PROTON ELASTIC AND INELASTIC SCATTERING AT INTERMEDIATE ENERGIES FROM ISOTOPES OF OXYGEN AND ^{9}Be 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 MIT-Bates Linac and intermediate energy proton scattering at IUCF as part of a unified study of the oxygen isotopes and ^{9}Be. In the last year we have used 10 shifts of 180-MeV polarized protons to measure the cross sections and analyzing powers for states of ^{16}O up to about 12.5-MeV excitation and of ^{9}Be up to 8-MeV excitation out to momentum transfers of about 3.0 fm^{-1}. We briefly describe here the progress in the data analysis and in the theoretical understanding of the effective interaction that has been achieved since our last report.

The structure of ^{9}Be is interesting from many points of view. For example, the molecular model describes ^{9}Be as a system of two alphas weakly bonded by a shared neutron. As a highly deformed system, a prominent rotational band is exhibited. However, because the binding is weak, the higher rotational states quickly fly apart and appear as broad resonances. In order to analyze the data for these states, and for the continuum, it was necessary to generalize our lineshape fitting procedures.

In the IUCF annual report for 1978, we commented on a general lineshape which accurately describes the resolution function for the QDDM Spectrometer. This shape is definitely not gaussian, and may be described in the central region by an asymmetric hypergaussian and in the wings by exponential tails. Further details may be found in Ref. 1. We have now generalized our fitting procedures to include the option of convoluting this resolution function with an intrinsic lineshape. The intrinsic lineshape may be chosen as gaussian, Breit-Wigner, or Lorentzian. The Lorentzian lineshape includes the proper threshold behavior, an effect which can be observed in our data. This new fitting program is called ALLFIT and also includes the kinematics for transfer reactions and an empirical lineshape that describes electron scattering experiments. For electron scattering, the exponential tail on the large energy loss side is replaced by an inverse polynomial radiative tail. The radiative corrections are applied. Many other options and features are available.

An example of the quality of fit that can be obtained is shown in Fig. 1, which displays a fitted

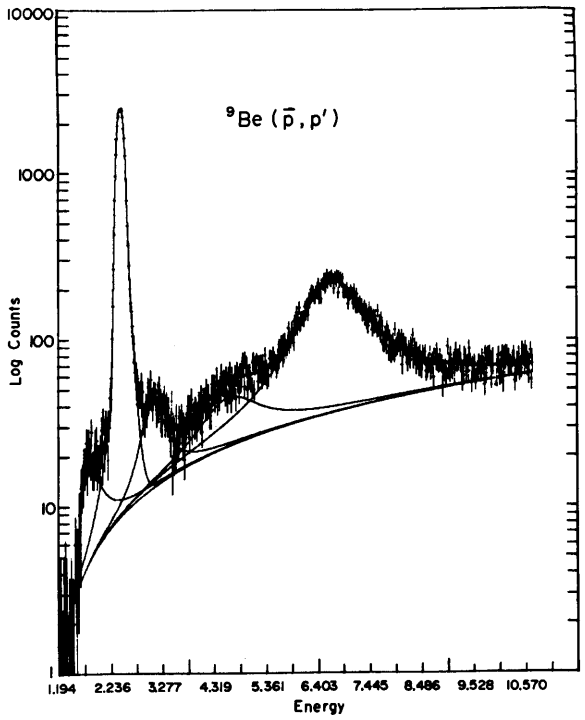

Figure 1. A fitted portion of a spectrum for 34° scattering of 180-MeV spin-up protons from ^{9}Be between 1.2 and 10.6 MeV inelasticity. Note the logarithmic verical scale.

portion of a ^{9}Be(p,p') spectrum for E_p = 180 MeV. Note the threshold at 1.66 MeV. The strong, narrow peak at 2.43 MeV is taken as the resolution function. The remaining peaks are described by Lorentzians whose widths are within the error bars of previous determinations of these widths.[2] It is important to realize that approximately 20% of the area of the dominant Lorentzian (6.76 MeV) is beyond the fitting region. Note that although the ability to convolute is not important for the broadest or narrowest states, it is important for the state nearest the threshold and for states whose intrinsic width is similar to the resolution width. This latter condition also occurs for several of the ^{16}O states of interest.

In our last report, we commented on the discovery of strong density dependence in the isoscalar spin-independent central component of the two-nucleon effective interaction near 150 MeV.[1,3] The cross section and analyzing power data exhibit striking signatures of this density dependence. These effects are well described by the local density approximation (LDA), in which the interaction is described by that appropriate to the scattering of a continuum nucleon by a nucleon in nuclear matter with the local density in the vicinity of the interacting nucleons. This effective interaction is constructed from the solutions of the scattering problem for nuclear matter,[4] given a two-nucleon potential for free nucleons.

