

PROTON ELASTIC AND INELASTIC SCATTERING AT INTERMEDIATE ENERGIES
FROM ISOTOPES OF OXYGEN AND ^9Be AS PART OF A UNIFIED STUDY OF THESE NUCLEI

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This report describes the status of an experimental and theoretical program that combines electron scattering at the M.I.T.-Bates Linac and intermediate-energy proton scattering at IUCF as part of a unified study of the oxygen isotopes and of ^9Be . In the last year we have used 14 shifts of 135 MeV polarized protons to measure the analyzing powers for states of ^{16}O up to about 12.5 MeV excitation and out to momentum transfers of about 3.0 fm^{-1} . The reduction of these data is almost complete.

The first objective of our program is to establish intermediate-energy proton scattering as a quantitative probe of nuclear structure. The proton transition densities are accurately measured by electron scattering and, for an $N=Z$ nucleus such as ^{16}O , we can reliably assume that the neutron and proton transition densities are equal. Therefore, we can use ^{16}O to study the reaction mechanism and two-nucleon effective interaction free of nuclear structure uncertainties. In the 1979 Annual Report¹⁾ we reported that the two-nucleon effective interaction is strongly density dependent and that the low momentum transfer (low- q) suppression of the differential cross section can be

qualitatively described by a simple modification of the impulse approximation (IA) that is based upon nuclear matter calculations. Since that time more complete calculations have been performed and published in Reference 2.

We have identified several striking signatures of density dependence in the isoscalar spin-independent central component of the two-nucleon effective interaction near 150 MeV. These effects are well described by the local density approximation (LDA), in which the interaction is taken from nuclear matter with the density prevailing in the vicinity of the interacting nucleons. As the density increases, the low- q (high- q) interaction is suppressed (enhanced) relative to the free interaction. Therefore, the low- q (high- q) differential cross section is suppressed (enhanced) relative to the IA prediction. The increased repulsion in the LDA interaction is also manifested in strikingly large negative analyzing powers near 2.4 fm^{-1} for normal parity transitions. The LDA description of these data is improved, particularly for analyzing powers, if the distorted waves are generated consistently by the same

interaction that induces the inelastic transition rather than if they are obtained from a phenomenological optical potential fitted, asymptotically, to elastic scattering data.

In Ref. 2 we presented calculations for ^{12}C , ^{16}O and ^{40}Ca that show quantitative agreement with IUCF differential cross section data and with older polarization data. In Fig. 1 we now present new analyzing power data for several states of ^{16}O . On the left side IA calculations are shown and on the right side LDA calculations are compared with the same data. The solid lines use consistent distorted waves while the dashed lines use phenomenological distorted waves.

The first four states shown are strongly excited and are probably dominated by the direct transition. The IA fails to describe these data. The consistent LDA describes these data quite well, out to about $q \sim 2.5 \text{ fm}^{-1}$. At least two difficulties arise at larger momentum transfer: 1) there are no electron scattering data past 2.5 fm^{-1} and 2) past the momentum transfer available to the two-nucleon system (2.5 fm^{-1}) we are depending on the Fermi-gas momentum distribution. Nevertheless, the agreement is striking. We note that the monopole and dipole transition densities peak in the nuclear interior where the density-dependent effects are largest.

The last two states shown in Fig. 1 are weakly excited and there is good reason to believe that two-step excitation of these transitions is important. For these states the LDA direct contribution underpredicts the differential cross sections by about fifty percent. The next phase of this experiment will address these possibly two-step excitations at a higher energy. The quantitative description of direct transitions suggests that we now know how to calculate matrix elements. If a microscopic coupled-channels

