lines approximately double the frequency of ordinary K-lines.*

Department of Physics,
University of Allahabad, Feb. 5.

*The following cablegram dated Feb. 29 has been received from Prof. Saha:

Double transition K-line approximately double frequency K-alpha three obtained copper.—SAHA.

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55. ON THE β-RAY ACTIVITY OF RADIOACTIVE BODIES

(Preliminary Communication)

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INTRODUCTION

The β-ray activity of radioactive bodies has up till now proved to be a baffling problem. The points at issue are summarised in Gamow's *Constitution of Atomic Nuclei*, pp. 52-54, and in *Radiations from Radioactive Bodies* by Rutherford, Chadwick and Ellis. They are also discussed at some length by Bohr in his *Faraday Lecture* (Feb. 1932). We shall later quote freely from Bohr, but some fundamental difficulties may be pointed out at the outset.

The older view of the constitution of the nucleus was that it should be regarded as composed of A protons (A=mass number) and $A-\mathcal{Z}$ electrons ($\mathcal{Z}$=nuclear charge). A large number of these protons and electrons may exist in the compound form of α particles ($4p+2e$) or some other composite structures. But even allowing for these, the existence of a number of free electrons had to be postulated inside the nucleus. On the other hand, the evidence of hyperfine structure, as was first pointed out by de Kronig, definitely proves that the electron cannot exist in the free state in the nucleus, for then the magnetic moment of the nucleus should have the magnitude of the Bohr magneton, while the hyperfine structure of spectral lines definitely shows that the moment has the magnitude of the protonmagnet ($\frac{1}{1836}$ times the Bohr-magneton). At the present time, it is almost universally held that the nucleus consists of $\mathcal{Z}$ protons, and $A-\mathcal{Z}$ neutrons, but it is quite possible that a number of these are combined in the form of α-particles, deutons, etc. *The nucleus contains no electrons free or bound.*[1,2]

But this conclusion is seemingly at variance with the observed fact that in a β-ray disintegrations the nuclei are observed to eject high speed electrons spontaneously. The situation is therefore paradoxical. Bohr puts it as follows:—

"Strictly speaking, we are not even justified in saying that a nucleus contains a definite number of electrons, but only that the negative electrification is equal to a whole number of units and in this sense, the expulsion of a β-ray from a nucleus may be regarded as the creation of an electron as a mechanical entity".

In a later passage, Bohr describes the other difficulties as follows:—

"As regards this last question, much theoretical interest has recently been aroused by the peculiar features exhibited by the β-ray expulsions. On the one hand, the parent elements have a definite rate of decay, expressed by a simple probability law, just as in the case of the α-ray disintegrations. On the other hand, the energy liberated in a single β-ray disintegration is found to vary within a wide continuous range, whereas the energy emitted in an α-ray disintegration, when due account is taken of the accompanying electromagnetic radiation and the mechanical energy conversion, appears to be the same for all atoms of the same element".

To the above remarks of Bohr, the following may be added:—

(*a*) The β-ray disintegration has been observed not only in the case of heavy elements, but also in the light elements potassium and rubidium (or rather the isotopes K^{41} and Rb^{87}). In the case of β-ray bodies associated with the main groups (U, Th, Ac), the life of β-ray bodies is found to vary from 16 years (RaD) to a few minutes, but the light elements K^{41} and Rb^{87} possess lives comparable

with those of some long-lived heavy radioactive bodies. The life of K^{41} has been estimated to be $7{\cdot}5 \times 10^{10}$ years, that of Rb^{87} to be 10^{11} years.[3] It is quite possible that there may be a number of β-ray elements possessing longer lives which are still undiscovered, as the activity of such bodies is likely to be extremely feeble, and difficult of detection. In support of our view, we may cite the case of Ac, RaD . . . which were long regarded as undergoing *rayless* changes. They are not actually rayless, but the β-rays are exceedingly feeble, on account of the long life of these bodies.

From these remarks it will be clear that there is no essential difference between the orders of ranges of the lives of β-ray and α-ray bodies.

(*b*) Ellis[4] has shown in numerous papers that one β-particle is emitted per one disintegrating atom, so that the possibility that the expulsions are due to some external agency seems to be ruled out. They are spontaneous processes like α-ray disintegration.

