MICROSCOPIC STRUCTURE OF THE CALCIUM ISOTOPES

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The scattering of intermediate energy nucleons is sensitive to both nuclear structure and to medium modifications of the two-nucleon effective interaction. Hence, knowledge of either the structure factor or the interaction factor enables us to determine the unknown factor from nucleon scattering data. When the transverse form factors are small, normal parity transitions are excited primarily by simple matter densities. Proton transition densities can be accurately determined from electroexcitation data. For self-conjugate nuclei, charge symmetry ensures that the neutron and proton transition densities are very nearly equal. Thus electroexcitation data for normal parity isoscalar excitations of self-conjugate nuclei provide accurate measurements of the structure quantities required to interpret complementary data for nucleon scattering. In this manner, nucleon scattering data for these states can be used to study the effective interaction with little uncertainty due to nuclear structure.

The two-nucleon effective interaction for E_p = 100-200 MeV is known to depend strongly upon the local density in which the interaction occurs. Density-dependent effective interactions calculated for infinite nuclear matter can be applied to scattering by finite nuclei using the local density approximation. However, although effective interactions based upon nuclear matter describe the qualitative nature of the medium modifications very well, we generally find the magnitude of these modifications to be smaller than required to describe the data quantitatively.[1] Therefore, we have constructed a parametrization that accurately reproduces the theoretical interaction but which can also be adjusted to reproduce experimental data. Cross section and analyzing power data for many states can be fitted simultaneously. States with strong transition densities in the high-density nuclear interior serve to determine the high-density properties of the effective interaction, while surface excitations determine its low-density properties. This procedure provides an independent test of the local density hypothesis, which requires the effective interaction to be independent of state and of target nucleus. If it is possible to obtain an empirical effective interaction satisfying these conditions, we can conclude that the local density approximation is a useful model of the effective interaction within finite nuclei. The empirical effective interaction can then be compared with the predictions of nuclear matter theory.

Having obtained an empirical effective interaction, proton scattering data can then be used to measure the radial form of neutron transition densities for nuclei with N>Z. We

have found that the intrinsic radial sensitivity of nucleon inelastic scattering is sufficient to determine neutron transition densities in the nuclear interior, especially for light to medium nuclei.[2] However, there exists as yet no independent means of verifying the accuracy of these fitted transition densities. Therefore, we propose to determine these densities using both 100 and 200 MeV protons. Because the interaction changes dramatically over this energy range, the degree to which the fitted structure depends upon projectile energy will provide an important measure of the residual errors in the procedure.

We have undertaken a program of systematic measurements of proton scattering from the calcium isotopes ^{40,42,44,48}Ca and ^{16}O for $E_p = 100$ and 200 MeV. Empirical effective interactions will be fitted to data for ^{16}O and ^{40}Ca simultaneously, using transition densities determined previously by electron scattering.[3,4] Neutron transition densities will be fitted to the data for the other calcium isotopes.

This experiment, E268, is the first to utilize the K600 spectrometer. We have had four production runs between January 1987 and March 1988, as well as several development runs. Data acquisition for both energies has been completed. The angular distributions for both energies span momentum transfers between about 0.4 and 2.7 fm^{-1}, emcompassing the range for which electroexcitation data exist. We have studied the performance of the detector system in considerable detail. Upon recovery of 2-hit events, we usually observe uniform chamber efficiencies of about 98%. We are now in the process of formulating the procedures for reconstruction of the scattering angle and subdivision of the acceptance. The data analysis is proceeding smoothly.

Sample inelastic spectra for the scattering of 200 MeV protons by each of our four calcium isotopes are shown in Fig. 1. A similar figure for 100 MeV was shown in the IUCF Newsletter of April, 1987. The elastic peak was blocked off. The 35 keV resolution is dominated by target thickness; the intrinsic resolution we obtianed for thin targets was about 20 keV. Notice that weakly excited 0^+ states are clearly evident in each spectrum. These states are particularly sensitive to the interior interaction.

