

L.—*Influence of Moisture on Chemical Change.*

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A YEAR ago, I communicated to the Society (Proceedings, 1893, p. 129) a note on some chemical actions which appeared to require the presence of water vapour: I have now the honour to lay before the Society the results of further investigation on this subject.

The actions previously known in which the presence of moisture seemed to be an important factor were mainly those which occur between elements. Whether moisture exerted a similar influence on other types of chemical action seemed to be worthy of trial; I therefore chose as an instance of an action involving two compounds that which takes place with some violence between sulphur trioxide and lime. The lime, prepared by the ignition of precipitated chalk mixed with sugar, was introduced while warm into a small bulb blown on a tube, at the other end of which was placed some phosphorus pentoxide; the two ends of the tube were then sealed. After standing for three days, the bulb, which was heated at intervals to distil any moisture into the phosphorus pentoxide, was sealed off.

A glass tube was dried by drawing a current of dried air through it, while it was heated nearly to its softening point. When cool, the bulb containing the dried lime was introduced at one end, and plugs of phosphorus pentoxide at the other; the tube was then exhausted, and allowed to stand two days, the part containing the bulb being heated at intervals with the object of drying it as completely as possible. One end of the tube was connected by a joint made of previously-ignited asbestos with a tube containing sulphur trioxide, which was gently heated. The point of the vacuous tube was then broken by pressing against the side of the sulphur trioxide tube, and the sulphur trioxide was thus drawn into the tube containing the bulb of lime; this tube being cooled by melting snow. The end was then sealed, and the whole set aside during a week; the part of the tube containing phosphorus pentoxide was then sealed off, and the bulb of lime was broken. Not a sign of combination appeared. Several similar tubes were prepared, and in each case the result was the same. As calcium sulphate is not unlike lime in appearance, experiments were made to see if any slow union had taken place. One tube was broken, and a little moist air allowed to enter. The lime and the sulphur trioxide then combined, the mass becoming vividly incandescent, proving that no action had taken place previously. With the view of showing the want of action of metallic oxides on sulphur

trioxide, without rendering it necessary to destroy the tube, a similar tube was prepared containing black copper oxide. No action was seen on breaking the bulb, and the sulphur trioxide crystallised on the black powder, apparently without converting any of it into the white anhydrous sulphate of copper.

Action of Lime on Ammonium Chloride.

This action seemed to be of interest, as water is formed as a product of the change. Pure lime was prepared as described above, but instead of allowing it to cool in the air, it was transferred, while still hot, to a red-hot tube, which was at once placed in a small desiccator containing phosphorus pentoxide. The ammonium chloride was purified by the method suggested by Stas, namely, boiling the sublimed chloride with dilute nitric acid and then with water. The crystallised product was found to be deliquescent, and this was the case even after it had been heated at 120° for six hours. In order to get rid of any traces of other substances, it was dissolved and recrystallised eight times. It was sublimed in a hard glass tube, and, while still hot, it was placed in the middle part of a hard glass tube in which were two constrictions; into one end of this tube, which had been previously heated to redness in dried air, lime was introduced, phosphorus pentoxide being placed in the other. One end was drawn out into a conducting tube, while the other was sealed. During 17 days' drying, the lime and the ammonium chloride were heated, but not so strongly as to volatilise the latter. The end of the conducting tube was broken under dried mercury, and part of the ammonium chloride shaken into the lime. They were mixed by shaking, and then the mixture was heated, when the ammonium chloride was seen to sublime from the lime; about 9 c.c. of gas was collected, but it had no smell of ammonia. The conducting tube was withdrawn from the mercury, and moist air allowed to enter the tube as it cooled. The rest of the ammonium chloride was then mixed with the lime, and the mixture heated; a copious evolution of ammonia took place, thus showing the effect of a trace of moisture on the action. It was found by several preliminary experiments that every one of the precautions mentioned above is necessary. It is easy to understand why this should be the case, as, if once the action commences, water is produced, and any subsequent drying is of no avail.

The interaction of Hydrogen and Chlorine.