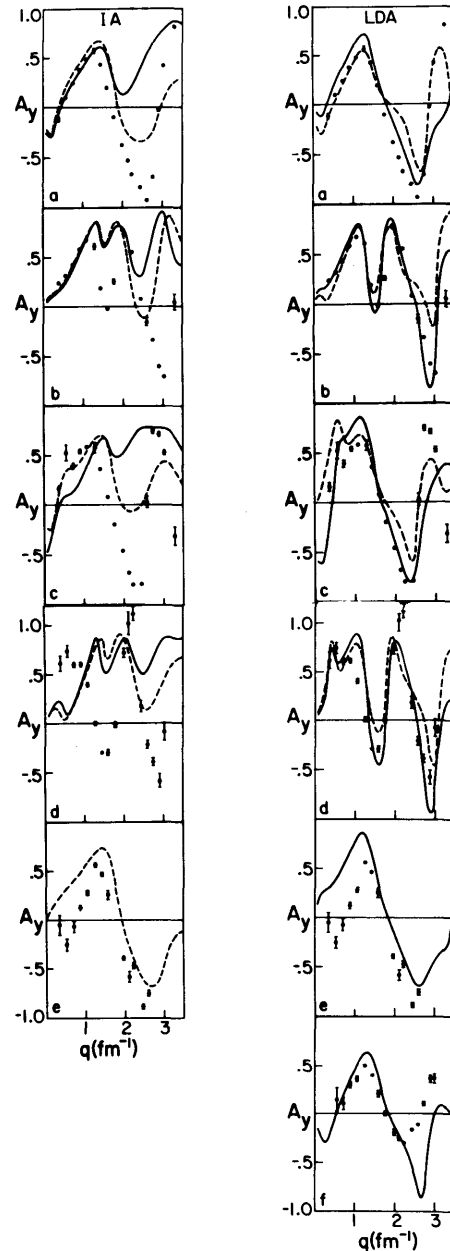


Figure 1. LDA (IA) on right (left) side. Solid (dashed) lines use consistent (phenomenological) distorted waves. ^{16}O states: a) 3^- at 6.130 MeV; b) 2^+ at 6.917 MeV; c) 1^- at 7.117 MeV; d) 0^+ at 12.053 MeV; e) 2^+ at 9.847 MeV; f) 4^+ at 11.09 MeV.

calculation can reproduce the data at two energies, the reaction mechanism will be confirmed and the interband matrix elements will then provide unique nuclear structure information.

Finally, we show two applications of the LDA to

the nuclear structure of ^{18}O . In both cases the proton transition density is specified by electron scattering and consistent distorted waves are used. In Fig. 2 we show the first 2^+ state of ^{18}O . The short-dashed curve assumes that the ratio of the neutron to proton transition density is N/Z , a collective model assumption that drastically underpredicts the forward angle cross section. The gamma decay rate in the mirror nucleus ^{18}Ne provides a constraint on the neutron transition density³⁾ of ^{18}O . The remaining two curves satisfy this constraint. The long-dashed curve assumes that $\rho_n = 2.26 \rho_p$, reproducing the forward-angle cross section while overpredicting the larger-angle cross section. The solid curve is calculated with a neutron transition density that has a larger transition radius but the correct neutron $B(\text{Cl})$ specified by the mirror decay rate. This curve nicely

reproduces that data and indicates that the neutron transition radius is about 4.1 fm compared with 3.5 fm for the protons.

Fig. 3 shows a similar analysis for the lowest 3^- state of ^{18}O . There is no electromagnetic mirror transition information available for this state. The dashed curve assumes that the neutron and proton transition densities are equal. For the solid curve the neutron transition was characterized by a core transition plus valence $1d+2p$ and $1d+1f$ transitions. The core neutron transition density was taken as equal to the measured proton transition density. The oscillator parameter was chosen appropriately for this core ($\alpha = 0.547 \text{ fm}^{-1}$). The solid curve has spectroscopic factors of 1.06 for the $1f$ and 1.22 for the $2p$ orbitals. That these spectroscopic factors are larger than unity may indicate a difference between the

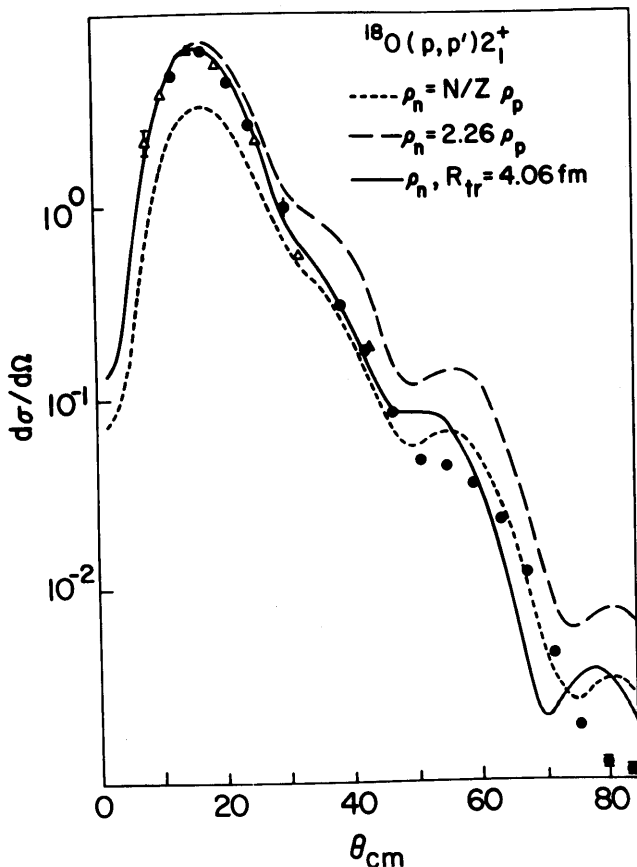


Figure 2. See text.

