ELASTIC AND INELASTIC PROTON SCATTERING

LARGE-ANGLE PROTON-NUCLEUS ELASTIC SCATTERING

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The elastic scattering of protons from nuclei is usually analyzed phenomenologically in terms of an optical model with Woods-Saxon forms for the radial potential shapes. Microscopic theories[1-5] predict a different radial dependence; e.g., near 200 MeV, the real part of the central potential is attractive in the nuclear surface while the nuclear interior is characterized by greatly reduced attraction, even repulsion. Recently, experimental evidence for such a feature has been found in 200 MeV $\vec{p}$ + ^{12}C scattering.[6] To allow additional comparisons to be made between theory and experiment, cross sections and analyzing powers of 200 MeV proton elastic scattering from ^{9}Be and ^{16}O were measured over a wide range of momentum transfer (>6 fm^{-1}) at IUCF. In addition, we extended some previously measured[7] 180 MeV p + ^{28}Si elastic scattering data to larger angles. These data will serve as input into a systematic study of both the phenomenological and microscopic descriptions of the real central potential in the proton optical model.

The measurements were carried out with BeO, enriched ^{9}Be and natural Si targets, using the QDDM spectrometer. The standard focal-plane detector array (position-senstitive gas detector and two large scintillators) was supplemented by two small-area scintillators positioned along the central ray leaving the QDDM. The standard detector array and the two small scintillators were placed in a threefold coincidence in order to reduce background due to neutron-induced reactions in the large detectors. The acceptance of this detector system was sufficient to contain the elastic proton group and allowed the measurement of cross sections as small as 1 nb/sr.

The new data are shown in Fig. 1 along with the previously measured[6] 200 MeV p + ^{12}C elastic scattering data. The data are plotted versus the product of momentum transfer q and a target size parameter $A_T^{1/3}$. When the data are displayed in this manner, one immediately observes that the cross sections for the spin-0 target nuclei have similar diffraction patterns; while the cross section for the ^{9}Be data appears to have the diffractive structure filled in. The analyzing powers for the spin-0 nuclei have the same period of oscillation for values of $qA_T^{1/3} < 8$ fm^{-1}; beyond this point any similarity breaks down. It is precisely this large q behavior in the data which we are interested in studying in the hope that it will provide new clues about the representation of the real central optical potential. Also, from the analyzing powers of the spin-0 nuclei one notices that the oscillations forward of $qA_T^{1/3} = 8$ fm^{-1} for ^{28}Si do not go as negative as the oscillations for ^{16}O, which in turn are slightly less negative than the ^{12}C data. This effect has been discussed within the framework of a standard phenomenological optical model by Schwandt et al.[8] and can be attributed to the interplay between the magnitudes and relative phases of the spin-up and spin-down partial cross sections. These partial cross sections, in turn, are sensitive to the interplay between the central and spin-orbit potentials.

The Woods-Saxon (WS) potential form can adequately reproduce most of the elastic scattering data from