The effect of moisture on the interaction of these gases has been studied by many chemists, notably by Pringsheim (*Ann. Chim. Phys.*, 1887, 421), and Dixon and Harker (*Man. Lit. and Phil. Soc.*, 1890). They have shown that the absence of moisture retards the

chemical change. In repeating their experiments, I wished to see if the separate drying of the gases would be more effectual than the drying of the mixture. Two bulbs of equal volume were connected by a tap, and the apparatus dried as thoroughly as possible. One bulb was filled with dried hydrogen prepared by the action of dilute sulphuric acid on magnesium, and the other with dried and purified chlorine from manganese dioxide and hydrochloric acid. Phosphorus pentoxide was introduced into the bulbs, which were closed and left for four days. The tap between the bulbs was then opened, and the gases, after being allowed to mix during 24 hours in the dark, were then brought into bright sunlight. No explosion took place. The mixed gases were left exposed at a south window four days, during two of which there was continuous bright sunshine. The mixture was then divided into two equal portions by closing the tap, and these were separately analysed in the dark room. The gas in one bulb was driven into an eudiometer, standing over a solution of potash, by a current of carbon dioxide. The residual gas was exploded with oxygen, and the amount of hydrogen thus determined. The other bulb was opened under mercury, which was immediately attacked. The amount of chlorine left in the mixture was determined by weighing the mercury which had entered the bulb; its volume was not quite equal to that of the hydrogen which had been obtained in the other analysis. I found, however, that the absorption had not been quite complete, the gas in the bulb still had a slight smell of chlorine, and bleached moist litmus paper. The analysis showed that more than a quarter of the mixture had been left uncombined after the exposure to two days' diffused and two days' bright sunlight.

Combination of Nitric Oxide and Oxygen.

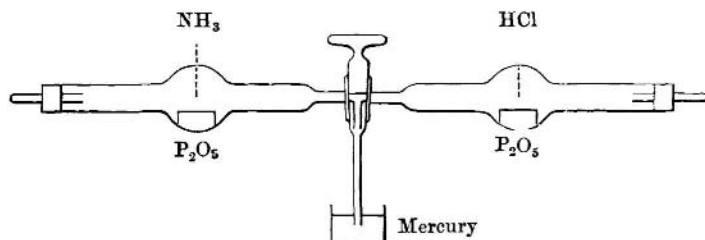
The action of these two gases on each other appeared to be uninfluenced by the presence of moisture, unless special precautions were used for ensuring the purity of the nitric oxide. In some preliminary experiments the gas was prepared in the ordinary way by the action of nitric acid on copper. No difference could be seen between the action of the dry and the moist gases. The effect was different, however, when the gas was prepared by warming the black compound of nitric oxide and ferrous sulphate; the gas was washed by passing through several long tubes containing water, and dried by sulphuric acid. It was introduced into one-half of a tube divided in the middle by a tap, the whole of which had been previously exhausted. Pure oxygen was admitted to the other. Each part of the tube contained plugs of phosphorus pentoxide, which dried the gases separately. After ten days, the tap

was opened and the gases allowed to mix, but no darkening of the gas could be seen, and on opening under mercury no contraction was observed. When a small quantity of water was introduced, dense brown fumes of the peroxide were immediately produced.

Combination of Hydrogen Chloride and Ammonia.

I was unaware, at the time when the note in the Proceedings was published, that Helmholtz and Richartz (*Ann. Phys. Chem.*, **40**, p. 161) had shown that no fumes are produced when these gases, previously dried, are brought together; they, however, believed that the chemical action still went on, although the ammonium chloride was not precipitated in the form of powder. A short account of some experiments on the subject may, therefore, still be of interest.

Ammonia, prepared by heating purified ammonium chloride with purified lime, was dried by passing it first over solid potash and then over a mixture of copper oxide and potassium oxide; the latter, which Stas recommends as being superior to phosphorus pentoxide as a drying agent, is made by fusing finely-divided copper with potassium nitrate. The ammonia was then introduced into one end of a tube divided in the middle by a three-way tap.



