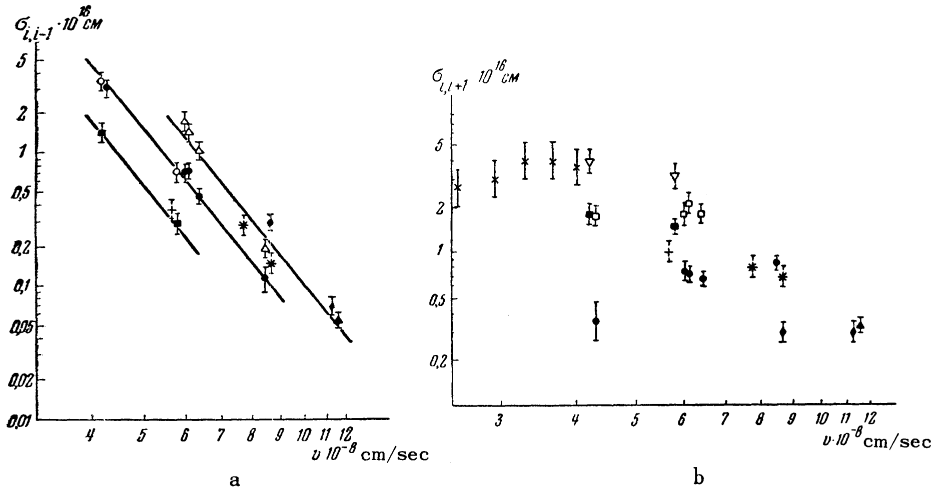

FIG. 1. Cross sections for (a) electron capture and (b) electron loss by nitrogen ions in nitrogen. The blacked-in symbols indicate directly measured values, and the symbols not blacked in indicate those calculated from the data on the equilibrium charge distribution. ▽ — i = 1, ■ — i = 2, ● — i = 3, ▲ — i = 4; +, *, ◆ — results of Nikolaev[2]; × — the values of σ_{12} obtained by Korsunskii et al.[3]

where a_0 and v_0 are the radius of the first Bohr orbit and the velocity of the electron in the hydrogen atom, and Z is the atomic number of the medium. (The values calculated according to the formula are shown in Fig. 1a by the solid lines.)

A theoretical calculation of the electron capture cross section performed by Nikolaev[2,4] gives a dependence of $\sigma_{i,\,i-1}$ on v, i and Z which is close to the experimental one. The electron capture cross sections in argon, as calculated by Gluckstern,[5] differs significantly from the experimental values. According to these calculations, the cross sections are proportional to $v^{-3.5}$, and are 1.5 times greater than the experimental values for $v \sim 7 \times 10^8$ cm/sec.

The cross sections $\sigma_{i,\,i+1}$ for electron loss (Fig. 1b) in the velocity region investigated hardly depend on v. This is in agreement with the assumption that $\sigma_{i,\,i+1}$ have maxima close to these velocities, since at high velocities the cross sections for loss should decrease,[2,6] and at velocities less than those of the removal electrons, they should also be small due to the adiabatic character of the collisions. The value of $\sigma_{i,\,i+1}$ in argon is between 2 and 2.5 times greater than, and in hydrogen is between 6 and 10 times less than, the cross section for loss in nitrogen.

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63

CAPTURE OF POLARIZED μ^--MESONS BY NUCLEI

B. L. IOFFE

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As has been shown by Lederman's[1] experiments, μ^--mesons coming from the decay of π^--mesons are polarized to a large degree, and this polarization is maintained to a measurable extent even after the μ^--meson is captured into a Bohr orbit. A theoretical examination of the capture of polarized μ^--mesons by nuclei is of definite interest, since a comparison of the experimental and theoretical results would then make it possible to arrive at certain conclusions on the character of the weak interaction between

μ^--mesons and nucleons.

Let us consider the capture of a completely polarized μ^--meson by a nucleus. The interaction Hamiltonian can be written as the sum of all five types of interactions, namely

$$H = {}^1/_2 \sum_i{}' g_i (\bar{\psi}_n O_i \psi_p)(\bar{\psi}_\nu (1-\gamma_5) O_i \psi_\mu) + \text{Hermitian conjugate} \tag{1}$$

(i = S, V, T, A, P). We shall consider the neutrino a two-component particle.[2-4]* When a μ^--meson is captured, the nucleons in the nucleus gain an energy no greater than a few Mev, so that for the S, V, T, and A interactions we may go over to the nonrelativistic approximation for the nucleons. The pseudoscalar interaction, which vanishes in the nonrelativistic approximation, then gives a contribution only if the coupling constant g_P is much greater than the coupling constants for the other interactions.

