27.00		
Nitrous oxide	50.20			63.30	36.70		
Nitrous gas	34.26			44.05	55.95		
Nitric acid	76.00		29.50	70.50			
					Nitrogene		Hydrogene
With hydrogene	Ammoniac		18.05	80.00	20.00		

Additional Observations.

a. In Ref. 1st. Div. IV. Sect. III. in the analysis of nitrous gas by pyrophorus, as no absorption took place when the residual nitrogen was exposed to water, I inferred that if any carbonic acid was formed it was in quantity so minute, as to be unworthy of notice. A few days ago, I completely decomposed a quantity of nitrous gas by pyrophorus, when the residual nitrogen was exposed to solution of strontian, the fluid became slightly clouded; but no perceptible absorption took place.

b. If there was the least probability in any of Dr. Girtanner's speculations on the composition of Azote,* the experiments on the exhausted capacity † of the lungs in Ref. III. might be supposed inconclusive. But there appears to

* Annales de Chimie, 100; and Mr. Tilloch's Phil. Magazine. 24.

† I regret much that I could not procure Dr. Menzies's observations on Respiration, while I was making the experiments on the capacity of the lungs: they would probably have saved me some labor.

be no more reason for supposing that hydrogen is converted into nitrogen by respiration, than for supposing that it is converted into water, carbonic acid or oxygen; for all these products are evolved when that gas is respired. From the comparison of Exp. 1 with Exp. 3, Ref. iii. Div. ii. Sec. 4, it is almost demonstrated that no ascertainable change is effected in hydrogen by respiration. The experiment of the accurate Scheele in which hydrogen after being respired thirty times in a bladder wholly lost its inflammability, may be easily accounted for from its mixture with the residual gases of the lungs.

About a fortnight ago, I respired, after forced voluntary exhaustion of my lungs, my nose being accurately closed, three quarts of hydrogen in a silk bag, at four intervals, for near five minutes. After this it was highly inflammable, and burnt with a greenish white flame in contact with the atmosphere; but was not so explosive as before.*

* If loosely combined carbon exists in venous blood, hydrogen may probably dissolve a portion of it when

c. From what we have lately heard of the curious experiments of Mr. Volta and Mr. Carlisle, it is very probable that the conversion of nitrous gas into nitrous oxide when exposed to wetted zinc, copper and tin, in contact with mercury, as described in Ref. I. Div. V. may in some measure depend on the action of the galvanic fluid. Whilst I was engaged in the experiments on this conversion, Dr. Beddoes * mentioned to me some curious facts noticed by Humboldt and Ritter, relating to the oxydation of metals by the decomposition of water, which induced me

respired and become slightly carbonated. At least there is as much probability in the supposition that carbon in loose affinity may combine with hydrogen at 98° as that it may combine with oxygen.

* Dr. BEDDOES has since favoured me with the following account of these facts.

“ Mr. Humboldt (ueber die gereizte Fafer I. 473, 1797) quotes part of a letter from Dr. Ash, in which it is said that *if two finely polished plates of homogeneous zinc be moistened and laid together, little effect follows—but if zinc and silver be tried in the same way, the whole surface of the silver will be covered with oxydated zinc. Lead and quicksilver act as powerfully on each other, and so do iron and*

to examine the phænomena with more attention than I should have otherwise done.—I recollect observing that some of the wetted zinc

copper.—Mr. Humboldt (p. 474) says that, in repeating this experiment, he saw air-bubbles ascend, which he supposes to have been hydrogen gas from the decomposition of water—When he placed zinc simply on moist glass, the same phænomena took place, but more slowly and later. The quantity of oxyd of zinc upon the glass alone was in 20 hours to that on the silver as one to three.

In a very ingenious but obscurely written tract by Mr. Ritter, entitled, *Evidence that the galvanic action exists in organic nature*, 8vo. Jena, 1800—The author observes, that the care of Dr. Ash and Mr. Humboldt that the metals should touch each other in as many points as possible was superfluous, even if we could grant that two metallic plates might be made by polishing, to touch in a number of points. To shew that it was sufficient if by touching in one point only they should form a complete galvanic circle, he dropped a single drop of distilled water upon the bust of a large silver coin. A piece of pure zinc was placed with its one end on the edge of the coin, while the other was supported by a bit of glass. The drop of water was neither in contact with the glass nor with the point at which the metals touched. The materials were left in this situation for four hours at the temperature of 68°. On taking them apart, the water had become quite milky and had half disappeared; and Mr. Ritter actually separated a quantity of white oxide that had been produced in the experiment.

