Origin of the Gamma Rays *

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IT has long been known that some of the radio-elements emit a penetrating type of X-rays known as the gamma rays. It is clear that these radiations arising from the nucleus of the radioactive atom represent in a sense some of the characteristic modes of vibration of the nuclear structure. The wave-length and quantum energy of many of the stronger lines in the complicated gamma ray spectrum have been determined by different methods, with concordant results. It has been difficult to determine with certainty the origin of this radiation. It was at first supposed that it must arise from the motions of electrons in the nucleus, but in recent years there has been a growing belief that the radiation is connected with the transition of an α-particle or proton which forms part of the nuclear structure.

It is not an easy matter to distinguish between the various hypotheses, since very little is known about the detailed structure of the nucleus. Fortunately, during the last two years, two different methods of attack on this problem have been developed. The first depends on an analysis of the groups of long-range α-particles which are emitted in small numbers from radium-*C* and thorium-*C*, and the other the analysis of the fine structure shown in the emission of α-rays from certain bodies. It may be supposed that the emission of a β-particle during a transformation causes a violent disturbance in the resulting nucleus, some of the constituent α-particles being raised to a much higher level of energy than the normal. These α-particles are unstable and after a very short interval fall back to the normal level, emitting their surplus energy in the form of a gamma ray of definite frequency. According to the ideas of wave mechanics, in this short interval there is a small chance that some of the α-particles in the higher levels can escape from the nucleus.

On these views, the escaping α-particles represent the long range α-particles observed, and the energy of the α-particles gives the value of the energy level in the nucleus which it occupied before its escape. Following out these ideas, the long range α-particles which escape from radium-*C* have been carefully analysed, using the new electrical methods of counting α-particles.

Nine distinct groups of particles were observed, and the energies of α-particles forming each group were determined. The differences of energy between the various groups were found to be closely connected with the energy of some of the most prominent γ-rays in the spectrum, and, in general, the experiments gave strong evidence that the γ-rays had their origin in the transition of one or more α-particles in an excited nucleus.

It has generally been supposed that in a radioactive transformation all the α-particles are expelled with identical speed. This is certainly the case for most bodies, but Rosenblum found that the element thorium-*C* emitted not one but five distinct groups of α-particles. This discovery was made possible by making use of the great Paris electromagnet in order to bend the α-particles into a semicircle. Gamow pointed out that the appearance of such a 'fine structure' in the α-ray emission should be accompanied by the liberation of γ-rays.

Owing to certain experimental difficulties, it is not easy to obtain a clear-cut decision on this point. Ellis concludes from his experiments that Gamow's view is correct, but Meitner, from similar experiments, reached an opposite conclusion. In view of this difference of opinion, I have made in conjunction with Mr. Bowden some experiments to throw light on this problem in another way. Recently Lewis and Wynn Williams found that the actinium emanation emitted two distinct groups of α-particles differing in energy by about 340,000 volts. It was seen that this observation offered a simple method of testing the theory of Gamow. The emanation was carried by a current of air into a separate chamber and the emission of β- and γ-rays tested directly. It was found that the transformation of the emanation was accompanied by a weak β-radiation and a strong γ-radiation. The experimental results were in good accord with the theory, and thus showed that the presence of a 'fine structure' in the α-ray emission is accompanied by the emission of γ-rays. At the same time, the results afford strong corroborative evidence that the γ-rays have their origin in the transitions of an α-particle in an excited nucleus.

It is of interest to consider how far these views can be carried into the region of the artificial disintegration of the elements resulting from the bombardment of certain light elements by α-particles. In some of these disintegrations it is necessary to assume that the α-particle can be captured in different energy levels, and that a γ-radiation is emitted as a result of the transition between the two levels. Penetrating radiations have, in fact, been observed in several cases when light elements are bombarded by α-particles. Some of these cases are of peculiar interest.

RADIATION FROM BERYLLIUM AND THE NEUTRON

In examining the artificial disintegration of light elements under the action of α-rays, Bothe and Becker in 1930 noted that beryllium under α-ray bombardment did not emit protons like boron or nitrogen, but gave out a weak radiation which was more penetrating in character than the γ-rays from radium. The absorption of this radiation in its passage through matter was later examined in detail by Mme. Curie-Joliot and M. Joliot, and by Webster.

It is usual in experiments of this kind to employ active preparations of polonium on a metal disc as a source of α-rays. This source is very convenient

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* Substance of the Friday evening discourse before the Royal Institution on March 18.

for the purpose, as the results are not obscured by the presence of β- and γ-rays which are so freely emitted from other α-ray sources such as radium-C and thorium-C.

