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Time Symmetry and the P-A Theorem in Nuclear Reactions

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Given a nuclear reaction and its inverse, involving particles with arbitrary spin

$$A + \vec{a} \rightleftarrows B + b \tag{1}$$

the following relation exists between the analyzing power $\vec{A}$ and the polarization $\vec{P}$

$$\vec{A}_b = \vec{P}_a \tag{2}$$

if time symmetry holds for the reaction, as proven by Satchler[1]. In recent years experiments have been carried out for a number of reactions [2-8] in order to test relation (2). A difference between $A_{b,Z}$ and $P_{a,Z}$, for example, may be construed as evidence for a violation of time symmetry. Analyzing powers are relatively easy to measure with contemporary ion-source produced polarized beams. Polarization measurements of reaction products, for instance in $B(b,\vec{a})A$, are time consuming due to the low counting rate. The difficulty is compounded by backgrounds underlying particle spectra. The measurements of Refs. 4, 6 and 8 were carried out with pairs of polarimeters placed at symmetric angles with respect to the beam. This technique is known to diminish considerably errors due to lateral beam displacement. The other measurements were carried out with a single polarimeter, displaced from the left to the right of the beam in some experiments (Ref. 3) or using magnetic analysis together with a criterion for centering the polarimeter (Ref. 7). Differences between polarization (P) and analyzing powers (A) have been observed in several reactions (Refs. 2, 4, 5, 6, 8). However, some authors (Refs. 4,5) are inclined to stress the difficulties inherent to polarization measurements, rather than to discuss the implications of the clear differences between P and A at some points. The reaction $^9Be(^3He,\vec{p})^{11}B$ and its inverse has been studied by four laboratories to date (Laval, Berkeley, Los Alamos and Bonn). The results of the Bonn group[7] are consistent with zero polarization. However, the criterion for centering the polarimeter should be in error when the angular dependence of the cross section has a non-zero derivative : $d/d\theta[d\sigma/d\Omega] \neq 0$. The results of the Los Alamos group[3] are consistent with the analyzing powers measured by the Laval-Berkeley group. The Los Alamos results are obtained with a single polarimeter, modified in order to extend the original design and calibration[9] (from 6 to 16 MeV protons) to 20 MeV protons, as required in the $^9Be(^3He,\vec{p})^{11}B$ reactions induced by a 14 MeV ^3He beam. The modified polarimeter was not calibrated. Backgrounds are usually a delicate problem in polarization measurements. Fig. 1 shows peaks from data published in Ref. 7, after performing two-channel sums. Fig. 3 of Ref. 3 shows their criterion for background subtraction, with the properly normalized random coincidence spectra, off the "prompt" peak in the time spectrum. These spectra yield for $\theta_L = 40^o$ (polarimeter-left of beam) $\varepsilon = -0.17$ and $P = \varepsilon/A_{eff} = 0.27 \pm 0.08$ with $A_{eff} = -0.63$. However, random coincidences are due to independent events in the passing and side detectors of their polarimeter. Due mainly to slit and multiple scattering, a background of <u>real</u> protons is also present. With the quite reasonable background subtraction of Fig. 1 one obtains $\varepsilon = -0.24$ and $P = 0.37 \pm 0.08$ <u>much higher</u> than the result using the criterion of Ref. 3, thus indicating a possible rather large systematic error, which could explain discrepancies with respect to Ref. 2.

It is pertinent to consider the plausibility attached to observed P-A differences and the sensitivity of polarization observables to the difference $\delta = M^{\dagger}-M^{i}$, compared to the sensitivity of cross sections (M is the transition matrix). It can be shown from the general structure of such observables, that P and A are much more sensitive to time symmetry violations[10]. Here we show simply a comparison of cross sections and polarizations (analyzing powers), from a calculation where $M^{\dagger} = M^{i} + \delta$ (δ small). For simplicity a system of spin ($\frac{1}{2}$, 0) has been considered, assuming that $[\Pi,H] \neq 0$, where Π is the parity operator, for example $^3He + {}^4He$ at 7.4 MeV. The transition matrices have been constructed from phase shifts. In particular M^{i} (for the inverse reaction) was obtained with phase shifts (in degrees) $\delta_0 = -60$, $\delta_1^+ = 135$, $\delta_1^- = 127$, $\delta_2^+ = 0$, $\delta_2^- = 5$, $\delta_3^+ = 171$, $\delta_3^- = 21$, M was obtained with phase shifts $\delta_0 = -60$, $\delta_1^+ = 135$, $\delta_1^- = 126$, $\delta_2^+ = 5$, $\delta_2^- = 0$, $\delta_3^+ = 170$, $\delta_3^- = 22$. The expressions for analysing powers and polarizations are respectively

