22 MeV polarized proton scattering from ^{40}Ca and effective NN interactions

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Abstract Analyzing powers and differential cross sections have been measured for elastic scattering of 22 MeV polarized protons from ^{40}Ca, ^{16}O and ^{12}C, and differential cross sections for inelastic scattering of 22 MeV protons from 3^-(3.736 MeV) and 5^-(4.491 MeV) states of ^{40}Ca have also been measured. The experimental data for polarized proton elastic scattering have been analyzed with a phenomenological optical potential parameters, the experimental data and theoretical values are in good agreement. In the theoretical frame of microscopic single scattering model, transition densities extracted from electron inelastic scattering and M3Y and Halderson's effective interactions have been utilized to analyze the experimental data of 22 MeV proton inelastic scattering from ^{40}Ca. Overall, it seems that Halderson's effective interaction can better describe the experimental data than M3Y although the degree of agreement between experimental and theoretical values needs to be improved.

Keywords Polarized proton scattering, Effective nucleon-nucleon interaction

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1 INTRODUCTION

Proton inelastic scattering is an important tool to study nuclear structure and effective nucleon-nucleon (NN) interaction. Much work has been done to try to extract almost all independent observables in nucleon- nucleus scattering with the help of polarized beams, polarized targets and even coincidence techniques between scattered nucleon and decayed γ-rays.[1~3] If as many independent observables as possible could be obtained, various aspects of nuclear structure and effective NN interaction could be studied in more detail. In the studies like this, polarized ion source, which provides polarized beams, is one of the most essential devices. A polarized ion source has been developed for years in China Institute of Atomic Energy (CIAE), this is the first time to try to use it in an experiment.

Effective NN interaction in nucleon-nucleus scattering has been a subject of interest for a long time. In high energy region (>100 MeV), several effective interactions are

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widely used in the analysis of nucleon-nucleus scattering such as LF[4], NL[5] and PH[6]; correspondingly, M3Y[7], ATB[8], HKT[9] and CEG[10] are effective interactions used in low energy region (<100 MeV), of which M3Y is the most widely used. On the other hand, the most extensive empirical work for effective NN interaction has been done for incident nucleon energies in excess of 100 MeV[11]; at the lower energy of interest here, very few empirical studies have been performed[12]. At present, in general, observables of nucleon-nucleus scattering in higher energy region can be described more successfully than in lower energy region[13]. As one of the efforts to improve the situation, the study of effective NN interaction is still interesting subject up to now. Recently, Halderson constructed a target-dependent effective NN interaction for lower incident energy region[14] by solving Bethe-Goldstone equation. Reid soft-core potential was used as the bare NN interaction and a prescription for starting energies was determined by comparing the results of translationally invariant, continuum shell model calculations with nucleon-scattering data for A=3 and 4 targets. ^{40}Ca is a spherical nucleus, its reaction mechanism is relatively simple in nucleon-nucleus scattering and also its nuclear structure has been well studied both experimentally and theoretically. Therefore, as a target, ^{40}Ca is a good choice for studying effective NN interaction. One of our aims in the present study is to test the ability of Halderson's effective interaction to describe the experimental data.

2 EXPERIMENTAL

The polarized ion source developed in CIAE is a Lamb-shift type. In the present experiment, the 22 MeV polarized proton beam current on target was about 10nA with a polarization of 36.77%. The beam polarization was measured via ^{7}Li(p,α)^{4}He reaction with a LiF polarimeter, which consists of a LiF target and a pair of Au-Si surface barrier detectors. The thickness of the LiF target was about 200μg/cm^2, the emitted α-particles were detected by the two Au-Si surface barrier detectors, which were placed at 45^0 symmetrically on opposite sides of the incident proton beam axis. The ^{7}Li(p,α)^{4}He reaction was found to be an excellent proton polarization analyzer in the energy range from 9 to 26 MeV with stable large cross section and reasonable large analyzing power(0.7~0.95)[15]. In our experiment, the polarization direction (spin up and spin down) of proton beams was reversed every 30 seconds, and the polarization was measured at the beginning and at the end of the experiment, which was stable within less than 2.5%. The ^{40}Ca target used was a naturally abundance CaO target with thickness of 154 μg/cm^2, deposited on a carbon film. Scattered protons were momentum analyzed by Beijing Q3D magnetic spectrometer in HI-13 tandem accelerator laboratory at CIAE and recorded by a focal plane detector which is composed of a single-wire position sensitive detector X, a gas proportional detector ΔE and a thick scintillation detector E. $\Delta E - E$ particle discrimination technique was used. Data acquisition system adopted was the XSYS system transplanted from Triangle Universities Nuclear Laboratory(TUNL). Analyzing powers and differential cross sections have been measured for elastic scattering of 22 MeV polarized protons from ^{40}Ca, ^{16}O and ^{12}C, and differential cross sections for inelastic scattering of 22 MeV protons from 3^-(3.736 MeV) and 5^-(4.491 MeV) isoscalar natural-parity states of ^{40}Ca have also been measured in the laboratory scattering angle range of 20°-90° in steps of about 5°. Experimental spectra obtained for proton elastic and inelastic scattering were analyzed by a spectrum fitting code ALLFIT[16]. Systematic error mainly stemmed from integration beam current, solid angle and the target thickness, in which the uncertainty in the measurement of target thickness and uniformity is of the order of 5% and constitutes the largest source of error. We believe that the total estimated systematic uncertainty is less than 10%. The systematic error due to uncertainty in the calibration of the beam polarimeter is about 3%. In Figs.1-2 only presented are statistical errors.