(*c*) The distribution of energy in the β-ray spectrum—This point has formed the subject of investigation by a large number of workers. The curves bear some resemblance to Planck's curve for blackbody radiation but unlike that curve, it has got a limit on the high energy side and the maximum is ill-defined. They also present some similarity to the curves obtained by Kuhlenkampf on the distribution of intensity in the continuous X-ray spectrum.

There has been an idea that the β-rays are probably emitted with quite a definite energy from the nucleus, but in its passage through the outer shell of electron, it suffers diminution in energy owing to collision or scattering but this view has been disproved by Ellis[5]. Lately, attempts have been made to determine the maximum energy as accurately as possible and to deduce from it a relation similar to that of Geiger and Nutall for α-ray bodies.

The latest exponent of this idea is Sargent[6] who found in a recent paper that every β-ray disintegrating atom is distinguished by having a definite end-point in its energy-spectrum. But a reference to his figures shown in Table VI, p. 670, and his curves on p. 671, Fig. 2, shows that there is not much evidence of a relation. For the points lie on three distinct curves, and the radioactive bodies belonging to the same family do not lie on the same curve. Secondly, if the Geiger-Nutall law for α-ray bodies is expressed in the form $\lambda = aE^n$ where E = energy of the α-particle varying between 4 to 8 million electron-volts, λ varies from 10^5 sec^{-1} (Th C′) to 10^{-18} $sec.^{-1}$ (U), n is found to vary from 65 to 100. But for the β-ray bodies, E varies from $3{\cdot}5 \times 10^4$ evs to $3{\cdot}15 \times 10^6$ evs, *i.e*, a range of about 1 to 100, but λ varies from 10^{-2} $sec.^{-1}$ to 10^{-9} $sec.^{-1}$ and if λ be put $= bE^n$, n varies from 3 to 7. The attempt to trace a causal connection between the decay constant and the maximum β-ray energy does not appear to have been successful. We shall see later that no such causal connection is expected.

The fact that the β-ray bodies follow the same law of decay as α-ray bodies can, however, point to only one conclusion, i.e., *the phenomenon is due to the leakage of α-rays through a potential barrier, but somehow the α-ray does not leave the nucleus, but a γ-ray is generated in its place.*

Bohr weighs the probability that the continuous β-ray energy spectrum may be due to differences in the energy contents of the individual parent atoms leading to small and undetectable differences in their mass, but finally decides against this view. The following are his words.

"Unless the expulsion of β-rays from atomic nuclei, contrary to expectation, is not a spontaneous process but caused by some external agency, the application of the principle of energy conservation to β-ray disintegration would accordingly imply that the atoms of any given radio element would have different energy contents. Although the corresponding variations in mass would be far too small to be detected by the present experimental methods, such definite energy differences between the individual atoms would be very difficult to reconcile with other atomic properties. In the first place, we find no analogy to such variations in the domain of non-radioactive elements. In fact, as far as the investigations of nuclear statistics go, the nuclei of any type, which have the same charge and within the limits of experimental accuracy, the same mass, are found to obey definite statistics in the quantum mechanical sense, meaning that such nuclei are not to be regarded as approximately equal, but as essentially identical. This conclusion is the more important for our argument, because in absence of any theory of the intra-nuclear electrons, the identity under consideration is in no way a consequence of quantum mechanics, like the identity of the extra-nuclear electronic configurations of all atoms of an element in a given stationary state, but represents a new fundamental feature of atomic stability. Secondly, no evidence of an energy variation of the kind in question can be found in the study of the stationary states of the radioactive nuclei involved in the emission of σ and γ rays from members of a radioactive family proceeding or following a β-ray product. *Finally, the definite rate of decay which is a common feature of α- and β-ray disintegrations points even for a β-ray product, to an essential similarity of all the parent atoms,* in spite of the variation of the energy liberated by the expulsion of the β-ray. In absence of a general consistent theory embracing the relationship between the intrinsic stability of electrons and protons and the existence of the elementary quanta of electricity and action, it is very difficult to arrive at a definite conclusion in this matter."

We have quoted this passage in full, because after this paper was written, we came across a paper by Beck[7] where this idea of hypothetical differences in the energy contents of the individual parent atoms resulting in small and undetectable differences in their mass has been revived

to account for the continuous energy distribution amongst the ejected β-rays.

