

CXXXII.—*The Action of Ammonia on Metals at High Temperatures.*

By GEORGE THOMAS BEILBY and GEORGE GERALD HENDERSON.

TEN years ago, while one of the authors was engaged in developing an industrial process which involved the passing of large volumes of ammonia gas through metal tubes at a red heat, some striking observations were made. In the first place, the statement of Ramsay and Young (Trans., 1884, 45, 88) that ammonia is decomposed into its elements with great rapidity by red hot iron was amply confirmed. When a current of ammonia at the rate of 4 litres per minute was passed through an iron tube 12·5 mm. in diameter and heated at 810° for 300 mm. of its length, only 27 per cent. of the ammonia escaped decomposition, 73 per cent., or nearly three-fourths of the whole, being decomposed. The velocity of the current through the heated part of the tube was about 1·5 metres per second, so that the ammonia molecules were only exposed to the hot metal for one-fifth of a second. Various observers had found that, for equal surfaces, copper has much less action on ammonia than iron. Experiments were accordingly made, using a solid drawn copper tube instead of an iron one. Under similar conditions of temperature and ammonia current, the quantity of ammonia decomposed by the copper tube in a given time was only about one-third of the quantity decomposed by the iron tube. This result was, so far, encouraging, and an attempt was made to use copper tubes for the industrial operation. However, after exposure to ammonia at a temperature of 800° for a few hours, the tube became so short and brittle that it could not bear its own weight without breaking. The next step taken was to strengthen the copper tube by slipping over it a sleeve pipe of iron, which fitted tightly and gave the necessary strength to resist bending or breaking. Thus protected, the copper tube could not break or crumble away, but it was soon found that it tended to close up until only a very small amount of gas could pass through it. Examination showed that the walls of the copper

tube had become very much thickened, and being unable to expand outwards, owing to the sleeve of iron, had expanded inwards until the bore of the tube was nearly closed. Observation with the microscope showed that the copper had become spongy and disintegrated throughout. It retained its colour, and, to a certain extent, its metallic lustre, but it appeared as if it had been in the fluid state, and blown up into a sponge by innumerable minute gas bubbles. Not only was the copper acted on, but the iron sleeve pipe had been reached and penetrated by the ammonia molecules. The iron pipe had become as brittle as hardened steel, so that it could be shattered by a blow with a hammer, and showed a bright, silvery fracture. Under the microscope, the iron also exhibited a spongy structure.

At this time, a number of other metals and alloys were experimented with, in the hope that something might be found which would resist the action of ammonia at a high temperature. Nickel, silver, platinum, gold, as well as a variety of alloys, were tried, but in every case the metal acquired the same spongy structure, and its strength and tenacity became seriously deteriorated. No metal we have tried is able to resist the attack of the ammonia molecule at a high temperature. To the already long list of the formidable properties of the nitrogen atom must now be added this power of attacking and disintegrating the most massive and refractory of metals, not even the noble metals being proof against its assaults.

In the case both of the iron and the copper tubes, it was found that under uniform conditions the quantity of ammonia decomposed remained fairly constant. While the continued action of ammonia tends to disintegrate the copper more and more, the greater surface thus exposed does not appear to add sensibly to the decomposition of ammonia by a given mass of metal. During the whole life of the protected copper tube (about 150 hours), the amount of ammonia decomposed did not vary much from 1 gram per minute. On the total life of 150 hours, this amounted to 9000 grams. This quantity of ammonia was many times the weight of the copper which decomposed it. It was evident, therefore, that the amount of ammonia decomposed was not in any way limited to what would be required to form a nitride or a hydride of copper. Examination of the decomposed gases showed that, on the average, the nitrogen and hydrogen were present in the proportion of 1 : 3 by volume. On the other hand, the appearance of the metals after exposure to ammonia clearly indicated that the melting point of the metal had been lowered by the action, and, therefore, that chemical combination between the metal and one or other of the gases had taken place at some stage in the operation. To produce a spongy mass, the metal must have been, at any rate, in a plastic or semi-fluid condition, but the structure rather suggested that