3 ANALYSIS

In Fig.1 are shown the experimental analyzing powers and differential cross sections of 22 MeV polarized proton elastic scattering from ^{40}Ca, ^{16}O and ^{12}C elements and the theoretical curves based upon the phenomenological optical potential parameters given by Fabrici *et al.*[17] The degree of agreement between the experimental and theoretical values for the three elements is very satisfactory. Because our aim is not to obtain the best optical potential parameters, the optical potential parameters used are not adjusted for best fitting to experimental data. For ^{12}C, due to the unknown thickness of carbon substrate, absolute experimental differential cross section data cannot be obtained, so the experimental differential cross section data are normalized to theoretical values for comparison. Comparison between experimental and theoretical differential cross sections for 22MeV proton inelastic scattering from 3^-(3.736 MeV) and 5^-(4.491 MeV) states of ^{40}Ca is plotted in Fig.2. The theoretical analysis has been carried out using a microscopic single scattering model[18] with the computer code LEA.[19] The optical potential parameters were taken from Ref.[17]. The empirical proton transition densities extracted from electron scattering[20] for the two isoscalar excitation states were adopted to minimize uncertainties introduced from shell model wavefunctions. Because of the charge symmetry and N=Z, the neutron transition densities for the two isoscalar states can be reliably set equal to the empirical proton transition densities. The effective NN interactions used in the present theoretical analysis are M3Y effective interaction and Halderson's effective interaction.

As can be seen from the theoretical results shown in Fig.2, the calculations for 3^- state reproduce acceptably the shape of differential cross sections, but overestimate the magnitude by a factor of approximately 2. For 5^- state, the theoretical result can overall reproduce the magnitude of the differential cross sections, but cannot reproduce the shape of the experimental data. In a word, the theoretical results cannot satisfactorily describe the experimental data. Moreover, it should be noticed that in the present theoretical analyses there are no free parameters. As to M3Y and Halderson's effective interactions, the two effective interactions provide similar predications for the differential cross sections of the two excitation states, and the magnitudes predicted by M3Y are somewhat higher than Halderson's effective interaction. Overall, it seems that Halderson's effective interaction can better describe the experimental data than M3Y. We have compared the various components of the two effective interactions and found that the small difference in magnitude predicted by the two effective interactions is mainly caused by the difference of triplet-even components (TE) of the two effective interactions. Obviously, the degree of agreement between experimental data and theoretical predictions for inelastic scattering should be improved. As indicated in Refs.[18] and [21], additional work must be done to gain a greater understanding of the components of the microscopic single scattering model, including effective NN interaction, for nucleon-nucleus scattering at energies below 100 MeV.

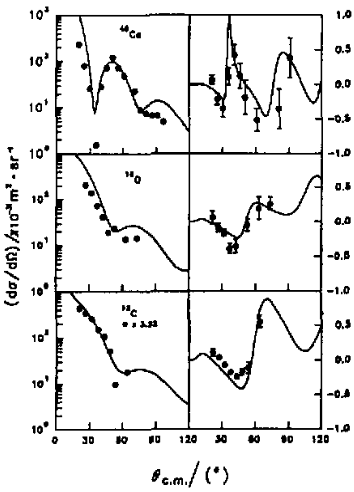

Fig.1 Experimental data of differential cross sections and analyzing powers of 22 MeV polarized proton elastic scattering from ^{40}Ca, ^{16}O and ^{12}C. Solid lines represent optical-model predictions

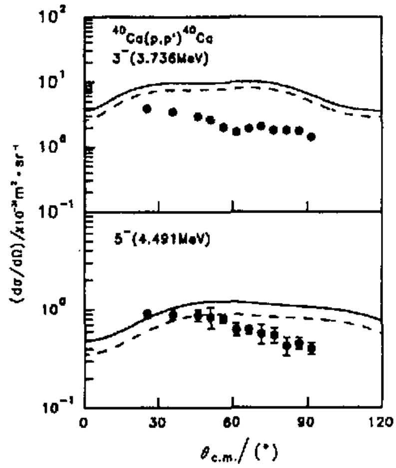

Fig.2 Experimental data of differential cross sections of 22 MeV proton inelastic scattering from the 3^-(3.736 MeV) and 5^-(4.491) states of ^{40}Ca. Solid (dashed) lines represent the microscopic single scattering calculations with M3Y (Halderson's) effective NN interaction

4 SUMMARY

In summary, we have measured the analyzing powers and differential cross sections for elastic scattering of 22 MeV polarized protons from ^{40}Ca, ^{16}O and ^{12}C, and differential cross sections for inelastic scattering of 22 MeV protons from 3^- (3.736 MeV) and 5^-

(4.491 MeV) states of ^{40}Ca. The experimental data for polarized proton elastic scattering have been analyzed with phenomenological optical potential parameters, the experimental data and theoretical values are in good agreement. The empirical transition densities extracted from electron scattering and M3Y and Halderson's effective interactions have been utilized to analyze the experimental data of 22 MeV proton inelastic scattering from ^{40}Ca. Overall, it seems that Halderson's effective interaction can better describe the experimental data than M3Y. However, it is clear that the degree of agreement between experimental and theoretical values for the inelastic scattering needs to be improved. Systematic analyses for proton scattering from ^{40}Ca in a wider span of lower incident energy are in progress in order to gain a greater understanding of the components of the microscopic single scattering model for nucleon-nucleus scattering at energies below 100 MeV. On the other hand, it is important that the present study also shows that the polarized ion source in CIAE has been ready to be used in the future physics experiment.

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