The selectivity of inelastic scattering to discrete nuclear states allows one to study the effective interaction from a greater variety of perspectives than are available in nucleon-nucleon experiments. Thus, it may be possible to use nucleon-nucleus scattering to distinguish between alternative potentials that provide essentially equivalent descriptions of the nucleon-nucleon data. Preliminary studies using the nuclear matter effective interactions generated by the Hamada-Johnston (HJ) and Paris potentials show that the data are sensitive to the differences between these potentials. The effective interactions we used in our LDA calculations were supplied by von Geramb.[5]

In Fig. 2 we compare the cross section and analyzing power predictions using the HJ and Paris potentials with our 135 MeV proton scattering data for the first 1^- state of ^{16}O. These calculations use distorted waves generated by the microscopic optical potentials calculated from the same interaction that induces the inelastic transition. The elastic scattering predictions are shown in Fig. 3. The details of these calculations may be found in Refs. 1,3.

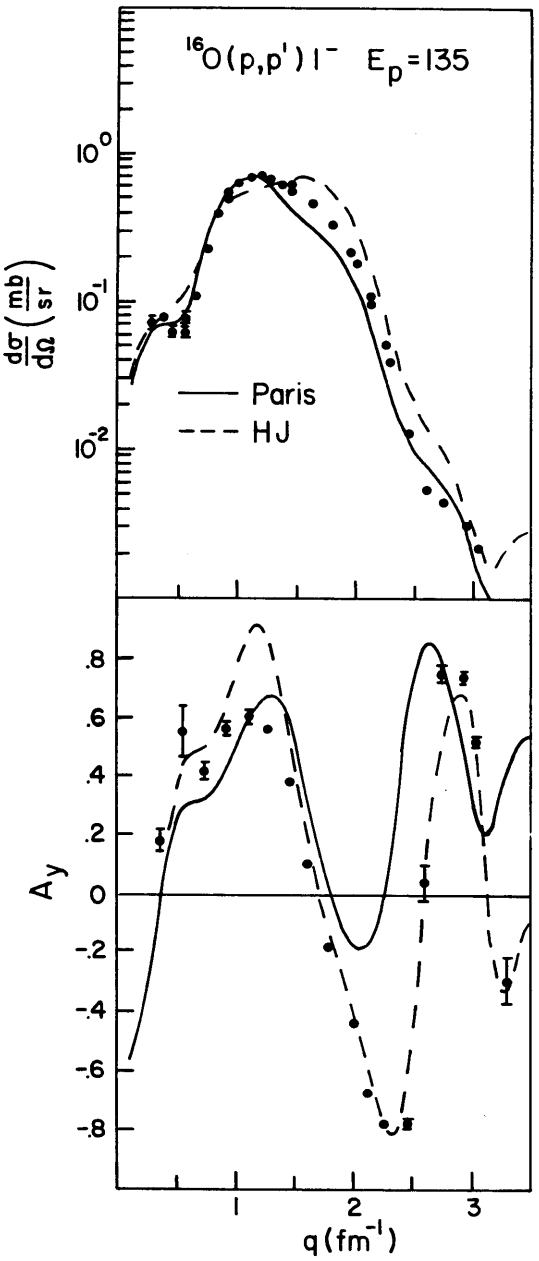

Figure 2. Comparison of consistent LDA predictions for the excitation of the first 1^- state of ^{16}O by 135 MeV protons using G-matrices based on the Paris and Hamada-Johnston (HJ) potentials.

