The Present Position of the Transmutation Controversy.

IF the genius of John Dalton gave the chemist a freehold title to the atom, the work of Becquerel and the Curies may be said to have transferred the title to the physicist, or at least to have granted him an indeterminable repairing lease of the property. The physicist has made good use of his tenure: he has determined the structure and conditions of stability of the atom, and by embellishing its parts with attractive and repulsive signs, he has thrown light upon many things that were previously obscure, and revealed new avenues of research for the investigator. Except for some tentative efforts to formulate an electronic theory of valency, the chemist has, for the most part, been out of the picture; and even when Rutherford used α-particles to disintegrate certain light atoms, the chemist was denied participation by the circumstance that the quantities of material involved were too minute to come within the range of his most delicate methods. In 1924, however, a vista of golden opportunity arose when Miethe and Stammreich announced that they had obtained from pure mercury gold in sufficient yield to be manipulated and determined by chemical means. The vista, although riddled by the barbed arrows of hostile criticism, is still above the horizon, and only the crucial test of further experimentation can decide its ultimate fate. Meanwhile, it may be of service to attempt a brief survey of recent happenings in this very interesting field of alleged transmutation.

It will be recalled that Miethe and Stammreich passed a strong current at 175 volts through a quartz mercury-vapour lamp containing, according to their statement, mercury free from gold, and that after working the lamp for 20-200 hours, gold to the amount of 0·1-0·001 mgm. was detected by chemical means in the mercury (*Naturwissenschaften*, August 1, 1924; NATURE, August 9, 1924). Afterwards, they found that the formation of gold was not bound up with any definite form of discharge, although a certain critical potential difference or electron velocity had to be exceeded; that the amount of gold produced was proportional to the current-strength and the time; and that the production was facilitated by a high pressure inside the apparatus. When they passed electric sparks between mercury poles in a paraffin dielectric, they found that gold was present in the mercury dispersed along the line of discharge, but not in the liquid mercury constituting the poles. Duhme and Lotz are reported to have observed the formation of gold when a sufficiently powerful current is passed between electrodes dipping into mercury; and investigators in the Siemens research laboratory to have produced gold by bombarding a mercury surface with electrons in a very high vacuum (*Naturwissenschaften*, July 17, 1925). In some of their experiments Miethe and Stammreich observed the production of a metal which resembled silver in its chemical properties. It is important to note that these authors have maintained throughout that the mercury they have experimented upon was in all cases proved to be free from gold by the very same tests which they used to prove its presence in the treated mercury.

In May 1925, Nagaoka reported in these columns that he and his co-workers had passed a discharge of P.D. about 15×10^4 volts/cm. for about 4 hours between terminals of tungsten and pure mercury, using paraffin oil as dielectric, and had detected gold in the resulting black mass of carbon, oil, mercury, etc., by the purple-of-Cassius test and by the formation of ruby glass. In a later communication (*Journal de Physique et le Radium*, 1925, **6**, 209) he stated that on passing a discharge through drops of mercury falling between iron electrodes, he observed, in addition to gold, the formation of a complex white metal consisting mainly of silver.

Early this year, in a preliminary announcement to NATURE (January 2, p. 13), Smits recorded the transmutation of lead into mercury and into thallium by means of a quartz lead-vapour lamp consuming 40 amp. at 80 volts. The initial purity of the lead and the subsequent presence of thallium and mercury were attested by the spectroscope. The method was varied by substituting sparks of high current-densities for a continuous current; using 60-100 amp. at make, all the lines of the mercury spectrum were visible after 9½ hours' sparking. Another method, in which sparks at 100,000 volts and 2 milliamp. were passed between electrodes of highly purified lead, immersed in a liquid dielectric, showed the transmutation of lead into mercury, the presence of which was proved by conversion into red mercuric iodide.