the metal had been suddenly cooled while in the act of boiling, bubbles in every stage of formation and bursting being fixed in the solidified metal. A spongy state may be produced in a material which is merely plastic, but this appearance of boiling could only be found in a material which had been fairly fluid. The temperature of the experiment was far below the melting point of copper or iron, therefore at some stage in the operation a more fusible compound must have existed. As everything pointed to the continuous formation and decomposition of some compound of the metal with ammonia or one of its constituent elements, some preliminary experiments were made to ascertain how far combination was taking place. Rolls of fine wire gauze of copper and of iron were heated in a porcelain tube at  $800^{\circ}$ , and a current of ammonia at the rate of 6.5—7 litres per minute was passed through the tube for 70 minutes. The following results were obtained. Weight of copper gauze before treatment, 42.04 grams; after treatment, 43.92 grams—a gain of 1.82 grams, or 4.47 per cent. Weight of iron gauze before treatment, 18.87 grams; after treatment, 20.02 grams—a gain of 1.15 grams, or 6.09 per cent. The iron gauze had become so brittle that it could not be bent without breaking. Its colour was bright silvery-grey, and under the microscope the spongy structure was very well marked. The copper gauze had become equally brittle. Its colour was a bright pink, and its surface was so completely disintegrated that metallic lustre had disappeared. Under the microscope, the bubble structure was very obvious. With both metals, the diameter of the wires had increased two or three times.

As already stated, a number of other metals were exposed to ammonia at a red heat. Although the energy of the action varied to some extent, all without exception were attacked in the same way, and became spongy and disintegrated. Even in the case of those metals, for example, gold and platinum, which did not show any obvious increase in weight through absorption of nitrogen, the appearance under the microscope was the same, and indicated that the action of ammonia had produced a certain degree of fluidity. This was shown in an interesting way when wires of different metals were twisted together and then heated in a current of ammonia. In many cases it was found that these metals had flowed together; thus, iron and copper, iron and gold, gold and platinum, gold and silver, became fused together. In the case of iron and gold, the gold sometimes flowed over the surface of the iron, forming a complete plating.

Up to this point, the investigation of this matter had been prosecuted mainly with the object of finding a suitable material for making tubes to resist the action of ammonia at a red heat. Two years ago, the authors began a more systematic examination of the behaviour of various metals under the action of ammonia. The scope of the inves-

tigation was not restricted to the study of the chemistry of certain nitrides, but was intended to cover the physical as well as the chemical action of gases on metals at high temperatures. The remarkably energetic action of ammonia on all metals at a high temperature, and the interesting physical changes in the metals brought about by this action, very naturally suggest that this particular case of the mutual action of gases and metals may supply a key to the study of the whole subject. It is not possible to examine the specimens of various metals which have been subjected to this action without being impressed with this view of the phenomenon and its probable bearing on the whole question of the occlusion of gases by metals, and the permeability of metals by gases.

The general method of experiment followed has been to pass a current of dry ammonia gas over the metals in the form of rod, wire, sheet, or foil, or sometimes in a fine state of division. The metals were placed in a porcelain tube, glazed inside and outside, and heated in a gas furnace to varying degrees of redness. The temperature was determined sometimes by the melting of pure salts and sometimes by a Le Chatelier thermo-junction. In the experiments carried out at temperatures below  $500^{\circ}$ , the tubes containing the metal were heated in a Meyer air-oven. As a general rule, a very rapid current of ammonia was passed through the tube, since experience showed that it was desirable that the gas should be present in large excess. After each experiment, the specimen of metal was left to cool in a current of ammonia before removal from the tube. Preliminary experiments proved that little or no decomposition of the ammonia resulted from passing the gas through a glazed porcelain tube 50 cm. in length and 12.5 mm. in internal diameter, even at a temperature of  $850^{\circ}$ . Many series of experiments were carried out in which the conditions were varied with respect to the state of aggregation of the metal, the velocity of the current of ammonia, the temperature to which the metal was heated, and the duration of the experiment. The results of the numerous experiments are summarised in the following paragraphs.

### *Iron.*

In January last, Mr. G. J. Fowler published an exhaustive paper on the formation of iron nitride by the action of ammonia on finely divided, freshly reduced iron (this vol., p. 285). Our independent conclusions as to the formation and decomposition of iron or copper nitride (arrived at nearly ten years ago as a result of working on an industrial scale), namely, that formation of the nitride occurs in presence of excess of ammonia molecules, whilst decomposition takes place when hydrogen molecules are present in excess, are completely confirmed by

Fowler's experiments with iron. We do not, therefore, propose to publish results which are simply a repetition of his, but as the conditions under which many of our experiments were carried on were different, we give a summary of our conclusions.