Preliminary angular distributions for several low-lying states are shown in Fig. 2 for 100 MeV and Fig. 3 for 200 MeV. The 100-MeV data are compared with calculations based upon both the Franey-Love[5] t-matrix and the Paris-Hamburg[6] effective interaction. For the 200 MeV data, we also show calculations based upon an empirical effective interaction fitted to 180 MeV data for ^{16}O.[7] All inelastic calculations use distorted waves generated by the microscopic optical potential based upon the Paris-Hamburg interaction and include the rearrangement correction to the effective interaction.[8]

For both energies, the density dependence of the nuclear matter interaction provides a substantial improvement over the impulse approximation but is not quite adequate to fit the data. We also observe that density dependent effects for calcium are qualitatively smaller than those for oxygen.[1,7] The enhanced density dependence of the empirical effective interaction generally improves the agreement between calculations and data. However, this particular interaction appears to depend somewhat too strongly upon density, especially for momentum transfers near 1 fm^{-1}. In light of the fact that the interaction was fitted to data for a single nucleus at a different energy, this level of consistency is quite encouraging. There is every reason to believe that a consistent fit of the ^{16}O and ^{40}Ca will be successful.
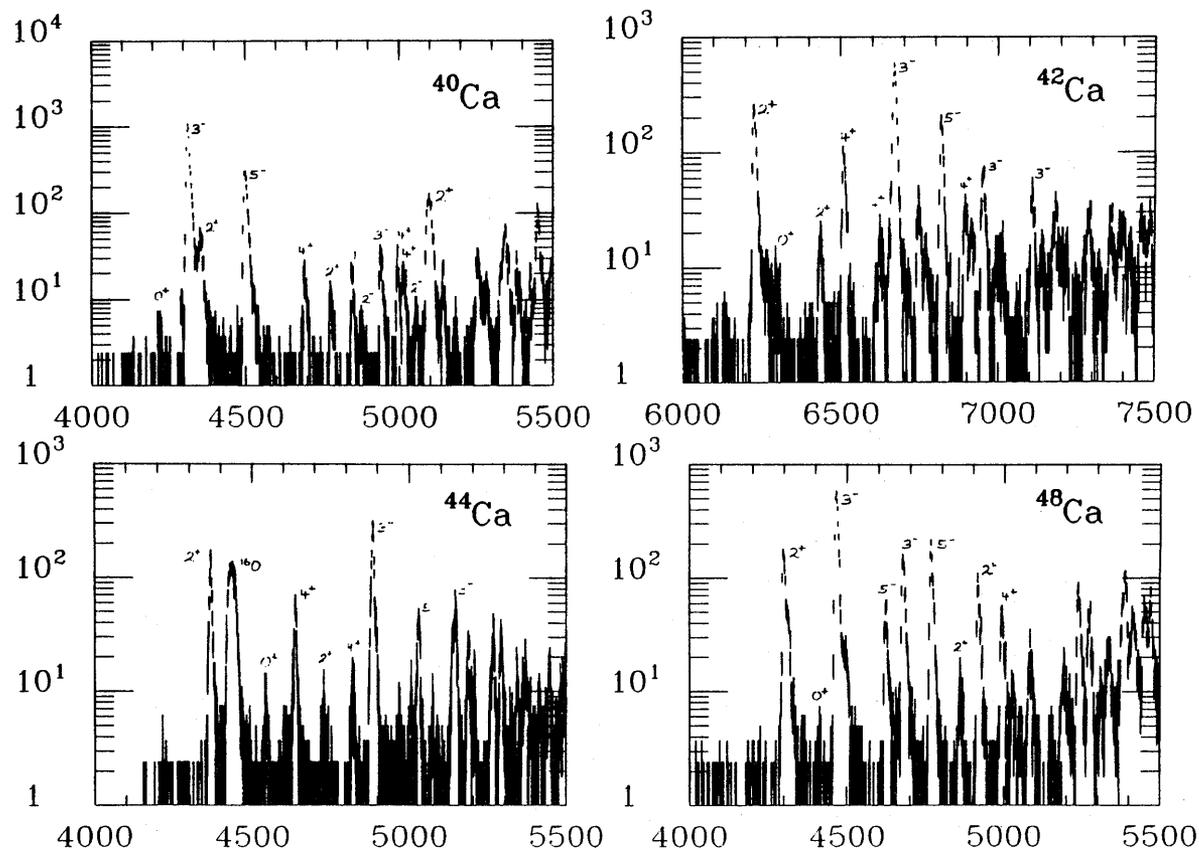
Figure 1. Representative inelastic spectra for the scattering of 200 MeV protons through 23°. Approximately 6 MeV of excitation energy is shown for each isotope and selected states are labeled.

