is the mass of the α particle, and U is the depth of the potential well.

Let us evaluate the exponent of Eq. (1) with $\tau_\alpha = 10^{-22}$ sec and for an energy E equal to the height of the Coulomb barrier U_c; we shall treat nuclei in which U is known. For C^{12} nuclei,[5] $U \approx 11$ Mev. For different nuclei the distance l can be chosen about equal to the α-particle diameter. For C^{12} we have $l \approx R = 1.4 \times 10^{-13} A^{1/3}$ cm and $U_c \approx 4$ Mev. With these assumptions the exponent for C^{12} is 1.2. For silver nuclei, we again set $E = U_c$ and assume that $l(\mathrm{Ag}) = l(C^{12})$ and $U(\mathrm{Ag}) \approx U(C^{12})$; the exponent is then -0.8.

These values of the exponents indicate that if $\tau_\alpha = 10^{-22}$ sec, the α-particle spectrum given by (1) should be measurably weakened in the energy region around $E = U_c$.

The situation changes drastically if τ_α is actually somewhat less than 10^{-22} sec. A lifetime smaller by a factor of 2 or 2.5 is sufficient to decrease the exponent for C^{12}, for instance, to 0.05 for $E = U_c$. Then for this energy there should be practically no α-particles knocked out, and they should appear in measurable quantities only for $E \geq E_{\alpha\,\mathrm{eff}} > U_c$.

Now 10^{-22} sec is the time it takes a 20-Mev nucleon in the nucleus to pass entirely through a C^{12} nucleus. It is very probable that internal α-particles can be destroyed in collisions with fast nuclei located in their vicinity when they are formed. There is therefore reason to suppose that τ_α is considerably less than 10^{-22} sec. If this is so, experiment should observe almost the complete absence of α particles knocked out in the energy region $U_c(A) < E < E_{\alpha\,\mathrm{eff}}$. An experimental determination of $E_{\alpha\,\mathrm{eff}}$ could be used to estimate τ_α.

It should be noted that this effect is more probably observable for nuclei with A around 12 or 20 than for nuclei with A around 100, since there may be quite a large number of α particles produced in the latter in a shell with low l.

Deuteron knockout will be observed if τ_d is less than τ_α, for if we consider deuterons with energy $E = U_c$ and set $U \approx 30$ Mev,[6] $l(d) = l(\alpha)$, and $\tau_d = 10^{-22}$ sec, the exponent in Eq. (1) becomes -0.6.

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NONLOCAL EFFECTS IN WEAK INTERACTIONS OF FERMIONS

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RECENTLY Lee and Yang[1] have studied the nonlocal four-Fermion interactions as applied to μ decay. Phenomenologically these interactions can be described using a Lagrangian corresponding to the interaction of pairs of fermions separated by a space-like interval of the order of 10^{-13} to 10^{-14} cm.

The present communication gives a similar treatment of nonlocal effects in μ^- capture by a proton. The neutrino is described by the two-component theory.[2-4]

1. The nonlocal Lagrangian for the interaction which gives rise to the $\mu^- + p \rightarrow n + \nu$ reaction is

$$L = \sum_i g_i \int [\bar{\psi}_n(x)\, O_i \psi_p(x)]\, K_i(x-x') \times [\bar{\psi}_\nu(x')\, O_i \psi_\mu(x')]\, d^4x\, d^4x';\ \psi_\nu = -\gamma_5\psi_\nu. \quad (1)$$

In this expression the summation is taken over all possible S, V, T, P, and A couplings; the O_i are the appropriate Dirac matrices, and $K_i(x-x')$ is an invariant function of $x-x'$ which accounts for the nonlocal extension of the interaction. Assuming that the space-time extension of $K_i(x-x')$ is smaller than the inverse of the energy momentum transfer involved in the process, we can write

$$K_i(x-x') = \delta^4(x-x') + \frac{\varkappa_i}{m^2}\frac{\partial^2}{\partial x_\lambda^2}\delta^4(x-x') + \ldots, \quad (2)$$

$$(i = S, V, T, P, A;\ \hbar = c = 1),$$

where m is the mass of the μ meson, and $|\kappa_i/m^2|^{1/2}$ is the length characterizing the nonlocal effect.* Using Eq. (2) and treating the case of the μ meson and proton at rest, we obtain

$$L = \sum_i g_i \int [1 + \varkappa_i (1 - 2p_\nu / m)] [\bar{\psi}_n O_i \psi_p] [\bar{\psi}_\nu O_i \psi_\mu] d^4x, \quad (3)$$

where p_ν is the neutrino momentum.

