SPIN FLIP AND POLARIZATION IN THE SCATTERING OF NUCLEONS BY HIGH ENERGY PARTICLES

I. I. LEVINTOV

Submitted December 27, 1968

Zh. Eksp. Teor. Fiz. 56, 2155–2157 (May, 1969)

Allowance for rescattering in the eikonal approximation shows that asymptotic spin flip effects (the parameters A and R) at small q should not depend on the energy and on the nature of the incident particles.

GRIBOV and Pomeranchuk[1] have shown that asymptotically the value of spin flip[1)] in the scattering of polarized nucleons does not depend on the energy and nature of the incident particles, providing that the amplitude is determined by one Regge pole. Under the same condition the asymptotic value of recoil nucleon polarization is equal to zero. These simple consequences of the factorization of residues and of the properties of the signature factor can be easily illustrated for the process $0 + \frac{1}{2} \to 0 + \frac{1}{2}$. We define the t-channel amplitudes in the s-channel without spin flip and with spin flip, respectively, as M_0 and M_1. When account is taken of one pole $M_0 \to M_0^P$, $M_1 \to M_1^P$,

$$M_0^P = g_\pi(t) g_{0N}(t) \xi(t) (E/E_0)^{\alpha(t)-1}, \qquad (1)$$

$$M_1^P = g_\pi(t) g_{1N}(t) \xi(t) (E/E_0)^{\alpha(t)-1} \sqrt{|t|/4m^2}, \qquad (1')$$

where m is the nucleon mass, $E_0 \cong 1$ GeV, $\xi(t)$ is the complex signature factor, and $g_\pi(t)$, $g_{0N}(t)$, $g_{1N}(t)$ are the real-valued contributions of the vertices in the diagram of Fig. 1, associated with the spin-zero particle and with the nucleon and corresponding, respectively, to scattering without change and with change of helicity. The spin flip $P_\perp$ and the polarization P_0 are expressed as:

$$P_\perp = -2\,\mathrm{Re}\, M_0 M_1^* (|M_0|^2 + |M_1|^2)^{-1}, \qquad (2)$$

$$P_0 = 2\,\mathrm{Im}\, M_0 M_1^* (|M_0|^2 + |M_1|^2)^{-1}. \qquad (2')$$

From (1), (1′) and (2), (2′) we obtain

$$P_\perp = -2\sqrt{\frac{|t|}{4m^2}}\frac{g_{1N}}{g_{0N}}\left(1 + \frac{|t|}{4m^2}\frac{g_{1N}^2}{g_{0N}^2}\right)^{-1}; \qquad (3)$$

$$P_0 = 0, \qquad (3')$$

which are the results of Pomeranchuk and Gribov.

There arises the question of how these conclusions are modified when account is taken of rescattering effects (branch cuts in the j-plane). The precise answer can hardly be obtained at present. Nevertheless it is possible to show that formula (3) remains approximately correct when account is taken of rescattering at the expense of one pole in the eikonal approximation[3], that is, with account taken of only one-particle intermediate states of the interacting particles. Stated more precisely, the independence of $P_\perp$ of the nature of the incident particles arises when

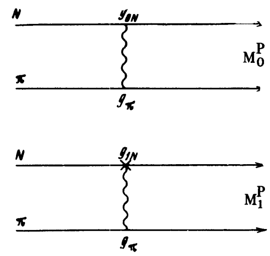

FIG. 1.

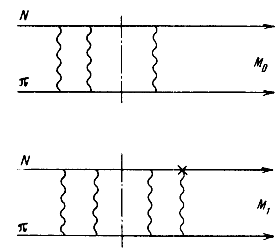

FIG. 2.

account is taken of all rescattering without helicity change and the rescattering with helicity change in first order (Fig. 2), if we make the assumption that $g_{0N}(t)$ and $g_{1N}(t)$ depend in like manner on t. This hypothesis seems physically reasonable, since the dependences of $g_{0N}(t)$ and $g_{1N}(t)$ are determined by the radius of the interaction, which should not depend much on how the scattering takes place - with or without spin flip. (In both cases the scattering proceeds by means of exchange of the same particles.)

