Here $\mathbf{p}_e$, $\mathbf{p}_\nu$, $E_e$, $E_\nu$ 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.

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## Diffraction Scattering of High Energy $\pi$-Mesons by Nuclei

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EXPERIMENTAL data indicate that the elastic collisions between high energy $\pi$-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 scattering is treated on the basis of general theory, without any special assumption as to the nucleonic model.

We shall take the following relations[5] as the basis:

$$\sigma_c = \pi\bar{\lambda}^2 \sum_{l=0}^{\infty} (2l+1)(1-|\beta_l|^2), \tag{1}$$

$$\sigma_s = \pi\bar{\lambda}^2 \sum_{l=0}^{\infty} (2l+1)\,|\beta_l - 1|^2.$$

We are neglecting here the spin dependence of nuclear forces and the change of the charge of $\pi$-mesons in collision with protons[6]. Here $\sigma_c$ is particle absorption cross section, $\sigma_s$ is the elastic scattering cross section, $\bar{\lambda}$ is the wavelength of the incident particle, $\hbar l$ is the orbital momentum and $\beta_l = \exp\{2i\eta_l\}$ where $\eta_l$ is the phase of scattering.

The differential cross section for elastic scattering is given by the following expression:

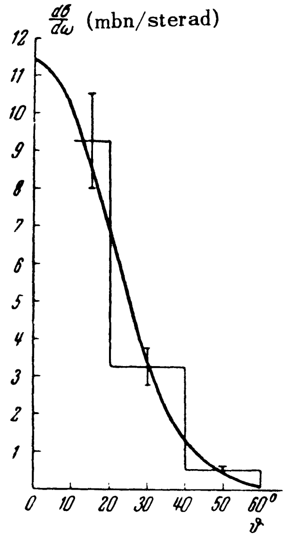
$$\frac{d\sigma_s}{d\omega} = |f(\vartheta)|^2, \tag{2}$$

$$f(\vartheta) = -\frac{i\bar{\lambda}}{2} \sum_{l=0}^{\infty} (2l+1)(\beta_l - 1) P_l(\cos\vartheta).$$

where $\vartheta$ is the scattering angle, $d\omega$ is the solid angle element and $P_l(\cos\vartheta)$ are the Legendre polynomials.

On the basis of the results of Ref. 6 we assume that in high energy region the imaginary part of the scattering amplitude is much larger than the real part and $\beta_l$ is therefore real. This fact greatly simplifies the phase analysis. If the function $d\sigma_s/d\omega$ were known sufficiently well from the experimental data, it would be possible to find a unique function $\beta_l$. In reality the present degree of precision of the experiments does not allow for unique phase determination. The experimental results obtained with high energy accelerators permit, nevertheless, an approximate phase analysis.

We shall turn now to the most complete experimental data available on the scattering of 1.4 bev $\pi$-mesons by nucleons[3]. The other experimental results[1,2,4] are in satisfactory agreement with the results of Ref. 3. Estimating the cross sections, its authors referred a part of the observed elastic scattering to processes directly connected with the absorption of pions. Indeed, as the result of the $\pi$-meson capture and the following decay of the compound system a noncoherent, almost isotropic elastic scattering should take place, which should be regarded as inelastic collision, contrary to the




Angular distribution of the diffraction scattering of $\pi$-mesons by a nucleon in the center-of-mass system according to Ref. 3. The solid theoretical curve calculated according to Eq. (2) and (6).

diffraction scattering. This division is not completely unambiguous. We shall note, however, that the number of elastic nondiffractive collisions found by the authors of Ref. 3 is in good agreement with the value obtained from the statistical theory[7]. According to the predictions of the statistical theory, the inelastic scattering practically disappears at high energies (4.5 bev). The cross section found for the inelastic and elastic collisions in Ref. 3 are: $\sigma_c = 26.7 \pm 1.3$ mbn and $\sigma_s = 7.3 \pm 1.0$ mbn. The ratio $\sigma_s/\sigma_c$ changes from 0.33 to 0.23. The angular distribution for the diffractive scattering was obtained as well (Fig. 1). In order to analyze the obtained data, we shall proceed as follows: for sufficiently large energies it is possible to pass over to integration in Eqs. (1) and (2):

$$\sigma_c = \pi\bar{\lambda}^2 \int_0^{\infty} 2la_l(2-a_l)\,dl; \quad \sigma_s = \pi\bar{\lambda}^2 \int_0^{\infty} 2la_l^2\,dl; \tag{3}$$

$$f(\vartheta) = -i\bar{\lambda} \int_0^{\infty} la_l J_0(l\vartheta)\,dl, \tag{4}$$

where $a_l = 1 - \beta_l$ and $J_0(l\vartheta)$ is the Bessel function of order zero.

