

MEASUREMENTS OF THE SPIN ROTATION FUNCTION Q IN 200-MeV PROTON ELASTIC SCATTERING

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During the past year, we have made measurements of the spin rotation parameter Q for the elastic scattering of 200-MeV protons from ^{12}C , ^{16}O , and $^{40,48}\text{Ca}$. In each case, these new measurements now form a complete set of elastic scattering observables, providing data to test phenomenological and impulse approximation descriptions of elastic scattering. Data on the first three of these isotopes supplement existing measurements of the cross section and analyzing power.¹⁻³ The two calcium isotopes were measured to provide information on the existence of a Dirac tensor potential. In the case of ^{48}Ca , new measurements were also made of the cross section and analyzing power. Final analysis is still in process, so the data presented here and the conclusions drawn are tentative.

The preparation and monitoring of the horizontally-polarized proton beam is discussed in the technical section of this report.

The focal plane of the QDDM spectrometer was instrumented with the standard helical position-sensitive wire chamber, followed by two 1/4"-thick scintillators that provided a fast particle timing signal and the pulse height information necessary to identify outgoing protons from all particle groups. Immediately behind the second scintillator was a high-density graphite target 3.3 cm thick. Protons elastically scattered from this target between about 8°

and 20° were detected by two detector telescopes mounted above and below the spectrometer median plane. These telescopes consisted of 0.8 cm of plastic scintillator followed by 10.0 cm of NaI(Tl). (In later runs, the NaI(Tl) counters were replaced by thick plastic scintillators to reduce the effects of pileup.) The count rate asymmetry in these two telescopes yielded information on the proton spin component that was sideways at the focal plane. Most of the spin rotation measurements were made at a focal plane position where the proton bend angle through the spectrometer was about 135°. For energies near 200 MeV, this makes the focal plane polarimeter most sensitive to the longitudinal outgoing spin component at the primary scattering target.

The efficiency of the focal plane polarimeter was slightly better than 1% (the sum of the useful elastic events in both the upper and lower telescopes). With the NaI(Tl), the energy resolution was about 2-3%, sufficient to isolate the elastic scattering events and give an analyzing power of about 0.54. The plastic scintillators used in later runs had broader resolution, and the inclusion of many inelastic events with the elastic peak sum reduced the analyzing power to about 0.41. The large efficiency and analyzing power permitted us to measure the spin rotation function between 7° and 50° with a statistical precision smaller than 0.03.

The ability to predict the spin rotation parameter Q from a phenomenological model fit to the cross section and analyzing power alone has been used as an argument⁴ in favor of the Dirac optical model at 500 MeV. At 200 MeV, the situation is less clear. Unlike at higher energies, both the real and imaginary parts of the potential are important at 200 MeV for a reproduction of the observed angular distributions, and this results in greater ambiguities within the model.

To test the predictability of Q , we made both relativistic and non-relativistic fits to the cross section and analyzing power measurements at angles less than 70° . It was hoped that this would avoid problems associated with channel-coupling. For ^{40}Ca , there is little difference between the predictions of Q , and both pick out the observed trends of the measurements. The differences can undoubtedly be reduced through minor parameter variations.

The situation for the lighter targets is very different. The model predictions for Q are shown in Fig. 1. For ^{12}C , the non-relativistic potential is the

double Woods-Saxon of Ref. 1. For the relativistic ^{12}C potential, the usual Woods-Saxon shape is multiplied by a $[1+\alpha r^2]$ factor that reduces the potential strength about 20% in the nuclear interior. The reproduction of the cross section and the analyzing power is satisfactory in both cases, yet the trends of Q are not well reproduced.

The predictions for ^{16}O in Fig. 1 are taken from the analysis of Ref. 2. In that paper, Glover found two distinct potentials that differed in the sign of the real, central potential at small radii: one was large and repulsive, the other was large and attractive. The potential with the attractive central piece gives a better reproduction of the Q measurements forward of 25° . At larger angles, neither potential gives satisfactory results.