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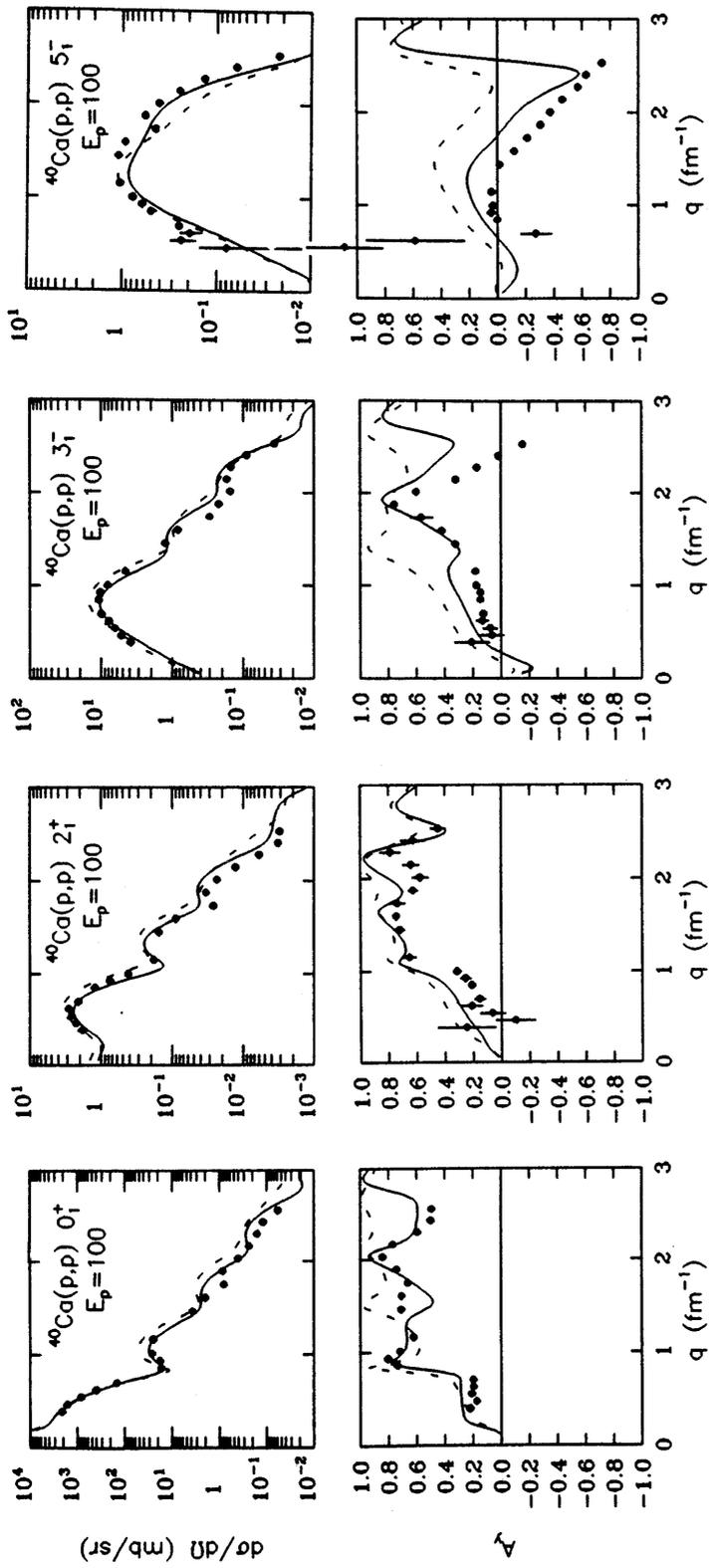8. T. Cheon, K. Takayanagi, and K. Yazaki, Nucl. Phys. **A437**, 301 (1985); **A445**, 227 (1985).

