

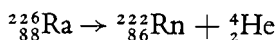
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## Chemical evidence of the transmutation of elements

*Nobel Lecture, December 12, 1935*

The interpretation of our first experiments was founded, as Madame Joliot-Curie has just explained, on facts of a purely physical order. We have considered the possibility, by using the methods of radiochemistry, of substantiating our hypotheses of providing a chemical proof of the reality of the transmutations brought about.

The first unquestionable proofs of the transformation of elements into different chemical elements have been provided by the study of the phenomena of radioactivity. There is no doubt that radium is transformed spontaneously into an active gas, radon, emitting at the same time alpha particles, or helions. We may write with certainty the corresponding nuclear reaction\*



for the quantities of the various elements taking part in this reaction can be considered sufficient for their successful identification chemically and spectroscopically.

The succession of radioactive transformations provides numerous examples in which the quantities of radio-elements are extremely small and not capable of being weighed, yet nevertheless, by the methods of radiochemistry it has been possible to examine correctly their chemical properties, and identify some of them as being isotopes of elements, active or inactive, available in large quantities.

This special kind of chemistry in which one handles unweighable quantities, sometimes of the order of  $10^{-16}$  g, is made possible thanks to the fact that one can determine and follow by measuring the radiation emitted, infinitesimal traces of radioactive matter dispersed in the midst of other matter.

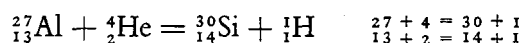
But while it is possible to write with certainty the nuclear reactions cor-

\* The atomic weight is placed above and to the left of the chemical symbol, and the atomic number to the left and below.

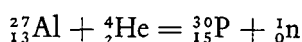
responding to most of the spontaneous transmutations, this is not the case for those artificially brought about.

The yield of these transmutations is very small, and the weights of elements formed by using the most intense sources of projectiles which we are able to produce at the present time are less than  $10^{-15}$  g, representing at the most a few million atoms. It is however possible to deduce the nature of the atoms formed with sufficient confidence, by assuming, in order to write the corresponding nuclear reaction, that there is on the one hand conservation of the atomic weight and on the other conservation of atomic number between the reacting elements and those formed.

Thus the aluminium nucleus capturing a helion must be transformed into silicon when a proton is emitted



The atom formed is very probably silicon, but being present in infinitesimal quantity, it is not possible to identify it chemically. On the other hand, when the atom formed is radioactive, it can be identified by applying radiochemical methods. For example, in the case where aluminium irradiated by alpha rays emits neutrons, the rule already mentioned enables us to write the following transmutation reaction



The atom formed being radioactive, it is possible to verify that it possesses the chemical properties of phosphorus.

A piece of thin aluminium sheet, irradiated beforehand by alpha rays is attacked and dissolved in a solution of hydrochloric acid (Fig. 1). The chemical reaction produces nascent hydrogen which carries over the radioactive element into a thin-walled tube where it is collected over water. This separation clearly demonstrates that some element other than aluminium has been formed on irradiation by helions. It furnishes an indisputable proof of the transmutation achieved; also, traces of phosphorus would be separated from the aluminium in the same experiment.

Finally, activated aluminium is dissolved in a mixture of acid and oxidant. To the solution is added a small quantity of sodium phosphate and a zirconium salt and it is found that the zirconium phosphate as it precipitates carries with it the radioactive element. For aluminium these experiments are

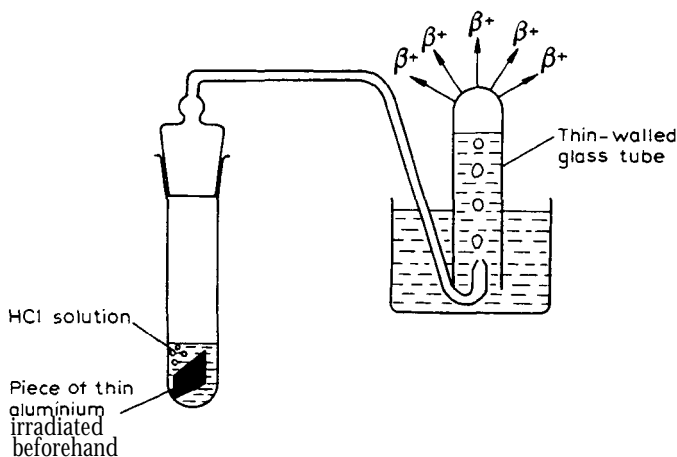


Fig. 1

delicate, for they must be made in about six minutes, the average life of the radioactive atoms which are formed being less than five minutes. Chemical tests of the same kind have shown us that the radio-element formed in boron under the action of alpha rays is an isotope of nitrogen.