In the experiments upon iron, the metal was used in the form of fine gauze, wires of different thickness, or rods. The general results of a large number of trials under varying conditions were as follows.

When iron in the compact state is heated in a current of ammonia under the necessary conditions, it is more or less completely converted into a nitride of iron of the formula  $\text{Fe}_4\text{N}_2$ ,\* which possesses characteristic properties of its own. A nitride of this formula contains 11.13 per cent. of nitrogen. We obtained products containing up to 10.59 per cent. of nitrogen, although, if the conditions were not favourable, smaller proportions of the nitride were formed.

The essential conditions for the formation of nitride of iron by the direct action of ammonia on iron in the compact state are, first, the presence of ammonia in large excess, and second, a sufficiently high temperature. If these conditions are satisfied, the action takes place with remarkable rapidity. An iron rod one-quarter of an inch in diameter was penetrated to the centre in 30 minutes when heated to bright redness in a rapid current of ammonia.

Unless care is taken to ensure the presence of a large excess of ammonia, very little or absolutely none of the nitride is obtained, but at the same time, the ammonia is more or less completely decomposed into its elements and the physical properties of the iron undergo an extraordinary change. It becomes highly lustrous and very brittle, and when examined under the microscope exhibits no trace of crystalline structure, but only the porous or spongy structure already referred to. It is evident that, under the conditions of our experiments, nitride of iron is not stable except in presence of excess of ammonia, and that the great alteration in the structure of the iron, even when no nitrogen is permanently fixed, is due to the continuous formation and decomposition of the nitride.

Nitride of iron can be produced from the compact metal within a fairly wide range of temperature. According to our experiments, the formation of the nitride begins somewhat below  $450^\circ$ , although the action is very slow at that temperature, and the nitride can also be produced at the highest temperature attainable in our furnace ( $850$ — $900^\circ$ ). There is, however, no reason to suppose that the latter temperature represents the highest limit at which the formation of nitride is possible. The most favourable temperature depends largely upon the state of aggregation of the iron, and particularly upon the

\* The formation of this nitride was first established by Stahlschmidt (*Ann. Phys. Chem.*, 1864, [ii], 125, 37).

surface exposed to the action of the ammonia. Thus, using a fine wire of 0.3 mm. diameter, the action proceeded most rapidly, and the largest proportion of nitride was obtained at a temperature somewhat below  $650^{\circ}$ , but when thicker wires or rods were used the most suitable temperature was found to be  $800-850^{\circ}$ .

As regards the properties of nitride of iron, our results generally corroborate those of Fowler. The nitride is very readily soluble in dilute hydrochloric or sulphuric acids, and it was proved by analysis that the whole of the nitrogen is then liberated in the form of ammonia. When heated to redness in a current of hydrogen, it is completely decomposed into iron and ammonia, and it is also decomposed when exposed to the action of steam at a red heat. It can, however, be heated to a high temperature in a current of ammonia without undergoing any change. Iron gauze or wire, when converted into nitride, acquires a silvery-grey colour and retains its external form, but the surface is penetrated by innumerable cracks and acquires a peculiar, "blistered" appearance, whilst in the case of the thicker wires the surface is also dotted over with crater-like openings with raised edges, as if bubbles of gas had forced their way through a fused or semi-fused mass. The product is so brittle that it can easily be broken into fragments with the fingers, and crushed to powder in a mortar. Under the microscope, the powder appears to consist of aggregates of lustrous, silvery particles, more or less spherical in form, which evidently had solidified from a fused, or at least pasty, state. When experiments with thick wires or rods were interrupted after passing the ammonia for short periods, a core of unaltered iron remained, whilst the outermost part was wholly converted into nitride.

Pure iron is rendered hard and brittle like steel by the absorption of small quantities of nitrogen. Tubes of malleable iron, after exposure for 7 days to the action of ammonia at  $800^{\circ}$ , became so brittle that they could be broken like porcelain by a blow with a hammer, and a rod of charcoal iron was made so hard that it could be used as a drill. It appears not improbable, in the authors' opinion, that some at least of the effects on the structure and properties of iron and steel which are at present attributed to other elements may in reality be due to the presence of traces of nitrogen.

The conflicting statements of earlier observers regarding the action of ammonia on iron at high temperatures can be reconciled if it is remembered, first, that although the physical properties of the metal are altered, no nitride is permanently formed unless the necessary conditions are observed; and second, that the proportion of the metal converted into nitride in a given time is dependent on the state of aggregation of the iron, as well as on the temperature and the quantity of ammonia present.

