P-odd asymmetry in proton-proton scattering

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(Submitted 13 May 1980
Pis'ma Zh. Eksp. Teor. Fiz. **32**, No. 1, 70–73 (5 July 1980)

The asymmetry in the scattering of longitudinally polarized protons by unpolarized protons was calculated using the weak-interaction (WI) potentials of nucleons from the ρ^0-and ω-meson exchange in the Weinberg–Salam model. The scattering amplitude was calculated with two strong-interaction potentials in the Born approximation with distorted waves. The obtained results are compared with the experimental data.

PACS numbers: 13.75.Cs

Weak interaction of nucleons produces an asymmetry in the scattering of longitudinally polarized protons by unpolarized protons

$$A = (\sigma_+ - \sigma_-) / (\sigma_+ + \sigma_-) , \tag{1}$$

where $\sigma_\pm$ are the scattering cross sections of protons with positive and negative helicities.[1)] The asymmetry (1) should be of the order of magnitude $Gm_\pi^2 \sim 10^{-7}$ ($G = 10^{-5} m_N^{-2}$ is the weak-interaction constant), since the amplification effects char-

 0021-3640/80/130058-05$00.60

acteristic of nuclei are missing in proton scattering.[1]

In this paper we present the results of a calculation of the asymmetry (1) of protons with an energy $E \leqslant 300$ MeV and compare them with the variable experimental data. The total (pp) scattering amplitude can be written in the form

$$F_{S'S} = f_{S'S} + g_{S'S}, \tag{2}$$

where S' and S are the total spins of the states, f is the strong interaction amplitude, and q is the weak interaction amplitude

$$g_{S'S} = \langle \Psi^{(-)}_{S'} | V | \Psi^{(+)}_{S} \rangle, \tag{3}$$

where V is the weak interaction potential of protons. The wave functions $\Psi^{(\pm)}$ at energies $E \leqslant 300$ MeV were calculated in the Born approximation of the distorted-wave method with the Hamada-Johnston potential (hard core) and Reid potential (soft core).[2] The weak interaction potentials of nucleons were obtained in the Weinberg–Salam model.[3] In the case of (pp) scattering they are the weak-interaction potentials of the neutral hadronic current corresponding to the ρ^0-and ω-meson exchange:

$$V\begin{pmatrix}\rho^0\\ \omega\end{pmatrix} = -\frac{G g_A m_\rho^2}{4\pi\sqrt{2}\, m_N}\begin{pmatrix}1-2\sin^2\theta_W\\ -2\sin^2\theta_W\end{pmatrix}\left\{ i\begin{pmatrix}1+\mu_V\\ 1+\mu_S\end{pmatrix}\right.$$

$$\left. \times\ [\vec{\sigma}_1\vec{\sigma}_2][\mathbf{P}, v(r)] + (\vec{\sigma}_1 - \vec{\sigma}_2)\{\mathbf{p}, v(r)\}\right\}\begin{pmatrix}\tau_1^3\tau_2^3\\ \frac{1}{2}(\tau_1^3+\tau_2^3)\end{pmatrix}, \tag{4}$$

where $g_A = 1.25$, θ_W is the Weinberg angle ($\sin^2\theta_W = 0.23 \pm 0.02$), $\mu_V = 3.7$ and $\mu_S = -0.12$ are the isovector and isoscalar anomalous magnetic moments of the nucleon, and $v(r) = \exp(-m_\rho r)/r$. It was assumed in expression (4) that $m_\rho \approx m_\omega$. The weak-interaction potentials[4] nucleons from the ρ^0- and ω-meson exchange[4] give the isospin selection rules $\Delta T = 0$ and $\Delta T = 1$, respectively. The states of the (pp) system with the total moment $0 \leqslant J \leqslant 4$ were taken into account in the calculation. At proton energies $E < 100$ MeV the contribution of the states with $J > 0$ to the (pp) scattering amplitude (2) is negligible but at $E > 100$ MeV their contribution, as the calculations show, is large. This is manifested very clearly in the differential asymmetry of proton scattering:

$$A(\theta) = \left(\frac{d\sigma_+}{d\Omega} - \frac{d\sigma_-}{d\Omega}\right) \Big/ \frac{d\sigma}{d\Omega} = 2\,\mathrm{Re}(f_{00}^* g_{01} + f_{11}^* g_{10}) \big/ (|f_{00}|^2 + |f_{11}|^2. \tag{5}$$