The pieces of metal were cleaned and laid together in

filings in nitrous gas on the side of the jar not in contact with the surface of mercury, were very slowly oxydated. Whilst on the surface of the mercury where small globules of that substance were mingled with the filings of zinc, the decomposition went on much more rapidly;

the same manner, only that now a piece of paper was put between the metals at their former point of contact. In four hours first, and afterwards in ten, a faint ring of oxide only had been produced of which the quantity could not be estimated, nor could it be separated. In this case, the zinc had scarce lost any thing of its splendour; in the former it had been corroded. In many repetitions of the experiment, he found that far more oxide was formed when the metals touched, than when they were separated to the slightest distance by an insulating body, even air.

On exposing these apparatuses with somewhat more water to a considerable heat for four minutes, the water in the interrupted circle continued quite clear, while that in the other had become milk-white.

The same phenomena were presented by other pairs of metals in a degree proportional to their galvanic activity; viz. by zinc and molybdæna, zinc and bismuth, zinc and copper, as also with tin and silver, tin and molybdæna, and lead and silver. The experiment with tin was particularly decisive, for when in contact with no other metal it was scarcely at all oxydated by water, though oxydation took place when tin was brought into contact with silver.

possibly through the medium of the moisture, a series of galvanic circles were formed.

d. In Ref. II. Div. I. it is stated, that nitrous oxide during its solution by common water, expels about $\frac{1}{16}$ of atmospheric air the volume of the water being unity.

and both were connected at the other end by a drop of water—What therefore took place in Dr. Ash's experiment, arose from an aggregation of galvanic circles of different forms.

By the foregoing experiments, concludes Mr. Ritter, which though capable of the most various modifications, uniformly coincide in their main result, it is abundantly proved that *galvanic circles can be formed of merely inorganic bodies, by whose completion there is produced an action which ceases when the circle is opened.* The manner in which this has been shewn, proves also that *this action can effectuate sensible modifications in organic bodies*; and the process by which these modifications have been effected, made it evident that they *were not consequences of a momentary action of the circle, but of an action that is kept up while the circle remains entire*; for the process which brought this action under the cognizance of the senses went on, while the circle was unbroken, and its figure not brought back to that of a line.

It is scarce necessary to observe that the experiments here quoted, are far from being the only ones on which the above conclusions rest.”

T. B.

From the delicate experiments of Dr. Pearson, on the passage of the electric spark through water, it appears however probable, that much more than $\frac{1}{16}$ of atmospheric air is sometimes held in solution by that fluid,* possibly the whole of the air is not expelled by nitrous oxide, owing to some unknown law of saturation by which an equilibrium of affinity is produced, forming a triple compound.

* Possibly a ratio exists between the solubility of gases in water, and the solubility of water in gases. It is probable from Mr. Wm. Henry's curious experiments on the muriatic acid, that the absolute quantity of water in *many* gases, may be ascertained by means of its decomposition by the electric spark.

DESCRIPTION OF A
MERCURIAL AIR-HOLDER,

Suggested by an inspection of Mr. WATT's Machine for
containing Factitious Airs,

By WILLIAM CLAYFIELD.

SEVERAL modes of counteracting the pressure of a decreasing column of mercury having been thought of in conjunction with Mr. W. Cox, the following was at last adopted as the most simple and effectual.

Plate 1 Fig. 1, represents a section of the machine, which consists of a strong glass cylinder A cemented to one of the same kind B, fitted to the solid block C, into which the glass tube D is cemented for conveying air into the moveable receiver E.

The brass axis F, Fig. 2, having a double bearing at *a, a*, is terminated at one end by the wheel G, the circumference of which is equal to the depth of the receiver, so that it may be drawn to the surface of the mercury by the cord *b* in one revolution; to the other end is fitted

the wheel H, over which the balance cord *c* runs in an opposite direction in the spiral groove *e*, a front view of the wheel H is shewn at Fig. 3.