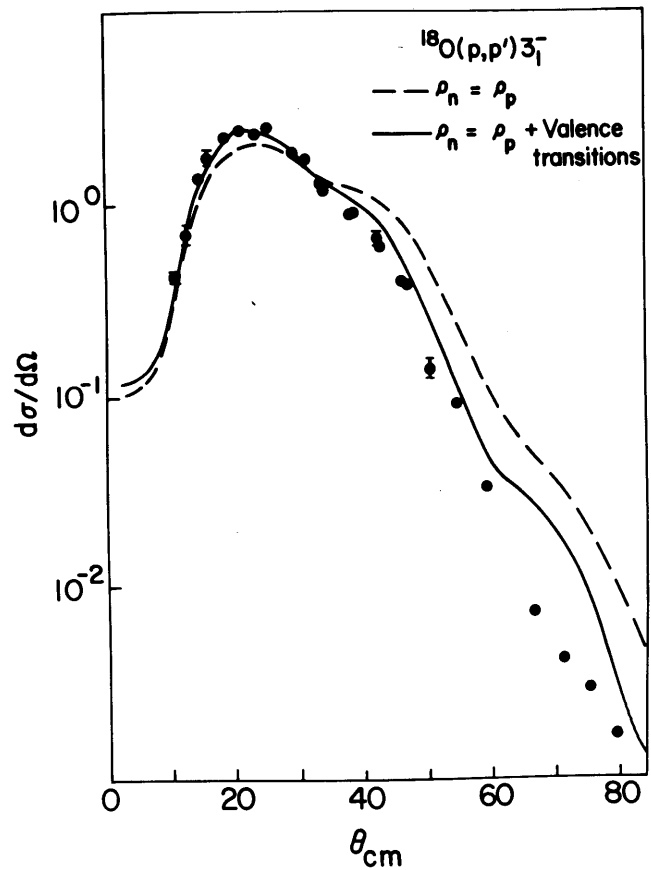


Figure 3. See text.

proton and neutron core contributions or a deficiency in the harmonic oscillator orbitals. The level of agreement here is comparable to that for the first 3^- state of ^{16}O for which the larger-angle cross section was also somewhat overpredicted. No attempt was made, for either ^{18}O state, to achieve a perfect fit. These two examples demonstrate the sensitivity of the inelastic cross section data to the neutron transition density. Regardless of whether the preliminary interpretation of the origin of these densities is valid, a model must nonetheless reproduce them.

In the immediate future we plan to make cross section and analyzing power measurements for ^{16}O at 180 MeV to test the energy dependence of the effective

interaction, in the LDA, and to test the reaction mechanism for those states that appear to have a significant two-step contribution. We plan to extend the analyzing power measurements to ^{17}O and ^{18}O and to higher excited states of ^{16}O as part of our unified study of the nuclear structure of the oxygen isotopes. The (p,n) reaction is also an integral component of this program.

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- 2) J. Kelly, et al., Phys. Rev. Lett. 45, 2012 (1980), and references therein.
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INELASTIC PROTON SCATTERING FROM ^{12}C AT 200 MeV

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As part of an ongoing program to examine the effective interaction of proton scattering from nuclei at intermediate energies, cross sections and analyzing powers for the $^{12}\text{C}(p,p')^{12}\text{C}$ reaction have been measured at 200 MeV. Earlier measurements of the cross sections at 122 MeV have been published and a paper regarding the analyzing powers at 120 MeV is in preparation. Although a description of the scattering in the impulse approximation was found to be moderately successful, particularly for isovector spin-flip transitions that are dominated by the long-range one-pion-exchange interaction, several difficulties were also encountered. The present data were obtained in order to elucidate the nature of the problems.

The data were obtained at IUCF with a polarized proton beam of energy 200 MeV. The beam polarization

was typically about 70% and the scattered protons were detected in a helical-cathode proportional chamber in the focal plane of the magnetic spectrograph. The data cover the entire excitation energy range of 0-21 MeV and they span the angular range 6-60°, typically in steps of 2-3°.

A spectrum of the unpolarized cross sections and analyzing powers for the high-excitation region is shown in Fig. 1. The three strong sharp peaks on the right-hand side correspond to the 1^+ states at 12.71 MeV (T=0) and 15.11 MeV (T=1), and to the 2^+ , T=1 state at 16.11 MeV. On the left-hand side very strong peaks are found near 18.4, 19.6 and 20.6 MeV. It is apparent from spectra at other angles that the peaks at the lower two energies each contain more than one state.