*Cobalt.*

In preparing cobalt nitride, we used the metal in the form of the powder obtained by reducing pure oxide of cobalt with hydrogen. When heated at a high temperature in ammonia, cobalt behaved similarly to iron as regards the decomposition of the ammonia into its elements, but no nitride was formed. At a temperature of about  $500^{\circ}$ , a slight increase in the weight of the metal was noted, and at a somewhat lower temperature the metal combined slowly with nitrogen until finally a product containing 10.33 per cent. of nitrogen was obtained. A nitride of cobalt of the formula  $\text{Co}_4\text{N}_2$  contains 10.63 per cent. of nitrogen, hence the conversion of the cobalt into nitride was practically complete. The formation of nitride of cobalt can only proceed within much narrower limits of temperature than that of nitride of iron, even when, as in all our experiments, ammonia is present in large excess. Thus, for example, a sample of cobalt which gained in weight slowly when heated in ammonia at  $500^{\circ}$ , lost again when the temperature was raised to  $600^{\circ}$ : The most favourable temperature for starting the formation of the nitride appears to be about  $470^{\circ}$ ; once the absorption of nitrogen has begun, the temperature may with advantage be lowered somewhat below this point.

Nitride of cobalt was obtained as a dull greyish-black powder. Under the microscope, the particles of powder are seen to be composed of aggregations of minute particles which are all more or less lustrous and to some extent spherical in form, as if they had been at any rate in a semi-fluid condition. The nitride dissolves rapidly and completely in dilute hydrochloric and sulphuric acids with formation of a cobaltous salt, and analysis showed that all the nitrogen is set free as ammonia. It is completely decomposed when heated to redness in hydrogen, the nitrogen being eliminated as ammonia, and it is also decomposed, slowly but completely, when heated in a current of steam.

*Nickel.*

In some of our experiments, the nickel was used in the form of wire 2 mm. in diameter. When the wire was heated in ammonia at a high temperature ( $800$ — $850^{\circ}$ ), no increase in weight was noted, but the ammonia was, to a large extent, decomposed into its elements, and the appearance of the metal was greatly altered. The surface became quite dull at first, and was soon penetrated by an irregular network of cracks, and the metal became quite brittle. When the temperature was lowered to about  $600^{\circ}$ , the metal began to gain in weight slowly, and after several hours' heating in a rapid current of ammonia, an increase of 5 per cent. in weight was attained. By dissolving some of the



product in dilute sulphuric acid, and estimating the ammonia liberated, it was proved that this increase was due to the formation of nitride of nickel. After this treatment, the surface of the wire was found to be penetrated by cracks and fissures, spreading in all directions, and the metallic lustre had quite disappeared. Under the microscope, the product was seen to be composed of minute, closely adhering particles, which were silvery in appearance, and all more or less spherical in form. Nitride of nickel, apparently, cannot be obtained at temperatures much above  $600^{\circ}$ ; at about  $550^{\circ}$ , it is produced fairly rapidly, but it is of advantage to lower the temperature somewhat once the process has started. Little or no nitride is obtained below  $400^{\circ}$ .

As in the case of iron, the essential conditions for the formation of nitride of nickel are the presence of ammonia in excess and a suitable temperature; under other conditions, no nitrogen is permanently fixed by the metal, but the ammonia is largely decomposed, and the properties of the metal are profoundly modified, owing to the continuous formation and decomposition of the nitride. The range of temperature within which nitride of nickel can be formed appears to be much narrower than in the case of iron, but, on the whole, there is great similarity in the behaviour of the two metals when exposed to the action of ammonia at high temperatures.

In order to prepare nickel nitride, finely divided nickel, obtained by reduction of the oxide with hydrogen, was heated in ammonia at about  $500^{\circ}$ . The metal gained in weight steadily but slowly until a product was obtained which, on analysis, was found to contain 7.5 per cent. of nitrogen. In none of our experiments was the metal induced to combine with a higher proportion of nitrogen than this. The formula  $\text{Ni}_3\text{N}$  requires 7.36 per cent., and the formula  $\text{Ni}_5\text{N}_2$ , 8.74 per cent. of nitrogen, and hence it appears that the nitride of nickel obtained in our experiments differs in composition from the nitrides of cobalt and iron. It was produced as a dull black powder, which was shown by the microscope to consist of aggregates of very minute, roughly spherical particles adhering closely together. It is readily soluble in dilute hydrochloric and sulphuric acids, and resembles the nitrides of cobalt and iron in its behaviour when heated in hydrogen and in steam.

