$(p,2p)$ reactions on ^{12}C, ^{40}Ca, ^{48}Ca and ^{90}Zr nuclei at 197 MeV

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Proton induced nucleon knockout reactions provide a direct means of studying the single particle structures of target nuclei. In particular, these reactions using polarized incident beams are expected to play a unique role in such studies because the j-dependence of these reactions makes it possible to determine the total angular momentum j, in addition to the orbital angular momentum l that can be obtained from the cross sections, of the single particle orbit. However, the evaluation of these reactions as a tool for extracting spectroscopic factors (S-factors) have not been conclusive enough. This is primarily caused by the difficulties in theoretical estimation of the absolute cross sections which are seriously affected by strong initial and final state interactions. In this work, we intend to examine the reliability of these reaction as a spectroscopic tool at an incident energy of 197 MeV at which clear j-dependence has been observed.

The differential cross sections and the analyzing powers of the $(p,2p)$ reactions leading to typical low lying states of residual nuclei have been measured for four kinds of target nuclei, shown in the title, in a wide range of the nuclear mass number. For ^{48}Ca target, measurement were extended up to an excitation energy 8.1 MeV of the residual ^{47}K. The experiment were performed using the two arm spectrometer system, which consists of the Grand Raiden (GR), and the large acceptance spectrometer (LAS). The setting angles of these spectrometers are fixed and so-called energy sharing cross sections and analyzing powers are measured by changing the magnetic fields. The setting angles are mostly about $\pm 40°$ at which the the momentum of the residual nucleus becomes close to zero when the energies of two outgoing protons are the same. In this kind of setting, it is known that the j-dependence is clearly observed at an incident energy of 200 MeV and the analyzing powers are well reproduced by DWIA calculations [1, 2]. Only for ^{40}Ca target, we used an asymmetrical angular setting, 29° for GR and $-54°$ for LAS. The purpose of this setting is to confirm observations at TRIUMF that the analyzing powers of the in-medium NN scattering deduced from experimental p-state and d-state knockout data in asymmetrical angular settings seem to be vanished [3]. The opening angles of the spectrometers are ± 20 mr wide and ± 30 mr high for GR and ± 50 mr wide and ± 45 mr high for LAS. The momentum bite of GR is $\pm 2.1\%$ of the central momentum and this momentum region was divided into two parts in data analysis procedure. Typical separation energy spectra are shown in Fig. 1. The overall energy resolutions achieved are 200 keV to 400 keV depending on the target thickness.

Figure 2 shows a part of experimental data, corresponding to the reactions leading to the ground states of the residual nuclei, and comparison with theoretical calculations using the computer code THREEDEE. In the DWIA calculations, the optical potential EDAD1, developed by Cooper *et al.* [4], with Darwin term were employed. The bound state wave functions were generated by the conventional well-depth method using Woods-Saxon potentials, and the geometrical parameters were taken from DWIA analysis of $(e,e'p)$ data [5]. A non-local

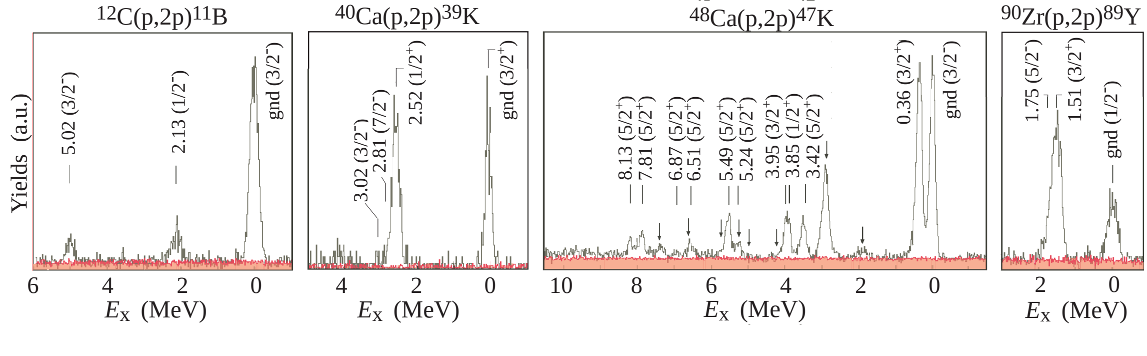

Figure 1: Typical excitation energy spectra of the residual nuclei. The shaded areas show chance coincidence events. In the plot of ^{48}Ca$(p,2p)$, the arrows indicate possible peak positions of ^{15}N states, caused by oxygen contamination in the target. Those yields were subtracted by using ^{48}CaO target data.