We have proposed that these new radio-elements (isotopes, not found in nature, of known elements) be called radio-nitrogen, radio-phosphorus, radio-aluminium (in the case of magnesium irradiated by alpha rays) and designated by the symbols:  $R^{13}N$ ,  $R^{30}P$ ,  $R^{28}Al$ .

Immediately after these first researches, we suggested that the same phenomenon might occur for the kinds of transmutations brought about by collisions with other particles than alpha rays, for example with protons, deuterons, and neutrons.

These experiments were taken up and further developed in several countries. In England and the United States, where physicists have at their disposal equipment of very high voltages, several new elements were prepared using protons and deuterons as projectiles. In Italy first, and then in other countries, research workers, in particular Fermi and his co-workers used neutrons, projectiles which are outstandingly suitable, to cause transmutations. A large number of new elements were created in this way, among which were radio-phosphorus  $R^{30}P$ , and radio-hafnium, with periods of 17.5 days and several months respectively. At the present time we know how to synthesize, often by several methods (radio-aluminium  $R^{28}Al$  can be made by five different kinds of transmutation) more than fifty new radio-elements, a number already greater than that of the natural radio-elements found in

the earth's crust. It was indeed a great source of satisfaction for our lamented teacher Marie Curie to have witnessed this lengthening of the list of radio-elements which she had had the glory, in company with Pierre Curie, of beginning.

The diversity of the chemical properties, diversity of the average lives of these synthetic radio-elements will without doubt enable further advances in research in biology and in physical chemistry to be made. In order to undertake this work properly, fairly large quantities will be required. This will be achieved by the use of artificially accelerated projectiles. Equipment suitable for this is already in existence in several countries. In France, we have built two installations with which we have recently been able to obtain radio-elements in quantities a hundred times greater than those which we obtained in our first experiments. This ratio will shortly be greatly exceeded.

The method of radioactive tracers until now confined to elements of large atomic weights can be extended to a large number of elements distributed over the full extent of the periodic classification. In biology, for example, the tracer method, making use of synthetic radio-elements, will simplify the problems of the location and elimination of the various elements introduced into living organisms. In this case, radioactivity serves only to determine the presence of an element in a particular region of the organism. There is no point, in research of this kind, in introducing large quantities of the radioactive tracer. The quantities are determined by the sensitivity of the radiation detecting apparatus and the size of the vegetable or animal organism. In places, which will be more readily known by the use of this method, the radiation emitted will produce its effect on the adjacent cells. For this second mode of employment, large quantities of radio-elements will be required. This will probably become a practical application in medicine.

From this overall mass of facts now evident we can realize that the few hundreds of atoms of different species which form our planet must not be considered as having been created all at one time and to last for ever. We are aware of them because they have survived. Others less stable have disappeared. It is probably some of these vanished atoms which have been recreated in our laboratories. Up to now, it has only been possible to obtain elements with a relatively brief life, extending from a fraction of a second to several months. In order to create an appreciable quantity of a much longer-lived element, an enormously intense source of projectiles would be required. Is there no hope at all of realizing this new dream?

If, turning towards the past, we cast a glance at the progress achieved by

science at an ever-increasing pace, we are entitled to think that scientists, building up or shattering elements at will, will be able to bring about transmutations of an explosive type, true chemical chain reactions.

If such transmutations do succeed in spreading in matter, the enormous liberation of usable energy can be imagined. But, unfortunately, if the contagion spreads to all the elements of our planet, the consequences of unloosing such a cataclysm can only be viewed with apprehension. Astronomers sometimes observe that a star of medium magnitude increases suddenly in size; a star invisible to the naked eye may become very brilliant and visible without any telescope- the appearance of a Nova. This sudden flaring up of the star is perhaps due to transmutations of an explosive character like those which our wandering imagination is perceiving now-a process that the investigators will no doubt attempt to realize while taking, we hope, the necessary precautions.