Letters to the Editor

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Mass of the Neutron

THE mass of the neutron has been calculated by Chadwick on the assumption that the neutrons of boron are emitted by the isotope $^{11}_{5}B$, according to the nuclear reaction

$$^{11}_{5}B + ^{4}_{2}He = ^{14}_{7}N + ^{1}_{0}n.$$

Using the exact masses of $^{11}_{5}B$, $^{4}_{2}He$ and $^{14}_{7}N$ and the maximum energy of the neutron excited by the α-rays of polonium, one may calculate for the neutron a mass 1·0068 (taking $^{16}O = 16$).[1]

We have suggested[2] that the emission of the neutron of boron is due to the isotope $^{10}_{5}B$ and not to $^{11}_{5}B$. The nucleus $^{10}_{5}B$ can suffer two kinds of transmutation under the action of the α-particles of polonium, one with the emission of a proton, one with the emission of a neutron and a positive electron, according to the equations :

$$^{10}_{5}B + ^{4}_{2}He = ^{13}_{6}C^{*} + ^{1}_{1}H$$

$$^{10}_{5}B + ^{4}_{2}He = ^{13}_{6}C + ^{1}_{0}n + \overset{+}{\varepsilon}.$$

Our latest experiments on the creation of new radio-elements have confirmed our interpretation of the transmutation of boron. Similar reactions are observed with the nucleus $^{27}_{13}Al$ and with $^{24}_{12}Mg$. The reactions can be divided in two steps :

$$^{10}_{5}B + ^{4}_{2}He = ^{13}_{7}N + ^{1}_{0}n \qquad ^{13}_{7}N = ^{13}_{6}C + \overset{+}{\varepsilon}$$

$$^{27}_{12}Mg + ^{4}_{2}He = ^{27}_{14}Si + ^{1}_{0}n \qquad ^{27}_{14}Si = ^{27}_{13}Al + \overset{+}{\varepsilon}$$

$$^{27}_{13}Al + ^{4}_{2}He = ^{30}_{15}P + ^{1}_{0}n \qquad ^{30}_{15}P = ^{30}_{14}Si + \overset{+}{\varepsilon}$$

$^{13}_{7}N$, $^{27}_{14}Si$, $^{30}_{15}P$ being unstable nuclei that disintegrate with the emission of positrons.

The complete reactions, with the masses and energy of all the particles are, for the two modes of transmutation of boron :

$$^{10}_{5}B + ^{4}_{2}He + W_{a} = ^{13}_{6}C + ^{1}_{1}H + W_{H} + W_{R},$$

$$^{10}_{5}B + ^{4}_{2}He + W_{a} = ^{13}_{6}C + ^{1}_{0}n + \overset{+}{\varepsilon} + W_{n} + W_{\varepsilon} + W'_{R},$$

where W_{a}, W_{H}, W_{n}, W_{ε}, W_{R}, W'_{R} are the energies of the α-particle and the corresponding energies of the ejected particles and of the recoil atoms in the reactions. Subtracting the first of these equations from the second gives :

$$^{1}_{0}n = \text{mass of proton} - \text{mass of positron} + Q,$$

where $Q = W_{H} + W_{R} - W_{n} - W'_{R} - W_{\varepsilon}$.

One gets exactly the same equation using the transmutations of aluminium and magnesium.

Thus these equations enable us to calculate the mass of neutron without using the exact masses of any nucleus, except the proton.

According to our most recent measurements, the positrons emitted by the new radio-elements form a continuous spectrum of maximum energy $1 \cdot 5 \times 10^{6}$ e.v. for $^{13}_{7}N$, 3×10^{6} e.v. for $^{30}_{15}P$ and approximately $1 \cdot 5 \times 10^{6}$ e.v. for $^{27}_{14}Si$. The emission of positrons is probably accompanied by the emission of neutrinos, but if the positrons have their maximum energy, the neutrinos will have a very small energy; the most recent hypotheses on the nature of this particle admits of a mass which is zero, or very small. So we need not take this particle into account in the calculations. The energy of the recoil atom in the disintegration with emission of a positron is negligible.

For the irradiation with the α-rays of polonium we have the following numerical values for the energies (expressed in 10^{6} e.v.).

	W_H	W_R	W_n	W'_R	W_ε	Q (10^6 e.v.)	Q in units of mass
B	8·05	0·23	3·3	0·59	1·5	+ 2·89	0·0031
Al	7·56	0·11	2	0·33	3·0	+ 2·34	0·0025
Mg	4·82*	0·21	1	0·48	1·5	+ 2·05	0·0022

One gets for the mass of neutron three values : 1·0098, 1·0092, 1·0089. These values agree approximately. Yet the first, deduced from boron, is the most precise. The energies of the neutrons of aluminium and magnesium and the energy of the positrons of magnesium are not well known.

From considerations on the stability of the nucleus $^{9}_{4}Be$, the mass of the neutron should have a minimum value 1·0107. But an error of 0·001 in the determination of the mass of Be seems quite possible.

We may adopt for the mass of the neutron a value 1·010, in which the error probably does not exceed 0·0005.

With the mass 1·010 for the neutron, the maximum energy of the neutron ejected from beryllium by α-particles from polonium should be about 9×10^{6} e.v. The emission of slow neutrons when lithium is bombarded with α-particles from polonium, according to the reaction $^{7}_{3}Li + ^{4}_{2}He = ^{10}_{5}B + ^{1}_{0}n$, cannot be explained unless the mass adopted for $^{10}_{5}B$ is too great, namely, by about 0·003.

If atomic nuclei contain only protons and neutrons, then the β-emission might be the consequence of the transformation of a neutron into a proton inside the nucleus, with the ejection of the negative electron and a neutrino, as has been suggested by several authors. The inverse processes would also be possible : transformation of a proton into a neutron with the ejection of a positron and a neutrino.

With the mass 1·010 for the neutron, the energy liberated in the transformation neutron → proton + $\overset{-}{\varepsilon}$ is $2 \cdot 1 \times 10^{6}$ e.v.; the energy absorbed in the transformation proton → neutron + $\overset{+}{\varepsilon}$ is $3 \cdot 1 \times 10^{6}$ e.v.

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* The maximum energy possible for the positrons does not correspond to a group effectively observed, but has been deduced by F. Perrin from the experiments of Bothe and Klarman, by the consideration of the energy balance relative to the groups of protons.

[1] Chadwick, *Proc. Roy. Soc.*, **136**, 692; 1932.
[2] I. Curie and F. Joliot, *C.R.*, **197**, 237; 1933.

Induced Radioactivity of Sodium and Phosphorus

IN view of the discovery of 'induced radioactivity' by F. Joliot[1], I have investigated several other elements with an apparatus specially designed for the study of activities with a very short lifetime. The substance to be investigated was attached to the end of a swinging arm, which made it possible to shift the substance within half a second from the α-ray source, consisting of about 1 millicurie of thorium B + C, to a Geiger-Müller counter with a window of 0·05 mm. copper foil.