Figure 2. Preliminary $^{40}Ca(p,p')$ data at 100 MeV. Dotted lines show IA calculations and solid lines show LDA calculations with the Paris-Hamburg interaction.
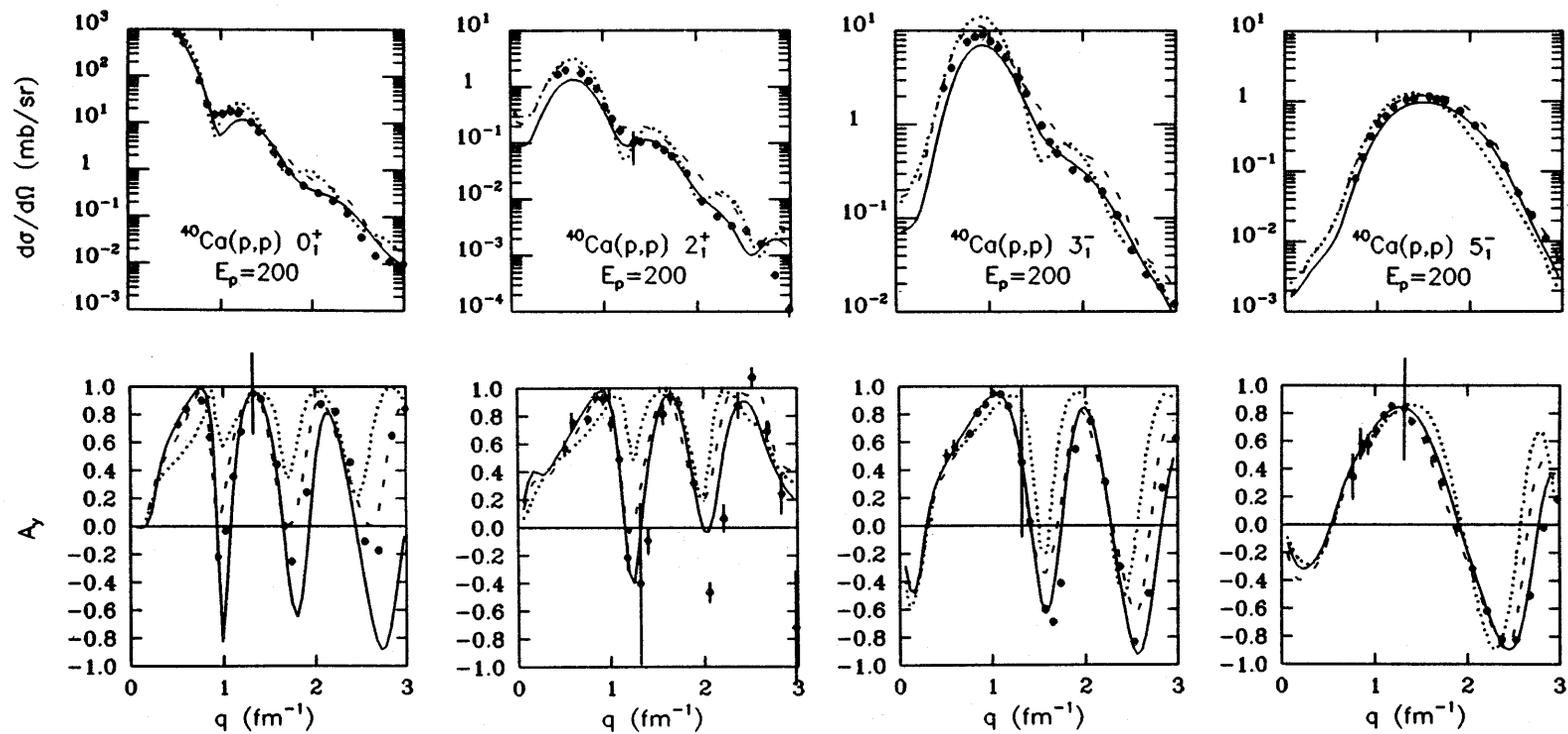
Figure 3. Preliminary ^{40}Ca(p,p′) data at 200 MeV. Dotted lines use a free interaction, dashed lines a theoretical effective interaction, and solid lines an empirical effective interaction.