A priori objections to these experimental results are not difficult to conceive. It might be thought that heavy atoms, like those of lead and mercury, would be more unstable and therefore easier to disintegrate than light atoms, because their nuclei contain a greater excess of positive over negative charges; but Rutherford's experiments with α-particles showed that the lighter atoms are the less stable. Most of the light elements which he decomposed have an odd atomic number; all, with the exception of nitrogen, have atomic weights that are multiples of that of helium plus 3 units; and none of them except boron exhibits isotopy. Now mercury and lead have each an even atomic number, their atomic weights do not follow the above-mentioned numerical rule, and both elements possess isotopes.

Aston, moreover, has advanced some weighty arguments against the probability of the alleged mercury-gold transmutations (NATURE, December 19, 1925). This transmutation might conceivably be effected by the addition of an electron to the mercury nucleus, or by the expulsion of a proton from it. The chance that an electron would hit a nucleus at which it was fired is remote; and if a mercury atom did absorb an electron its weight would not be sensibly increased. Hönigschmid, however, has determined the atomic weight of Miethe's gold and has found it to be 197·2 (the same as that of ordinary gold), a number which is appreciably different from the atomic weight of mercury. Theoretically, it is possible for a mercury isotope of atomic weight 197 to absorb an electron and so produce ordinary gold; but none of the six isotopes of mercury identified by Aston possesses this atomic weight. The alternative hypothesis, that the mercury nucleus may be disrupted with the ejection of a proton, is held by

Aston to be quite untenable, because the forces employed are "ludicrously inadequate" for the purpose. The components of a nucleus are bound together by forces of the order of millions of volts, and these are not yet available to the laboratory worker, except in the form of swiftly moving α-particles from radium-C, as employed by Rutherford.

Possible explanations of the production of mercury and of thallium from lead have been considered recently in these columns by A. C. Davies and F. Horton (NATURE, January 30, 1926, p. 152), who think that investigators should attempt to determine if hydrogen or helium is evolved during the changes: their production would indicate a disruption of the nucleus, their absence would favour the hypothesis of electron absorption. Up to the present no one has observed the liberation of these gases during the reported transmutations.

Criticisms of the experimental findings of Miethe and Stammreich, and of Nagaoka, centre around the question of the purity of the mercury used by them; Was it really free from gold? The answer to this question must depend upon the analytical method employed and upon the 'personal equation' of the observers. The method used by Miethe and Stammreich was to dissolve the mercury in nitric acid (1 : 4), fuse the undissolved residue with borax (0·1 gm.), and to measure the resulting sphere of gold, if any, under the microscope. They state that the limiting concentration of the detectable gold in an amalgam is $1 : 10^7$ to $1 : 10^{12}$, and that the amounts of gold obtained by transmutation were within 10^3–10^4 of these limits. In one of their experiments they distilled *in vacuo* 1 kilogram of purified mercury, which showed no trace of gold, with 0·5 mgm. of silver and 0·5 mgm. of gold, until only 1 gram of the mixture was left; in this residue they found *all* the silver and gold that had been put in (*Zeitschrift f. technische Physik*, 1925, **6**, 74, 76).

In spite of such evidence, it is freely contended that distillation is not a trustworthy method of separating metals of high boiling-point from mercury, and that all the mercury that has been used in transmutation experiments was auriferous. Stammreich has discussed (*loc. cit.*) the possible ways in which gold might be carried over during the distillation of a gold amalgam. (*a*) It might distil over in virtue of its own vapour pressure. The vapour above the amalgam would contain gold, if only in an infinitesimal amount, and this amount would not sensibly increase when the amalgam was boiled. In the above experiment the vapour pressure of the gold must have been very nearly zero, and any error due to gold distilling over in the vapour phase would be well within the limits of accuracy of the method employed for determining the gold. (*b*) The vapour pressure of a gold amalgam might be higher than that of pure mercury. Such a phenomenon would be against all experience. (*c*) Vapour or minute drops of the (auriferous) mercury used for the mercury-pump might be carried over into the distillate. Miethe and Stammreich state that the distilling apparatus used by them precluded the possibility of such an occurrence.

