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SPIN OBSERVABLES FOR $^{208}Pb(\vec{p},\vec{p})$ ELASTIC SCATTERING AT 290 MEV.

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Abstract

A newly constructed focal plane polarimeter for the medium resolution spectrometer at TRIUMF has been used to measure polarizations and spin rotation parameters for protons elastically scattered from ^{208}Pb at 290 MeV. These results combined with existing cross section data at 300 MeV completely determine the elastic scattering amplitudes for momentum transfers $q<2.6\ fm^{-1}$. The data are in quantitative agreement with Dirac calculations which take the effects of Pauli blocking into account, but disagree at small momentum transfer with density-dependent Schrödinger calculations.

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Conventional non-relativistic theories of nucleon-nucleus scattering [1] are known to fail badly when confronted with complete measurements of elastic proton scattering observables at small momentum transfer [2]. These discrepancies can be remedied somewhat when many-body corrections from density-dependent effects in the nuclear medium are included [3].

More recently it has become increasingly popular to analyze such data with the relativistic impulse approximation (RIA) based on the Dirac equation for the proton, with large scalar and vector potentials of opposite sign [4,5]. Remarkably good agreement with experiment is obtained, especially with the spin observables at 500 MeV [6]. The main reason for the success of the Dirac approach lies in the inclusion of $N\bar{N}$ pair terms [7] which remove short range structure from the particle propagator and lead to enhanced spin orbit and to a 'wine bottle' shape of the optical potential [8,9]. Thies [8] has shown that suppression of small-distance scattering in a Schrödinger approach by arbitrarily introducing momentum dependent potentials can reproduce the results of the Dirac approach. In any case, the Dirac models have provoked a re-evaluation of nucleon-nucleus scattering and it is of considerable importance to determine experimentally their limits of applicability.

We present here measurements of polarizations and spin-rotation parameters for $^{208}Pb(p,p)$ elastic scattering at 290 MeV. Together with existing data on cross sections and analyzing powers at 300 MeV [10] the elastic scattering amplitudes are completely determined. Experiments at energies below 500 MeV are particularly worthwhile. Within the RIA there are ambiguities in the NN amplitudes from adopting either pseudoscalar (γ_5) or pseudovector coupling ($\not{q}\gamma_5$) which may lead to significant differences in the optical potentials at lower energies [11]. Also the neglect of exchange terms in the RIA may be more significant near 300 MeV [12]. Finally, corrections might arise, at a lower energy and for a heavy nucleus such as ^{208}Pb, from Pauli blocking. This effect is estimated to become significant somewhere between 200 and 400 MeV according to both relativistic [12] and non-relativistic [3] calculations.

The experiment was carried out at the upgraded medium resolution spectrometer (MRS) making use of the polarized proton beam from the TRIUMF cyclotron. The beam energy of 290 MeV was chosen to avoid a known depolarization resonance near 300 MeV. Before striking the target the proton beam passed through the axial field of a superconducting solenoid which rotated the proton spin from the normal (P_n) to the horizontal (P_s) direction. Both polarization components ($|P_s|=0.77$ and $P_n \sim 0$) were continuously measured with an in-beam polarimeter which was used to determine up-down and left-right asymmetries in the counting rates of protons scattered at 17° from a thin CH_2 foil.

After scattering from the 60 mg/cm² thick ^{208}Pb target foil, and before entering the MRS QD system, the protons passed through a front-end wire chamber which was used to determine scattering and solid angles. At large angles (16°-38°) this wire chamber was at 0.63 m from the target with a scattering angle acceptance of 2.8°, whereas at small angles (3°-15°) a larger distance (1.7 m) and smaller angle acceptance (1°) were used to allow a copper beam stop to be inserted between target and wire chamber. The resolution of the system of ~180 keV was more than sufficient to resolve elastic and inelastic groups from ^{208}Pb.