Finally, in order to explain events, Bohr wants to sacrifice the law of conservation of energy and suggests the following process:

"At the present stage of atomic theory, however, we may say that we have no argument, either empirical or theoretical, for upholding the energy principle in the case of β-ray disintegrations, and are even led to complications and difficulties in trying to do so. Of course, a radical departure from this principle would imply strange consequences, in case such a process could be reversed. Indeed if, in a collision process, an electron could attach itself to a nucleus with loss of its mechanical individuality, and subsequently be recreated as a β-ray, we should find that the energy of this β-ray would generally differ from that of the original electron. Still just as the account of those aspects of atomic constitution essential for the explanation of the ordinary physical and chemical properties of matter implies a renunciation of the classical ideal of causality, the features of atomic stability, still deeper-lying responsible for the existence and the properties of atomic nuclei, may force us to renounce the very idea of energy balance."

The above short summary will probably convey some idea regarding the complexity of the problem.

2. Electrofission of Light Quanta

It appears that the β-ray disintegration admits of a rather simple interpretation on the basis of the recent experiments by Anderson and Neddermeyer[8], Meitner and Hupfeld[9], Curie and Joliot[10] on the production of pairs of positrons and electrons by impact of hard γ-rays with atomic nuclei. As the description of this fundamental discovery, which promises to throw a flood of light on nuclear physics, is still scattered over the pages of many scientific journals, we try to give a connected account of it here. Skobelzyn[11] was the first to use vertical Wilson Chambers placed within a horizontal magnetic field for photographing the track of cosmic rays. He found that the cosmic rays gave rise to tracks of β-rays possessing extremely high energy. In some cases, the mass-equivalent of the energy was as great as 50-100 times the rest-mass of the electron. On repeating these experiments, Anderson[8] found that in addition to the tracks due to high energy β-rays there were others possessing equal curvature, but bent in the opposite direction. From the nature of ionisation along these tracks, it was clear that they were due to particles of the same type as electrons, but possessing an opposite, *i.e.*, a plus charge. To this particle, which is the exact positive analogue of the electron, the name *positron* was given. Subsequently Meitner and Hupfeld[9] obtained similar paired tracks of electrons and positrons by taking Wilson photographs of Be-radiations impinging on Pb and Anderson and Neddermeyer and Curie and Joliot[10] showed that even the hard γ-rays from ThC'' having the energy 2·6 *mevs* can give rise to such paired tracks (*mevs* stands for million electron volts).

How are the pair positron and electron produced?

Anderson and Neddermeyer, and Blackett and Ochialini[11] further showed that this production of "paired ions" accounts for a number of unexplained facts. Gray and Tarrant[12] had previously shown that hard γ-rays show an anomalous absorption which is not accounted for by the Klein-Nishina formula for scattering. The anomalous absorption was found by them to start at the γ-ray energy 2 to 3 mevs. Later Gentner[13] fixed the limit at 1.2 mevs. We have to remember in this connection that m_0c^2, the rest energy of the electron corresponds to 5×10^5 *evs* and thus the energy of a pair of electron and positron at rest is equivalent to 1 *mevs*. Hence there is a connection between the beginning of anomalous absorption, and the production of "paired ions." Blackett and Ochialini[11] suggested that within the nucleus, the γ-ray is split up, under the intense electric field, into a pair consisting of a positron and an electron. Oppenheimer and Plessett[14] regarded the phenomenon as a photo-electric effect, the γ-ray quantum lifting an electron occupying one of Dirac's negative energy states into a positive energy state, thus simultaneously creating an ordinary electron and a "hole" which according to the ideas of Dirac will correspond to the positron (*vide* § 3). Curie and Joliot[10] have proposed to denote this phenomenon as "*materialisation of quanta.*"

Blackett further showed that the hypothesis of the splitting of the quantum inside the nucleus explains another interesting observation by Gray[12] and others. The former has subjected the nuclei of many atoms to hard γ-rays from ThC'' and found that the nuclei were thereby excited to a fluorescent radiation of approximate wavelengths 12X. units and 24X. units. The first possesses an energy of 1 *mevs* and the second $\frac{1}{2}$ *mevs*. According to Blackett, though the γ-ray may split up inside the nucleus into a pair of positrons and electrons, but the two may again combine either inside the nucleus or just outside. When they combine inside the nucleus only one quantum of energy 1 *mevs* units may be produced. If they combine outside, two quanta each of energy 0·5 *mevs* units will be produced.