In support of possibility (*a*), the critics quote the work of G. A. Hulett (*Physical Review*, 1911, **33**, 307). This investigator submitted a mixture of 6·75 kgm. of thrice-distilled mercury and 45·5 gm. of electrolytically refined gold to two distillations *in vacuo*, and the second distillate was found by a colorimetric method due to T. K. Rose (*Chem. News*, 1892, **66**, 271) to contain nearly 2 mgm. of the noble metal. It will be noted that the concentration of gold in the initial mixture was more than 1300 times greater than that in the mixture used by Miethe and Stammreich (*v.s.*). These authors attribute Hulett's result to spirting or irregular ebullition of the amalgam during distillation.

More recently Riesefeld and Haase have distilled an amalgam containing about 1 part of gold in 10 million of mercury under very carefully controlled conditions, using distilling apparatus specially designed to prevent mercury vapour diffusing back from the mercury-pump, and to prevent gold being carried over mechanically (*Berichte*, 1925, **58**, 2828). The distillate was found to contain gold in determinable amount.

In their reply, Miethe and Stammreich adhere to their contention that gold enters the distillate either from the pump or as the result of irregular ebullition. They point out that the microbalance which Riesefeld and Haase used for weighing their gold had an error of 0·003 mgm. and that this was exactly the weight of the gold they extracted from the third distillate. They note that the isolated gold was not pure, and they reaffirm that the mercury used in their own transmutation experiments was always previously purified from gold, to which end only two or three distillations were required as a rule, although so many as fifteen distillations had on occasion to be performed (*Berichte*, 1926, **59**, 359).

In a discussion of this subject held at the third assembly of the Deutscher Physikertag in Danzig (September 1925), it was suggested that gold and mercury might distil over together as a constant-boiling mixture. Prof. Miethe replied that in all constant-boiling mixtures the boiling-points of the components are of the same order (mercury boils at 357° C. under atm. press., gold at above 2600° C.), and that the components are present in commensurable proportions; he had investigated the possibility and had concluded that such amalgams do not exist.

Another suggestion made was that the mercury used for the transmutations may have contained gold in a state unrecognisable by the chemical tests employed, *e.g.* in colloidal solution or as a chemical compound, and that these were afterwards broken down by the electric discharge. There is, however, no experimental basis for this explanation. Finally, it was suggested that a decisive answer could be obtained by collecting the mercury dispersed in the dielectric by the discharge (*v.s.*), purifying it from gold, and then resubmitting it to the discharge: if it was found that more gold was produced, transmutation would be established. The experimental difficulties of such a test would be very great; the highest gold-concentration hitherto obtained in the mercury-mud of the dielectric is 1 : 10,000.

This short sketch of the main issues of the controversy will leave the impression that the question is still *sub judice*. On one hand, we have the perfectly definite statements of Prof. Miethe, who is an experimenter of acknowledged ability, and has shown much skill in parrying the attacks of his critics. On the other

hand, the accounts of some of his experiments, notably in regard to the distillation apparatus he employs, are somewhat lacking in precise detail; several investigators have entirely failed to reproduce his results (*e.g.* Tiede, Schleede, and Goldschmidt; Sheldon and Estey, NATURE, November 28, 1925, 792; Piutti and Boggio-Lera, NATURE, April 24, 1926, p. 604); and the considerations put forward by Dr. Aston still await a reply. Claims to have effected 'the great work' of transmutation have been made at frequent intervals since alchemy fell into disrepute, and their ignoble fate must make us sceptical of more recent contentions; but if these are proved to be baseless, it will be admitted that modern research into the constitution of the atom gave them a rational basis of possibility such as was never dreamed of by the medieval alchemist, even in his most fantastic flights of imagination.

