Polarization Effects in High-Energy Weak Interactions (*)

S. L. Adler (**)

Palmer Physical Laboratory, Princeton University - Princeton, N. J.

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Summary. — The cross-section for the production of a polarized lepton and baryon in the reaction

\[ \text{neutrino} + \text{nucleon} \rightarrow \text{lepton} + \text{baryon} \]

is computed exactly to lowest order in the weak interaction. Results are given (a) in covariant form, and (b) in the center-of-mass system of the reaction, expressed directly in terms of the lepton and baryon decay asymmetries. The results are discussed with special emphasis on determining the form factors in the strangeness-changing weak interactions, on isolating induced scalar and induced pseudoscalar effects, and on testing time-reversal invariance in high-energy weak interactions.

1. — Introduction.

The purpose of this paper is to show that useful information about the weak interactions at high energy may be obtained by studying polarization effects. The specific interactions considered are:

1a) \[ \nu + n \rightarrow l + p \],

1b) \[ \nu + n \rightarrow l + \Sigma^+ \],

1c) \[ \bar{\nu} + p \rightarrow \bar{l} + n \],

1d) \[ \bar{\nu} + n \rightarrow \bar{l} + \Sigma^- \],

1e) \[ \bar{\nu} + p \rightarrow \bar{l} + \Lambda \],

1f) \[ \bar{\nu} + p \rightarrow \bar{l} + \Sigma^0 \].

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where \((\nu, l)\) are either \((\nu_e, e^-)\) or \((\nu_\mu, \mu^-)\) and \((\bar{\nu}, \bar{l})\) are either \((\bar{\nu}_e, e^+)\) or \((\bar{\nu}_\mu, \mu^+)\).

In the reactions of eqs. \((1b, c, f)\), the hyperon polarization is automatically analysed in the hyperon decay. If the final lepton is a muon and if its decay can be observed, its polarization can also be measured.

It thus is important to have expressions for the final lepton and baryon polarizations, and for correlation effects involving both polarizations, expressed in terms of the weak interaction form factors. We have calculated these expressions exactly to lowest order in the weak interaction, assuming that the basic weak coupling is of the vector-axial vector type and retaining all «induced» terms which appear at nonzero momentum transfer \((^1)\). In Section 2 we give the notation used and state the results. In Section 3 we discuss the results, with special emphasis on the questions of (A) determining the form factors in the strangeness-changing \((\Delta S \neq 0)\) weak interactions, (B) isolating induced scalar and induced pseudoscalar effects, and (C) testing time-reversal invariance in the high-energy weak interactions.

2. - Notation and Results.

A) Notation. - We consider reactions of the form

\[
\nu(\bar{\nu}) + N' \rightarrow b + l(\bar{l}) \, ,
\]

with \(N\) a nucleon of mass \(M_1\), \(b\) a baryon of mass \(M_2\), and \(l(\bar{l})\) a lepton of mass \(m_1\). We denote by \(k_1, k_2, p_1\) and \(p_2\) the momentum four-vectors \((^2)\) of \(\nu(\bar{\nu}), l(\bar{l}), N'\) and \(b\), respectively, and define Mandelstam variables \(s, t, u\) by

\[
s = - (p_1 + k_1)^2 ,
\]
\[
t = - (k_2 - k_1)^2 ,
\]
\[
u = - (p_2 - k_1)^2 .
\]

We denote by \(q\) the momentum transfer to the leptons, \(q = k_2 - k_1\), so that \(t = -q^2\). We take \(h = c = 1\) throughout.

\(^1\) Certain partial results have been calculated previously. T. D. Lee and C. N. Yang: Phys. Rev., 126, 2239 (1962), present expressions for longitudinal polarization effects in the reactions \(\nu + n \rightarrow l + 1 + p\) and \(\bar{\nu} + p \rightarrow \bar{l} + n\). Ya. I. Azimov and V. M. Shekhter: Zhurn. Eksp. Teor. Fiz., 41, 592 (1961) [Translation: JETP, 14, 424 (1962)], have calculated the dependence of the rate of \(\mu^- + p \rightarrow \Lambda + \nu\) on the initial \(\mu^-\) polarization.

\(^2\) We use complex four-vectors, \(e.g., \, P_1 = (p_1, ip_{10})\). \(P_1^2 = -M_1^2\). The \(\gamma\)-matrices satisfy \(\{\gamma_\alpha, \gamma_\beta\} = 2 \delta_{\alpha\beta}\).