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Short Note

The Mass and the Life Time of the Mesotron.)2ポ

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According to the new field theory of the nuclear forces and the β-decay, the mesotron with the charge $-e$ (or $+e$) can transform into a negative (or positive) electron and an antineutrino (or a neutrino) even in vacuum, the mean life time due to this process being proportional to the energy.[1] In the previous papers,[2] the proper life time of the mesotron τ_0, i. e. the mean life time of it at rest, was calculated by assuming the interaction of it with the light particle, which was equivalent to that in Fermi's theory of β-decay. The result was

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$$\frac{1}{\tau_0} = \frac{g'^2}{\hbar c}\cdot\frac{m_u c^2}{\hbar}\left\{\frac{2}{3}\lambda_1^2 + \frac{1}{3}\mu_1^2\right\}, \qquad (1)$$

which has the numerical value

$$\tau_0 = 1.3 \times 10^{-7}\,\mathrm{sec} \qquad (2)$$

for $m_u = 200\,m$, $g' = 4 \times 10^{-17}$ and $\lambda_1 = \mu_1 = 1$.[3] The life time for the interaction equivalent to that in Konopinski-Uhlenbeck's theory was smaller by a factor $(m/m_u)^2$ than (1).

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1) Bhabha, Nature 141, 117, (1938),
2) Yukawa, Sakata and Taketani, Proc. Phys.-Math. Soc. Japan 20(1938), 319; Yukawa, Sakata, Kobayasi and Taketani, ibid., 993. The latter will be referred to as IV.
3) IV, §6.

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On the other hand, the proper life time was determined by several authors[4] from the experiments on the cosmic ray according to the suggestion of Euler and Heisenberg.[5] Their results all point to a value about

$$\tau_0 = 2\times 10^{-6}\,\mathrm{sec}, \tag{3}$$

which is in qualitative agreement with the theoretical value for the Fermi interaction. The discrepancy of a factor 10 between the numerical values (2) and (3) seems to be due to ~~inacc~~ inaccuracies in the theoretical estimation rather than to experimental errors. Indeed, the life time as given by (1) increases rapidly with the decreasing mass m_u, owing to the fact that the constant g' depends critically on m_u, as will be shown in the following.

In the first place, the constants ~~g_1, g~~ g_1, g_2, which are characteristic of the interaction between the mesotron and the heavy particle, can be chosen in the following way. The interaction between two heavy particles in S state is given by

$$V_{12} = \vec{\tau}^{(1)}\vec{\tau}^{(2)}\left\{\frac{1}{8}+\frac{5}{24}(\vec{\sigma}^{(1)}\vec{\sigma}^{(2)})\right\}\frac{g^2e^{-\varkappa r}}{r} \tag{4}$$

in the first approximation, if we assume

$$g_1^2 = g^2/4, \qquad g_2^2 = 5g^2/8 \tag{5}$$

according to Kemmer.[6] From the small binding energy 2.17×10^6 eV of the deuteron, it follows that

$$a = g^2M/\hbar^2\varkappa = g^2/\hbar c\cdot M/m_u \tag{6}$$

changes slowly with m_u, where M is the mass of the heavy particle.[7] According to the result of numerical solution of the deuteron problem by assuming

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4) Blackett, Phys. Rev. 54(1938), 973; Nature 142(1938), 992; Rossi, ibid. 993; Ehrenfest and Freon, C. R. 207(1938), 853; Johnson and Pomerantz, Phys. Rev. 55(1939), 104.
5) Euler, Naturwiss. 26(1938), 382; Zeits. f. Phys. 110(1938), 450; Euler and Heisenberg, Ergeb. exakt. Naturwiss. 17(1938), 1. See also Ferretti, Nuovo Cimento 15(1938), 421.
6) Kemmer, Proc. Camb. Phil. Soc. 34(1938), 354. See further IV, §2.
7) Bethe and Bacher, Rev. Mod. Phys. 8(1936), 82.

$$G_1^2 = \left(\frac{m^2 c}{\sqrt{2\pi^3} \cdot \hbar^3} \cdot \frac{4\pi g g'}{\kappa^2} \right)^2 \left(\frac{\lambda_1^2}{4} + \sqrt{\frac{5}{8}}\, M_1^{*} \right)$$

$$\left(\frac{5}{8} M_1^2 \right)$$

$$G^2 = \;''$$

$$\frac{1}{4} \qquad \frac{5}{8}$$

$$\frac{m^4 c^2 \cdot 16\pi^2 g^2 g'^2}{2\pi^3 \hbar^6 \kappa^4}$$

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the potential of the form (4),[8] ~~we obtain~~ a depends on m_u as shown in Table 1.