Since the above account was written, a lecture given by Prof. F. Haber to the Kaiser Wilhelm-Gesellschaft, in Berlin, has been published in the issue of *Die Naturwissenschaften* for May 7, in which he communicated the results of prolonged investigations on the alleged transformations of mercury into gold. These results, which appear quite convincing, show that the gold obtained by Nagaoka and by Miethe and Stammreich did not in all probability pre-exist in the mercury, but was derived from auriferous metal constituting the electrodes or other metallic parts of the apparatus employed.

Prof. Haber has worked out two chemical processes for separating and determining gold in the presence of a large excess of mercury, but in the experiments now recorded he used mercury which had been purified by extremely slow, repeated distillation. Nagaoka's experiment was repeated several times, using a less powerful discharge, which, however, was continued for fifty hours, and gold up to 1×10^{-7} gram was obtained; but Miethe's experiment of passing a discharge through paraffin between mercury poles gave no gold whatever. The mercury-lamp method, when modified to give electrons with much greater velocity, gave small amounts of gold, which, however, did not increase when the period of the discharge was prolonged from four to fifty-six hours.

Using a kind of X-ray tube with a cathode of tungsten wire, an anticathode of strongly cooled mercury, and 30,000 volts, Prof. Haber also obtained gold; in one experiment so much as $1{\cdot}6 \times 10^{-6}$ gram. This led him to examine the metallic connexions of the tube, and he found that whereas the parts of these within the apparatus contained 2×10^{-6} gram of gold before the experiment, only one-fortieth of this amount was present at the end, the difference corresponding approximately with the weight of gold found in the mercury. But the most important evidence he obtained was that gold was never found when he used electrodes completely free from that metal. He analysed electrolytic copper wire, nickel wire, steel screws and Swedish iron, and found them all to be auriferous; only thin tungsten wire contained no trace of gold. The silver obtained in transmutation experiments is believed to have a similar origin.

Prof. Haber does not propose to repeat Nagaoka's experiment with higher voltages, because he foresees little chance of success; voltages of the order of two million might lead to results, but at present one million volts is about the limit for laboratory work.

An interesting feature of the recent work on transmutation is the extraordinary delicacy of the tests now used for detecting gold. Prof. Haber relates that one of his young collaborators suddenly found traces of gold in a material he was analysing, but no one else could confirm the observation on other samples of the material. It turned out that the chemist was in the habit of removing his gold spectacles before he made an observation, and that on the occasion in question he had removed them and then grasped a strip of the purest lead to put into the crucible he was using in the analysis. On another occasion, some one in the laboratory was heating gold to a high temperature, and shortly afterwards a worker *in the next room* detected this metal in a substance which was known to have been previously quite free from it.

High-Frequency or 'Ironless' Induction Furnaces.

THE emergence of the high-frequency induction furnace from the scientific worker's laboratory into the world of industrial production has aroused widespread interest. True, induction furnaces have long found successful application in the commercial world, but these have all been characterised by some form of iron core and have operated at relatively low frequencies. Although the possibilities of high-frequency inductive heating were demonstrated so far back as 1905 by Schneider, not much advance was made until 1919, when Northrup published an authoritative paper which renewed interest in the subject. How rapid has been the progress from that date may be judged from the fact that in 1925 high-frequency furnaces capable of handling 600-lb. charges of nickel alloys were in operation.

A high-frequency induction furnace, whether large or small, usually consists of a helix of copper tubing the turns of which are somewhat flattened and are separated from one another by a suitable electrical insulator. Electric currents (or oscillations) of the desired frequency are then passed through the furnace helix or inductor, which would speedily become hot were it not for a stream of cooling water passing through the interior of the copper tubing. Powerful eddy currents are induced in any conducting mass placed inside the helix, and a rapid rise of temperature of the material ensues provided conditions are suitable.

In practice, the charge (or metal to be heated) is contained in a crucible which is separated from the inductor coil by some refractory substance which acts both as a thermal and electrical insulator. The reader will in all probability have already surmised that the simple type of furnace (shown diagrammatically in Fig. 1) required for high-frequency inductive heating is not the most complicated part of the plant. Indeed the design of apparatus for the generation of oscillations of the desired frequency has made the greatest