We are of opinion that the phenomenon of conversion of a γ-ray into a pair of ions of opposite sign, confirmed by so many investigators in different parts of the world, should be designated by a more expressive term than Curie and Joliot's *Materialisation of Quanta* and the round-about phraseology about holes, etc., borrowed from Dirac's theory should be avoided, and we have ventured to suggest the term '*Electrofission of Light Quantum*. . .which clearly

expresses the idea that under the influence of the nuclear fields, the quantum of energy undergoes a *'fission'* into elementary charges of opposite sign, the balance of energy being distributed as kinetic energy amongst the two products in a way which is still to be determined. The possibility of the reverse process of two charges neutralising each other in a direct collision has been postulated by many astrophysicists in a slightly different form. But when these predictions were made, the positive unit of electricity was known to be always associated with the mass in a proton, and nobody could conceive of a positron, hence they always talked of annihilation of proton and electron, but the hypothesis has always lacked vigour on account of want of experimental proof. The process as now actually found is different from the early hypothesis about annihilation in many other points.

Theoretical Predictions about Positron

It may be added at this stage that grounds for the advent of the positron were to some extent prepared by the predictions of Dirac[15] from his relativistic theory of the electron. In this he was first led to postulate the existence of an elementary particle having the charge-e but possessing the negative energy—mc^2. Such a particle (the anti-electron) would possess very weird properties which have not been observed. We quote from Gamow

"For such particles the force and acceleration are directed in opposite directions. If two electrons, one of 'positive' and the other of 'negative' mass, meet then the first will be repelled and the second attracted to the other one; both electrons will fly away one behind the other with infinitely increasing velocity, giving an amusing picture of electronic races."

Later, Dirac developed a theory of 'holes' to account for 'positive charges'. He postulated that in Nature all the negative energy states are usually fully occupied, but sometimes a hole may appear. A positive energy electron will then jump into the hole, resulting in the neutralisation of charges and release of the energy $> 2m_0c^2$ as radiation in the form of one or two quanta. The process is thus equivalent to the so-called annihilation of charges. The 'hole' can be identified as a "unit positive charge". But it could not be identified with the 'proton' because the mass of the proton is 1836 times heavier than that of the 'hole'. The discovery of the positron exactly corresponds to Dirac's hole, but sweeps away the misleading ideas about particles capable of possessing "negative energy-state". These ideas are not a little responsible for creating confusion in contemporary scientific thought. Instead of an anti-electron with a negative energy we have now a straight-forward positive analogue to the electron with positive charge and positive energy.

The Proton

The question of the nature of the Proton now becomes a problem. According to one view, the proton is not a fundamental particle but is a compound of the neutron and the positron. If this view be correct, the neutron is merely 'mass' possessing an inherent tendency to capture positrons, but behaving in a different way towards electrons which they cannot capture for if this could take place, we could obtain a negative proton. There is also certain amount of experimental evidence in favour of this view. Anderson and Neddermeyer, as well as Curie and Joliot found in their experiments on *Electrofission* of ThC' γ-ray quantum that more electrons are obtained than positrons, Curie and Joliot[10] give the following figures.

Number of positrons per 100 *electrons* (*Magnetic field* 1100 *gauss*).

Al	Cu	Pb	U
5	18	30	40

But working with cosmic rays which can now be definitely taken to be super γ-rays, it has been found by Anderson as well as Kunze[16] that the number of positron tracks is equal to the number of electron tracks. These results, can be explained on the hypothesis that positrons are easily absorbed by the constituents of the nucleus, possibly neutrons, while electrons are repelled by them. Only very high energy positrons can resist capture by nuclei. Further, if the neutron, the electron and the positron are fundamental particles, they should possess the angular momentum $\frac{1}{2}\frac{h}{2\pi}$ (and be guided by Fermi-Statistics). The protons according to this view may have varying angular momentum depending upon the state of the combination between the neutron and the positron, a view which seems to be in agreement with the latest results of Stern and Eastermann.[17] According to Chadwick,[18] however, the proton is probably fundamental, and the neutron is a "dipole" composed of the proton and the electron. As the difference of mass on the two views is of the order of ·00054, the question cannot probably be ever determined by a precision estimation of masses, but only by investigation of the response of the neutron to light quanta. For, Chadwick's neutron being a dipole, would be highly reactive towards electromagnetic radiation, while the mere 'mass-neutron' is not expected to be reactive. Even on this point, we are not on very sure grounds, for according to one of us, the neutron is a magnetic dipole, composed of two free Dirac's magnetic poles separated by a distance of $\frac{e^2}{Mc^2}$ which is $\frac{3}{2}$ times the protonic radius, but these views have no effect on the present course of investigation.

