Measurement of the effect of photon screening in a deuteron in the pion double charge exchange reaction

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A method for experimentally determining the correction δ_p for the screening of the proton in a deuteron in the reaction $\pi^- d \to \pi^+ X$ (π^+ forward) is proposed and realized. The method is based on comparing the cross section of this reaction with the cross section of the reaction $\pi^- p \to \pi^+ X$ in the missing-mass region $M_x^2 \le 1.48$ GeV^2, which lies below the threshold of the $\pi^- n \to \pi^+ X$ reaction. The value $\delta_p = 0.20 \pm 0.10$ determined in this manner agrees with that calculated on the basis of the diffraction theory of multiple scattering.

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The cross section σ_d of the inclusive double charge exchange of a π^- meson on a deuteron with emission of a π^+ meson forward

$$\pi^- + d \to \pi^+ + X \tag{1}$$

can be represented in the form [1)]

$$\frac{d^2\sigma_d}{d\Omega^* dM_X^2} = \frac{d^2\sigma_p}{d\Omega^* dM_X^2}(1-\delta_p) + \frac{d^2\sigma_n}{d\Omega^* dM_X^2}(1-\delta_n). \tag{2}$$

Here σ_p and σ_p and σ_n are the cross sections of the reactions

$$\pi^- + p \to \pi^+ + X \tag{3}$$

and

$$\pi^- + n \to \pi^+ + X, \tag{4}$$

Ω^* is the solid angle in the c. m. s. of the reaction (3) or (4), M_X^2 is the square of the π^+ missing mass if the target is regarded as a nucleon, and the corrections δ_p and δ_n take into account the effects of the screening of the proton by the neutron and of the neutron by the proton.

In the calculation of the corrections δ_p and δ_n for the process $\pi^- d \to pX$ [1] we

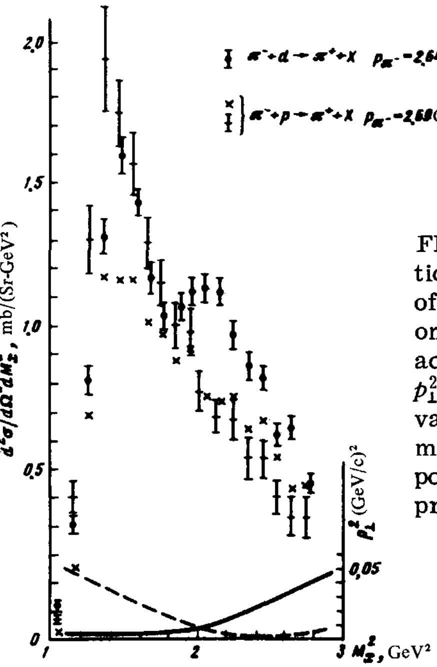

FIG. 1. Measured cross section of the reactions $\pi^- d \to \pi^+ X$ (Ⅰ) and $\pi^- p \to \pi^+ X$ (×) (the scale of the errors is the same as in the reaction on deuterons). The cross section of the reaction $\pi^- p \to \pi^+ X$ (Ⅰ), has been recalculated for $p_\perp^2 = (p_\perp^2)_d$. The lower curves are the mean values of the squares of the transverse momenta of the π^+ mesons, corresponding to exposures to deuterons $(p^2)_d$ (solid curve) and protons $(p^2)_p$ (dashed curve).

have noted earlier that these corrections can reach 10 – 15%, so that they must be taken into account if we are to determine the cross section of the reactions on a neutron, on the basis of a difference experiment, with accuracy better than 10%. In [1] these corrections were calculated on the basis of the diffraction theory of multiple scattering. Account was taken here of only the absorption of the π^- mesons and protons, and the interaction of the undetected particles was neglected by virtue of the statements proved in [2]. To verify the theoretical methods of the calculation of δ_p and δ_n and to investigate the role of the interaction of the particles that cannot be detected, great interest attaches to a direct experimental determination of these quantities.

We propose here a method of experimentally determining δ_p, based on a comparison of the cross sections of the reactions (1) and (3) in the region of the squared missing masses $M_X^2 \leq (m_n + 2m_\pi)^2 = 1.48$ GeV^2, which lies below the threshold of the reaction (4) with respect to M_X^2 (the threshold of this reaction is connected with the channel $\pi^- n \to \pi^+ \pi^- \pi^- n$). In this mass region, only the channel $\pi^- p \to \pi^+ \pi^- n$ is open, and the following equality holds:

$$\left(d^2\sigma_p / d\Omega^* \, dM_X^2\right)\delta_p = \frac{d^2\sigma_p}{\Omega^* \, dM_X^2} - \frac{d^2\sigma \, d}{d\Omega^* \, dM_X^2} \qquad (5)$$

To determine δ_p we used the cross sections of the reactions (1) and (3) which were measured earlier with the three-meter spectrometer of our Institute [3]

