associated difficulties are also inherent in the method here described. This hampers the comparison of the solution of (12) and of the expression derived therefrom for the scattering phases, etc., with the results obtained by the usual renormalization method[1].

I wish to express my profound gratitude to Academician I. E. Tamm and to his collaborators for their discussion of this note and for valuable suggestions.

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[1] Silin, Tamm and Fainberg, J. Exptl. Theoret. Phys. (U.S.S.R.) **29**, 6 (1955); Soviet Phys. JETP **2**, 3 (1956).

[2] M. Neumann, Phys. Rev. **85**, 129 (1952).

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Neutrino Induced Deuteron Disintegration

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IT has recently been clearly established that the β-interaction is a mixture of the scalar and tensor types. The scalar interaction constant has been determined by measuring f^t for the β-decay of 0^{14} to N^{14} [2]. The nuclear matrix element of β^+-decay of 0^{14} can be obtained by an exact theoretical calculation since this is an $0+\to 0+$ transition with identical nucleonic wave functions in the initial and final nuclei.

The tensor interaction constant cannot be determined directly from β-decay since the matrix element for the tensor type cannot be calculated exactly. In this case the spin direction of the decaying nucleus is changed, and since spin-orbit coupling and the relative orientation of nucleonic spins play an important part in nuclear interactions the nucleonic wave functions of the initial and final nuclei will differ. But since we must know the form of the initial and final nucleonic wave functions in order to calculate the matrix element of the nucleus, whereas the exact form of a nucleonic wave function in the nucleus is unknown, the matrix element for the tensor type of β-interaction cannot be calculated exactly.

The only nucleus for which the nucleonic wave functions are known well is the deuteron, which is not β-active. However, it is possible to determine the tensor interaction constant directly and independently of the scalar interaction constant by measuring the cross section for the absorption of an antineutrons by a deuteron:

$$D+\tilde{\nu}\to n+n+e^+ \tag{I}$$

(ν denotes a neutrino and $\tilde{\nu}$ an antineutrino). This process, as is indicated by an estimate given below, has a cross section which is smaller by an order of magnitude than the $p+\tilde{\nu}\to n+e^+$ cross section; this process has apparently been observed by the annihilation radiation of the positrons. The cross section is of the order of magnitude 10^{-44} cm^2.

The present note deals with the determination of the antineutrino absorption cross section for deuterons.

The following simple considerations show that the scalar interaction makes a small contribution to the cross section as compared with the tensor interaction. The neutrons emitted in process (I) will possess very small velocities since the larger part of the energy evolved in the interaction is borne off by the electron. We can therefore assume that both neutrons are formed in an S-state. By the Pauli principle the spin part of the wave function for the final state of the neutrons must be antisymmetric, i.e., the neutrons spins must be antiparallel. The spin part of the deuteron wave function is symmetric--the nucleonic spins in the deuteron are parallel,. Consequently, the relative direction of the spins must be changed. This is possibly only by a tensor interaction type and is impossible by a scalar type.

For the purpose of obtaining the differential cross section of process (I) the deuteron wave function was taken in the usual form; the wave function of the final state was made antisymmetrical in all variables of the neutrons.

For the differential cross sections, summed over all polarizations of the final states and averaged over all polarizations of the initial states of the particles, the following expressions are obtained:

$$d\sigma_S=\frac{2\pi\varkappa}{(2\pi)^5}G_S^2\left(\frac{1}{\varkappa^2+p_1^2}-\frac{1}{\varkappa_2+p_2^2}\right)^2\frac{E_eE_\nu-\mathbf{p}_e\mathbf{p}_\nu}{E_eE_\nu}\frac{p_1E_1\,do_1p_eE_e\,do_e\,dE_e}{1-(E_1p_2/p_1E_2)\cos\theta_{1,2}}; \tag{1}$$

$$d\sigma_T=\frac{2\pi\varkappa}{(2\pi)^5}G_T^2\left\{\frac{2}{(\varkappa^2+p_1^2)^2}+\frac{2}{(\varkappa^2+p_2^2)^2}+\left(\frac{1}{\varkappa^2+p_1^2}-\frac{1}{\varkappa^2+p_2^2}\right)^2\right\}\times\frac{E_eE_\nu+{}^1/_3\,\mathbf{p}_e\mathbf{p}_\nu}{E_eE_\nu}\frac{p_1E_1\,do_1p_eE_e\,do_e\,dE_e}{1-(E_1p_2/p_1E_2)\cos\theta_{1,2}}. \tag{2}$$

