SOVIET PHYSICS JETP VOLUME 13, NUMBER 1 JULY, 1961

POLARIZATION EFFECTS IN THE SCATTERING OF MUONS ON PROTONS

G. V. FROLOV

Radium Institute, Academy of Sciences, U.S.S.R.

Submitted to JETP editor July 29, 1960

J. Exptl. Theoret. Phys. (U.S.S.R.) **40**, 296-297 (January, 1961)

The polarization of recoil protons and scattered μ mesons during the scattering of polarized μ mesons on unpolarized protons is computed by taking into account the proton electromagnetic form factors.

We report here the calculated polarization of the recoil protons and scattered μ mesons in the scattering of polarized μ mesons by unpolarized protons at rest. The form factors of the protons are taken into account. The calculations were similar to those carried out for electrons,[1,2] the only exception being the account of the μ-meson rest mass m.

We shall define the polarization of the recoil proton in terms of a vector $\mathbf{Z}_2^0$, the average value of the spin operator in the rest system. The polarization vectors for the incident and scattered μ mesons are denoted ζ_1^0 and ζ_2^0, respectively. It is convenient to resolve the polarization vectors into longitudinal and transverse components, defined for the incident meson in the following fashion:

$$\zeta_{1l}^0 = \zeta_1^0 \mathbf{p}_1 / |\mathbf{p}_1|, \qquad \zeta_{1t}^{0\perp} = \zeta_1^0 \mathbf{n}, \quad \zeta_{1t}^{0\parallel} = \zeta_1^0 [\mathbf{p}_1 \mathbf{n}] / |\mathbf{p}_1|. \quad (1)^*$$

Here $\mathbf{n} = (\mathbf{p}_1 \times \mathbf{p}_2)/|(\mathbf{p}_1 \times \mathbf{p}_2)|$, where $\mathbf{p}_1$ and $\mathbf{p}_2$ are the momenta of the incident and scattered mesons. For the recoil proton and the scattered meson the definitions are analogous to (1).

We obtain for the polarization of the recoil protons

$$Z_{2l}^0 = \alpha_{ll}\zeta_{1l}^0 + \alpha_{lt}\zeta_{1t}^{0\parallel},$$
$$Z_{2t}^{0\parallel} = \alpha_{tl}\zeta_{1l}^0 + \alpha_{tt}\zeta_{1t}^{0\parallel}, \qquad Z_{2t}^{0\perp} = \alpha_{22}\zeta_{2t}^{0\perp}, \qquad (2)^*$$

where

$$\alpha_{ll} = 2M\eta\varkappa(1+\mu)[\xi^2 - \eta\xi - m^2(1+\eta)/M^2],$$
$$\alpha_{lt} = m\eta\varkappa(1+\mu)\,\mathrm{tg}\,\vartheta\,[2\eta + 2\eta\xi - \xi^2 + m^2/M^2],$$
$$\alpha_{tl} = M\xi\varkappa(1-\mu\eta)\,\mathrm{tg}\,\vartheta\,[\xi^2 - 2\eta\xi - 2\eta - m^2/M^2],$$
$$\alpha_{tt} = -2m\eta\varkappa(1-\mu\eta)(1+\xi),$$
$$\alpha_{22} = -2m\eta(1+\mu)(1-\mu\eta)/MN,$$
$$\varkappa = (\eta/(\eta+1))^{1/2}(1+\mu)/|p_1|N,$$
$$N = \eta(1+\mu)^2(2\eta - m^2/M^2) + (1+\mu^2\eta)(\xi^2 - 2\eta\xi - \eta).$$

We use the following notation: ϑ — scattering angle, $\xi = E_1/M$, $\mu = b/a$, $\eta = (p_1 - p_2)^2/4M^2$, E_1 — energy of incident meson, a and b — electric and magnetic form factors of the proton, respectively.[1]

For the polarization of the scattered μ mesons we have

$$\zeta_{2l}^0 = \beta_{ll}\zeta_{1l}^0 + \beta_{lt}\zeta_{1t}^{0\parallel},$$
$$\zeta_{2t}^{0\parallel} = \beta_{tl}\zeta_{1l}^0 + \beta_{tt}\zeta_{1t}^{0\parallel}, \qquad \zeta_{2t}^{0\perp} = \beta_{22}\zeta_{1t}^{0\perp}, \qquad (3)$$

where

$$\beta_{ll} = \{(1+\mu^2\eta)[\xi(\xi-2\eta)(1+\cos^2\vartheta) - 2\eta - m^2M^{-2}\sin^2\vartheta] + 2\eta(1+\mu)^2[\xi(\xi-2\eta)\sin^2\vartheta - 2\eta - m^2/M^2]\}/2N\cos\vartheta,$$
$$\beta_{lt} = m\sin\vartheta[(1+\mu^2\eta)(\eta-\xi) + \eta(1+\mu)^2(\xi+2\eta)]/MN,$$
$$\beta_{tl} = m\sin\vartheta[(1+\mu^2\eta)(\xi-\eta) - \eta(1+\mu)^2\xi]/MN,$$
$$\beta_{tt} = \{(1+\mu^2\eta)[\xi(\xi-2\eta)(1+\cos^2\vartheta) - 2\eta - m^2M^{-2}\sin^2\vartheta] - 2\eta(1+\mu)^2m^2M^{-2}\cos^2\vartheta\}/2N\cos\vartheta,$$
$$\beta_{22} = \{(1+\mu^2\eta)(\xi^2 - 2\eta\xi - \eta) - m^2\eta(1+\mu)^2/M^2\}/N.$$

The proton form factors contained in these formulae are determined from electron-scattering experiments. The only assumptions made in the derivation of the formulae were that the first Born approximation in the electromagnetic field is valid and that the μ meson is point-like. Consequently if the deviations from these formulae exceed the corrections of the second Born approximations, this will serve as evidence of the presence of μ-meson structure.

[1] Akhiezer, Rozentsveĭg, and Shmushkevich, JETP **33**, 765 (1957), Soviet Phys. JETP **6**, 588 (1957).

[2] G. B. Frolov, JETP **34**, 764 (1958), Soviet Phys. JETP **7**, 525 (1958).

Translated by J. G. Adashko
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*$[\mathbf{p}_1 \mathbf{n}] = \mathbf{p}_1 \times \mathbf{n}$; tg = tan