When the ammonia was dried in this way, it had no apparent action on phosphorus pentoxide; if, however, the tube had not been carefully dried, the pentoxide absorbed the ammonia, and formed a hard brown mass, a large amount of heat being developed. The hydrogen chloride was prepared by the action of pure sulphuric acid on recrystallised sodium chloride, and introduced into the other part of the tube. After standing a week, the gases were allowed to pass through the tap and mix by diffusion; no white fumes were produced. On connecting the interior of the tube with dried mercury, by means of the third limb of the tap, no rise of the mercury took place, showing that no combination of the gases had taken place. I afterwards found that the long drying tubes used for the ammonia gas were not absolutely necessary. If the phosphorus pentoxide be saturated with ammonia gas, the substance produced acts as a drying agent, though not so efficiently as the unaltered pentoxide.

If a trace of moist air be admitted to the mixture of dry gases, dense white fumes are at once produced, and the mercury rushes up into the tube. As will be seen later, a large number of experiments have been done with these gases, all confirming the conclusion that, when dried, they do not unite directly.

Dissociation of Ammonium Chloride.

It was thought that a convenient method for obtaining the mixture of dry ammonia and hydrogen chloride gases would be to heat dry ammonium chloride in a dry tube, and, since it dissociates, the tube would be left filled with the dry gaseous mixture. Soft glass tubes were first taken, heated to near their melting point while a current of air was passed through them, and allowed to cool. Plugs of phosphorus pentoxide were introduced into one end, and freshly sublimed purified ammonium chloride into the other. The tubes were then exhausted, sealed, and allowed to stand a fortnight. The parts containing the phosphorus pentoxide were sealed off, and the closed tubes, containing dried ammonium chloride in a vacuum, were heated at 350° in an air bath during two hours. While still hot, the ends of the tubes were broken under mercury; this rose, on an average, about a third of the height of the tube. There was no contraction on adding a trace of moisture, but, on introducing water, the liquid rose and filled the tube; the water was very strongly alkaline, and smelled of ammonia. Into another tube undried hydrogen chloride gas was added over mercury; white fumes were produced, and the mercury rose to the top. The gas left in the tube must have been pure ammonia. I suppose the hydrogen chloride combined with the alkali constituent of the glass, as the latter showed some signs of being etched. I found afterwards that in his determination of the vapour density of ammonium chloride, Bineau (*Ann. Chim. Phys.*, **68**, 416) noticed that a soft glass globe was etched by ammonium chloride vapour.

Experiments similar to the above were then tried with hard glass tubes; in every case, whether the heating was continued five minutes or three hours, the cooled tubes, on being opened under mercury, were completely filled with the liquid, leaving no gaseous residue whatever. The conclusion was then either that (1) dry ammonia and dry hydrogen chloride combine when dry, which, after some 30 experiments to the contrary, I could not believe, or (2) that dry ammonium chloride does not dissociate on heating. The second hypothesis I proceeded to test. A Victor Meyer's apparatus was constructed by blowing a long bulb of 250 c.c. capacity on a piece of hard combustion tubing; and, in doing this, I found how very valuable was the suggestion of Mr. Shenstone, that the oxy-hydrogen

blowpipe should be used. The necessary conducting tube and means of dropping the substance into the bulb, without opening the apparatus, were then sealed on. The bath was of iron, in which mercury was boiled, the bath being enclosed in a jacket of asbestos cloth. The apparatus was dried by heating it in the bath and drawing through it a current of dried air. The purified and dried ammonium chloride was introduced in a small hard glass tube. The results of the experiments were as follows.

I.	II.	III.	IV.	V.	VI.	Mean.	Calculated for no dissociation.
28.8	29.5	26.3	28.6	26.8	26.8	27.8	26.75

The determinations were made in four different bulbs, all made of hard glass, but of different sizes.

Several attempts were made to confirm the result of the density of dry ammonium chloride vapour obtained above, using Dumas' method. In all cases, the determinations gave values between 13.2 and 13.9, showing that complete dissociation had taken place. As, however, the exit tube was unavoidably open to the air during three quarters of an hour, the result is scarcely to be wondered at, and I think it may be assumed that when dried ammonium chloride is heated at 350°, it does not undergo dissociation.

Dissociation of Nitrogen Tetroxide.

