POLARIZATION IN MEDIUM-ENERGY PROTON-NUCLEUS ELASTIC SCATTERING

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The optical-model (OM) analysis of elastic scattering differential cross section measurements at IUCF for p + ^{40}Ca, ^{90}Zr, and ^{208}Pb at proton energies from 80 to 180 MeV exhibited considerable sensitivity to the parametrization of the complex spin-orbit potential[1]. Nevertheless, significant parameter ambiguities remained in both central and spin-orbit terms of the OM potential as determined by the above cross section data. Sufficiently precise and extensive polarization data, when combined with the existing high-quality cross section data in the analysis, should impose more severe constraints on the parametrization of the proton-nucleus optical potential. In particular, the empirical values of the real and imaginary spin-orbit strengths (or volume integrals) should become more firmly established for medium-energy proton scattering and permit definitive comparison with impulse approximation calculations of the first-order optical potential in terms of realistic 2-nucleon transition matrices[2].

Although some older polarization data exist for the above nuclei around 155 and 185 MeV proton energy[3], those data are in most cases limited in both quantity (small angular range, $\theta \lesssim 40°$; few data points, $\lesssim 20$) and quality (relative errors $\Delta P \gtrsim .02 - .10$). Inclusion of these data in the OM analysis[1] either has little influence on the potential parameters or, in some cases, yields results in conflict with the cross section data in the sense that no common potential can be found which produces a good qualitative description of both types of data.

With the recent availability of the polarized proton beam at IUCF we initiated a modest program of measuring detailed angular distributions of the analyzing power $A_y(\theta)$ for polarized proton scattering from a few nuclei (e.g. ^{90}Zr, ^{208}Pb) at a few proton energies (e.g. 135, 180 MeV). While we may eventually propose a more systematic and comprehensive program of analyzing power measurements, the intent of the initial measurements is to supplement the corresponding detailed cross section measurements with high-quality A_y data in those cases where no previous data exist, or where existing data yields contradictory potential sets.

The first measurements of $A_y(\theta)$ were carried out for ^{90}Zr at 135 MeV using the QDDM magnetic spectrograph over the angular range $10° \leq \theta \leq 60°$ in 0.5° to 1.5° steps. Data were taken at a few angles for a given sign of the incident beam polarization, then the beam polarization was changed in sign by reversing the direction of the magnetic guide field in the ionizer of the polarized ion source (P.I.S.)[+], and the measurements repeated. This procedure proved convenient and acceptable because of the good stability of the beam polarization P_B(changes in P_B of less than $\pm$ 0.01/hr and $\pm$ 0.02/day were observed). The beam intensity on target ranged from 10 to 80 nA; the average beam polarization was $P_B = 0.70$. The polarization of the beam prior to injection into the main cyclotron stage was monitored before and after every spin flip with a low-energy ^{4}He polarimeter[4]. Twice in the course of the experiment, the beam polarization on target was determined from the asymmetry produced in 135 MeV proton scattering from ^{12}C at $\theta_L = 9°$ and $\theta_L = 12.5°$ where previous double-scattering measurements[5] had established the absolute analyzing power as $A_y(9°) = 0.405$ and $A_y(12.5°) = 0.48$. These measurements of the polarization of the 135 MeV proton beam yielded $P_B = 0.70$ and $P_B = 0.73$ at widely separated times. As