In examining the absorption of this beryllium radiation by the ionisation method, Mme. Curie-Joliot and M. Joliot made the striking discovery that hydrogen material, when exposed to this radiation, emitted swift protons. In explanation, they suggested that the protons gained their energy by a radiation recoil in a process similar to the well-known Compton effect, and estimated that the quantum energy of the radiation must be of the order of 50 million electron volts.

J. Chadwick, using direct counting methods of great sensitiveness, found swift recoil atoms were liberated not only in the passage of the radiation through hydrogen, but also in other light elements, including helium, lithium, beryllium, carbon, air, and argon. In a letter in Nature of Feb. 27, he pointed out that the results in this and other directions were difficult to reconcile with the hypothesis of a quantum of radiant energy of such high frequency. He suggested that the effects observed were not due to a γ-radiation at all, but to the liberation from the bombarded beryllium of a stream of swift uncharged particles or ‘ neutrons ’.

The idea of the possible existence of neutrons, that is, of a very close combination of a proton and electron to form an uncharged nuclear unit of mass nearly 1, is not new to science, but it has been very difficult to find any definite evidence of its existence. I discussed the properties of such a neutron in the Bakerian Lecture before the Royal Society in 1920, and both the late Dr. Glasson and Dr. Roberts made experiments in the Cavendish Laboratory to test whether neutrons were produced in strong electric discharge through hydrogen, but without success.

It is to be anticipated that a projected neutron would produce little, if any, ionisation in its passage through matter, and would pass freely through the outer structure of atoms. A swift neutron should, however, indicate its presence by the recoil of an atomic nucleus with which it collided. This recoiling nucleus would spend its energy of motion in ionising the gas, and should thus be readily detected by its electrical effect or by the trail of water drops it produces in a Wilson expansion chamber. In some respects, however, the effects produced by a neutron would be very similar to those due to a quantum of high-frequency radiation, and careful experiment is required to distinguish between them.

The velocity of the neutron at the moment of its liberation is estimated to be about 3×10^9 cm./sec., or about one-tenth of the velocity of light. By comparison of the velocity of recoil of different atoms, Chadwick finds that the mass of the neutron is about the same as that of the hydrogen atom. In addition, the velocity of recoil of a given atom falls off when the radiation is passed through increasing thicknesses of an absorbing material like lead. This is exactly the behaviour to be expected for the neutron, but not for a high-frequency radiation.

Very valuable information on this problem can be obtained by photographing the effects due to the passage of this new type of radiation through a Wilson expansion chamber. A number of such experiments have been made by N. Feather and P. I. Dee in the Cavendish Laboratory in association with Dr. Chadwick. For example, it is to be anticipated that the neutron would occasionally collide with the electrons in its path, and thus give rise to an electron track of maximum length corresponding to twice the velocity of the neutron. This is exactly analogous to the well-known production of δ-particles by the passage of α-particles through gases.

Several such short electron tracks have been photographed by Dee which have about the right length, and for which it is difficult to suggest any other explanation. Feather has obtained photographs of more than a hundred recoil tracks produced in an expansion chamber filled with nitrogen. He has observed another very interesting effect. In addition to the straight recoil tracks, he has obtained photographs of a number of branching tracks which indicate that the nitrogen has disintegrated in a novel way. These branch tracks are believed to be produced by the recoiling nucleus and by some particle which is ejected from the struck nucleus. The identity of this latter particle has not yet been definitely established.

It will take time to analyse the results obtained, and to examine the effects produced in other gases. The peculiar properties of the neutron allow it to approach closely, or even to enter, nuclei of high atomic number, and it will be of great interest to study the effects of such collisions. It is, however, evident that this new radiation has surprising properties, and there is every promise that it may prove an effective agent in extending our knowledge of the artificial disintegration of elements. It will, for example, be of much interest to decide whether the neutron is captured in such disintegrating collisions, or whether it merely passes through the nucleus on which it has such a catastrophic effect.

Mme. Curie-Joliot and M. Joliot and Dee have independently noted that some swift electron tracks are observed in the expansion chamber. The exact origin and nature of these particles will require careful examination. It is possible that a γ-radiation is emitted from beryllium as well as the neutron. Mme. Curie-Joliot and M. Joliot found that the radiation from boron bombarded by α-particles behaved similarly to that from beryllium. It is possible that other elements will also give rise to radiations of this kind.

Whatever may be the final explanation of the interesting facts observed, it is clear that if they are due to a quantum of radiation, we must relinquish the laws of the conservation of energy and of momentum in the production of this radiation and its inter-action with matter. If we wish to retain these laws, the neutron hypothesis seems the only alternative. In any event, it is evident that these new discoveries have opened up a new region of research which is of great interest and promise.