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USEFULNESS OF SPIN DEPENDENT ELECTROMAGNETIC
HADRONIC INTERFERENCE EXPERIMENTS

E. Leader ^{*)}

CERN - Geneva

ABSTRACT

For the collision of a beam of neutral spin $\frac{1}{2}$ particles A with a polarized target of spin $\frac{1}{2}$ charged particles B, it is shown that many spin dependent observables display a simple and characteristic structure in t which can be utilized to measure directly the magnitude and phase of the hadronic amplitudes, both helicity-flip and non flip, in the forward direction.

*) Permanent address: Westfield College,
London NW3 7ST.

Long ago Schwinger¹⁾ noted that the polarization P_n of the neutron in an np elastic collision would show a maximum of almost 100% at very small t as a result of interference between Electromagnetic and Hadronic forces. Recently Buttimore, Gotsman and Leader (referred to as BGL) have given a very detailed treatment of the interference effects in many spin dependent observables²⁾ for spin $\frac{1}{2}$ - spin $\frac{1}{2}$ scattering. Our aim here is twofold:

- i) To show that several of the observables examined in BGL display the same simple pattern in t . They all have a maximum (or minimum) at essentially the same value of t .
- ii) To emphasize the theoretical significance of a measurement of the maximum (or minimum) values of these observables.

Consider the collision of neutral particles A with charged particles B. We are thinking particularly of $np \rightarrow np$ or $\Lambda p \rightarrow \Lambda p$. The invariant differential cross-section is given, for small t , by

$$\frac{d\sigma}{dt} = 4\pi \left\{ \frac{I^{(1)}}{\tau} + I^{(0)} \right\} \quad (1)$$

where

$$\tau = -t \quad (2)$$

$$I^{(1)} = \frac{\alpha^2 \kappa_A^2}{4 m_A^2} \quad (3)$$

with κ_A the anomalous magnetic moment of A, α the fine structure constant, m_A the mass of A, and, aside from very small correction terms,

$$I^{(0)} = \left(\frac{1}{4\pi} \frac{d\sigma^N}{dt} \right)_{t=0} \quad (4)$$

The superscript N indicates an essentially hadronic quantity³⁾.

We assume in the following that $I^{(0)}$ is known, either from a measurement of $d\sigma/dt$ according to Eq. (1) or by means of an estimate based on the optical theorem, which would give

$$I^{(0)} \approx \left(\frac{\sigma_{TOT}}{8\pi} \right)^2 \quad (5)$$

Many interesting observables X have the following behaviour for small τ :

$$X \frac{d\sigma}{dt} = 4\pi \left\{ \frac{\alpha \chi_A X^{(1)}}{\sqrt{\tau'}} + \sqrt{\tau'} X^{(0)} \right\} \quad (6)$$

where $X^{(1)}$ and $X^{(0)}$ are of hadronic magnitude. The expression for X itself

$$X = \sqrt{\tau'} \frac{\alpha \chi_A X^{(1)} + \tau X^{(0)}}{I^{(1)} + \tau I^{(0)}} \quad (7)$$

ought not be expanded in τ , since for the interesting range of τ both terms in the denominator can be of comparable size.

These observables X all have a maximum (or minimum) at essentially the same point ⁴⁾

$$\tau = \tau_m = \frac{I^{(1)}}{I^{(0)}} = \frac{\alpha^2 \chi_A^2}{4 m_A^2} \cdot \frac{1}{I^{(0)}} \approx \left(\frac{4\pi \alpha \chi_A}{m_A \sigma_{TOT}} \right)^2 \quad (8)$$

and their values at this point are

$$X = X^{MAX} = \frac{m_A X^{(1)}}{\sqrt{I^{(0)}}} \quad (9)$$

where small terms of order α have been neglected.

Thus the measurement of X^{MAX} provides a direct measure of the hadronic quantities in $X^{(1)}$. In the table we list important observables X and the corresponding expressions for X^{MAX} in terms of the hadronic amplitude at $t=0$. Since the results are always ratios of amplitudes the normalization convention for the ϕ_1^N is irrelevant. Of course, if absolute magnitudes are desired, then $\text{Im}(\phi_1^N + \phi_3^N)$ would have to be obtained via the optical theorem which in the convention of BGL reads

$$\text{Im}(\phi_1^N + \phi_3^N) = \frac{\sqrt{s} P_{c.m.}}{2\pi} \sigma_{TOT} \quad (10)$$