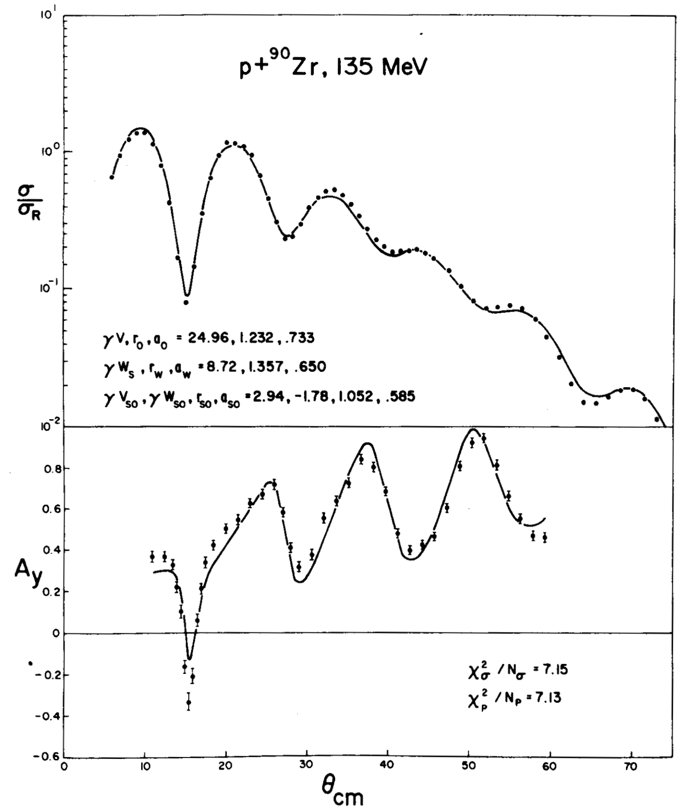

Figure 1.

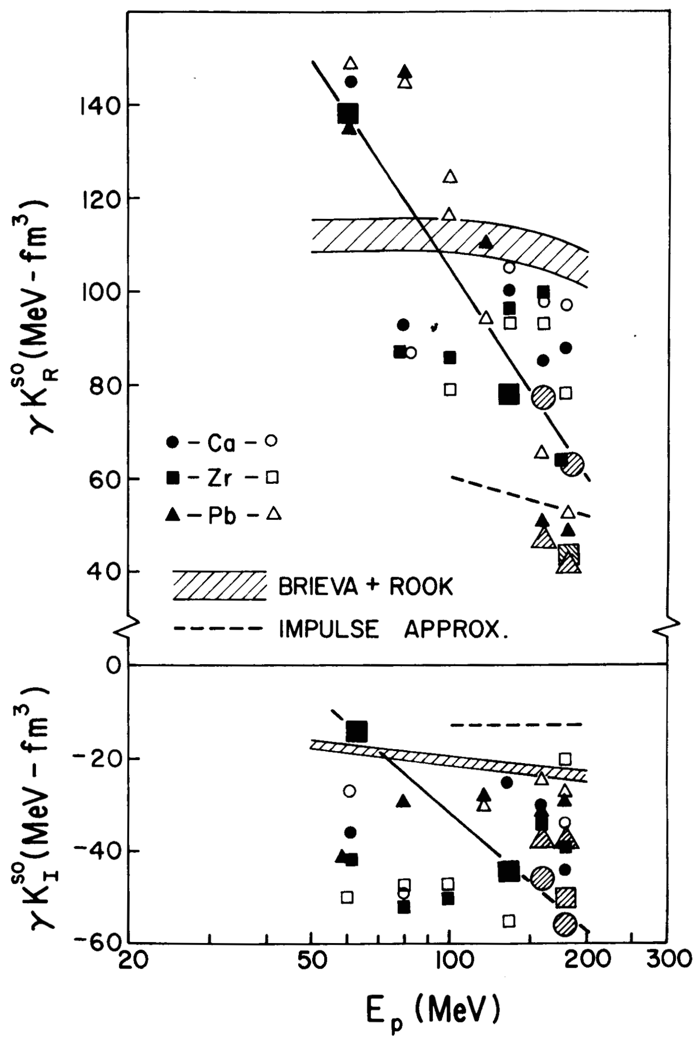

Figure 2.

the corresponding results from the low-energy polarimeter were P_B = 0.695 and P_B = 0.715, respectively, we conclude there is no discernible depolarization resulting from passage of the beam through the main cyclotron at this energy. The low-energy polarimeter results were thus used for calculation of the analyzing power data reported here.

Charge integration for each spin direction of the incident beam (required for a one-arm polarization measurement in the absence of a reliable polarization-insensitive monitor of the scattered yield) was accomplished using a solid carbon beam stop inside the spectrograph target chambers. To eliminate false asymmetries arising from differences in average beam position on target for the two counting intervals (spin "up" and "down"), the beam stop was split in half along the beam axis to allow automatic left-right centering of the beam.