Lead nitrate was purified by recrystallisation and heated to fusion in a carefully dried tube containing phosphorus pentoxide. A part of this tube, in the form of a U-tube, was cooled in a freezing mixture. The colourless liquid given off on heating the lead nitrate became red on the temperature being raised, and the red gas was very perceptibly darkened by heating. It seems probable, as all possible precautions were taken to dry the gas, that dried nitrogen tetroxide does undergo dissociation.

Combustion of Carbon Bisulphide in Oxygen.

I showed some years ago (*Phil. Trans.*, 1888, 582) that a mixture of very carefully purified and dried carbon bisulphide and dried oxygen exploded apparently at the same temperature, and with as much violence as when moisture was present. This is the more surprising, as the elements of which the bisulphide is composed do not burn in oxygen, even when very strongly heated. In a tube in which excess of carbon bisulphide vapour had been exploded with dried oxygen it was noticed that, besides sulphur, there was a black deposit, which proved to be carbon. It was possible that the decomposition of the bisulphide had been brought about by the shock of the explosion. To test this, carbon bisulphide vapour was mixed with dried

purified nitrogen in a bent tube standing over mercury. The closed end of the tube, which was horizontal, was heated in an air-bath, side by side with a tube of the same kind of glass containing a thermometer. The air-bath was provided with a window through which changes in the tube could be observed. Decomposition of the carbon bisulphide began at 216° ; in another similar experiment the temperature was 218° . A third tube was exhausted before the bulb containing the carbon bisulphide was broken; the temperature at which decomposition began in this tube was 201° . By observing the temperature at which carbon bisulphide exploded when mixed with dried oxygen, it was found that decomposition always must begin before interaction with oxygen could take place. In the two experiments tried explosion took place at 258° and 260° . This gives a possible explanation of the burning of dried carbon bisulphide; in what is called "the nascent state," it is not unlikely that elements may combine whether moisture is present or not.

Decomposition of Potassium Chlorate.

The salt was purified by several crystallisations, and heated to incipient fusion to get rid of the moisture. A small quantity was placed in a hard glass tube already dried, and into which plugs of phosphorus pentoxide had been introduced. The tube was sealed at one end and drawn into a conducting tube at the other. The potassium chlorate was heated for many hours at about 250° to drive off moisture, the part of the tube containing phosphorus pentoxide being kept cool. After three weeks the end of the conducting tube was broken under dried mercury and the potassium chlorate heated. The decomposition took place apparently without any difficulty. The gas evolved did not attack mercury, and there was no alteration in volume on the addition of a trace of moisture; it was therefore ordinary oxygen. Similar experiments with dried silver oxide gave the same result.

Formation of Ozone from Oxygen.

Mr. W. A. Shenstone (Trans., 1888, 53) has described experiments on the action of the electric discharge on pure dried oxygen, which I have repeated with as much care as I was capable of bestowing, both in obtaining pure oxygen and in drying the tube as well as the gas. Two experiments were made, one in which the drying lasted one month, and another in which it was continued for six months, the tube being heated at intervals in a bath of mercury vapour to drive moisture from the glass to the phosphorus pentoxide. I am happy to be able to confirm Mr. Shenstone's results in every particular. Ozone was formed, as far as I could judge, as rapidly in the dried gas as

it was in the same tube when the oxygen had been dried only by sulphuric acid. I also observed the curious action, which he mentions, of the dried ozone on mercury; when the metal which had completely lost its mobility was shaken with water, it became quite bright and apparently free from any trace of the change it had undergone.

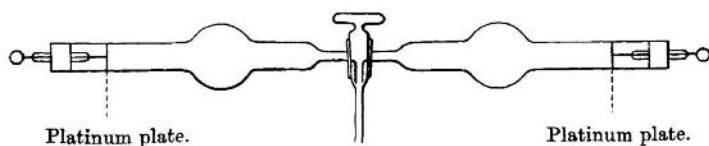
Theory of the Influence of Water Vapour.

