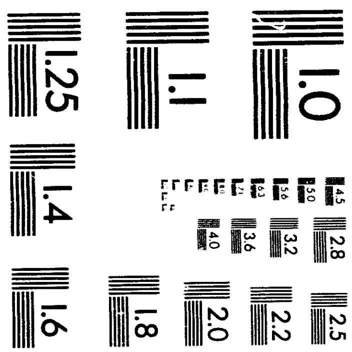
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ANL/PHY/CP-80848
Conf-9305211--1

Proton Inelastic Scattering on ^{56}Ni in Inverse Kinematics

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Abstract

Inelastic proton scattering to the first excited 2$^+$state at 2.701 MeV in doubly magic ^{56}Ni was studied at 101 MeV/u in inverse kinematics. The radioactive ^{56}Ni ion beam was obtained from the SIS heavy ion synchrotron at GSI Darmstadt via fragmentation of a ^{58}Ni beam, and separation by the fragment separator (FRS). A value $B(E2, 0^+ \rightarrow 2^+) = 600 \pm 120\ e^2\ fm^4$ was obtained which corresponds to a deformation parameter β (^{56}Ni) = 0.173 ± 0.017.

Introduction

The availability of radioactive beams opens the possibility for nuclear structure studies with direct reactions on unstable nuclei. In particular, for doubly magic nuclei away from stability (for example ^{56}Ni, ^{132}Sn) nucleon stripping and pick up reactions and inelastic scattering will provide valuable information on the shell model and eventually on the matrix elements of the effective nucleon-nucleon interactions in a domain that has so far been inaccessible. As a first experiment, in a program to study such direct reactions at the GSI accelerators[1] (with the goal to utilize the ESR heavy-ion storage ring[2] in the future), inelastic proton scattering on ^{56}Ni has been investigated at E_{lab}=101 MeV/u. The measurement was intended to yield a more accurate value for the poorly known matrix element for the transition connecting the 0$^+$ ground state to the first excited 2$^+$state. Due to the kinematics for this inverse reaction at these energies (Figure 1) a measurement near 80° in a narrow angular range will provide unambiguous excitation energy spectra even if the energy spread of the beam is the 1-2%, that is the consequence of the fragmentation process and the FRS acceptance.

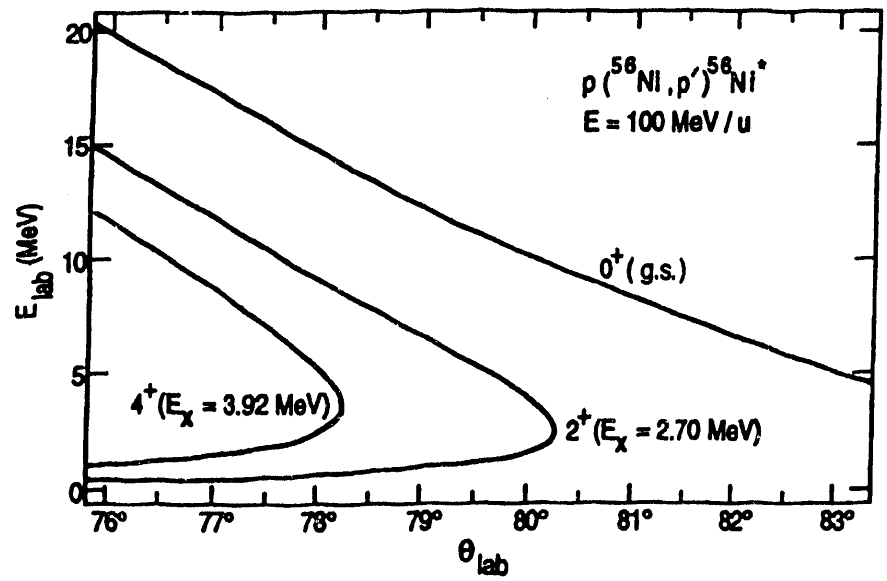

Fig. 1. Kinematics of the recoil protons from the p(^{56}Ni, p′) ^{56}Ni inverse reaction to low-lying states in ^{56}Ni.*

Experimental Setup

^{58}Ni beams of about 2×10^8 ions per spill (spill duration about 2 seconds) were incident on a $4 g/cm^2$ beryllium production target. The secondary isotopes produced were separated in the GSI Fragment Separator (FRS)[3], operated in the achromatic mode and with an aluminum degrader of 824 mg/cm^2. Together with a scintillation detector of 1mm thickness positioned at the central focal plane of the fragment separator, the total degrader thickness corresponded to about 50% of the range of the secondary ions leaving the production target. The detector setup to identify ^{56}Ni and the detector and target configuration for the proton scattering experiment are schematically shown in Figure 2. A time-of-flight start detector (1mm scintillator) was located at the midplane of the fragment separator, the stop detector was 40m downstream at the focal plane position after the fragment separator, and the time resolution was about 200 psec. Together with the energy loss measurement for the 101 MeV/u ^{56}Ni ions in a 0.5mm thick position sensitive plastic scintillator (PSD1) and the focal-plane position measurement, the isotope mass A and nuclear charge Z of the secondary reaction products can be unambiguously identified (see Figure 3).