Further attempts to improve the reproduction of the measurements by using the new values of Q to constrain the parameters has met with success so far only for carbon. If only the measurements forward of 70° are included in the calculation, then Q is reproduced with high precision. The new potential differs from the old in that the repulsion in the real central potential is less pronounced, and there is a larger imaginary spin-orbit term.

It is clear from the investigation to this point that a satisfactory phenomenological reproduction of the measurements is likely to be possible, but only if more general radial shapes are used to describe the optical potentials. So far, neither the relativistic nor the non-relativistic optical model appears better adapted to a description of these measurements.

The most successful impulse approximation calculations for elastic scattering are presently those of Tjon and Wallace.⁵ In all previous cases, the interaction has been written in terms of invariants

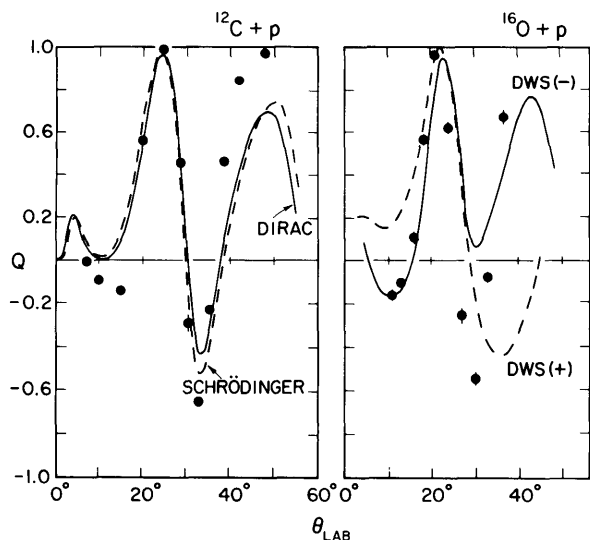


Figure 1. Measurements of the spin rotation parameter Q for elastic proton scattering from ^{12}C and ^{16}O at 200 MeV. The curves are predictions using models described in text.

(such as scalar and vector) that operate on the full Dirac wavefunction, including both upper and lower components. In Ref. 5, this set has been expanded to include classes that operate on only the lower spinor of the wavefunction in either the entrance or exit channels, or both. The size of these operators is given by meson exchange.

Figure 2 contains the measurements for the elastic scattering of 200-MeV protons from ^{40}Ca . The

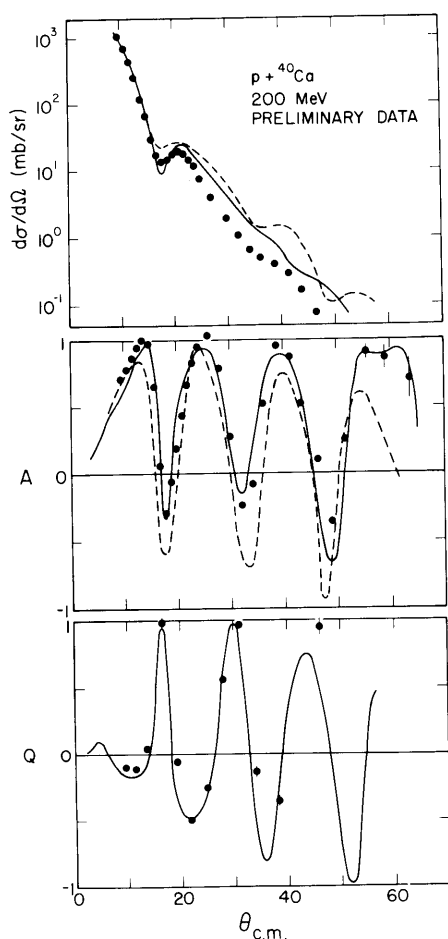


Figure 2. Measurements of the cross section and spin dependence for the elastic scattering of 200 MeV protons from ^{40}Ca . The calculations of Tjon and Wallace are based on the impulse approximation. The potential that generates the solid curve contains additional terms that operate on the lower spinor in the wavefunction.