With regard to the explanation of the influence of moisture, many suggestions have been offered. Professor H. B. Dixon (*Phil. Trans.*, 1884, Part II, 629), whose work on the effect of moisture on the explosion of carbon monoxide and oxygen first brought the subject prominently into notice, suggested a purely chemical hypothesis, that the water vapour gave up oxygen to the carbon monoxide, and that the liberated hydrogen combined with more oxygen. Traube has suggested (*Ber.*, 26, 1471) that hydrogen peroxide is first formed, water thus acting as a carrier for oxygen, by combination, rather than as in Professor Dixon's theory, by decomposition. Mr. A. Vernon Harcourt, in a discussion at the Ashmolean Society in Oxford, in 1884, first suggested that the explanation was to be sought rather from a physical than a chemical point of view. Dr. Armstrong's theory of "reversed electrolysis" is well known. I hope in the second part of my paper to deal with the question of bodies which will behave as substitutes for water vapour in bringing about the combination of purified substances.

With regard to the explanation of the phenomena, I may perhaps be allowed briefly to indicate the direction in which I am working, although the experiments in some cases are not complete. I have long believed in the possibility of an electrochemical theory of combination which should be free from the objections urged against that of Davy and Berzelius. It seemed desirable to investigate the questions which apparently lie at the root of the whole matter, whether the molecules of substances capable of combining are at a different electric potential, and whether this difference of potential increases as the bodies are brought, either by increase of temperature or otherwise, nearer to the point of chemical combination. Also, if this difference of potential should be proved to exist, whether it was in any way proportional to the chemical attraction between the substances. Finally, if conditions which affected chemical change, affected in the same direction the passage of electric discharge.

The direct investigation of the electrical conditions of the molecules of gases in a mixture seemed to be an impossibility. By an indirect method, however, I have obtained some results which I believe throw some light on the matter. Dried hydrogen chloride does not combine

with dry ammonia. A mixture of these gases in equal volumes was introduced into a glass tube about half a metre long, divided in the middle by a three-way tap; at the ends of the tube were pieces of platinum to which were attached platinum wires, sealed into glass tubes, which passed through the stoppers of the large tube.



The two parts of the tube being in connection, the platinum plates were connected to the terminals of a small Wimshurst machine, which at the time gave sparks 3 cm. long in air. The machine was worked continuously during three hours in the first experiment. The tap was then closed, and the gases in the two parts of the tube were examined. Separation of the mixture was found to have taken place; the gas in the part of the tube containing the positive plate reddening litmus, while the gas in the other part turned it blue. The experiment was several times repeated, and always with the same result. To make the evidence of the separation more complete, an experiment was done without previously mixing the gases. Ammonia gas was placed in the part containing the positive plate, and hydrogen chloride in that containing the negative plate. After an hour's electrification of the plates, the ammonia was found in excess in the part containing the negative plate, and the hydrogen chloride in excess in the other. The amount of separation was never very great, but the evidence of it was always conclusive.

Similar experiments with air, dried by sulphuric acid, showed that after the electrification there was 1·8 per cent. more oxygen in the part of the tube containing the positive plate than there was in that containing the negative plate. Using a mixture of hydrogen and oxygen, dried by phosphorus pentoxide, analysis showed an excess of 2·3 per cent. of oxygen in the part of the tube containing the positively charged plate. These experiments seem to show that mixed gases can be partially separated by the attraction of their molecules for plates which are oppositely charged.* It is probable, therefore, that

* While these experiments were in progress, a paper by Mr. E. C. C. Baly was communicated to the Physical Society (Nov., 1892), in which results of much the same kind as those described above are recorded. He showed that separation of gases in a mixture could be brought about by a discharge through nearly exhausted tubes. I do not think my results are brought about by the same causes as his, as no discharge would be likely to pass through a tube half a metre long, filled with gases at the ordinary pressure. Possibly his results may be explained by

the molecules of such gases are themselves electrically charged. Whether this charge on the molecules, if it exists, is theirs intrinsically, or if it is produced by contact, like the charges of zinc and copper when joined, could be shown by similar treatment of a single gas. If it has an intrinsic charge, there should be greater condensation at one plate than at the other. This experiment I have not yet tried.