In the eikonal approximation we have

$$M_0 = 4\pi i \int (1 - e^{i\delta_0(b)} \cos\delta_f(b)) J_0(qb)\, b\, db, \qquad (4)$$

$$M_1 = -4\pi i \int e^{i\delta_0(b)} \sin\delta_f(b) J_1(qb)\, b\, db. \qquad (5)$$

Here $q = \sqrt{|t|}$, the normalization is chosen such that $\sigma_{tot} = \mathrm{Im}\, M_0(q = 0)$,

$$\delta_0(b) = \frac{1}{4\pi}\int M_0^P J_0(qb)\, q\, dq, \qquad (6)$$

$$\delta_f(b) = -\frac{1}{4\pi}\int M_1^P J_1(qb)\, q\, dq. \qquad (7)$$

Differentiating (6) with respect to the impact parameter b, we obtain, under the assumption of the same dependence of $g_{0N}(t)$ and $g_{1N}(t)$ on t,

$$\delta_f(b) = \frac{1}{2m}\frac{g_{1N}(0)}{g_{0N}(0)}\frac{d\delta_0(b)}{db}. \qquad (8)$$

If we now expand M_0 and M_1 in terms of $\delta_f(b)$, and confine ourselves to the first term in the expansion, then the result corresponds to just the diagrams of Fig. 2. The amplitude M_0 can now be written down in the form

$$M_0 \cong 4\pi i \int (1 - e^{i\delta_0(b)}) J_0(qb)\, b\, db; \qquad (9)$$

and M_1 with the calculation of (8) in the form

$$M_1 \cong -4\pi i \frac{1}{2m}\frac{g_{1N}(0)}{g_{0N}(0)} \int d(1 - e^{i\delta_0(b)}) J_1(bq)\, b. \qquad (10)$$

[1)]The value of spin flip $P_\perp$ is simply related to the parameters A and R of Wolfenstein: $P_\perp = A\cos\theta + R\sin\theta$, where θ is the proton scattering angle in the laboratory system. [2]

Integrating (10) by parts and using the relation $d[bJ_1(bq)] = J_0(qb)qbdb$, we obtain for M_1:

$$M_1 \cong 4\pi i \frac{q}{2m} \frac{g_{1N}(0)}{g_{0N}(0)} \int (1 - e^{i\delta_0(b)}) J_0(qb)\, b\, db; \qquad (11)$$

i.e.,

$$M_1 \cong \frac{\sqrt{|t|}}{2m} \frac{g_{1N}(0)}{g_{0N}(0)} M_0. \qquad (12)$$

The relation (12) immediately leads to a formula for $P_\perp$, analogous to (3), in which $g_{1N}(t)$ and $g_{0N}(t)$ must be taken at $t = 0$. As is evident, the polarization in the approximations (9)—(12) is, as before, equal to zero.

The polarization with allowance for one pole is due to diagrams corresponding at least to double and triple rescattering with a change in helicity respectively in M_0 and M_1, i.e., due to expansion terms containing $(\delta_f)^2(b)$ in M_0 and $(\delta_f)^3(b)$ in M_1. At $t \cong 0$ the relative contribution of these terms to M_0 and M_1 is of the order of $(\delta_f)^2_{max}$ and turns out to be small, since according to the pole parametrization given by Phillips and Rarita[4], $(\delta_f)^2_{max}$ lies between the limits of 10^{-2} and 10^{-3}. Substantial deviations from (12) and the emergence of considerable polarization at $E \cong 100$ GeV can, apparently, take place at $|t| \cong 1(\text{GeV}/c)^2$, when M_0 falls to 10^{-2} of its value at $t = 0$. The polarization arising because of the rescattering due to the Pomeranchuk pole must evidently become the same in π^+p and π^-p scattering. At very high energies the phases δ_0 and δ_f become purely imaginary and the polarization tends to zero for all t. In this manner allowance for the branch cuts in the eikonal approximation leads to the conclusion that asymptotic spin flip effects at small t should not depend on the energy and on the nature of the incident particles.

I express thanks to A. B. Kaĭdalov and K. A. Ter-Martirosyan for a discussion of the questions of the eikonal approximation, and to B. N. Gribov for critical comments.

[1] V. N. Gribov and I. Ya. Pomeranchuk, Phys. Rev. Letters **8**, 412 (1962).

[2] I. I. Levintov and R. M. Ryndin, Yad. Fiz. **7**, 413 (1968) [Sov. J. Nucl. Phys. **7**, 266 (1968)].

[3] R. Arnold, Phys. Rev. **153**, 1523 (1967).

[4] R. J. N. Phillips and W. Rarita, Phys. Rev. **139B**, 1336 (1965).

Translated by N. S. Thornber
249