We shall make the simplest assumption, namely, we shall put $\alpha_l = \alpha \exp(-\bar{\lambda}^{-2}l^2/R^2)$ where the values $\alpha$ and $R$ have to be determined from experiment. Substituting the function $a_l$ into Eq. (3) we obtain:

$$\sigma_c = \frac{\pi\alpha^2}{2} R^1 \left(\frac{4}{\alpha} - 1\right); \qquad \sigma_s = \frac{\pi\alpha^2}{2} R^2. \tag{5}$$

The values of $\alpha$ and $R$ corresponding to the experimental results lie within the following limits: from $R = 0.86 \times 10^{-13}$ cm and $\alpha = 0.74$ to $R = 0.74 \times 10^{-13}$ and $\alpha = 0.99$. The values, corresponding to the mean values of $\sigma_s$ and $\sigma_c$, are $R = 0.8 \times 10^{-13}$ and $\alpha = 0.85$. Furthermore, substituting the function $a_l$ into Eq. (4), we can calculate the function $f(\vartheta)$:

$$|f(\vartheta)| = \lambda\!\!\!^{-} \int_0^\infty \alpha J_0(l\vartheta)\, e^{-\lambda\!\!\!^{-2} l^2/R^2}\, l dl \tag{6}$$

$$= \alpha \frac{R^2}{\lambda\!\!\!^{-}} \int_0^\infty e^{-y^2} J_0\left(\vartheta \frac{R}{\lambda\!\!\!^{-}} y\right) y dy =$$

$$= (\alpha R^2/2\lambda\!\!\!^{-}) \exp\{-\vartheta^2 R^2\ 4\lambda\!\!\!^{-2}\}.$$

The angular distribution $d\sigma/d\omega$ is determined by the function $|f(\vartheta)|^2$. The angular distribution calculated according to the formula (6) using the values $\lambda\!\!\!^{-} = 2.7 \times 10^{-14}$ cm, $R = 0.8 \times 10^{-13}$ cm and $\alpha = 0.9$, which correspond to $\sigma_c = 28$ mbn and $\sigma_s = 81$ mbn, is given in Fig. 1. The experimental data fit satisfactorily the theoretical curve.

The value $Z_l = 1 - |\beta_l|^2$, the physical meaning of which is the ' sticking probability " of particle, is of interest:

$$Z_l = \alpha e^{-\rho^2/R^2} (2 - \alpha e^{-\rho^2/R^2}), \tag{7}$$

where $\rho = \lambda\!\!\!^{-} l$. We shall note that for $\rho = 0$ the value of $Z$ is close to unity for a wide interval of values of $d$. Thus, even for $\alpha = 0.73$ $Z_{\rho=0} = 0.93$. The mean square value of the impact parameter [averaged over the function (7)] is:

$$\rho_{cp} = (\overline{\rho^2})^{1/2} = \sqrt{\frac{1-\alpha/8}{1-\alpha/4}}\, R. \tag{8}$$

The values $\overline{\rho}$, satisfying the experimental data are contained in the interval $(0.8 - 0.9) \times 10^{-13}$ cm. We shall note that, contrary to what is maintained in Ref. 3, the fact that the nucleon cannot be regarded as a black body does not imply that the statistical theory of multiple production is not applicable.

The function (7) gives the probability of inelastic scattering taking place for the impact parameter $\rho$. The inelastic scattering can be treated on the basis of the statistical theory, too[8]. It is of interest to perform a similar analysis for nucleon-nucleon collisions.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## Radiative Disintegration of $\Lambda^0$-Particle

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BESIDES the normal decay scheme of the $\Lambda^0$-particle

$$\Lambda^0 \to p + \pi^-, \tag{1}$$

the following decay scheme is possible:

$$\Lambda^0 \to p + \pi^- + \gamma. \tag{2}$$

It is known from the experimental data that the spin of the $\pi^-$-meson is zero and therefore the spin of the $\Lambda^0$-particle must be half-integral. In the present work the influence of the spin of $\Lambda^0$-particle upon the shape of the $\gamma$-quanta spectrum is investigated.