Having loaded the receiver with the weight I, something heavier than may be necessary to force it through the mercury, it is balanced by the small weight K, which hangs from that part of the spiral where the radius is equal to that of the wheel G, from this point the radius of the spiral must be increased in such proportion, that in every part of its circuit, the weight K may be an exact counterpoise to the air-holder. In this way, so little friction will be produced, that merely plunging the lower orifice of the tube D under mercury contained in the small vessel L, will be sufficient to overcome every resistance, and to force the gas discharged from the beak of a retort into the receiver, where whatever may be its quantity, it will be subjected to a pressure exactly corresponding to that of the atmosphere. The edge of the wheel H being graduated, the balance cord *c* may be made to indicate its volume.

Should it at any time be necessary to reduce

the pressure to the medium standard of the barometer, it may easily be done by graduating the lower end of the tube D, and adding to the weights I or K, as may be found necessary; the surface of the mercury in the tube pointing out the increase or diminution.

The concavity at the top of the internal cylinder is intended to contain any liquid it may be thought proper to expose to the action of the gas.

The upper orifice *f*, with its ground-stopper, is particularly useful in conveying air from the retort *g*, with its curved neck, into the receiver, without its passing through the tube D. In all cases where a rapid extrication of gas is expected the retort *g*, should be firmly luted to the orifice, and the weight I, removed from the top of the receiver, this by diminishing the pressure, will admit the gas to expand freely in the air-holder at the instant of its formation, and prevent an explosion of the vessels. The same caution must be observed whenever any inflammation of gas is produced by the electric spark.

The air may be readily transferred through water or even mercury by the tube *h*, Fig. 1.

To prevent an absorption of mercury in case of a condensation taking place in the retort made use of for generating air, Mr. Davy has applied the stop-cock *i*, to which the neck is firmly luted. This stop-cock is likewise of great service in saturating water with acid or alkaline gases, which may be effected by luting one end of the tube *k* to the stop-cock, and plunging the other into the fluid in the small vessel *l*, cemented at top, and terminating in the bent funnel *m*—the tube *b* having been previously removed, and the lower orifice of the tube *D* either sunk to a considerable depth in mercury, or closed with a ground stopper. The bend of the funnel *m*, may be accurately closed by the introduction of a few lines of mercury.

The application of the stop-cock *n*, has enabled Mr. Davy to perform some experiments on respiration with considerable accuracy.

Note. This apparatus was first described in the third part of Dr. Beddoes's Considerations; its relation to Mr. Davy's experiments with the improvements it has lately received, may probably be deemed sufficient to excuse the re-printing it.—The weight I. Fig. 2, having been omitted in the plate, the reader must supply the deficiency,

W. C.

PROPOSAL
FOR
THE PRESERVATION
OF
ACCIDENTAL OBSERVATIONS
IN
MEDICINE.

IN times beyond the reach of history, the medicinal application of substances could have arisen from no other source than accident. Among articles of the *materia medica* of known origin, we are indebted to accident for some of the most precious.

Accident is every day presenting to different individuals the spectacle of phenomena, arising from uncommon quantities of drugs on the one hand, and on the other, from uncommon conditions of the system, where ordinary powers only have been knowingly or recently applied. What is said of drugs may be extended to natural agents and mental affections.

From conversation with a variety both of medical practitioners and unprofessional observers, the author of this proposal is persuaded that such authentic occurrences only, as have presented themselves to persons now living would, if they could be brought together, compose a body of fact, so instructive to the philosopher, and useful to the physician, that he despairs of finding a term worthy to characterize it.

In some cases, the influence of unsuspected powers would be detected. In others, resources available to the purpose of restoring health in desperate situations would be directly presented, or could be detected by a short and easy process of reasoning. Some anomalous observations, by shewing the absence or agency of contested causes, would perform the office of *experimenta crucis*—Unusual affections occur of which an exact account would be among the means of removing from physic its opprobrious uncertainty: for this uncertainty frequently depends upon our inability to distinguish the subtler differences in cases which resemble each other in their grosser features.