### *Copper.*

Copper, like iron, is very sensitive to the action of ammonia at high temperatures, and there is considerable similarity in the behaviour of the two metals.\* If the ammonia is in large excess, the copper is converted, at least partially, into a nitride, which, however, is only stable

\* The statements of earlier observers regarding the action of ammonia on copper at high temperatures are very contradictory.



under definite conditions, and is readily decomposed into its elements. Hence no nitride is formed when copper is heated in ammonia unless a large excess of the latter is present, but on the other hand, the ammonia is decomposed into hydrogen and nitrogen (although the amount of the decomposition is only about one-third of that effected by iron under similar conditions), and the metal suffers a very marked change in its physical properties. It loses most of its metallic lustre, acquires a pink colour, develops much the same spongy structure as has been described in the case of iron, and becomes extremely brittle. Examination with the microscope leads to the conclusion that the metal has been in at least a semi-fluid state, and has been rendered porous and spongy by the escape of numerous minute bubbles of gas. The ammonia penetrates into the metal very quickly. For example, a copper rod, one-quarter of an inch in diameter, was attacked through to the centre when heated in a current of ammonia for 30 minutes. But disintegration of the metal goes on almost indefinitely. Copper exposed to the action of ammonia for seven days at  $800^{\circ}$  became reduced to a fine, spongy powder.

In our experiments, the metal was used in the form of gauze, wire, foil, and rod. The maximum quantity of nitrogen fixed in any experiment was 4.5 per cent. A nitride of copper of the formula  $\text{Cu}_3\text{N}$  contains 6.86 per cent. of nitrogen. The nitride is very easily decomposed by heating in hydrogen, and apparently can only exist within a comparatively narrow range of temperature. The change in the physical properties of the metal, even when no nitrogen is retained by it, is no doubt to be attributed in this case also to formation and decomposition of the nitride.

### *Silver, Gold, and Platinum.*

In our experiments with silver, gold, and platinum, the metals were used both in the form of wire and in the spongy state. They were heated in ammonia at temperatures varying from  $400^{\circ}$  up to nearly  $900^{\circ}$ , but in no case was the formation of a nitride indicated by any increase in the weight of the metal, however rapid the stream of ammonia through the tube. In every instance, however, the ammonia suffered decomposition into its elements, although to a far smaller extent than with the metals of the iron group, and the physical properties of the metals were altered, to some extent in all cases, and very markedly in the experiments conducted at temperatures from  $750^{\circ}$  upwards.\*

\* "Ammoniacal gas is scarcely acted on in an ignited porcelain tube when clean and empty, but more readily when it contains fragments of porcelain; with still greater facility when it contains platinum, silver, or gold wire; more easily still when it contains copper wire, and most quickly and completely when iron wire is

When heated in ammonia at  $800^{\circ}$ , the polished surface of fine silver wire acquired a "frosted" appearance, and when examined with the microscope the wire was found to be covered all over with minute rounded blisters or bubbles, while there was also very distinct evidence of "spitting." The elasticity of the metal was also very greatly reduced.

Gold wire was also greatly changed in appearance by exposure to the action of ammonia at  $800^{\circ}$ . The colour was changed, and the entire surface of the wire was seen under the microscope to be closely covered with small blisters or protuberances which appeared to have solidified after partial fusion. When precipitated gold was similarly heated in ammonia, the brown masses shrank together and became much more compact, the colour changed to light yellow, and metallic lustre made its appearance. The microscope showed that the product was composed of roughly spherical particles which adhered closely. When a current of ammonia was passed at the rate of 2 litres per hour over gold heated at  $800^{\circ}$ , fully 10 per cent. of the gas was decomposed.

When platinum wire was heated in ammonia at  $800^{\circ}$ , the surface of the metal became duller, less lustrous, and showed a more or less blistered appearance under the microscope. In most cases, a fine, black deposit was formed on the surface of the metal. The deposit was sometimes closely, sometimes loosely, adherent, but could be rubbed off easily with filter paper or cotton wool. On examination, it was found to be nothing but platinum black, which clearly had been formed by disintegration of the surface of the compact metal. When a rapid current of ammonia was passed over platinum wire heated at  $800^{\circ}$ , the gas was decomposed to the extent of about 8 per cent.