$$\vec{A}_b = \mathrm{Tr}(M\vec{\mathcal{P}}_b M^\dagger)/\mathrm{Tr}(MM^\dagger) \quad ; \quad \vec{P}_a = \mathrm{Tr}(\vec{\mathcal{P}}_a M^i M^{i\dagger})/\mathrm{Tr}(M^i M^{i\dagger}) \qquad (3)$$

where $\vec{\mathcal{P}}$ is defined by the normalized spin components. The results are shown in Fig. 2 for a component of $\vec{A}_b$ and $\vec{P}_a$. While the cross sections show unmeasurably small differences (with the present state of the art) polarisation observables bear important differences. Clearly P and A show a magnifying glass effect. The curves look rather similar and this might compound difficulties in comparative measurements, introducting subjective factors during data analysis. From a fundamental point of view, several authors have discussed time symmetry violation and its implications for nuclear forces and observables[11]. It should be understood that P≠A implies time symmetry violation within the structure of quantum mechanics, with linearity of operators and hermiticity of observables, and other assumptions required for the proof of the theorem. In conclusion, the high sensitivity of polarization observables may render P-A differences consistent with small time symmetry violations in nuclear reactions.

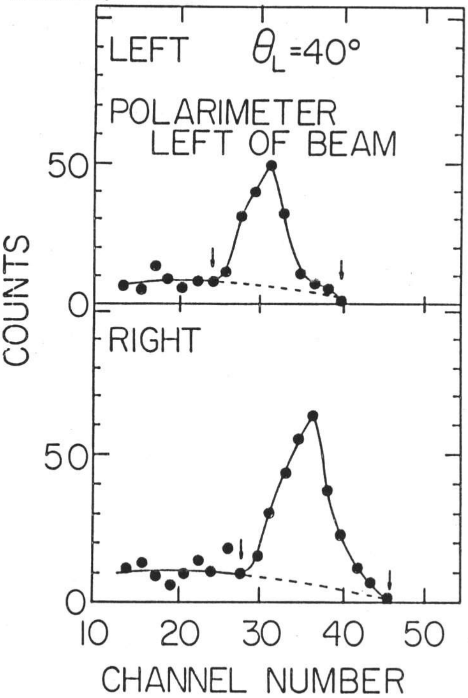

Fig. 1 - Background subtraction to spectra of Ref. 3 (dashed line)

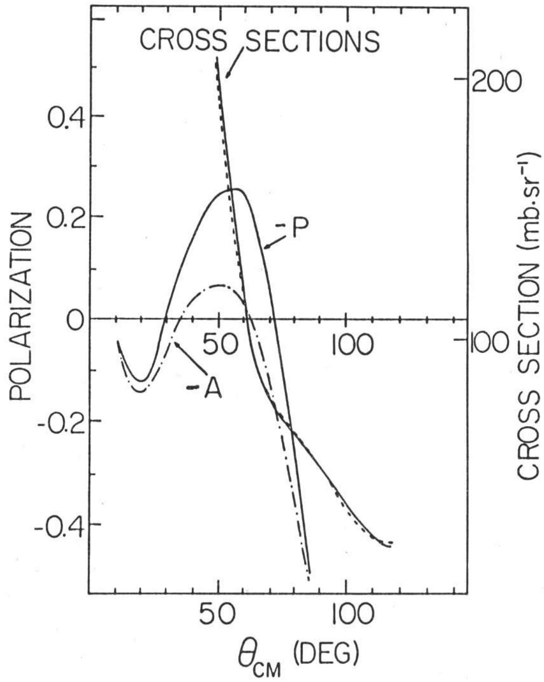

Fig. 2 - P and A comparisons in elastic scattering. Note the unmeasurably small differences in cross sections.

References

1) G.R. Satchler, Nucl. Phys. 8 (1958) 65.
2) R.J. Slobodrian et al., Phys. Rev. Lett. 47 (1981) 1803.
3) R.A. Hardekopf, P.W. Keaton, P.W. Lisowski and L.R. Veeser, Phys. Rev. C25 (1982) 1090.
4) B.L. Burks et al., Phys. Rev. C25 (1982) 1168.
5) A.L. Sagle et al., Phys. Rev. C25 (1982) 1685.
6) C. Rioux, R. Roy, R.J. Slobodrian et H.E. Conzett, Nucl. Phys. A394 (1983) 428.
7) R.P. Trelle et al., Phys. Lett. 134B (1984) 34.
8) J. Pouliot et al., J. Physique (Paris) 45 (1984) 71.
9) R. Hardekopf, D.D. Armstrong and P.W. Keaton, Nucl. Instr. and Meth. 114 (1974) 17.
10) R.J. Slobodrian, Hadronic J. 4 (1981) 1258.
11) Santilli, Hadr. J5 (1982) 264; Sachs, Lett. Nuovo Cim. 34 (1982) 441; Moravcsik, Phys. Rev. Lett. 48 (1982) 718 .