Table 1.

m_u	100 m	125 m	160 m	200 m
a	3.48	3.15	2.78	2.70

~~The numerical values of~~

In order to determine g', we have to consider the theoretical mean life time of the β-radioactive nucleus T, which is given by

$$\frac{1}{T} = \frac{mc^2}{\hbar}\{G_1^2|M_1|^2 + G_2^2|\vec{M}_2|^2\}\int_1^{\varepsilon_0}(\varepsilon_0-\varepsilon)^2\sqrt{\varepsilon^2-1}\cdot\varepsilon\, d\varepsilon \qquad (7)$$

with

$$G_1 = \frac{m^2c}{\sqrt{2\pi^3}\cdot\hbar^3}\cdot\frac{4\pi g_1 g'\lambda_1}{\kappa^2} \qquad G_2 = \frac{m^2c}{\sqrt{2\pi^3}\cdot\hbar^3}\cdot\frac{4\pi g_2 g'\mu_1}{\kappa^2} \qquad (8)$$

$$M_1 = \iiint \tilde{v}_m u_n dv \qquad \vec{M}_2 = \iiint \tilde{v}_m \vec{\sigma} u_n dv \qquad (9)$$

where u_n, v_m are the wave functions of the neutron and the proton respectively and ε_0 is the upper limit of the energy spectrum of the β-ray divided by mc^2.[9] By comparing (7) with the corresponding expression in Fermi's theory, we obtain the relation

$$G_1 = 0 \qquad G_2 = G \qquad (10)$$

for the special case

i) $\lambda_1 = 0 \qquad \mu_1 = 1$

and the relation

$$G_1 = G \qquad G_2 = 0 \qquad (11)$$

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8) Sachs and Goeppert-Mayer, Phys. Rev. 53(1938), 991; Wilson, Proc. Camb. Phil. Soc. 34(1938), 365.
9) IV, §5.

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for the case

ii) $\lambda_1 = 1$ $\mu_2 = 0$

with

$$G = \frac{g_F \cdot m^2 c}{\sqrt{2\pi^3}\cdot \hbar^3} = 1.1 \times 10^{-13}, \tag{12}$$

where g_F stands for Fermi's constant $g = 4 \times 10^{-50}$ cm³ erg.

By inserting (10) or (11) in (8) and by using (5) and (6), we obtain

$$\frac{g'^2}{\hbar c} = \frac{\pi}{5}\frac{G^2}{a}\left(\frac{M}{m}\right)\left(\frac{m_u}{m}\right)^3 \tag{13}$$

for the case i), or

$$\frac{g'^2}{\hbar c} = \frac{\pi}{2}\frac{G^2}{a}\left(\frac{M}{m}\right)\left(\frac{m_u}{m}\right)^3 \tag{14}$$

for the case ii). Hence, (1) takes the form

$$\frac{1}{\tau_0} = \frac{\pi}{15}\frac{G^2}{a}\left(\frac{m_u}{m}\right)^4 \frac{mc^2}{\hbar} \tag{15}$$

for the case i), or

$$\frac{1}{\tau_0} = \frac{\pi}{3}\frac{G^2}{a}\left(\frac{m_u}{m}\right)^4 \frac{mc^2}{\hbar} \tag{16}$$

for the case ii). These expressions show that the proper life time of the mesotron increases rapidly with the decreasing mass m_u, the numerical values for several cases being summarized in Table 2.

Table 2.

	m_u	~~100~~ m	125 m	160 m	200 m	
τ_0	case i)	9.5×10^{-6}	3.5×10^{-6}	1.2×10^{-6}	4.6×10^{-7}	sec
	case ii)	1.9×10^{-6}	0.7×10^{-6}	2.4×10^{-7}	0.9×10^{-7}	sec

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Thus, the agreement between theory and experiment is very satisfactory, if we assume a value of m_u intermediate between 100 m and 200 m, as long as

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the constant μ_1 has, at least, the same order of magnitude as λ_1. In this connection, it is interesting that the K-electron capture of ^{7}Be can be explained satisfactory, only if ~~is not smaller than~~ ~~10~~ the latter condition is fulfilled.[10]

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10) Breit and Knipp, Phys. Rev. 54(1938), 652.