The elasticity of both gold and platinum, like that of silver, is reduced to an enormous extent by exposure to a current of ammonia at high temperatures, and the resistance of each metal to the passage of an electric current is perceptibly increased.

Comparison of our experiments on silver, gold, and platinum with those on the metals of the iron group and on copper, leads to the conclusion that the very marked change in the physical character of the former metals, which is produced by the action of ammonia on them at high temperatures, is likewise due to the formation of metallic nitrides, which, however, are quite unstable, even in presence of a great excess of ammonia, and therefore readily decompose into metal and nitrogen. The continuous formation and decomposition of these nitrides would, of course, account for the observed disintegration of

introduced. These metals, for the most part, do not undergo any observable alteration in weight; but copper and iron become brittle, while gold and platinum remain perfectly unchanged."—GMELIN, *Handbook of Chemistry*, vol. II., p. 421.

the metals under the attack of strongly heated ammonia. The instability of these nitrides probably arises from their temperatures of formation and decomposition lying close together. It seems not improbable that the formation of spongy deposits on the outside of platinum crucibles heated by Bunsen burners, as well as the disintegration of the platinum wires of pyrometers exposed to furnace gases, may, sometimes at least, be accounted for by the presence of traces of ammonia in the furnace gases.

### *Conclusions.*

A number of other metals, including aluminium, zinc, tin, and lead, and many different alloys, for example, brass and aluminium bronze, have also been examined with regard to their behaviour when subjected to the action of ammonia at temperatures below their melting points. In every case, changes in the physical structure of the metals and alloys similar to those already described have been observed, and the ammonia has been decomposed to a varying extent into nitrogen and hydrogen. It would be tedious and unprofitable to describe our experiments in detail; suffice it to say that they all tend to confirm the following general conclusions at which we have arrived.

Metals in general, when exposed to the action of ammonia at high temperatures, are either converted into nitrides—wholly or partially—or else profoundly changed in their physical properties, even although no nitrogen is permanently fixed by the metal. The changes include alterations in the colour, lustre, tenacity, elasticity, and electrical conductivity of the metals, and are caused by the disintegration of the metal due to the continuous formation and decomposition of unstable nitrides. When the altered metals are examined under the microscope, it is seen that these nitrides must be more fusible than the metals, for a characteristic spongy structure, due to the escape of innumerable minute bubbles of gas from a molten or pasty mass, is clearly visible in all cases. The maximum absorption of nitrogen by each metal is determined by (1) the state of aggregation of the metal, (2) the temperature, (3) the excess of ammonia, (4) the time. Nitrides can hardly be obtained by the direct action of ammonia on metals at high temperatures unless an excess of ammonia is present, since all are easily decomposed into metal and nitrogen by heating in hydrogen.

If we follow the action closely, for example, in the case of copper, it appears probable that it begins by the ammonia molecules attacking the surface molecules of the metal and forming a fusible nitride. If a plentiful excess of ammonia molecules are present to overpower the hydrogen molecules which result from the decomposition of the ammonia, a theoretical absorption of nitrogen takes place. But the

nitride which is formed, being fusible at the temperature of formation, penetrates into the copper, and the further action tends to take place at some distance from the surface, where the ammonia molecules are fewer, and the hydrogen molecules are relatively more numerous. At a certain distance from the surface, a point will be reached at which the ammonia and the hydrogen molecules so exactly balance each other that no nitrogen is absorbed, or rather that, as soon as a molecule of nitride is formed, it will be immediately decomposed with evolution of nitrogen. The hydrogen resulting from the decomposition of the ammonia, together with the nitrogen from the decomposition of the nitride, force their way to the surface of the fluid nitride, causing the appearance of boiling—the particular structure which is found in all metals which have been acted on by ammonia.

It is clear that some such explanation as this is necessary if we are to account for the continuous and practically constant decomposition which takes place at a given metallic surface, and for the disintegration of the metal itself. We hope to extend our investigations on the action of gases on metals in the near future.

We take this opportunity of expressing our thanks to Messrs. P. W. Tainsh, A.I.C., and F. W. Watson, B.Sc., Nobel Company's Prizemen, and B. G. McLellan, A.I.C., Research Student in the Glasgow and West of Scotland Technical College, for much assistance in the experimental part of this investigation. We are also greatly indebted to Messrs. Johnson and Matthey, London, for their courtesy in preparing and placing at our disposal the pure gold and platinum which we required.

GLASGOW.

---