Though not directly connected with the subject-matter of this article, it may be pointed out that the two views regarding the proton will have different consequences in

astrophysics. According to many astrophysicists, hydrogen is found in abundance in many stars, and there is a likelihood that the chief constituent of all stellar matter is hydrogen. This must exist in the interior as protons. The proton, if it is a compound will be further broken up into the neutron and the positron, for the binding energy is small, between 10^4 to 10^5 evs, and even the smallest temperature ascribed to stellar interiors is sufficient for the complete breaking of the proton. The other (Chadwick's) view does not allow this breaking, for the proton being fundamental cannot be further subdivided. So on the first view the stellar core will consist of neutrons, positrons and electrons; while on the second view, it will consist of protons and electrons. This is fraught with far-reaching consequences. For the neutrons have been found to possess the remarkable property of passing through matter till they are stopped by the nucleus, and when they strike the nucleus, they excite radical changes in it, resulting in the emission of protons, γ-rays. α-particles. One of us is at present engaged in working out a model of a star whose interior is mainly composed of neutrons.

Annihilation of Charges

In this connection, we may refer to the hypothesis about annihilation of matter advocated by Jeans and Eddington[19] to account for the source of stellar energy. A certain amount of vagueness is always attached to such hypothesis, for annihilation literally means to be reduced to nothing, but the process described here is very different from unalloyed nihilism on the part of fundamental particles, for when an electron and proton hit each other, a neutron and a γ-ray is produced. There is no violation of the principle of conservation of energy or momentum, so nothing is annihilated except that the charges seemingly disappear. The energy of the γ-ray is available for supplying the stellar energy, but it is not yet known whether the mass of the neutron can be converted into energy. Again, when an electron and positron collide outside a nucleus an application of the principle of conservation of energy and linear momentum shows that two quanta must be produced in their place. If they collide inside the nucleus, there may be one quantum as the nucleus can bear certain amount of the shock and thus ensure the obedience to the law of conservation of momentum. In both these processes, there are more variables than equations, and hence the energy of the quanta cannot be uniquely determined. In none of these processes of collision there is either annihilation of mass, or energy, and not even of charges, for in the quantum formed, the two charges probably retain their individual existence as components of a dipole moving with the velocity of light, and they can again be separated when a "fission" takes place. This picture is very different from what is conveyed by Eddington's picturesque description of the phenomenon as a "joint suicide of the electron and the proton."

3. Explanation of β-Ray Activity

We shall now discuss how the β-ray activity can be explained. It is clear that if a γ-ray or supergamma (cosmic) ray coming from outside can split up inside the nucleus into an electron and a positron, it will be much more easier for a γ-ray, of sufficient energy, which is produced within the nucleus to undergo spontaneously such a process of electrofission. Of the pair produced, the electron will be ejected as a β-ray , but the positron cannot usually escape, for it will be prevented by the potential barrier from escaping when such barriers exist, or attach itself to some neutron which is present inside the nucleus. For we have already seen that the neutron has an affinity for the positron, but none for the electron. The net charge in any case will be increased by unity, as is observed in β-ray disintegration. It attaches itself to a neutron, γ-rays of small energy of the order of ·05 mevs would probably be given off, which are always observed in a β-ray disintegration. It is not difficult to account for the continuous distribution of β-ray energy, for the primary γ-ray while undergoing '*Internal electrofission*' may have its energy divided between the pairs within wide limits and a certain amount of energy will be communicated to the nucleus. But exact mathematical calculations can be carried out only when more data are forthcoming. The problem of annihilation of two charges of opposite sign which is the converse of the present problem has been discussed by Dirac[20], Tamm, and Oppenheimer on the basis of Dirac's holes as positrons.

According to the above view, the β-ray emission is only a secondary process, the primary phenomenon which starts the chain of events which we call a β-ray disintegration is the generation of primary γ-ray within the nucleus. We may now ask ourselves: how is this γ-ray generated ? For this, a discussion of the recent theories of a α-ray disintegration is necessary.

