The enclosed paper is a contribution to the proposal "Measurement of the polarization parameter in p-n elastic and charge exchange scattering at 24 GeV/c" (CERN/EEC-76/17).

CERN-LAPP(Annecy)-Oxford Collaboration
ON THE IMPORTANCE OF MEASURING NEUTRON - PROTON ELASTIC
AND CHARGE EXCHANGE POLARIZATIONS AT HIGH ENERGIES

C. BOURRELY, A. MARTIN and J. SOFFER
Centre de Physique Théorique, C.N.R.S., MARSEILLE

In this short note we would like to mention some of the reasons why measuring neutron-proton elastic and charge exchange polarizations is of physics interest.

I - Introduction

The polarization in neutron-proton elastic scattering has only recently been measured at Argonne between 2 and 6 GeV/c \(^1\). The results have been largely unanticipated and have shed new light on the exchange which are presumed to give rise to the nuclear force. The utility of having the p-n polarization in addition to the existing p-p data, is that the sum and difference of these allow the separation of different groups of exchanges corresponding to isospin 0 and 1. The difference in energy behavior of the two, which is the striking discovery of the experiment of Diebold et al. \(^1\) has elicited different theoretical proposals \(^2, 3, 4\) which differ widely in their predictions for the intermediate energy range, 6-30 GeV/c, where Regge pole exchange is most applicable. Measurements at these and higher energies would therefore be crucial in deciding between these alternative explanations and in investigating the possible spin-dependence of the Pomeron as we will see below.

The charge-exchange (CEX) polarization has been measured between 3 and 12 GeV/c \(^5\) and found very large and growing roughly as \(\sqrt{s}\). The theoretical interpretation for these data is rather unclear and we will only give, as a guide for experimentalists, the results of a simple parametrization which reproduces fairly well the main features of the data.
Determination of $\text{Re} \phi_5$ from n-p elastic polarization

The nucleon-nucleon interaction has a rich spin structure, expressible in terms of 5 s-channel helicity amplitudes $\phi_i$ ($i=1...5$) depending on energy and momentum transfer. An experimental program is under way at the ZGS (Argonne) with the goal of complete reconstruction of these amplitudes at 6 and 12 GeV/c (6). However, under traditional assumptions it can be seen that polarization measurements teach us about the real part of the single helicity flip amplitude $\phi_5$.

Let us recall the expressions of the differential cross section and polarization in terms of the amplitudes $\phi_i$ ($i=1...5$)

$$\frac{d\sigma}{dt} = |\phi_1|^2 + |\phi_2|^2 + |\phi_3|^2 + |\phi_4|^2 + 4 |\phi_5|^2,$$

$$\frac{d\sigma}{dt} P = -2 \text{Im} \left( (\phi_1 + \phi_2 + \phi_3 - \phi_4) \phi_5^* \right),$$

where $\phi_1$ and $\phi_3$ are the non-flip amplitudes, $\phi_2$ and $\phi_4$ the double-flip amplitudes, and $\phi_5$ the single-flip amplitude. It is commonly accepted that:

i) the non-flip amplitudes dominate the cross section; (in particular $\phi_2$ and $\phi_4$ are negligible in the polarization)

ii) the non-flip amplitudes are predominantly imaginary at least to $t = 1 \text{ GeV}^2$.

iii) $\phi_1$ is approximately equal to $\phi_3$.

iv) the single-flip amplitude $\phi_5$ is predominantly real, which is supported by simple duality arguments.

Under these assumptions one has

$$\text{Re} \phi_5 = -\frac{1}{2} \sqrt{\frac{d\sigma}{dt}} P.$$

The amplitudes can be decomposed into isoscalar ($P, \omega$) and isovector contributions ($\rho, A_2, \pi$) in the t-channel so we have for the two cases p-p and n-p:

$$\text{Re} \phi_5(I_t=0) + \text{Re} \phi_5(I_t=1) = -\frac{1}{2} P_{pp} \sqrt{\frac{d\sigma_{pp}}{dt}}$$

$$\text{Re} \phi_5(I_t=0) - \text{Re} \phi_5(I_t=1) = -\frac{1}{2} P_{np} \sqrt{\frac{d\sigma_{np}}{dt}}$$
In addition \( \frac{d\sigma_{pp}}{dt} = \frac{d\sigma_{np}}{dt} \) within experimental errors (i.e. the isovector contributions to the non-flip amplitudes, which are, moreover, bounded by the n-p CEX differential cross section, are very small) so

\[
\text{Re} \, \hat{A}_5(I_t=0) = -\frac{1}{4} \sqrt{\frac{d\sigma}{dt}} \left[ P_{pp} + P_{np} \right]
\]

\[
\text{Re} \, \hat{A}_5(I_t=1) = -\frac{1}{4} \sqrt{\frac{d\sigma}{dt}} \left[ P_{pp} - P_{np} \right]
\]

For \( t \)-values between 0.15 and 0.65 GeV\(^2\) the energy behavior for \( 2 \leq \sqrt{s} \leq 5 \) GeV/c observed from experiment (1) is very different for the two contributions because one has

\[
\text{Re} \, \hat{A}_5(I_t=1) \sim \frac{1}{s}
\]

and

\[
\text{Re} \, \hat{A}_5(I_t=0) \sim \frac{1}{s^2}
\]

The fundamental issue is the question posed by these two different energy dependences.

The energy behavior of the \( I_t=1 \) contribution is expected from standard Regge exchange such as \( Q, A_2 \) with a trajectory \( \alpha = 0.5 + t \). The \( I_t=0 \) contribution has a peculiar \( s \)-dependence which requires a new interpretation. Various approaches have been taken for this:

1) \( P', \omega \) decouple from \( \hat{A}_5 \) which is then dominated by a lower lying trajectory. This is the solution advocated by Dash and Navelet (2) who invoke the \( \Xi \)-trajectory \( \alpha_\Xi = -0.5 + t \). The immediate consequence is that at higher energies the polarizations approach mirror symmetry i.e. \( P_{pp} = -P_{np} \).