The angular distribution of $A_y(\theta)$ obtained for $\vec{p}$ + ^{90}Zr at 135 MeV is displayed in fig. 1, together with a partial distribution of the differential cross section $\sigma(\theta)$ (the full set of cross section data extends to 126°). The errors indicated, $\Delta A_y = \pm 0.02$ to ± 0.04, are mainly statistical; the absolute normalization is estimated to be uncertain by a similar amount. The curves shown represent simultaneous OM fits to both $\sigma(\theta)$ and $A_y(\theta)$ obtained by varying the real central, imaginary central, and complex spin-orbit potential parameters. The resulting parameters indicated in fig. 1$^{\dagger)}$ do not differ drastically from those parameters which provided a best fit to $\sigma(\theta)$ only; the differences are nevertheless significant since the prediction of $A_y(\theta)$ by the parameter set based on $\sigma(\theta)$ differs substantially from the actual $A_y(\theta)$ measurements.

The fit to $A_y(\theta)$ is qualitatively good overall but does not agree with the measurements in detail, particularly forward of 20°. For $\sigma(\theta)$ the agreement between calculation and measurement is only slightly worse than for the best fit to the $\sigma(\theta)$ data only. These discrepancies may reflect some intrinsic inadequacy in the particular form of the OM used here, e.g., in the form factors used (Woods-Saxon and derivatives) or in the arbitrary choice of a common geometry for real and imaginary spin-orbit formfactors. More detailed analyses to investigate various refinements of the model are in progress. The main premise underlying the motivation for these A_y measurements, namely that they would be a necessary, if not sufficient, ingredient in the unambiguous definition of the main features of the proton OM, certainly appear to be born out by the new data.

A further illustration of this is given in fig. 2 where the volume integrals of the real and imaginary spin-orbit potential,

$$K_R^{so} \equiv \frac{1}{A^{1/3}}\int 4\pi r^2 \mathrm{Re}U_{so}(r)dr, \quad K_I^{so} \equiv \frac{1}{A^{1/3}}\int 4\pi r^2 \mathrm{Im}U_{so}(r)dr,$$

are presented as function of proton energy. The small-size symbols indicate values obtained from fits to $\sigma(\theta)$ data only and show substantial scatter. The large-size symbols represent values obtained from fitting $\sigma(\theta)$ and $A_y(\theta)$ data (the shaded symbols correspond to the older, lower-quality A_y data referred to above; the solid large symbols for ^{90}Zr are based on the present 135 MeV A_y data and the recent, high-quality 65 MeV A_y measurements of Nakamura *et al.*[6]). Incorporating the newer A_y data (for ^{90}Zr) along with the best of the older A_y data (for ^{40}Ca) in the analysis clearly helps to establish the proper trend with energy (solid line in fig. 2) and also emphasizes the possible exceptions to such a trend provided by the older A_y data for ^{208}Pb near 160 and 180 MeV (which we found to be inconsistent with the IUCF $\sigma(\theta)$ data and which we intend to remeasure). Also indicated on this graph are predictions of two microscopic models of the proton-nucleus optical potential which appear to be at variance with the trend of the phenomenological OM results.

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+A fast spin-flip method employing rapid switching between two different RF transition cavities in the P.I.S. is presently being implemented.

†The factor γ represents a renormalization of the potential in a relativistic modification of the Schrödinger equation.[1]

1) P. Schwandt *et al.*, IUCF Techn. and Scient. Report 1977, p. 79.

2) P. Schwandt *et al.*, contribution to this IUCF 1978 Report, p. 27.

3) C. Rolland *et al.*, Nucl. Phys. **80**, 625 (1966); A. Willis *et al.*, J. Physique **30**, 13 (1969). A. Ingemarsson and G. Tibell, Physica Scripta **4**, 235 (1971). W.T.H. van Oers *et al.*, Phys. Rev. **C10**, 307 (1974).

4) Contribution to this IUCF 1978 Report, pp. 133, 140.

5) O.N. Jarvis, B. Rose and J.P. Scanlon, Nucl. Phys. **77**, 161 (1966).

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