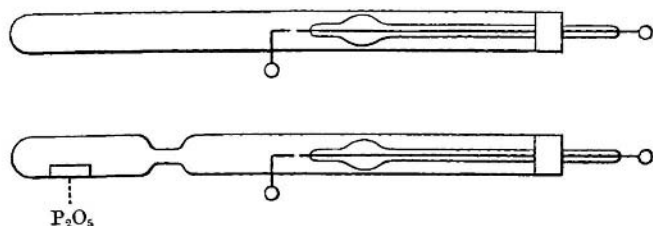
With the view of finding out if gases were electrified by contact with substances with which they may, under some circumstances, combine, experiments were made to measure the electrification of pure mercury when shaken in tubes containing different gases. The arrangement consisted of a long glass tube, into one end of which a platinum wire was sealed. Dried re-distilled mercury was introduced into it, and the tube was heated while a current of dried air passed through it. Phosphorus pentoxide was introduced at one end, and the tube was filled with the gas to be used, by exhausting while still hot, and then admitting the purified gas; this process being repeated four times before the tube was sealed. After being left in contact with the phosphorus pentoxide for a fortnight, the part containing the pentoxide was sealed off. By shaking the mercury at one end and allowing it to run down to the other, which was furnished with the platinum wire, the electrification could be seen by joining the wire to the knob of a quadrant electrometer. In pure oxygen the electrification was very large, the image of the mirror swinging quite off the scale, but when nitrogen was used the deflection was only 20 divisions out of 100 on the same scale.

This method is unsatisfactory because the electrification of the mercury due to its contact with the glass is measured as well as that due to its contact with the gas. The very decided difference showed however that the nature of the gas had an effect on the electrification of the metal. Professor J. J. Thomson (*Phil. Mag.*, April, 1894) has devised a method which is free from the objection stated above, by measuring the electrification of drops of various liquids after they have fallen through different gases. From his results, I think it may be concluded that the electrification of the drops is dependent on the chemical attraction for the gases through which they fall, and that it also varies if the temperature is altered.

I have begun some experiments on the thermo-electric behaviour of metals in different gases; the differences noticed are very remarkable, but as yet the experiments have not been repeated often enough for the results to be published.

supposing that the discharge in some cases first brought about combination of the gases in the mixture, and that the compound produced underwent electrolysis, such as Professor J. J. Thomson has shown to take place when an electric discharge is passed through steam.

With the object of finding if electric discharge bears any analogy to the process of chemical combination, or has any relation to it, some experiments were undertaken a year ago with the view of finding whether electric discharge could take place in a dried gas. Tubes were constructed as shown in the diagram, in which platinum wires could be made to move, so that the gap between them could be increased or diminished.



One tube contained air dried by sulphuric acid, and another air dried by phosphorus pentoxide. In one experiment, using three bichromate cells, sparks could be obtained in the moist tube by bringing the wires into contact and then disconnecting them, but none could be seen in the dry tube, even in the dark. When using a feeble discharge from a Ruhmkorff's coil no sparks passed in the dried air, although sparks passed readily in the moist tube, even when the sparking distance was greater; this result confirms that obtained by Professor J. J. Thomson (*Phil. Mag.*, Oct., 1893). When a strong discharge from a Wimshurst machine was used, it was found to pass readily in the dried air, and the air now allowed the feebler discharge to pass. The result of this experiment bears a striking relation to the phenomenon discovered by Faraday, that a strong discharge through a gas renders a feeble one capable of passing along its path.

In investigating the electrification of mercury in different dried gases, some tubes were exhausted. It was found that the beautiful glow produced by shaking the mercury, gradually diminished as the drying action by phosphorus pentoxide proceeded, and disappeared altogether after the gases had been drying about two days. The disappearance of the glow might have been caused by the heightening of the vacuum by the removal of moisture to such an extent that a discharge could not take place. To show that this was not the case, dried gas was admitted to one tube which was then re-exhausted, but no glow could be obtained.

I believe that the above experiments indicate that, with regard to the presence of moisture, electric discharge is affected in the same way as chemical combination. This may only be a coincidence, but if it can be regarded as proved that substances which are capable of

chemically combining are electrically charged, the result will have great significance.