The spin of elastically scattered protons is rotated in the scattering plane by an angle β which is related to the spin rotation para-

meter Q by the expression [13], $Q = \sqrt{1-P^2} \sin \beta$, where $P=P_n'$ is the induced polarization normal to the scattering plane. Both P and Q have been obtained from simultaneous measurements of all three polarization components after scattering, P_s',P_l' and P. This is feasible because spin precession in the horizontal fields of the MRS dipole (precession angle $\xi = 141°$) converts about 62% of the longitudinal component into the normal direction, i.e. $P_n'' = P_l' \sin\xi + P\cos\xi$. Separation of $P_l'$and P is achieved by flipping the spin of the incoming beam ($P_s \rightarrow -P_s$):P_l' changes sign whereas P does not.

This method leads to systematic errors when an unknown longitudinal component P_l exists in the incident beam. For this reason the same sideways polarization P_s, but longitudinal polarizations of oppposite sign, were obtained using different combinations of spin of the proton beam from the cyclotron (up/down) and solenoid currents (+/-). Runs with unpolarized beam were also taken to provide five independent measurements per scattering angle.

The proton polarizations after momentum analysis in the MRS, P_s'' and P_n'' were measured by inclusive scattering in 7.5 cm of carbon using a newly constructed focal plane polarimeter. This polarimeter has a large momentum acceptance ($dp/p \sim 8\%$) and utilizes the azimuthal asymmetries for events with polar scattering angles between 5° and 20°. A detailed description of the polarimeter and the procedures used in the data analysis can be found elsewhere [14]. The present experiment was one of the first carried out with the instrument and provided calibration data for effective analyzing powers at an average proton energy of 260 MeV. The measured angular dependence of the analyzing power for inclusive scattering from carbon, A_c (θ_{scat}), agrees well with the expression used by Aprile-Giboni et al. [15] to fit existing data between 95 and 570 MeV. Instrumental asymmetries were investigated and found to be negligible from measurements of P_s'' using unpolarized beam. Because of parity conservation such a sideways component cannot be present, and this was confirmed with an accuracy of ~1%.

From a total of ten polarizations (P_n'' and P_s'') determined for each scattering angle with the focal plane polarimeter and from the P_s and P_n values for the beam polarization we derive [16] four independent quantities: the polarization P, the spin transfer coefficients $D_{ss'}$ and $D_{sl'}$ (which correspond to the Wolfenstein parameters R and -A, respectively), and the longitudinal component for the incident beam, P_l. The spin rotation parameter Q is then calculated using the expression [13]

$$Q = D_{ss'} \sin\theta - D_{sl'} \cos\theta \qquad (1)$$

where θ is the scattering angle in the laboratory frame.

The data were sorted into 0.5° and 0.7° angle bins at small (3° - 15°) and large (16° - 38°) angles, respectively. Such small bin widths are necessary to resolve the sharp structures in both the induced polarisation P (fig. 1) and the spin rotation parameter Q (fig. 2). A useful consistency check was carried out between the present polarisation data at 290 MeV and the analysing powers at 300 MeV, also from TRIUMF [10]. The equality for elastically scattered protons from a spin-zero target, $P(q) = A_y(q)$, was extremely well fulfilled when the two data sets were compared at the same momentum transfer q [16]. The important new information from the present experiment comes from the spin rotation parameter Q which together with the results from [10] completely determines the elastic scattering amplitudes for $q<2.6\ fm^{-1}$ at $E_p \sim 300$ MeV.

The experimental results of figs. 1 and 2 are compared to the most elaborate relativistic and nonrelativistic calculations available at present. Both of these go beyond the simple impulse approximation (RIA and NRIA, respectively) and include exchange effects and modifications arising from the nuclear medium. The dashed lines represent a nonrelativistic calculation by Dymarz [17] whose folding optical potential was derived in a local density approximation from a G-matrix based on the Paris NN interaction [3]. The inclusion of medium effects changes the periodicity of the oscillations at large angles from that of the NRIA (not shown, see [16,17]) improving the agreement with experiment for both P and Q. However at small angles the inclusion of density dependence does not remove substantial disagreement between data and calculation in P, and especially in Q. We have verified that this disagreement at small angles is an inherent feature of the nonrelativistic approach [3] and cannot be remedied by reasonable changes in the nuclear densities. For example, proton and neutron densities from relativistic mean field theory [18] instead of those from ref. [17] produce only minor modifications in the nonrelativistic predictions for P and Q.