The matrix element calculated from (1) is

$$\begin{gathered} M = {}^1/_2 \bar{u}_\nu (1-\gamma_5)\{g_S I + g_V I\beta + g_T \mathbf{S}\boldsymbol{\sigma} + g_A \mathbf{S}\boldsymbol{\sigma}\beta + g_P P\} u_\mu, \\ I = \int \Psi_f^* \Psi_i e^{-i\mathbf{qr}} d\tau; \quad \mathbf{S} = \int \Psi_f^* \boldsymbol{\sigma} \Psi_i e^{-i\mathbf{qr}} d\tau; \quad P = \int \Psi_f^* \gamma_5 \Psi_i e^{-i\mathbf{qr}} d\tau, \end{gathered} \tag{2}$$

where Ψ_f and Ψ_i are the final and initial wave functions of the heavy particles, and $\mathbf{q}$ is the neutrino momentum. Let us denote the mean value of the μ-meson spin by $\boldsymbol{\sigma}_0$. We now calculate the square of the matrix element of Eq. (2), obtaining (setting $\boldsymbol{\nu} = \mathbf{q}/q$):

$$\begin{gathered} 2|M|^2 = |(g_S+g_V)I + g_P P|^2 (1+\boldsymbol{\sigma}_0\boldsymbol{\nu}) + |g_T + g_A|^2 \{|\mathbf{S}|^2(1-\boldsymbol{\sigma}_0\boldsymbol{\nu}) + S_i S_k^* (\nu_k \sigma_{0i} + \nu_i \sigma_{0k}) + i[\mathbf{S}\mathbf{S}^*](\boldsymbol{\nu} - \boldsymbol{\sigma}_0)\} \\ + 2\mathrm{Re}\{(g_T+g_A)[(g_S+g_V)^* I^* + g_P^* P^*](\mathbf{S}\boldsymbol{\sigma}_0 + \mathbf{S}\boldsymbol{\nu} - i\mathbf{S}[\boldsymbol{\nu}\boldsymbol{\sigma}_0])\}. \end{gathered} \tag{3}$$

Let us consider the most common case, when capture of the μ^--meson leads to a neutron and a recoil nucleus. Quadratic combinations of the matrix elements I, **S**, and P, after they are averaged over projections of the nuclear spin, can depend only on two vectors. These are the unit vector **n** directed along the neutron momentum **p** = **n**p, and the unit vector $\boldsymbol{\nu}$. Further, we shall select only those cases in which $\mathbf{n} = -\boldsymbol{\nu}$, which can be done by selecting neutrons whose energy lies close to the upper bound of the neutron energy spectrum. The products of matrix elements that enter into Eq. (3) can then depend only on $\boldsymbol{\nu}$. It follows from this that after averaging over projections of the nuclear spin, $\overline{IP^*}$, $\overline{[\mathbf{SS}^*]}$, and $\overline{I^*\mathbf{S}}$ must vanish. Indeed, $\overline{IP^*}$ is a pseudoscalar,† and $\overline{[\mathbf{SS}^*]}$ and $\overline{I\mathbf{S}^*}$ are pseudovectors and can therefore not be constructed with the aid of a single vector $\boldsymbol{\nu}$. Let us write

$$\overline{|I|^2} = |C_I|^2, \qquad \overline{|P|^2} = |C_P|^2, \qquad \overline{|\mathbf{S}|^2} = |C_S|^2.$$

The most general forms for $\overline{S_i S_k^*}$ and $\overline{P^*\mathbf{S}}$ are

$$\overline{S_i S_k^*} = |C_S|^2 \frac{1}{1+\alpha}\left(\frac{1}{3}\cdot\delta_{ik} + \alpha\nu_i\nu_k\right), \quad \overline{P^*\mathbf{S}} = C_P^* C_S \gamma \boldsymbol{\nu}, \tag{4}$$

where $\alpha > -1/3$. Inserting (4) into (3), we obtain

$$\begin{gathered} 2|M|^2 = \{|g_S+g_V|^2 |C_I|^2 + |g_P|^2 |C_P|^2 + 2\mathrm{Re}\, g_P^* (g_T+g_A) C_P^* C_S \gamma\} \\ \times (1+\boldsymbol{\sigma}_0\boldsymbol{\nu}) + |g_T+g_A|^2 |C_S|^2 \left(1 - \frac{1}{3}\frac{1-3\alpha}{1+\alpha}\boldsymbol{\sigma}_0\boldsymbol{\nu}\right). \end{gathered} \tag{5}$$