It may be possible, by a further study of the action of light on chemical combination, to establish some connection between its influence and the remarkable influence of light on electric discharge noticed by Hertz and others.

General Conclusions.

1. Sulphur trioxide does not combine with dry lime or dry copper oxide.

2. Dried ammonium chloride may be sublimed from a mixture of the salt with dried lime without ammonia being liberated.

3. Dried hydrogen and chlorine may be exposed to sunlight for two days without anything like complete interaction taking place.

4. Purified and dried nitric oxide and dried oxygen do not interact.

5. Hydrogen chloride when dried does not combine with dried ammonia gas.

6. Dried ammonium chloride does not dissociate when heated to 350°.

7. Nitrate of lead decomposes when dried, and the red fumes darken on heating.

8. The combustion of carbon bisulphide in dried oxygen is probably due to the previous splitting up of the substance when heated.

9. Dried potassium chlorate and silver oxide decompose on heating, giving off ordinary oxygen.

10. Ozone is produced by the electrification of dried oxygen.

11. Dried ammonia and hydrogen chloride can be partially separated from a mixture of these gases when oppositely charged plates are placed in the mixture, the ammonia passing to the negative plate and hydrogen chloride to the positive.

12. Low tension electric discharges do not pass in dried gases unless a strong discharge has been previously sent through them.

I wish to give my best thanks to Dr. Armstrong for much kind encouragement during the progress of this research, to the Royal Society for a Government Grant to enable me to carry it on, and I wish also to express my sense of obligation to Shrewsbury School, in whose laboratory a considerable part of the experimental work was done.

APPENDIX.

Chemical actions on which the effect of the presence of moisture has been investigated.

(a.) Combinations of elements—

Sodium and chlorine (Wanklyn, *Chem. News*, **20**, 271).

Other metals and chlorine (Cowper, *Trans. Chem. Soc.*, 1876).

Hydrogen and chlorine (Pringsheim, *Ann. Chim. Phys.*, 1887, 421; Dixon and Harker, *Owens College Researches*, **1**).

Potassium and sodium with oxygen (Holt and Sims, *Trans. Chem. Soc.*, 1894).

Hydrogen and oxygen (Dixon, *Phil. Trans.*, 1884; v. Meyer, *Ber.*, 1893).

Carbon, phosphorus, sulphur, boron,* arsenic,* antimony,* selenium,* tellurium and oxygen (Baker, *Phil. Trans.*, 1888).

(b.) Interactions of compounds with elements—

Carbon monoxide and oxygen (Dixon, *Phil. Trans.*, 1884).

Nitric oxide and oxygen.

(c.) Decomposition of compounds by elements—

Cyanogen and oxygen (Dixon, *Trans. Chem. Soc.*, 1886).

*Carbon bisulphide and oxygen (Baker, *Phil. Trans.*, 1888).

Sodium and aluminium with hydrogen chloride (Cohen, *Chem. News*, **54**, 102).

(d.) Combinations of compounds with compounds—

Ammonia and hydrogen chloride.

Lime and sulphur trioxide.

Copper oxide and sulphur trioxide.

Lime and carbon dioxide (Veley, *Trans. Chem. Soc.*, 1892).

(e.) Double decompositions—

Lime and ammonium chloride.

Hydrogen sulphide and metallic salts (Hughes, *Phil. Mag.*, 1893).

Hydrogen chloride and calcium carbonate (Hughes and Wilson, *Phil. Mag.*, 1892).

(f.) Dissociations—

Ammonium chloride.

*Nitrogen tetroxide.

(g.) Allotropic changes—

*Amorphous phosphorus to yellow phosphorus by heat, yellow phosphorus to amorphous by exposure to sunlight.

*Oxygen to ozone (Shenstone and Cundall, *Trans. Chem. Soc.*, 1887).

* Unaffected by the presence of moisture, so far as the actions have been investigated.

(h.) Decompositions—

*Carbon bisulphide.

*Potassium chlorate.

*Silver oxide.

*Lead acetate.

The investigation of the actions to which no reference is appended is described in the foregoing paper.