Here $\mathbf{p}_e$, $\mathbf{p}_\nu$, E_e, E_ν are the momentum and the total energy of the positron and antineutrino, respectively; $\mathbf{p}_1$, $\mathbf{p}_2$, E_1, E_2 are the momenta and total energies of the emitted neutrons; $\theta_{1,2}$ is the angle between $\mathbf{p}_1$ and $\mathbf{p}_2$; do_1 and do_2 are the element of solid angle of one of the emitted neutrons and of the positron, respectively; G_T and G_s are the dimensionless tensor and scalar interaction constants, $\varkappa$ is the reciprocal of the deuteron radius (units have been chosed to give $\hbar = c = m_0 = 1$). The following momentum and energy conservation laws are satisfied:

$$\mathbf{p}_\nu - \mathbf{p}_1 - \mathbf{p}_2 - \mathbf{p}_e = 0, \qquad E_D + E_\nu - E_1 - E_2 - E_e = 0. \tag{3}$$

Here $E_D = W + M_p + M_n$, where M_p and M_n are the mass of the proton and neutron, respectively, and W is the deuteron binding energy.

In the cross section for process (I) we neglected the term resulting from the interference of the scalar and tensor interactions. As can be shown by a direct calculation, this term is directly proportional to the velocity difference of the initial and final states of the nucleon which absorbs the neutrino and can therefore be neglected (an error $\sim 0.1\%$ is thus introduced).

From (1) and (2) it can be seen that

$$\frac{d\sigma_s}{d\sigma_T} \approx \left(\frac{G_s}{G_T}\right)^2 \frac{(E_1 - E_2)^2}{2\,(\varkappa^2/2M_n + E_1 - M_n)^2 + 2\,(\varkappa^2/2M_n + E_2 - M_n)^2 + (E_1 - E_2)^2}. \tag{4}$$

An estimate of the ratio of the integral cross sections gives $\sigma_s/\sigma_T \approx 10^{-2}$. Since (as has been indicated above) the energy evolved in the reaction is borne off by the electron, it is possible to estimate the total cross section of the process without an exact integration of (1) and (2). For this estimate we can use certain average values of the energies and momenta. Then $\overline{E}_1 \approx \overline{E}_2 \approx \overline{E}$, where $\overline{E}$ is the average energy of a nucleon in the deuteron and

$$\sigma_s \approx 0,\ \sigma \approx \sigma_T \approx \frac{2\varkappa}{3\pi^2}\frac{G_T^2}{(\overline{p}^2 + \varkappa^2)^2}\,\overline{p}\,\overline{E}\,\overline{p}_e^3. \tag{5}$$

By substituting in (5) the calculated values $G_T \approx 4 \times 10^{-12}$ (see, for example, Ref. 2), $\overline{E} \approx 2 \times 10^3$, $\overline{p} \approx \varkappa \approx 87$, $\overline{p}_e \approx 1$ to 2 (the energy of the antineutrino must then be $E_\nu \approx 4.2 - 4.6$ mev; the reaction threshold $E_\nu = 4.03$ mev; the average energy of the antineutrinos emitted by a reactor* is 2.5 mev) we obtain as an estimate of the total cross section $0.1 \times 10^{-45} - 1 \times 10^{-45}$ cm^2.

In conclusion, the author wishes to thank I. S. Shapiro for suggesting the problem and for valuable comments.

* For an estimate of the average energy of antineutrinos emitted by a nuclear reactor, see Refs. 3 and 4.

[1] Maxson, Allen and Jentschke, Phys. Rev. **97**, 109 (1955).

[2] I. B. Gerhart, Phys. Rev. **95**, 288 (1954).

[3] F. Reines and C. L. Cowan, Phys. Rev. **92**, 830 (1953).

[4] K. Way and E. P. Wigner, Phys. Rev. **73**, 1318 (1948).

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Diffraction Scattering of High Energy π-Mesons by Nuclei

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EXPERIMENTAL data indicate that the elastic collisions between high energy π-mesons (1.4 bev and more) and nucleons are of a markedly diffractive character, i.e, small angle scattering is prevalent[1-4]. In Ref. 3 an attempt was made to analyze the diffraction scattering theoretically. However, the authors assumed for the nucleonic model a sphere with sharp boundaries and certain transparency, an assumption which is usually made with respect to the nucleus. In the case of a nucleon, nevertheless, there is no cause to choose such a model. In the present note the diffraction