

“Possibilité d’émission de particules neutres de masse intrinsèque nulle dans les radioactivités β ,” C. R. Acad. Sci. (Paris) **197** (1933), 1625-1627.

Possibility of the emission of neutral particles of zero intrinsic mass during β -radioactivity

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The electrons that are emitted by atomic nuclei during β -radioactivity have energies that are distributed in continuous spectra that extend up to an upper limit E_0 in each case. As is shown notably by a comparison of the liberation of energy under the two sequences of transformations that relate Thorium C to Thorium D (either by way of Th C' or by Th C''), that upper limit can correspond to the difference between the internal energies, and as a result, the masses of the atoms of the initial radioactive substance and those of the substances that were formed ⁽¹⁾. When a nucleus transforms by emitting an electron that has an arbitrary energy on the continuous spectrum, it will then have (at least, in appearance) lost or experienced the disappearance of energy ($E_0 - E$), which is the difference between the energy of the transformation and the energy that is converted into kinetic form. No release of energy in any other form can actually be detected – for example, in the typical case of Radium E, for which the heating of a calorimeter in which one has placed it will correspond to the mean energy \bar{E} of the emitted electrons, and not to their maximum energy E_0 .

Meanwhile, one can think, as Pauli had proposed, that there is conservation of energy under these transmutations upon assuming that the apparent energy that is lost under the emission of an electron is associated with the simultaneous emission of a neutral corpuscle of very small mass with a penetrating power that can consequently be very large, and that would make it extremely difficult to observe. Pauli supposed that the mass of the hypothetical particle, which is referred to by the name of *neutrino*, is equal to that of the electron. Meanwhile, the energy of the Coulombian electric field certainly constitutes an important part of the mass of the electron, and there is no reason why a neutral particle to have a mass that is close to that of the electron, even by analogy with it, moreover.

One can try to deduce some indication about the value of that unknown mass m of the neutrino from the form of the continuous β -emission spectra. Indeed, if it is equal to the mass m of the electron then one would expect that the maximum intensity of a spectrum that is produced by such a subdivision would be equal to the available energy between the electron and the neutrino. Now, the maximum will always correspond to an energy that is less than one-half of the limiting energy. N. F. Mott has suggested that one can

⁽¹⁾ C. D. ELLIS and N. F. MOTT, Proc. Roy. Soc. **141** (1933), pp. 502.

understand this to mean that several neutrinos of mass m are emitted at the same time as the electron. However, it seems simpler to explain that fact by assuming that the neutrino has a mass that is smaller than the electron, and that the most likely possibility corresponds to the equality of the impulses of the two emitted particles, which is an equality that will always be realized when the electron and neutrino separates without interacting with other bodies, which will happen, on average, in the presence of an atomic nucleus.

The equality of the impulse of the electron and the neutrino is written:

$$\frac{m\beta c}{\sqrt{1-\beta^2}} = \frac{\mu\beta' c}{\sqrt{1-\beta'^2}},$$

in which βc and $\beta' c$ are the velocities of the particles. The corresponding kinetic energies have the values:

$$E_m = mc^2 \left(\frac{1}{\sqrt{1-\beta^2}} - 1 \right), \quad E'_m = \mu c^2 \left(\frac{1}{\sqrt{1-\beta'^2}} - 1 \right),$$

and one must have:

$$E_m + E'_m = E_0.$$

One deduces from these relations that:

$$E_m = \frac{1}{2} E_0 \frac{E_0 + 2\mu c^2}{E_0 + (\mu + m)c^2}.$$

That value E_m must undoubtedly be compared, not with the value of the energy that corresponds to the maximum intensity of the continuous spectrum (which is a value that depends upon the variable that is utilized to represent that spectrum, moreover), but with the mean value \bar{E} of the emitted electron. For the only β -spectrum that is very well known – namely, Radium E – one will have (up to a factor of 10 or 100, undoubtedly) ⁽¹⁾:

$$E_0 = 1.2 \times 10^6 \text{ eV}, \quad \bar{E} = 0.36 \times 10^6 \text{ eV}.$$

One can approximate E_m with the value \bar{E} only if one takes $\mu = 0$ – i.e., *if one supposes that the intrinsic mass of the neutrino is zero* ⁽²⁾. One then finds that $E_m = 0.42 \times 10^6$ eV for Radium E, and one will have:

$$E_m = \frac{1}{2} E_0 \frac{E_0}{E_0 + mc^2},$$

in a generally fashion.

⁽¹⁾ SARGENT, Proc. Camb. Phil. Soc. **28** (1932), pp. 550.

⁽²⁾ A hypothesis that was also envisioned by Pauli, but with no supporting argument.

An intrinsic mass of zero for the neutrino demands that it must always have a velocity that is equal to the velocity c of light, and that its impulse will be obtained by dividing its energy by its velocity c , as one does for the photon. The neutrino will then be more analogous to a photon than it is to an electron or a neutron. However, it is at least distinguished by the absence of an associated electromagnetic field, which is a field that would determine its interaction with electrons.

If the neutrino has an intrinsic mass of zero then one must also think that it does not already exist in the atomic nucleus, but that it is created during emission, like the photon. Finally, it seems that one must attribute a spin of $1/2$ to it, in such a way that one can have conservation of spin under β -radioactivity, and more generally, under any possible transformations of neutrons into protons (or conversely) with the emission and absorption of electrons and neutrinos.