It is now well known that classical mechanics offered no solution to the problems of radioactivity. Gamow, and Gourney and Condon first suggested methods for explaining many features of radioactivity from the standpoint of wave-mechanics. The methods were elaborated in great detail by Gamow who succeeded in achieving a good deal of success in explaining the essential features of α-ray disintegration and γ-ray origins. Very substantial contributions were also made by Laue, Fowler, Fowler and Wilson, Atkinson and Houtermans, Schrödinger and others.[21]

All these works suffer from the defect that we have as yet no sure knowledge of the structure of nucleus, *i.e.*, of the constituent particles, the statistics obeyed by them and the laws of interaction towards each other. Hence, as in the earlier stages of study of many other branches of

science, ad hoc hypotheses based on previous knowledge, have to be invented, and the value of these hypotheses is determined by the amount of success achieved by them. It now seems to be fairly certain as mentioned in the introduction that the nucleus consists of protons and neutrons only, and that there are no free electrons (or negative charge in any form) in the nucleus. Most of the protons are combined in the form of α-particles. From a scrutiny of Aston's mass-defect curves it has been deduced that elements after Pb are mostly built up by the addition of only α-particles to the Pb nucleus. Thus U (238/92) the parent of radioactive elements having $A=4n+2$ consists of a Pb nucleus (206/82) with 8 α-particles about it. Th (232/92) the parent of radioactive elements having $A=4n$ consists of the lead nucleus (208/82) with 6 α-particles about it. The mass-defect curve shows that the binding force of these α-particles is very small, *i.e.*, they can be regarded as free to a certain extent. They are prevented from leaving the nucleus by the existence of a potential barrier about the nucleus, whose height is larger than the energy of the α-particles in the crater. According to classical mechanics it will be impossible for the particles to leave the nucleus, but it was suggested by Gamow, and Gourney and Condon that according to wave-mechanics they can be regarded as waves, and thus possess the property of leaking through the barrier. The rate of leakage through the barrier determines the decay of the elements. Various hypotheses have been postulated regarding the height, size and form of the barrier, but the final results agree in their essential features. There is, however, a large amount of divergence in the methods of mathematisation of the ideas. Laue and others take simplified cases[21], in which the process is regarded as stationary and calculate the rate of leakage through an oblong-shaped potential barrier. Though the mathematics is much simplified, the picture does not evidently correspond to facts as the process cannot be regarded as stationary (independent of time). Gamow,[22] on the other hand, introduces complex eigen-values, and by a suitable formulation of boundary conditions, obtains values of decay constants as well as of the eigen-values for the energy of the α-particles inside the crater. His final results are

$$\log \lambda = \log \frac{h}{4mr_0^2} - \frac{8\pi^2 e^2 (Z-2)}{hV_s M} + \frac{16\pi e m^{\frac{1}{2}} (Z-2)^{\frac{1}{2}}}{hM} r_0^{\frac{1}{2}},$$

$$E = \frac{n^2 h^2}{8mr^2} + U_0 = \tfrac{1}{2} m V_e^2,$$

where e, h and Z have their usual meaning. M is the mass of the α-particle and V_e is the velocity with which it escapes. r_0 is the "radius" of the product nucleus and V_0 mean potential energy of an α-particle inside it.

It is seen from the above formula that they involve two constants, *viz*, r_0 the equivalent radius of the crater, and V_e the velocity of ejection of the α-particle. According to our picture, r_0 should not much vary for elements belonging to the same radioactive family while the radius v_0 is found to vary in a regular way from U to RaC and from Th to Th A. We get abnormally low values for it when we come to those interesting products RaC, ThC and AcC which disintegrate in a dual fashion, emitting both α- and β-rays. The value of r_0 falls from $8{\cdot}3\times10^{-12}$ for RaA to $6{\cdot}3\times10^{-12}$ for RaC; and from $8{\cdot}1\times10^{-12}$ for ThA to $6{\cdot}6\times10^{-12}$ for ThC.