From this we immediately obtain an expression for $1/\tau$, the probability of μ^- capture by hydrogen, and an expression for $w(\theta)$, the angular distribution of the neutrons in the capture of polarized μ^- mesons.[6-8] These expressions are

$$1/\tau = p_\nu^2 \xi / 2\pi^2 a^3, \quad w(\theta) = 1 + \alpha \cos\theta, \quad (4)$$

where a is the Bohr radius of the muonium atom, θ is the angle between the spin of the μ^- meson and the neutron momentum, and

$$\begin{aligned} \xi &= |f_S + f_V|^2 + 3|f_A + f_T|^2, \\ \alpha\xi &= -|f_S + f_V|^2 + |f_A + f_T|^2, \quad (5) \\ f_i &= g_i [1 + \varkappa_i (1 - 2p_\nu / m)]. \end{aligned}$$

For the $\mu^- + p \rightarrow n + \tilde{\nu}$ reaction, ξ by ξ', and $\alpha\xi$ are replaced by $-\alpha'\xi'$.

2. Let us assume the existence of a universal AV interaction.[9] As is known, it is then possible to choose the coupling constant G for β decay so as to obtain excellent agreement with experiment for the μ meson lifetime.

It is easily shown, however, that nonlocal effects in β decay are quite negligible. If such effects actually exist, they should be observed in μ decay, by a definite change in the coupling constant.

For the universal AV interaction in μ decay, Feynman and Gell-Mann take the expression

$$8^{1/2} G (\bar{\psi}_\mu \gamma_\lambda a \psi_\nu)(\bar{\psi}_\nu \gamma_\lambda a \psi_e), \quad (6)$$

where $a\psi$ is a two-component wave function, and $G = (1.01 \pm 0.01) 10^{-5}/M^2$ (where M is the mass of the nucleon). The μ-meson lifetime is then given by

$$1/\tau_\mu = G^2 m^5 / 192\pi^3.$$

The nonlocal interaction corresponding to (6), namely

$$8^{1/2} G (\bar{\psi}_\mu \gamma_\lambda a \psi_\nu(x)) K(x - x') (\bar{\psi}_\nu \gamma_\lambda a \psi_e(x')) \quad (7)$$

(this corresponds to Lee and Yang's[1] Lagrangian L_{II}) gives

$$1/\tau_\mu = (G^2 m^5 / 192\pi^3)(1 + {}^3/_5 \bar{\zeta}_2),$$

for the μ-meson lifetime, where ζ_2 is a parameter characterizing the nonlocal effects, introduced by Lee and Yang.[1] Bearing in mind the experimental uncertainty in the determination of G, we obtain an upper limit for $|\bar{\zeta}_2|$ compatible with the universality of G. This is

$$|\bar{\zeta}_2| \leqslant 0.07. \quad (8)$$

Lee and Yang (using the nonlocal Lagrangian L_{II}) have found the value of $\bar{\zeta}_2$ for which the two-component theory will give a Michel parameter ρ in agreement with experiment. This value is $\bar{\zeta}_2 = -0.21$, which is too large by a factor of three.

It should be noted that if the nonlocal effects (with $\bar{\zeta}_2 > 0$) are attributed to the propagation of a heavy virtual particle, its mass M_0 must, according to (8), satisfy the inequality $M_0 \geq \sqrt{14}\, m$.

The formulas given in Sec. 1 for the nonlocal interaction in the capture of a μ^- meson by a proton may be useful in establishing the magnitude of κ, which characterizes the length involved in the nonlocal effects, if there exists a universal AV interaction.

Radiative μ^- capture ($\mu^- + p \rightarrow n + \nu + \gamma$) may in general be helpful in establishing κ_i.

In conclusion, I take this opportunity to express my gratitude to Professor G. R. Khutsishvili for interest in the work and to Iu. G. Mamaladze for discussion of the results.

*We note that if the nonlocal effects are assumed to be caused by virtual π mesons, the capture probabilities obtained fail to agree with experiment.[5]

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