POLARIZED PROTON SCATTERING AT 134 MeV FROM DEFORMED RARE EARTH NUCLEI

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The reliable extraction of nuclear shape information from inelastic scattering with hadronic probes requires a detailed understanding of the reaction mechanism. A phenomenological analysis of the scattering can aid us greatly in understanding this mechanism. Recent studies[1,2] of proton inelastic scattering from deformed nuclei in the rare earth and actinide regions have employed a multipole moment analysis advocated by Mackintosh.[3] In this approach the data are fitted using a phenomenological deformed optical model potential. The multipole moments of the real part of the potential should be well determined and can be simply related[3] to the moments of the matter distribution under certain assumptions about the reaction mechanism. This method thus circumvents most model or reaction dependences, such as those which arise when comparing deformation parameters or deformation lengths from experiments with different projectiles. If one assumes that the proton and neutron deformations are equal and that the nucleon-nucleon interaction is density-independent, the moments from proton inelastic scttering (properly normalized) should equal those from electron scattering and Coulomb excitation. If, on the other hand, the charge and matter moments are different, one or both of the assumptions above must be incorrect.

Many of the previous proton inelastic scattering experiments on deformed systems have been carried out at energies (such as those available from tandems) where there are significant Coulomb effects. A recent study[1] of ^{154}Sm, ^{176}Yb, ^{232}Th and ^{238}U at MSU using 35 MeV protons indicated no large differences between moments extracted from proton scattering, electron scattering, and Coulomb excitation at least for the lower order moments, and showed that moments from proton inelastic scattering are in better agreement, in general, with the electromagnetic study results than those from α-particle scattering. Very recent studies[2] at LAMPF support the MSU work.

Few investigations of heavy, deformed systems have been made using energies between 35 MeV and 800 MeV. It is important to fill this gap for several reasons. First, inelastic proton scattering studies at intermediate energies on such nuclei at ^{12}C, ^{28}Si and ^{208}Pb have been analyzed[4,5] in terms of distorted-wave Born-approximation calculations, whereas multistep processes have been shown to be important for ^{12}C and ^{24}Mg at both 35 MeV and 800 MeV. It will be valuable to investigate the importance of coupled-channel effects as a function of bombarding energy in other deformed regions. In the rare-earth region, data exist at 35 MeV and 800 MeV and only a measurement at intermediate energies is needed to extend the data set.

Second, the 35 MeV data on the rare-earth nuclei are found to have some sensitivity to β_6 deformations. This sensitivity is expected to increase at intermediate energies, as indicated by coupled-channel calculations. The strength and structure of the 6^+ angular distribution should yield a more reliable determination of the β_6 deformation parameter than was possible at 35 MeV. Thus, the higher order moments should be obtained more accurately than at 35 MeV.

Third, it is also important to establish precisely the systematic behavior of the moments as a function of energy. Recently Brieva and Georgiev[6] have calculated the deformed optical potential for proton inelastic scattering from a deformed matter density folded with a realistic internucleon force. They predict an energy dependence in the moments. The energy dependence is stronger for the hexadecapole and the hexacontatetrapole (6th order) moments than for the quadrupole moments and is especially strong for moments of the imaginary part of the potential.

Finally, little is known about the full importance of spin-orbit interaction effects in proton inelastic scattering from heavy deformed nuclei. Our earlier studies[1] at 35 MeV of deformed rare earth and actinide nuclei showed the need to include a spin-orbit interaction. Our latest study[7] showed that a spherical (no spin-orbit deformation) interaction was sufficient in fitting the angular distribution data. This is in contrast to proton scattering at 800 MeV where Ray[8] has shown that the inclusion of a spin-orbit interaction has only a small influence on fits of the angular distribution data. Near 135 MeV, spin-orbit effects are large, and it has been shown[9,10] from a study of the ^{208}Pb(p,p') reaction that the spin-orbit form factors can have strikingly different deformations from the central ones. These differences show up in the analysis of angular distribution data for states with spins $J > 4$. This is in contrast to what is found[11] for lighter nuclei at lower incident energies. There the quadrupole deformation parameter in the spin-orbit interaction can be twice as large as in the central potential.

We have therefore begun a program of inelastic proton scattering on strongly deformed rare earth nuclei (^{154}Sm and ^{166}Er) to investigate these phenomena.