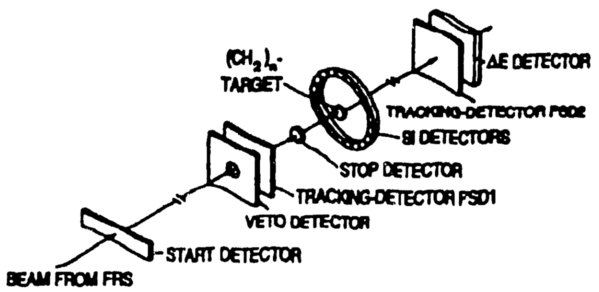

Fig. 2. *Experimental Setup*

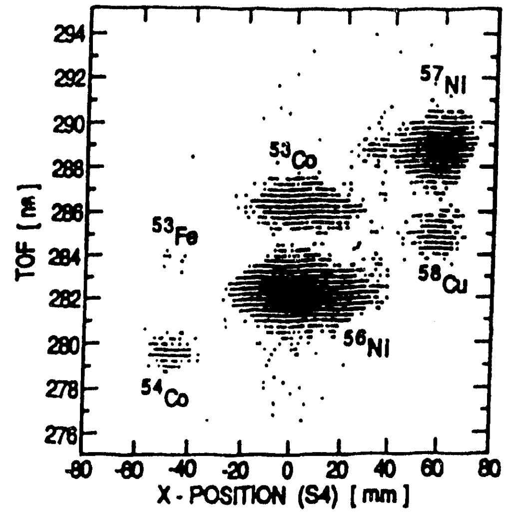

Fig. 3. *Illustration of secondary isotope identification via time-of-flight (TOF) and focal plane position measurement.*

The ^{56}Ni beam was incident on a 1 mg/cm^2 thick $(CH_2)_n$ proton target and the recoil protons were detected in a detector ring extending over the complete azimuthal angle and positioned at a polar angle near 80°. To correct for the large angular spread of the poor-emittance secondary beam (measured as 26πmm mrad), two 2-dimensional scintillation tracking detectors with a position resolution of 1mm were used. The recoil proton energy spectrum was also corrected for the recoil angle shift using these tracking detectors. From the measured signals, the energy vs. scattering angle distribution was reconstructed as illustrated in Figure 4a. Elastic scattering, and inelastic scattering to the first excited state are clearly identified and the overlap between these channels is removed. The final results, together with Monte Carlo simulations taking into account beam emittance and the geometry and response of the experimental set-up, are shown in Figure 4b. Excellent agreement is observed between the predicted and measured energy spectra. Using the well known ^{58}Ni inelastic scattering yield for normalization, the ^{56}Ni inelastic excitation probability can be cleanly extracted. In the analysis, optical model parameters obtained from 100 MeV proton scattering on ^{58}Ni were used.[4] As the final result we obtained a value B(E2) = 600 ± 120 e^2 fm^4 or, within the vibrational model, a deformation parameter β=0.173±.0.017.