2) Another possibility proposed by Irving (3) consists of having for \( \hat{A}_5 \) two contributions of opposite signs so in this case

\[
\text{Re} \, \hat{A}_5 = A_s + B_s \alpha_R(t) \quad \text{with} \quad A/B < 0
\]

where the first term is the Pomeron and the second term is a standard Regge. The cancellation of these two terms produces a more rapid energy
fall off.

iii) An eikonal model proposed by us (4), combining both mechanisms, which gives a fairly good fit to the p-p and n-p polarizations at 6 GeV/c (see fig. 1).

The three above models give different predictions for the n-p elastic polarization at 24 GeV/c (see fig. 2).

Concerning the t-dependence, we recall that at $P_{lab} = 12.33$ GeV/c the p-p polarization exhibits a pattern of double zeros at $t \cong -0.9$, $-2.5$, $-5.$, GeV$^2$ (7). Here simple Regge models fail to explain this phenomena and one is led to consider a geometric approach which should be applicable to the $I_t=0$ contribution, for instance $\text{Im} \Phi_1 \sim J_1(R \sqrt{-t})/R \sqrt{t}$ (black disk) and $\text{Re} \Phi_5 \sim J_1(R \sqrt{-t})$ (peripheral) (8). The oscillations of $\text{Im} \Phi_1$ and $\text{Re} \Phi_5$ approximately coincide, which yields double zeros in the polarization. In the case of n-p scattering polarization measurements only go to $t = -1$ GeV$^2$ and do not allow the identification of such a structure in the separated amplitude, so it is of interest to measure n-p polarization (with high precision) at large $t$ in order to conclude that the mechanism producing zeros is of a geometric nature or may be due to an interference between the $I_t=0$ and the $I_t=1$ contributions. The t-dependence for models i) to iii) is exhibited in fig. 2 and note that for models i) and ii) predictions are limited to $t = -1$. GeV$^2$.

3 - The spin properties of the diffractive part

A very interesting problem concerns the nature of the Pomeron or diffractive part of the scattering amplitude. In particular one would like to learn more about the factorization properties of this contribution and to decide how important it is in the single flip amplitude. Evidence for such a component exists also in $\pi$-N scattering (see Ref. (4) for a discussion on this point). If it is negligible one would expect, as stated above (see model i)), a mirror symmetry in the polarizations p-p and n-p at high energies. On the contrary, if the two polarizations have more and more the same shape as energy increases, this would mean definitely the presence of a flip component in the diffractive scattering. Of course it would be most interesting to perform these experiments in the SPS energy range.
4 - Nucleon-nucleon charge exchange polarization

This reaction is dominated near the forward direction by the pion exchange which produces a very narrow peak (see fig. 3) and experimentally \( \frac{p_{\text{lab}}^2}{d\sigma}{d\beta} \) is roughly energy independent out to \(-t = 1 \text{ GeV}^2\). The pion contributes equally to \( \Phi_2 \) and \( \Phi_4 \) by parity, and is known to be strongly absorbed in \( \Phi_2 \). Theoretically one can try a simple model of the type Poor Man's Absorption (PMA) (9) such as

\[
\Phi_2 = \frac{g^2}{4\pi} \left[ t \frac{e^{c_1 t}}{t^{\mu^2}} - B \frac{e^{c_2 t}}{t} \right]
\]

\[
\Phi_4 = \frac{g^2}{4\pi} te^{c_3 t} \left( \frac{4}{c_0^2} = 14.6 \right)
\]

The polarization is large and positive and grows with \( s \) (see fig. 4). The energy dependence follows a power law \( p_{\text{lab}}^n \) with \( n = 0.5 \) approximately as indicated on fig. 5. Because of this polarization one must also include a single flip amplitude, dominated by a standard trajectory, whose imaginary part is

\[
\text{Im} \Phi_5 = g_5 \left( -t \right)^{c_4 t} \frac{1}{s^{0.5+ t}}
\]

We have obtained a fairly good fit to the existing data between \( 3 < p_{\text{lab}} < 27 \text{ GeV/c} \) and \( |t| < 1 \text{ GeV}^2 \) as shown on figs. 3 and 4 with the following parameters \( c_1 = 9.61 \text{ GeV}^{-2} \), \( c_2 = 3.64 \text{ GeV}^{-2} \), \( c_3 = 10 \text{ GeV}^{-2} \), \( c_4 = -1.16 \text{ GeV}^{-2} \) and \( g_5 = -0.39 \text{ GeV}^{-1} \). As mentioned above this is only a numerical parametrization to be used as a guide for experimentalists.
- REFERENCES -

(1) R. DIEBOLD et al.

(2) J.W. DASH and H. NAVELET
LBL-4215 preprint, July 1975.

(3) A.C. IRVING
LTH 6 preprint Liverpool, July 1975.

(4) C. BOURRELY, A. MARTIN and J. SOFFER
Saclay preprint (in preparation).

(5) M.A. ABOLINS et al.

(6) Report of the ANL Technical Advisory Panel preprint
Argonne ANL-HEP-CP 75-73, November 1975.

(7) G.W. ABSHIRE et al.

(8) A.W. HENDRY and G.W. ABSHIRE

(9) P.K. WILLIAMS
Fig. 3

np → pn

3 GeV/c

4 GeV/c

5 GeV/c

8 GeV/c

11 GeV/c

27 GeV/c

15 GeV/c

\frac{d\sigma}{dt} (mb \times GeV^{-2})

t (GeV)^2