No striking fact can be accurately stated, in conjunction with its antecedent and concomitant circumstances, without improving our acquaintance with human nature. Our acquisitions in this most important branch of knowledge, may be compared to a number of broken series, of which we have not always more than one or two members. But every new accession bids fair to fill up some deficiency; and a large supply would contribute towards connecting series apparently independent, and working up the whole into one grand all-comprehending chain.

There are complaints, and those by far too frequent, where no known process has a claim to the title of *remedial*. Here the whole chance of preservation depends on the physician's capacity for bringing together facts that have heretofore stood remote. But no power of combination can avail where there are no ideas to combine.

Every new observation therefore, may be considered as a standard trunk, sending forth analogies as so many branches crowned with blossoms, some of which cannot fail to be succeeded by salutary fruits. And were it not absurd to extend the illustration of so plain a point, it might be added,

that when by the continual interposition of new trunks, the branches are brought near together, the produce of each will be ennobled by the action of their respective principles of fecundation.

Whenever the author has been able to obtain certain information concerning any unusual appearance in animal nature, it has been his custom to preserve it; and among his papers he has memorandums which prove that to our present circumscribed ideas concerning the dose of medicines may be sometimes imputed failures in practice; that certain signs are not to be taken in the received signification; and that many measures are adopted or omitted to the detriment of invalids, because it is assumed that circumstances are necessarily connected which may exist separately, or that one given natural operation is inconsistent with another, to which it may really be synchronous or next in order.

Affiduous observation of the daily states of the human microcosm will be the unfailing consequence of attention to its striking phænomena. Such is the progress of curiosity. Such the origin of all the sciences. The more uniformly clear the sky under which they tended their flocks, the less likely were the shepherds of Chaldæa, to found the science of the stars. And however the disposition to study astronomy might have been strengthened by the coincidence between the heliacal rising of Sirius and the overflowing of the Nile, it must, I conceive, have been awakened by the aspect of meteors and eclipses.

Whatever minute and authentic information this imperfect statement may produce, as soon as it shall amount to a certain mass, the author will present it to the public arranged. He flatters himself that no correspondent will eke out by supposition the defect of genuine observation, without

clearly distinguishing the one from the other. He still more confidently hopes that none will be infligated by this advertisement to exercise his invention in the manner of Pfallmanafar and Chatterton. Whether any literary forgery can be innocent is questioned—but a forged medical report is a drawn dagger which the arm of a credulous physician may any day plunge into the heart of his defenceless patient. The author has heard some inconsiderate wits avow, that they have tranfmitted to the venders of quack medicines imaginary cures, attested by fictitious signatures; and it is not without apprehension from the propensity of men to display ingenuity and to relate wonders that he announces the present design. But he shall be on his guard, and hopes to baffle attempts at imposition.

THOMAS BEDDOES.

RODNEY-PLACE, Clifton, June 1800.

END.

ERRATA.

Page	19	line 15	for <i>is</i>	read	<i>are</i>
—	35	— 7	— for <i>principle</i>	read	<i>principles</i>
—	42	— 11	— for <i>take</i>	read	<i>takes</i>
—	68	Table 5	— for 5,88	read	15,88
—	94	— 4	— for $1 \frac{1}{12}$	read	$\frac{1}{12}$
—	95	— 4	— for 37	read	30,7
—	96	— 3	— for 38	read	$\frac{1}{38}$
—	105	— 9	— for <i>exactitude</i>	read	<i>exactness</i>
—	129	— 21	— for 41	read	4,1
—	132	— 4	— for <i>into</i>	read	<i>in</i>
—	143	— 13	— for 25	read	.25
—	186	— 15	— for <i>by</i>	read	<i>from</i>
—	208	last line	— for <i>abstracted</i>	read	<i>attracted</i>
—	238	— 5	— for <i>gas</i>	read	<i>oxide</i>
—	259	— 4	— for 12	read	2
—	283	— 4	— for <i>potash</i>	read	<i>iron</i>
—	315	— 14	— dele		<i>in</i>
—	409	— 15	— for <i>respiration</i>	read	<i>expiration</i>
—	464	— 10	— for <i>latter end</i>	read	<i>end</i>
—	543	— 3	— for <i>exhalation</i>	read	<i>inhalation.</i>

A few literal errors are left to the reader's correction.