calculations of Ref. 5 at 181 MeV have been replotted here at 200 MeV by assuming that the observables would be similar at the same value of momentum transfer. The dashed curves show the result for only the traditional scalar and vector parts of the interaction, while the solid curves also include those terms with projection operators on the lower spinor of the Dirac wavefunction. The scalar and vector densities for ^{40}Ca are taken from the calculations of Horowitz and Serot.¹⁵ In almost all respects, the calculation with the extra terms provides a strikingly better reproduction of the measurements. All of the observables are less diffractive, and the analyzing power is generally more positive. The only problem stems from the overestimate of the large-angle cross section, a problem common to all impulse approximation calculations of elastic scattering near 200 MeV.

It has recently been pointed out by Miller⁷ that the Dirac-equation description of nucleon scattering permits a tensor potential in addition to the often-mentioned scalar and time-like vector potentials. The tensor potential is derived from the nuclear tensor density, which is composed of the overlap of the upper and lower component wavefunctions in the target nucleus. The tensor potentials derived from these densities are small, since the tensor t -matrix elements are about an order of magnitude smaller than the t -matrix elements for the vector and scalar interactions.

An investigation⁸ of tensor potential contributions to 500 MeV scattering from ^{40}Ca demonstrated that the changes in this case are small. Attempts to determine the presence of such a potential phenomenologically have produced the same results.⁹ Indeed, there are transformations which can make a tensor potential phase-shift equivalent with either a

vector or scalar potential in the Dirac equation for elastic scattering,¹⁰ so that there may be no clear evidence of the need for including a tensor potential from phenomenological representations of the elastic scattering data.

Calculations from Clark¹¹ with and without a tensor potential are shown in Fig. 3 for the spin-dependent data from ^{40}Ca and ^{48}Ca . The potentials used in these calculations are based on the nuclear densities of Ref. 6. In agreement with the results at 500 MeV, the effects of the tensor potential are small, and affect the spin rotation function more strongly than the analyzing power. These differences are, however, much smaller than the differences between the

calculations and the measurements, and at this point there is no clear indication of the need for including the tensor potential in the treatment of elastic scattering. The tensor density in the calculation of Ref. 6 for ^{40}Ca originates in the lack of cancellation among the contributions from closed nuclear shells, and is comparable in size to the density for ^{48}Ca which contains the added contribution for the $f_{7/2}$ neutrons. Thus, there is little difference in the calculated effects of the tensor potential between ^{40}Ca and ^{48}Ca , and a comparison of these two isotopes does not provide a better basis for studying the tensor potential.

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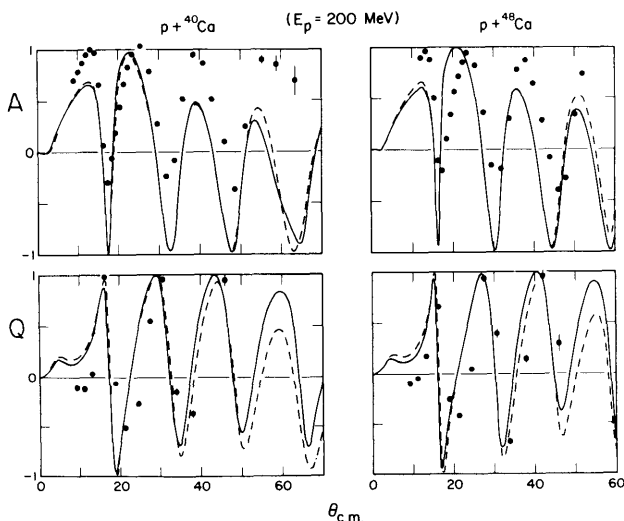


Figure 3. Measurements of the spin dependence in 200-MeV proton scattering from ^{40}Ca and ^{48}Ca . The Dirac optical model calculations are made with (solid) and without (dashed) a tensor potential.

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