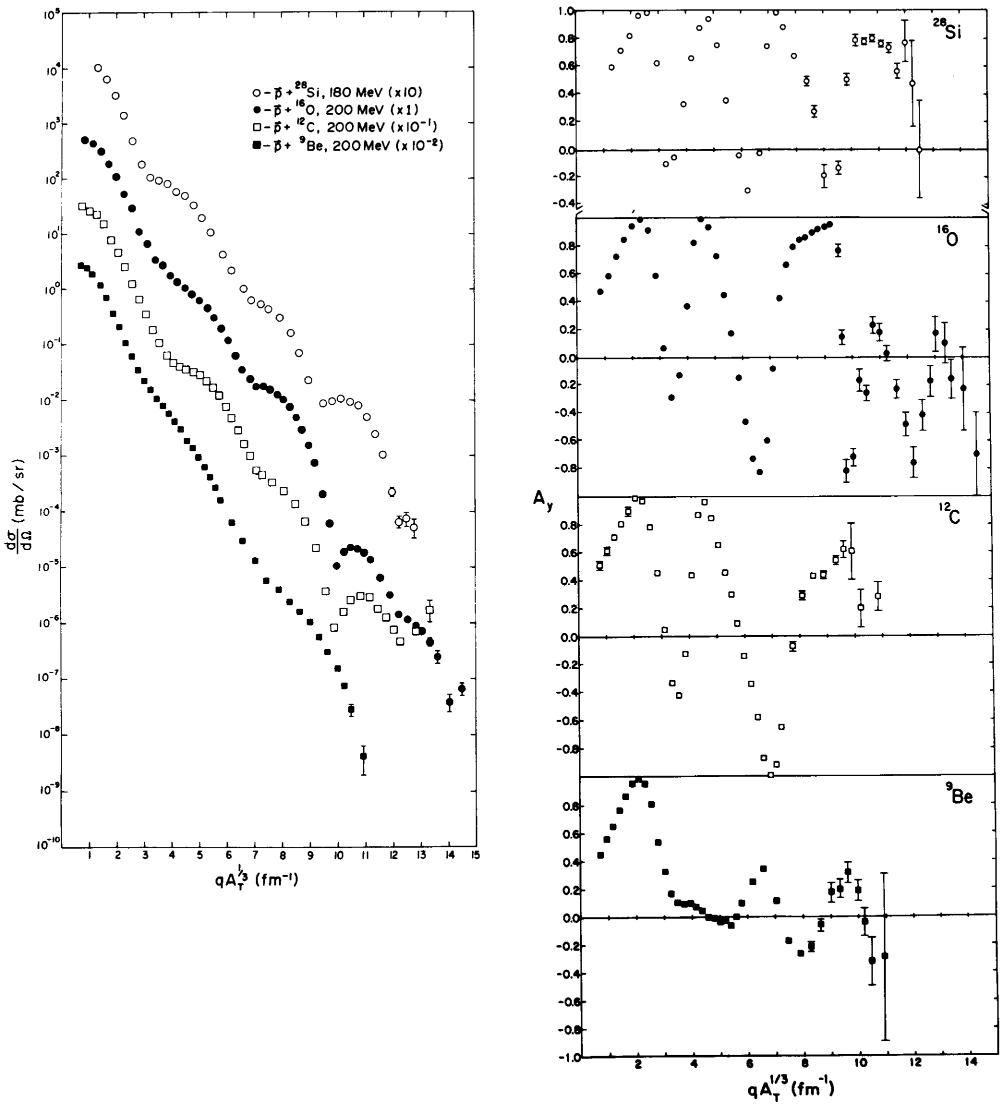

Figure 1. Elastic scattering cross sections and analyzing powers for 180 MeV p + ^{28}Si and 200 MeV p + ^{16}O, ^{12}C, ^{9}Be are plotted as a product of momentum transfer q and a target size parameter $A_T^{1/3}$.

low-mass target nuclei (A < 40) that have been measured at IUCF energies. However, almost all the measured data extend over a limited angular range that corresponds to momentum transfers of $q < 3.5\ fm^{-1}$. Recently, Meyer et al.[6] have shown that the standard optical model using WS potential forms cannot reproduce the 200 MeV $\vec{p} + {}^{12}C$ elastic scattering cross section and analyzing power distributions when measurements over a large angular range (corresponding to momentum transfers q up to ~6 fm^{-1}) are taken into account. To obtain better agreement with the data in the analysis of ref. 6, the real part of the central optical potential was modified by taking the sum of two WS-shaped wells (one attractive, the other repulsive). The resulting real central potential remains attractive near the nuclear surface while becoming weakly repulsive in the nuclear interior, thus leading to a "wine-bottle-bottom" shape for the real central potential.

A non-WS radial shape for the real central optical potential is interesting theoretically because two independent microscopic derivations of the optical potential lead to a similar radial shape (i.e., with a strong depression or change of sign for the interior part of the potential in the 200-400 MeV bombarding energy range). We refer specifically to the treatment of the nucleon-nucleon interaction in nuclear matter in terms of a Brueckner-Hartree-Fock (BHF) expansion, and its application to finite nuclei via a local density approximation,[1-3] and to an independent relativistic approach starting from the Dirac-Hartree (DH) model using scalar and vector meson exchange NN interactions.[4,5] These models predict that the real central potential exhibits roughly a WS shape at low energies (E < 100 MeV), but gradually develops a characteristic central depression (the "wine-bottle-bottom" shape) as the bombarding energy is raised toward 200 MeV.

A systematic analysis of the ^{9}Be, ^{12}C, ^{16}O and ^{28}Si data is underway to determine the extent to which phenomenological WS and non-WS (e.g., double-WS) potential forms can describe the data. The results of this analysis are expected soon. The data will also be compared with predictions of the BHF and DH microscopic optical models.

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ANALYZING POWER OF PROTON-NUCLEUS ELASTIC SCATTERING BETWEEN 80 AND 180 MEV AND THE OPTICAL POTENTIAL

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For proton-nucleus scattering, the importance of the projectile spin-dependent interaction increases dramatically relative to the central interaction as one increases the bombarding energy to the medium-energy range. For example, a previous investigation focusing on cross-section $\sigma(\theta)$ measurements[1] showed a surprising sensitivity of $\sigma(\theta)$ to the spin-orbit potential, manifested in a pronounced damping of the characteristic diffractive oscillations at intermediate angles for bombarding energies greater than ~100 MeV. Although the spin-orbit potential parameters were better defined by the cross-section measurements than expected, appreciable ambiguities and uncertainties remained. Both additional and higher-quality polarization data were called for in order to refine the parametrization of the spin-dependent potential in this energy regime.

This report presents the final results of an experimental program in proton-nucleus elastic scattering between 80 and 180 MeV carried out with a polarized proton beam at the Indiana University Cyclotron Facility. The 16 data sets presented here are restricted to measurements of the analyzing power $A_y(\theta)$ since most of the corresponding cross section angular distributions have already been reported in the literature.[1] The $\sigma(\theta)$ and $A_y(\theta)$ data have been