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POLARIZATION EFFECTS IN n-p SCATTERING

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September 26, 1951

Berkeley, California
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The expected azimuthal asymmetry in a double scattering of high energy neutrons by protons has been calculated using the 'half exchange' n-p interaction of Christian and Hart

If the first incident beam and both targets are unpolarized, then the intensity of the twice-scattered neutrons is given by:

\[ J(\theta_1, \theta_2, \phi_2) = I_1(\theta_1) I_2(\theta_2) + Q_1(\theta_1) Q_2(\theta_2) \cos \phi_2. \]

\[ P_y(\theta_1, \phi_1=0) = \frac{Q_1(\theta_1)}{I_1(\theta_1)} \] is the component of polarization, normal to the plane of the first scattering of the once scattered neutron beam. \( Q_2 \cos \phi_2 \) is the \( I_p \) defined by Wolfenstein. \((\theta_1, \phi_1=0)\) are the coordinates of the second target with the first target as origin and the incident beam as z-axis. \((\theta_2, \phi_2)\) are the coordinates of the twice-scattered neutrons with the second target as origin and a z-axis defined by the two targets; \( \phi_2 \) is measured from the plane of the first scattering. \( I_1(\theta_1), I_2(\theta_2) \) are the differential cross sections with polarization terms omitted.

Although polarization effects vanish in the Born approximation, the higher angular momentum states in a partial wave analysis can profitably be so calculated since interference terms with states of
lower angular momentum (computed exactly) do not vanish. Accordingly
the calculations were carried out using the phase shifts of Christian
and Hart in the $^3S_1$, $^3D_1$, $^3D_2$, and $^3D_3$ states, with all higher
included in the Born approximation.

$Q_1$ and $Q_2$ are equal (at the same angle and energy),
provided that, in a partial wave analysis, all Wronskian conditions
on the phase shifts of the coupled equations are satisfied. In
Figure 1, values of $Q(\Theta)/I(\Theta)$ are plotted as a function of center
of mass angle for any single n-p scattering. One can see from the
equations of Wolfenstein* that $Q(\Theta)$ is antisymmetric about $\pi/2$
for odd or even parity states alone (hence zero at $\pi/2$), but
symmetric for odd-even interference terms. Detection of azimuthal
asymmetry at $\pi/2$ would therefore indicate the presence of both
odd and even terms, and so disprove the 'even' exchange hypothesis.
In the case of p-p scattering, the $\pi/2$ point should of course give
no polarization regardless of the assumed interaction since the
even triplet states are not present.

It is of interest to note that almost the entire energy
dependence of the polarization $Q(\Theta)/I(\Theta)$ lies in the differential
cross section $I(\Theta)$. This behaviour is not entirely surprising,
since $Q(\Theta)$ is determined principally by the $^3S - ^3D$ interference
terms; the $S$ phase shifts decrease and the $D$ increase with increasing
energy apparently in such a way as to leave $Q(\Theta)$ almost independent
of energy between 90 Mev and 285 Mev.

With energies of 220 Mev and 160 Mev for the two scatterings,
respectively, the ratio

$$\frac{J(\beta_2=0)}{J(\beta_2=\pi)}$$

is $1.12 \pm 0.03$ at $\Theta_1=65^\circ$, $\Theta_2=60^\circ$. 
The ±.03 is based on an estimate of the accuracy to which the phase shifts are known.

Although the problem has been formulated for two scatterings of a neutron beam, the first scattered beam could just as well have arisen from a (p,n) reaction. This follows from the equality of polarization of the two scattered particles and from the invariance of the scattering amplitude under the substitution Θ → Θ' and Φ → Φ + Ψ' because of the exchange dependence assumed. A similar argument for the second scattering shows that the scattered intensity of the protons at any angle is the same as that of the neutrons.

In an accompanying letter, L. Wouters reports an experiment in which a beam of polarized neutrons was produced by a (p,n) reaction in LiD and detected by means of an n-p scattering. The resulting asymmetry agrees in sign and order of magnitude with the above calculations. The experiment was also carried out with LiH as first target; for this case no significant asymmetry was detected.

A more refined interpretation of the results could be obtained by calculating the polarization from the D(p,n) reaction, here assumed equivalent to a scattering of protons by free neutrons. The failure to detect asymmetry with the LiH target does not seem particularly disturbing since scattering from neutrons bound in Li⁷ might reasonably be expected to yield less polarization than would scattering from free neutrons, sufficiently less to escape detection in Wouters' experiment.

The experimental results, although consistent with the 'even' theory, are not of sufficient precision to allow one on this
basis to rule out interaction in the odd triplet states. This point is under further investigation in the hope that a quantitative argument can be made.

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REFERENCES


2. L. Wolfenstein, Phys. Rev. 76, 541.

FIGURE CAPTION

Figure 1: The polarization \( P_y(\theta, \varphi=0) = \frac{Q(\theta)}{I(\theta)} \) as a function of scattering angle \( \theta \) (c.m. system) for a single n-p collision at laboratory energies of 40, 90, 200, 285 Mev.
Fig. 1