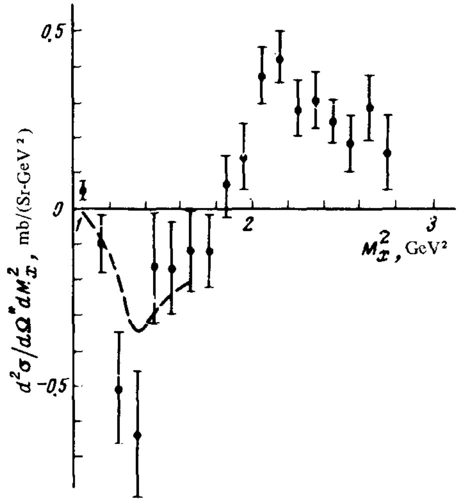

FIG. 2. Difference of the cross sections
$$\frac{d^2\sigma_d}{d\Omega^* dM_X^2} - \frac{d^2\sigma_p}{d\Omega^* dM_X^2}$$
for $p_\perp^2 = (p_\perp^2)_d$. Dashed line—calculation of this difference on the basis of the diffraction theory of multiple scattering.

at 2.64 and 2.69 GeV/c, respectively.[4] The obtained differential distributions (see Fig. 1) pertain to several different regions of the values of the square $p_\perp^2$ of the transverse momentum of the π^+ meson. Therefore for each interval of M_X^2 the cross section $d^2\sigma_p/d\Omega^* dM_X^2$ was referred to the value of $p_\perp^2$ corresponding to the measurement of $d^2\sigma d/d\Omega^* dM_X^2$. We used here an exponential dependence of $d^2\sigma_p/d\Omega^* dM_X^2$ on $p_\perp^2$ with parameters measured by us earlier at $p_\perp = 3.25$ GeV/c.[4] The cross section obtained by such a recalculation is also shown in Fig. 1; the corresponding corrections, as can be seen, turned out to be maximal in the region $1.0 \leq M_X^2 \leq 1.4$ GeV^2. The difference between the measured cross section of the reaction (1) and the recalculated cross section of the reaction (1), equal to $\delta_p d^2\sigma_p/d\Omega^* dM_X^2$ at $M_X^2 \lesssim 1.5$ GeV^2, is shown in Fig. 2; in this interval of M_X^2 the average value of δ_p is 0.20 ± 0.10.

To calculate δ_p, we use the diffraction theory of multiple scattering and write down the amplitude of the reaction (1) in the form

$$F_{fi}(\mathbf{p}_\perp) = \frac{ik}{2\pi} \int d^2\mathbf{b}\, d^3\mathbf{r} \exp(i\mathbf{p}_\perp \mathbf{b})\phi_f^*(\mathbf{r})\phi_i(\mathbf{r})$$
$$\times \left\{ \Gamma_{12}^p\left(\mathbf{b} + \frac{\mathbf{s}}{2}\right)\left[1 - \theta(-z)\Gamma_{\pi^- n}\left(\mathbf{b} - \frac{\mathbf{s}}{2}\right) - \theta(-z)\Gamma_{\pi^+ n}\left(\mathbf{b} - \frac{\mathbf{s}}{2}\right)\right]\right\}. \quad (6)$$

Here Γ_{12}^p, $\Gamma_{\pi^- n}$ and $\Gamma_{\pi^+ n}$ are the amplitudes of the reactions (3), $\pi^- n \to \pi^- n$ and $\pi^+ n \to \pi^+ n$ in the representation of the impact parameter b; ϕ_i and ϕ_f are the wave functions of the deuteron and of the final two-baryon system X; the z axis is directed along the momentum of the incident particles; $\mathbf{s}$ and z are the transverse and longitudinal components of the vector $\mathbf{r}$; $\theta(z) = 1$ at $z \geq 0$ and 0 at $z < 0$. In our experimental setup, summation takes place over all the possible final states

$$\sum_f |F_{fi}(\mathbf{p}_\perp)|^2.$$

The completeness approximation usually works well for nucleon systems in this case. In our case the system X contains also a pion. If it is assumed that the completeness approximation is also applicable to systems of nucleons and pions, then on the basis of expression (6), with allowance for the smallness of the radius of the $\pi\pi$ interaction in comparison with the radius of the deuteron, we obtain at $p_\perp = 0$

$$\delta_p = \frac{\langle r^{-2}\rangle}{4\pi}\left[\sigma^{tot}_{\pi^-n} - \sigma^{el}_{\pi^-n}\frac{b_{el}^-}{b_{el}^- + b_{12}} + \sigma^{tot}_{\pi^+n} - \sigma^{el}_{\pi^+n}\frac{b_{el}^+}{b_{el}^+ + b_{12}}\right], \qquad (7)$$

where the Glauber parameter $\langle r^{-2}\rangle = 0.038\ mb^{-1}$, and $b^{\pm}_{el}$ and b_{12} are the slopes of the differential cross sections of the elastic $\pi^{\pm}p$ scattering and of reaction (3).

The dashed curve in Fig. 2 represents the quantity $\delta_p(d^2\sigma_p/d\Omega^*\, dM_x^2)$, where $\delta_p = \delta_p^{\text{theor}} = 0.17$ was calculated on the basis of (7). On the average, the results of the calculations are in satisfactory agreement with the experimental data. Further experimental study of the reactions (1) and (3) in this mass region is undoubtedly of interest.

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[1)]Here and below the effects of Fermi motion are not taken into account, since they are small as a result of the near equality of the momenta of the π^- and π^+ mesons.

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