The dependence of the asymmetry (1) on the energy of the incident proton is shown in Fig. 1 for the Hamada-Johnston (solid curve) and Reid (dashed curve) strong-interaction potentials. The dependence can be accounted for in the following way. We shall

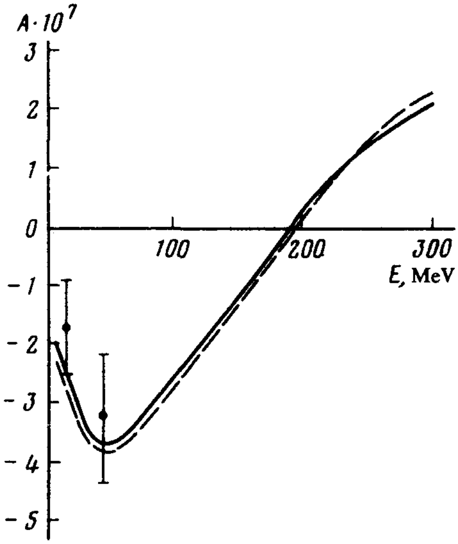

FIG. 1.

represent the total (pp) scattering amplitude (2) in the form $F = \Sigma_J [F(J) + g(J)]$ and examine only a part of this sum that corresponds to $J = 0$. At low energies ($E < 50$ MeV) the weak-interaction amplitudes $g_{01}(0)$ and $g_{10}(0)$ of the protons are monotonically decreasing functions of the energy. The strong-interaction amplitudes $f_{00}(0)$ and $f_{10}(0)$ are proportional to $\sin\delta\,(^1S_0)$ and $\sin\delta\,(^3P_0)$. The energy dependence of the δ phases is shown in Fig. 2. Thus, a part of the numerator in Eq. (5) corresponding to $J = 0$ decreases with increasing E, reaches a minimum, and then passes through zero near $E = 200$ MeV. The denominator in Eq. (5) in this case does not vanish. The contributions of the larger moments, especially $J = 2$ and $J = 4$, become large as the

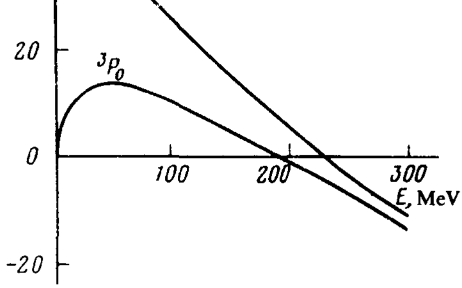

FIG. 2.

energy increases. Since they have opposite signs relative to the contribution of the moment $J = 0$, they partially compensate for this contribution. The effect can be observed in the shift of the minimum of the asymmetry A toward the proton energy $E = 50$ MeV, and of the zero toward $E < 200$ MeV. As follows from Fig. 1, the asymmetries (1) for strong interaction potentials with soft and hard cores differ by $\leqslant 20\%$. Figure 1 also shows the experimental asymmetries $A = (-1.7 \pm 0.8) \times 10^{-7}$ for $E = 15$ MeV (Ref. 4) and $A = (-3.2 \pm 1.1) \times 10^{7}$ for $E = 45$ MeV.[5] Although the experimental errors are large, these data are described quite satisfactorily within the context of an analysis—with the weak-interaction potentials of the neutral hadronic currents (4) and with allowance for the strong interaction in the Born approximation of the distorted-wave method. In view of this, we should mention that allowance for the neutral currents in the weak interaction of nucleons does not eliminate the discrepancy of about two orders of magnitude between the theoretical results[3] and the experimental data[6] for the circular polarization of photons in the $n + p \rightarrow d + \gamma$ process. The contribution of the phenomenological, isovector, two-pion, weak-interaction potentials of charged currents to the asymmetry (1) was calculated in Ref. 7. Despite the large range of action of such potentials $r \sim (2m_\pi)^{-1}$, their contribution to the asymmetry is negligible $A \lesssim 10^{-8}$. Moreover, at energies $E < 200$ MeV they give an asymmetry $A > 0$, inconsistent with the experiment.

The author thanks I. S. Shapiro for a discussion of the results and R. Yu. Nesterenko for assisting with the numerical calculations.

[1)]Coulomb interaction of protons is disregarded.

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