From Eq. (5) one can conclude that when the capture process gives rise to neutrons whose momentum is in the direction opposite to that of the neutrino, these neutrons are directed primarily along (or against) the μ-meson spin, and their angular distribution is given by the expression $dW/d\Omega = 1 - \beta\cos\theta$, where θ is the angle between the direction of motion of the neutron and the μ-meson spin. For the scalar, vector, and pseudoscalar interactions (and their cross products) $\beta = 1$. For the tensor and axial vector interactions (and their cross products) β cannot in general be calculated from (5). (It follows from (5) that $\beta = -(1-3\alpha)/3(1+\alpha)$, where $-1/3 < \alpha < \infty$, so that $-1 < \beta < 1$.) For μ^--meson capture by protons, $\alpha = 0$ and $\beta = -1/3$. Since nonzero values of α are due to trapping of the neutron in the nucleus, one may expect that in lighter nuclei α is almost zero, so that for these, β is close to $-1/3$.

If we select neutrons whose energy lies in the upper part of their energy spectrum, where the intensity begins to decrease (the neutron energy is greater than, or of the order of E_0, the binding energy of

*The factor $1-\gamma_5$ in Eq. (1) corresponds to the creation of a neutrino whose spin is directed along its momentum; $\gamma_5 = \begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix}$.

†The bar indicates averaging over spin projections of the initial nucleus and summing over those of the final.

the neutron in the nucleus), their angular distribution will be confined to a relatively narrow cone about a direction opposite to that of the neutrino momentum. The width of this angular distribution is of the order of $\Delta \cos \vartheta \sim mE_0/pq \sim 0.4$.

Thus an experimental measurement of the angular distribution of the high-energy neutrons arising from the capture of polarized μ^--mesons by light nuclei may make it possible to distinguish between two classes of interaction between μ^--mesons and nucleons. One class comprises the scalar, vector, and pseudoscalar ($\beta = 1$) interactions, the other the tensor and axial-vector ($\beta \approx -1/3$) interactions.

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Translated by E. J. Saletan
64

ON THE POSSIBLE EFFICIENCY OF THE CATALYSIS OF NUCLEAR REACTIONS BY MESONS

IA. B. ZEL'DOVICH

P. N. Lebedev Physical Institute, Academy of Sciences, U.S.S.R.

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THERE exists at present experimental evidence[1] of the ability of negative mesons to catalyze a nuclear reaction between two singly charged ions (p, d, t) by bringing the reacting nuclei closer together (see Zel'dovich and Sakharov,[2] where additional references are given). The meson is not lost in the nuclear reaction.

For μ-mesons in a liquid mixture of p and d, the reaction probability is no greater than several hundredths per meson entering the mixture. This small probability is determined by the ratio between the mean time for creating a mesomolecule ($pd\mu$, $dd\mu$) and the lifetime of the μ meson, which is 2×10^{-6} sec. One is naturally led to enquire whether there exist in nature some long-lived mesons, and whether such mesons may not in practice make possible a self-maintaining nuclear reaction of hyperon isotopes.

The second of these questions can definitely be answered in the negative. For all imaginable reactions there exists the probability that the meson will be bound to the helium nucleus produced in the nuclear reaction. Owing to the positive charge of the $He\mu$ system, other nuclei, including those of hydrogen, cannot come very close, so that the bound meson leaves the reaction and can no longer perform its catalyzing action.

The probability of binding was calculated by a method developed by Migdal[3] in treating the probability that an atom is ionized during β-decay. At the time the nuclear reaction is taking place, the two nuclei involved are close together and the wave function of the meson in the adiabatic approximation is that of the mesohelium ion $\psi_i(r)$, where r is the distance between the meson and the point at which the two nuclei meet.

The helium nucleus produced in the reaction has a definite energy E_0 (which is 0.8 Mev for $d + d \rightarrow He^3 + n$, and 3.5 Mev for $d + t \rightarrow He^4 + n$) and a corresponding velocity. To account for this, the meson wave function should be multiplied by $e^{ipz/\hbar}$, where the z axis is along the direction of motion of the nucleus, and the momentum p is the product of the nuclear velocity by the reduced mass $m = M\mu/(M + \mu)$, where μ is the meson mass and M is the mass of the helium nucleus. Expanding $\psi_i(r)e^{ipz/\hbar}$ in meson eigenfunctions in the field of the helium nucleus, we obtain the probability for one or the other final meson states after the nuclear reaction.