The dotted curves in figs. 1 and 2 are the result of a relativistic 'Love-Franey' calculation [11,12] in which the 5 Lorentz invariant NN amplitudes are separated into direct and exchange terms. This procedure allows a choice to be made between pseudovector (shown here) or pseudoscalar coupling, although in the present case there is very little difference between the predictions from both. The inclusion of exchange causes a damping of the oscillatians in P and Q which worsens the agreement with the data compared to the simple RIA (see [16,17]). The relativistic calculations have been extended to include medium modifications due to Pauli-blocking by rescaling the impulse approximation potential based on the effects of Pauli-blocking in nuclear matter [11]. The Pauli-blocking effect at 290 MeV turns out to be substantial, and the resulting predictions (solid lines in Figs. 1 and 2) are in good agreement with the experiment over the full range of momentum transfers.

In summary the present work has shown that medium modifications are necessary in both relativistic and nonrelativistic models to account for the complete set of spin observables in $^{208}Pb(\vec{p},\vec{p})$ elastic scattering at 290 MeV. In the relativistic calculations the inclusion of Pauli blocking is essential to cancel and overcompensate the exchange effect. Further complete measurements of P (or A_y) and Q for different proton energies and target masses would be valuable in mapping out the importance of medium corrections in elastic proton scattering. The nonrelativistic calculations seem to predict more pronounced oscillations in P and Q at small momentum transfers ($q<1.4$ fm^{-1}) than is experimentally observed. This problem can likely be attributed [7,8] to large contributions from small-distance scattering which are a consequence of a purely local, nonrelativistic theory.

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Figure Captions

Fig. 1 Induced polarisation P for elastic scattering of 290 MeV protons from ^{208}Pb. The solid and dotted lines correspond to relativistic calculations with and without Pauli blocking, respectively. The dashed line represents a nonrelativistic calculation based on a folding optical potential derived with a medium-modified effective NN interaction.

Fig. 2 The spin rotation parameter Q for elastic scattering of 290 MeV protons from ^{208}Pb. The meaning of the theoretical curves is explained in the caption of Fig. 1.

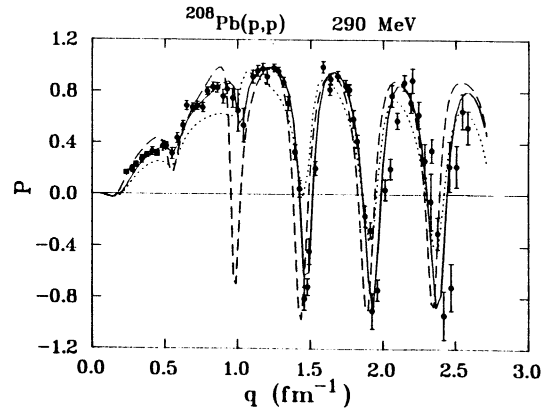

Fig. 1

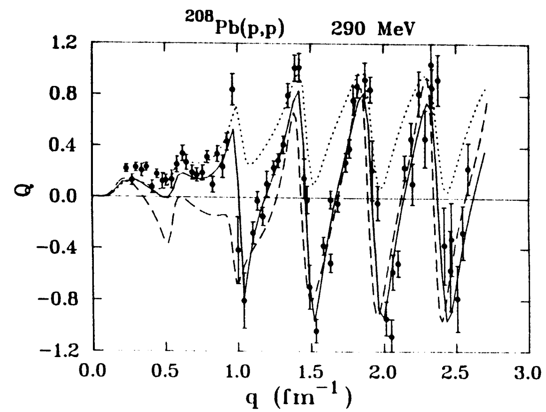

Fig. 2