Observable X	Value X^{MAX} at $t = -\tau_M$
Polarization of A: P_A	$(1 + \rho^2)^{-1/2} \quad (a)$
Polarization of B: P_B	$\frac{\text{Im } \Phi_2^N}{\text{Im}(\Phi_1^N + \Phi_3^N)}$
Spin correlation parameter: A_{SL}	$-\frac{\text{Re}(\Phi_1^N - \Phi_3^N)}{\text{Im}(\Phi_1^N + \Phi_3^N)}$
Spin correlation parameter: A_{LS}	$-\frac{\text{Re } \Phi_2^N}{\text{Im}(\Phi_1^N + \Phi_3^N)}$
Depolarization parameters for A: $D_{LL}^{(A)} \sin \theta_L - D_{LS}^{(A)} \cos \theta_L \quad (b)$	$\rho \quad (a)$

$$(a) \quad \rho = \frac{\text{Re}(\Phi_1^N + \Phi_3^N)}{\text{Im}(\Phi_1^N + \Phi_3^N)} \quad \text{at } t = 0.$$

(b) θ_L is the LAB scattering angle.

Strictly speaking, the expression for P_A^{MAX} should be

$$P_A^{\text{MAX}} = \left\{ 1 + \rho^2 + \left(\frac{|\Phi_1^N - \Phi_3^N|}{\text{Im}(\Phi_1^N + \Phi_3^N)} \right)^2 + 2 \left(\frac{|\Phi_2^N|}{\text{Im}(\Phi_1^N + \Phi_3^N)} \right)^2 \right\}^{-1/2} \quad (11)$$

and the expressions for all the other X^{MAX} should be multiplied by this factor. The correction terms in (11) are almost certainly negligible. Once, however, P_A^{MAX} is measured, and if it is found to differ significantly from 100%, then the other expressions given in the table become exact for the experimental ratios $X^{\text{MAX}}/P_A^{\text{MAX}}$ rather than for the X^{MAX} themselves.

We turn now to the significance of the quantities measured.

- i) Strangely, it is very difficult to measure ρ for a neutral-charged collision. P_A provides an insensitive measure of ρ ($\rho \ll 1$), and the depolarization experiment requires monitoring of the polarization of the fast scattered neutral particle - feasible perhaps for Λ^S but impractical for neutrons.
- ii) The recent measurement of the transverse cross-section difference $\Delta\sigma_T$ in $pp \rightarrow pp$ at Argonne ⁵⁾ surprised many people by showing that $\text{Im}\Phi_2^N(t=0) \neq 0$ in $pp \rightarrow pp$. Most theories now attribute this to $I=1$ exchange. If so we expect to find $\Phi_2(np \rightarrow np) = -\Phi_2(pp \rightarrow pp)$. A check would be valuable.
- iii) The measurement of the longitudinal cross-section difference $\Delta\sigma_L$ in $pp \rightarrow pp$ at Argonne ⁶⁾, which showed that $\text{Im}(\Phi_1^N - \Phi_3^N)_{t=0} \neq 0$, was even more surprising. A whole generation of physicists have assumed $\Phi_1 = \Phi_3$! The difference is now hypothesized as due to A_1 exchange. If so, then $(\Phi_1 - \Phi_3)_{np \rightarrow np} = -(\Phi_1 - \Phi_3)_{pp \rightarrow pp}$. Knowledge of $\text{Re}(\Phi_1 - \Phi_3)$ will allow a check on the phase of $\Phi_1 - \Phi_3$, and thus on the trajectory of the A_1 .
- iv) Even more dramatic than (ii) above could be the measurement of $\text{Re}\Phi_2^N(t=0)$ in $np \rightarrow np$. This has always been supposed to be given by the absorptive corrections to π -exchange - in practice by the Williams model. It is also supposed to be measured in forward np charge exchange scattering. A direct measurement of $\text{Re}\Phi_2^N$ would provide the first genuine test of what has become a folk-myth in physics.

We note that $\text{Im}(\Phi_1^N - \Phi_3^N)$ is the only non-zero forward amplitude not measured by the above experiments. It can be found by interference type measurements but requires the monitoring of the polarization of 3 particles.

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REFERENCES

- 1) J. Schwinger, Phys. Rev. 73, 407 (1948).
- 2) N.H. Buttimore, E. Gotsman and E. Leader, "Spin Dependent Phenomena Induced by Electromagnetic-Hadronic Interference at High Energies", Westfield College Preprint, May 1977.
- 3) These "hadronic" quantities do suffer some electromagnetic contamination, which in some cases can be quite serious. A detailed discussion is given in Ref. 2.
- 4) A more accurate result is
$$\tau_M = \frac{I(1)}{I(0)} \left\{ 1 + \frac{\alpha_A^2}{m_A^2} \frac{X(0)}{X(1)} \right\} .$$
The correction would be significant only if $X^{(0)} \gg X^{(1)}$.
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