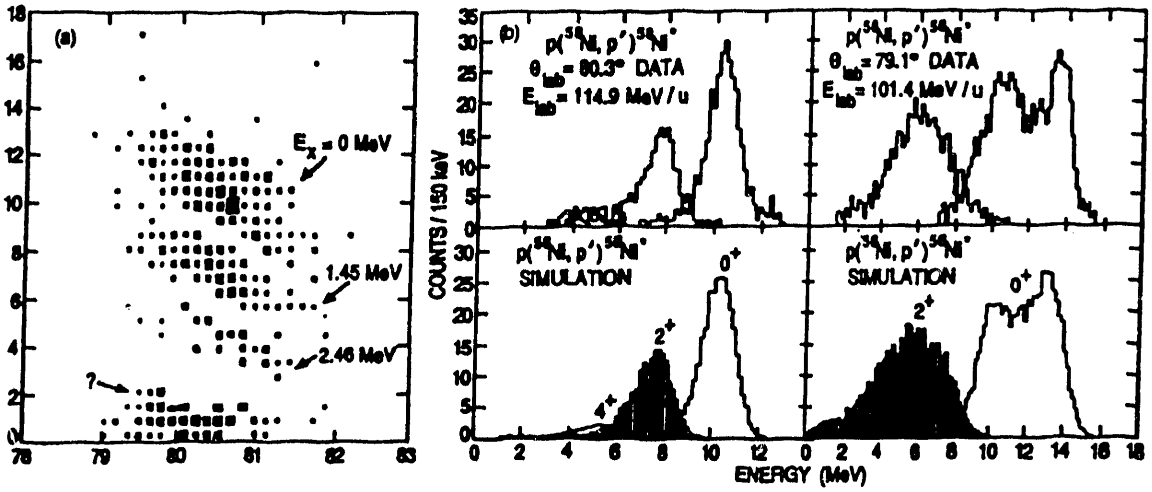

Fig. 4. Energy spectra for recoil protons from the $p(^{58}Ni, p')$ $^{58}Ni^*$ and $p(^{56}Ni, p')$ $^{56}Ni^*$ inverse reactions. a): 2-dimensional scatter plot of proton events for the ^{58}Ni reaction in the energy vs. scattering-angle plane b) projected proton energy spectra for both reactions (top: data; bottom: simulation).

Discussion and Comparison with Theory

Figure 6 shows the excitation energies and B(E2) values for the first excited 2^+ states for nuclei with N and/or Z=28. Results from the literature are compared with the result from this work. For the excitation energy one notices that ^{48}Ca and ^{56}Ni have a 2^+ state which is about 2-3 times above the excitation energy of neighboring N/Z=28 nuclei. However, when comparing the B(E2) values one notices a smooth dependence of neighboring N/Z=28 nuclei. The fact that the 2^+ excitation energy is high, partially reflects a lowered ground-state binding energy due to the $f_{7/2}$ shell closures. However, the B(E2) values involve open $p_{1/2}$, $p_{3/2}$, $f_{5/2}$ shells which are readily available for all these nuclei including ^{56}Ni (but not for ^{48}Ca, with a closed sd proton shell; the $f_{7/2}$ neutron shell closure will not effect the B(E2) very much because of the low proton core polarization and correspondingly small effective charge). The B(E2) values increase as the $f_{7/2}$ proton shell is filled, and then remain approximately constant in the Ni isotopes. Recent shell model calculations by B. A. Brown[5] (based on new empirical nucleon-nucleon interaction for the region of the fp-shell from a fit of two-body matrix elements and single particle energies to 494 experimental values of nuclei in the range $41<A<66$) yield a value of 681 e^2fm^4 for ^{56}Ni in good agreement with the experimental value of 600 ± 120 e^2fm^4.

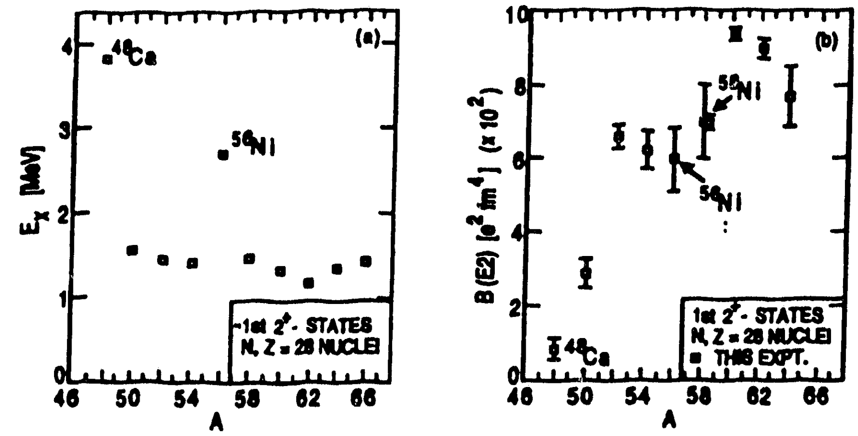

Fig. 5. a) Excitation energies E_x of the first excited 2^+ states and b) B(E2) values for the $0^+ \rightarrow 2^+$ transitions in N,Z=28 nuclei.

References:

1) K. Blasche, D. Böhne, B. Franzke, H. Prange, 1985 Particle Acc. Conf., Vancouver, IEEE Trans. NS 32 (1985).

2) B. Franzke et al., Zwischenbericht zur Planung des Experimentier-Speicherrings (ESR) der GSI, GSI-SIS-INT/84-5, August 1984; B. Franzke, Nucl. Instr. and Meth. B25/25 (1987) 18.

3) See paper by H. Geissel, these Proceedings.

4) K. Kwiatkowski et al. Nucl. Phys. A301 (1978) 349.

5) B. A. Brown, private communication.

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