We revert again to the question as to how the primary γ-ray referred to above which, by undergoing internal electrofission gives rise to the observed β-decay, is generated. It is reasonable to postulate that there are more than one potential barrier inside a nucleus, though their exact nature (*i.e.*, their height and width) and forms can only be determined when we have a sufficient knowledge of the structural arrangement of the particles constituting the nucleus. Our assumption is that the primary γ-ray is generated by the leakage of an α-particle through an internal potential barrier, *i.e.*, the α-particle leaks from one crater to another, both within the nucleus. It occupies a lower energy level in the new crater and the balance of energy constitutes the primary γ-ray. This primary γ-ray suffers an electrofission producing a positive and a negative electron. The positive electron attaches itself to one of the neutrons present inside the nucleus, thus raising the nuclear charge by unity. The negative electron is ejected, which constitutes the usual β-ray. The combination of the positron with the neutron will liberate some energy (nearly equal to the difference between the masses of positron+neutron, and the proton) and this may account for the soft γ-rays that usually accompany a β-disintegration. The life of the β-decay is determined by the rate of leakage of the α-particle from one inside crater to another and hence to the first order will be independent of the energy of the β-rays. Thus no simple relation (unlike the case of α-decay) is expected to exist between the maximum energy of β-rays and the life of β-decay, a conclusion which is more or less borne out by Sargent's curves.

On the above view it is to be expected that occasionally a positron may not be captured by the neutron, and it may emerge. The presence of positrons associated with the natural β-decay as suggested by Skobelzyn's experiments lends support to the views herein stated.

The explanation of the continuous energy distribution in the β-ray spectrum offers no special difficulties. In our case the energy of the primary γ ray is shared between the positron and the electron, and so the energy of the electron can vary from zero to a maximum ($h\nu=\epsilon+2m_0c^2$). The exact form of the distribution curve can only be calculated when we make additional assumptions regarding the mechanism of interaction. This will be examined on a future occasion.

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56 (a). A SUGGESTED EXPLANATION OF BETA-RAY ACTIVITY

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THE β-ray activity of radioactive bodies has until now proved to be a very baffling problem. The points at issue are summarised in Gamow's "Constitution of Atomic Nuclei", etc. (pp. 52-54), and in "Radiations from Radioactive Bodies" by Rutherford, Chadwick and Ellis (p. 385). They are also discussed at some length by Bohr in his Faraday lecture (1930).

Briefly speaking, the chief points under discussion are the following: the disintegration electrons (β-rays) from a radioactive body are not emitted with a single velocity as in the case of α-rays, but show a distribution of velocities over wide ranges, though the breaking-up of the atom is a unitary process, as is proved by the fact that the life-period is definite and there is one electron for each disintegrating atom. It has further been proved that the continuous distribution of velocities is a nuclear process, and not due to action of the surrounding shell of electrons.

It appears that the β-ray disintegration admits of a very simple explanation on the basis of the recent experiments by Anderson and Neddermeyer, and Curie and Joliot on the production of positrons by the impact of hard γ-rays with the nuclei of elements. These experiments have been interpreted by Blackett and Occhialini as indicating the conversion of a γ-ray quantum into an electron and a positron near the nucleus. Curie and Joliot have brought further evidence in favour of this view by showing that γ-rays of thorium C'' (energy $2{\cdot}6\times10^6$ electron volts) are converted inside all matter into an electron (mass 9×10^{-28} gm., energy $m_0c^2=0{\cdot}51\times10^6\ eV$) and a positron (having the same mass and energy as the electron), the excess energy being distributed as the kinetic energy of the two particles, and the energy of the residual quantum. They have denoted this phenomenon by the term 'materialisation of light quanta'. They have further shown that a proton is a complex structure, being a compound of the neutron and a positron. As pointed out by Blackett and Occhialini, this explains the anomalous absorption of γ-ray quanta observed by Gray and Tarrant, which Gentner has found to commence with the γ-ray possessing the limiting energy 1·1 million electron volts.

The discovery, which is confirmed by so many workers, promises to be of great importance, as it establishes for the first time, on experimental grounds, the splitting up of a quantum into two charged particles of opposite sign. Many astrophysicists have postulated the probability of the annihilation of the proton and the electron with their mass energies converted into quanta, but the actual process, as revealed by these experiments, seems to be very different. For the quantum breaks up into charged particles possessing opposite charges, but having equal mass, and the positron being absorbed by the neutron forms the proton which is thus seen to be complex. The phenomenon is therefore not a "materialisation of the quantum" as Curie and Joliot suggest, for the neutron appears to be the fundamental mass-particle, but it consists in a splitting of the quantum into two fundamental opposite charges. We may call it 'electro-division of the quantum'.

Let us see how we can explain β-ray activity. If the 'electro-division of a quantum' can be brought about by a nucleus when the quantum hits it from the outside, it is