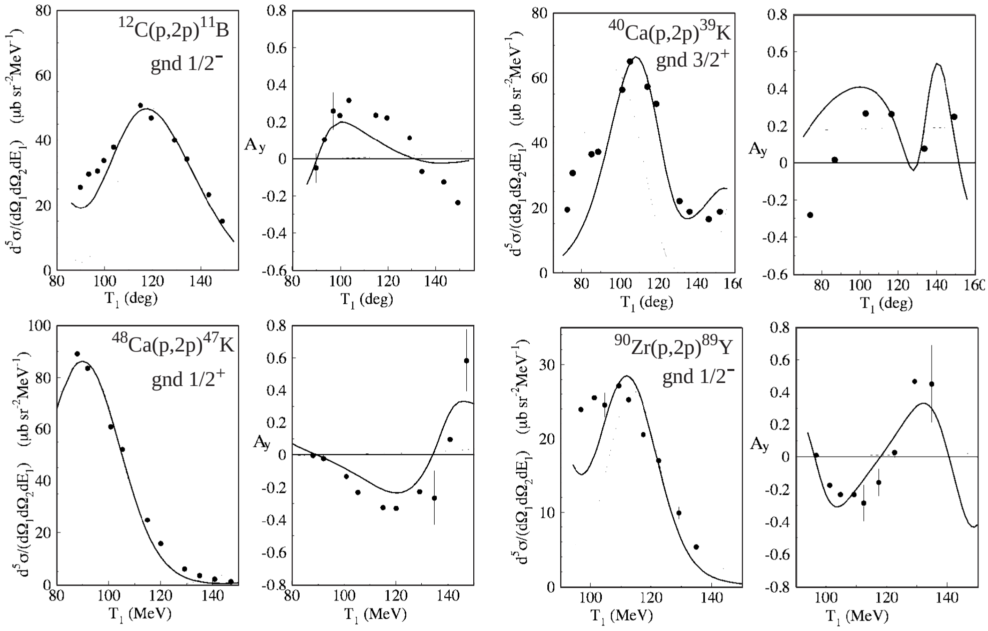

Figure 2: Experimental data and comparison with theoretical calculations. The abscissa is the energy of protons detected by GR. The solid (dashed) lines are DWIA (PWIA) results.

correction using the Perey factor with a range parameter value of 0.85 fm was applied only to the bound state wave functions. As shown in the figure, both of the cross sections and analyzing powers are fairly well reproduced by the DWIA calculations.

Next, S-factors were extracted from the rations of experimental and theoretical cross sections and compared with those extracted using $(e, e'p)$ reactions. Figure 4 shows the comparison. In this figure, the S-factors deduced in the present work are plotted relative to those reported from $(e, e'p)$ studies by Kramer *et al.* [5]. The left panel of the figure is a plot of the S-factors corresponding to various excites states of residual ^{47}K in the case of the ^{48}Ca target. Because of insufficient energy resolution in the present work, the $1/2^+$ state and the $3/2^+$ states at excitation energies of approximately 3.9 MeV are not separated each other and the multipole decomposition analysis was employed. Similarly, some $5/2^+$ states which are not well separated, or which statistics are too low for separate treatment, are jointly analyzed and sum values are compared with the $(e, e'p)$ results. As seen in the plot, the present S-factors are consistent with the $(e, e'p)$ result mostly within 10% to 15% except those for two $1/2^+$ states which are significantly smaller. The right plot is similar comparisons for ^{12}C, ^{40}Ca and ^{90}Zr target nuclei. The horizontal axis scale represents the target mass number though different orbits having the same target nucleus have been shifted slightly to avoid overlapping. In this case, the ratio for ^{12}C nucleus are somewhat smaller but those for ^{40}Ca and ^{90}Zr are consistent with unity. As a whole, it is summarized that S-factors using $(p, 2p)$ reactions at around 200 MeV incident energy are consistent with those from $(e, e'p)$ reactions typically within 15% level besides a few exceptionally deviated cases.

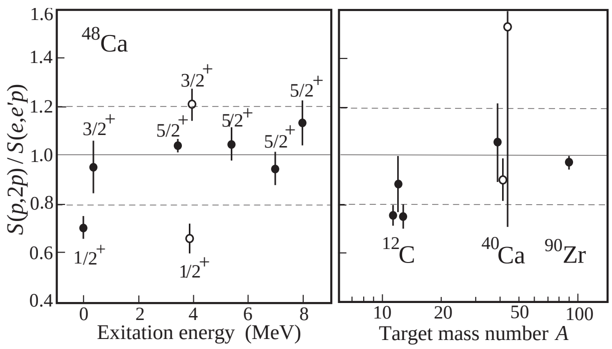

Figure 4: The ratios of S-factors deduced using $(p, 2p)$ reactions and $(e, e'p)$ reactions. Open circles indicate that the S-factors from $(p, 2p)$ reactions are results of multipole decomposition analyses.

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