N. B. The term ignited is sometimes used to signify any temperature equal to or above a red heat, whether applied to solids, fluids, or aëriform substances.

The reasons for the use of the terms nitrogene and nitrous oxide, are given in Mr. Nicholson's Journal for January.

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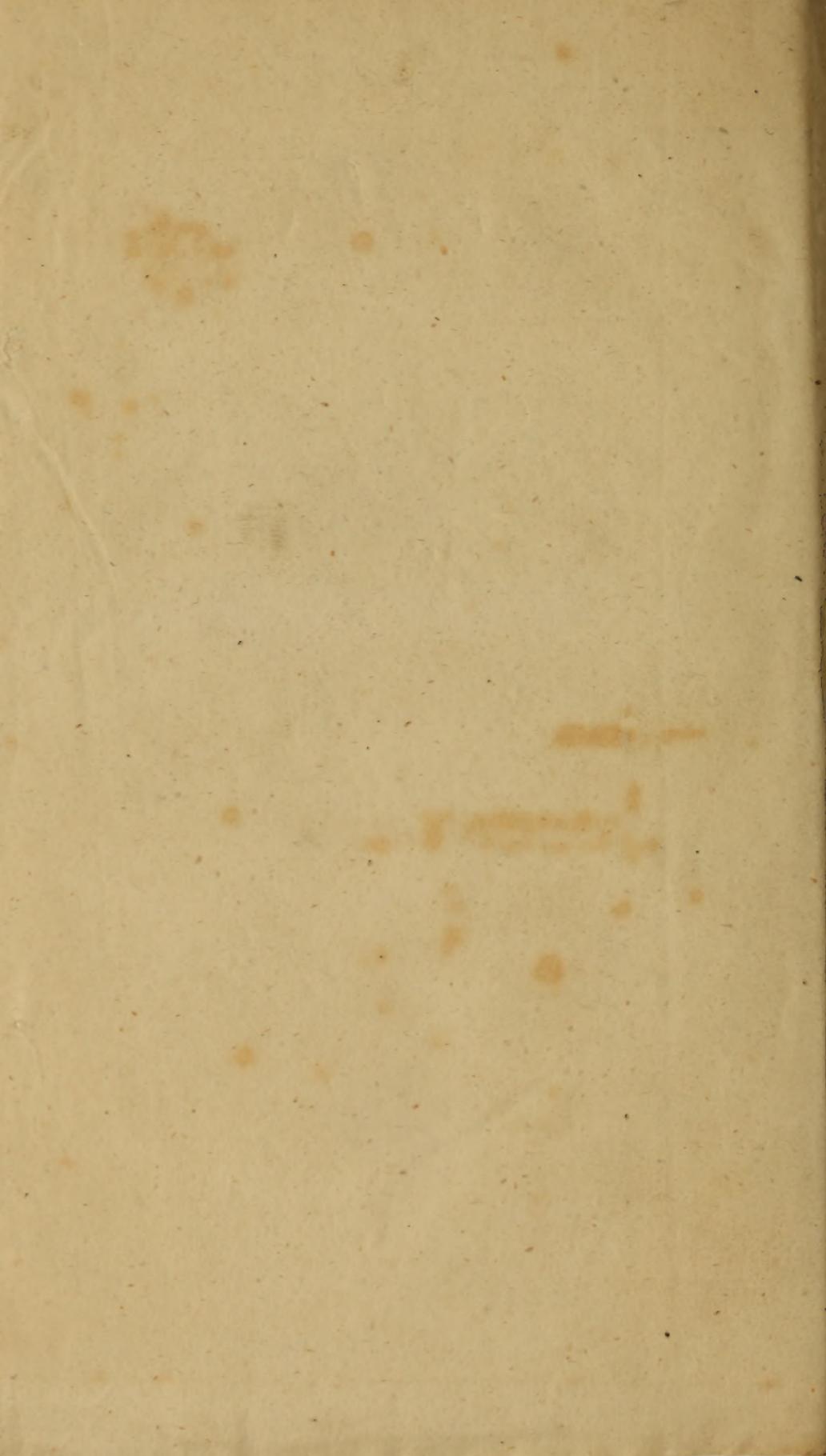
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