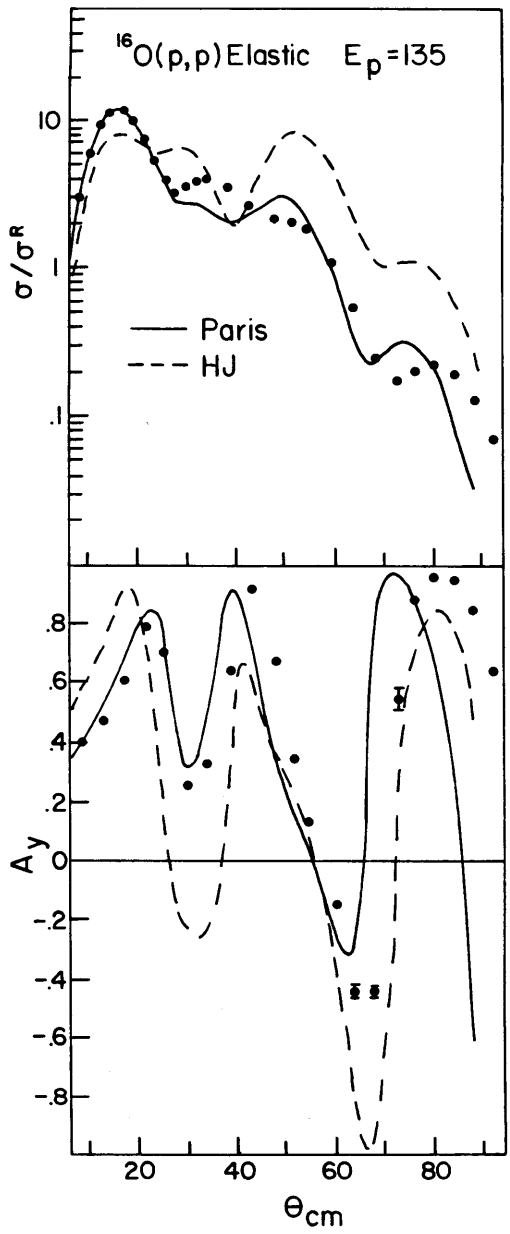

Figure 3. Elastic scattering comparison similar to Fig. 2. Note the suppressed zero for the horizontal scale.

The elastic scattering predictions generated by the Paris potential are in much better agreement with the data than are those of the HJ potential. For the elastic scattering, the most important difference between these interactions is the exchange mixture. In the case of the HJ potential, the direct and exchange contributions to the real central optical potential are both very large and of opposite sign, cancelling to produce a much smaller result. Thus, the local approximation for exchange fails for the elastic scattering calculations using the HJ potential.[7] In the case of the Paris potential, on the other hand, the direct and exchange contributions have the same sign,

improving the accuracy of the local exchange approximation.

For the inelastic scattering predictions, the most important difference between these interactions is the strength of their high-q repulsion. The central interactions are compared, as functions of density and momentum transfer, in Fig. 4. The inelastic cross

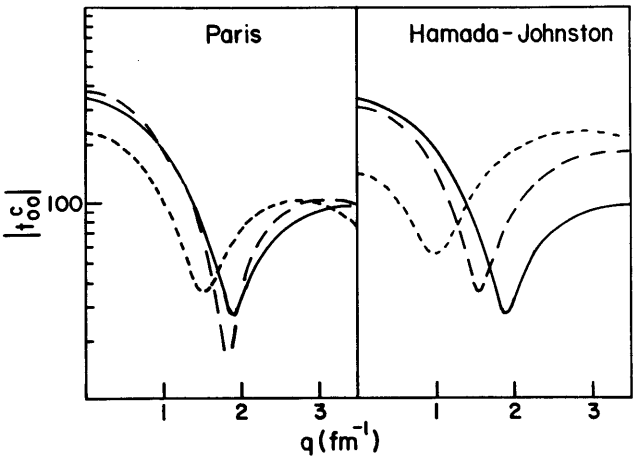

Figure 4. Modulus of the isoscalar spin-independent central interaction. For the interactions based on the Paris and HJ potentials, the long (short) dashed curves represent the low (saturation) density limits. The Love-Franey[6] free t-matrix is shown on both sides as the solid curve.

section predictions are similar at low q and then begin to diverge at the minimum of the central contribution. The HJ potential tends to overpredict the high-q cross section, particularly for surface transitions that are dominated by the low density limit of the effective interaction. The HJ potential correctly predicts the strong negative analyzing powers that result from the enhanced repulsion of the central interaction at high density. The Paris potential, on the other hand, is less repulsive at high-q and tends to underpredict the high-q cross section. The Paris potential analyzing power predictions do not become sufficiently negative. Therefore, we conclude that the high-q repulsion in the isoscalar spin-independent central component of the two-nucleon effective interaction based on the HJ potential is too strong while that of the Paris potential is too weak. This high-q repulsion arises from the core of the nucleon-nucleon potential. Therefore, we conclude that the core of the nucleon-nucleon potential should be intermediate between the extreme hard core of the HJ and the soft core of the Paris potentials.

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135 MeV PROTON SCATTERING FROM ^{13}C

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The data from the ^{13}C(p,p') reaction, reported in the 1980 Annual Report, has been supplemented in two short experiments, both of which were aimed at elucidating the structure, and its nature, at about 12 MeV in excitation. The second of these used a polarized proton beam, and it is expected that the asymmetry