Elastic and inelastic scattering measurements were performed with a 134 MeV polarized proton beam from the Indiana University Cyclotron Facility using a helical-wire position-sensitive proportional counter in the focal plane of the QDDM spectrograph. The targets were metallic foils enriched in ^{154}Sm and ^{166}Er, and also ^{208}Pb for supplementary absolute cross section, optical model, and peak shape information. Angular distribution data for ground state rotational band states were measured at laboratory angles from 22.5° to 70° (^{166}Er) or 77.5° (^{154}Sm) in 2.5° steps. Two spectra are shown in Fig. 1. The resolution was typically 55 keV, this being sufficient for obtaining reliable peak areas after careful peak shape analysis. The data for the 6^+ states show that the overall magnitudes of the cross sections for the two nuclei are quite different and that the respective angular distributions are out of phase for most of the angular range. Coupled-channel calculations using the spherical optical model parameters of Nadasen et al.[12] plus deformation parameters from earlier studies fit the preliminary elastic scattering cross sections reasonably well, thus providing good starting values for the deformed optical model parameters.

All spectra have now been reduced to obtain cross sections and asymmetries. This was done, independently, at Michigan State University and Melbourne University, to insure reliable spectral analysis. The results are now being collated and an extensive coupled-channel analysis will soon begin.

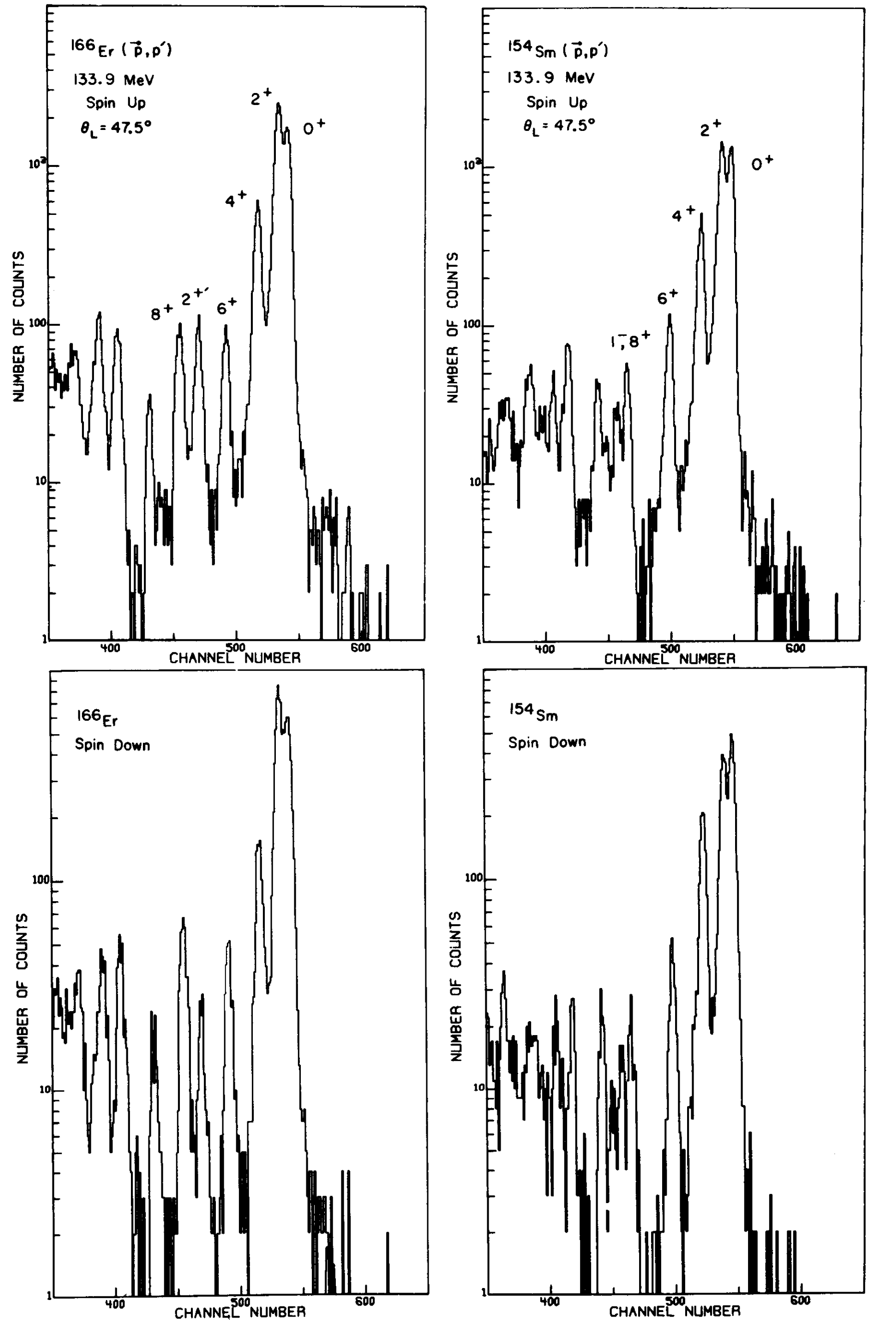

Figure 1. Spectra from the ^{154}Sm, ^{166}Er(p,p') reaction at 134 MeV. Spin up and down data are shown for θ_L=47.5°.

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