THE RESCATTERING BACKGROUND IN THE KNOCKOUT REACTION ^{40}Ca($p, 2p$) INDUCED BY 392 MeV PROTONS

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It is well known that rescattering is a dominant process in nucleon knockout reactions with energetic protons. Although a proportion of the multiple scattering is manifested as events which are expected to be redistributed along a specific kinematic locus, a large fraction should proceed with energy transfer to the recoiling heavy system. Therefore, some of the knockout reactions that originate from collisions with valence nucleons in the target nucleus, and which subsequently undergo further rescattering, would in principle obscure the signature of pure knockout from deeper-lying shell-model orbitals. This process could consequently limit the extraction of information from knockout of nucleons from those deeply-bound shell-model states.

In this work we investigate the reaction ^{40}Ca$(p, p'p'')$ at an incident energy of 392 MeV in a kinematic and angular range that is optimized for a study of the rescattering process. The high-resolution magnetic spectrometer "Grand Raiden" was set up at a fixed forward angle of 25.5° and a central momentum which corresponds to 220 MeV in primary proton energy. The momentum acceptance of this detector for protons was equivalent to a kinetic energy range of 20 MeV.

The large acceptance spectrometer LAS was operated in coincidence with Grand Raiden and four overlapping field settings allowed the measurement of the energy distribution of emitted secondary protons from a threshold of approximately 50 MeV, up to the kinematic limit. Secondary scattering angles of 25.5°, 40°, 60°, 80°, 100°, and 120° on the opposite side of the beam were explored in the measurements.

The $(p, p'p'')$ rescattered component of the data were assumed to proceed as an initial knockout interaction, which was calculated in the Distorted Wave Impulse Approximation (DWIA) [1], followed by rescattering of the struck nucleon. This rescattering of the bound nucleons was interpreted in the spirit of the multistep direct process [2, 3]. However, instead of using, for example, the theory of Feshbach, Kerman, and Koonin [3] to evaluate the cross sections and angular distributions, we interpolated the available (p, p') experimental data [4] on ^{40}Ca over the required range of effective incident energies.These data are known to be successfully described in terms of the required statistical multistep direct model [3]. The participation of struck neutrons was included by a scaling based on experimental guidelines[5][6].

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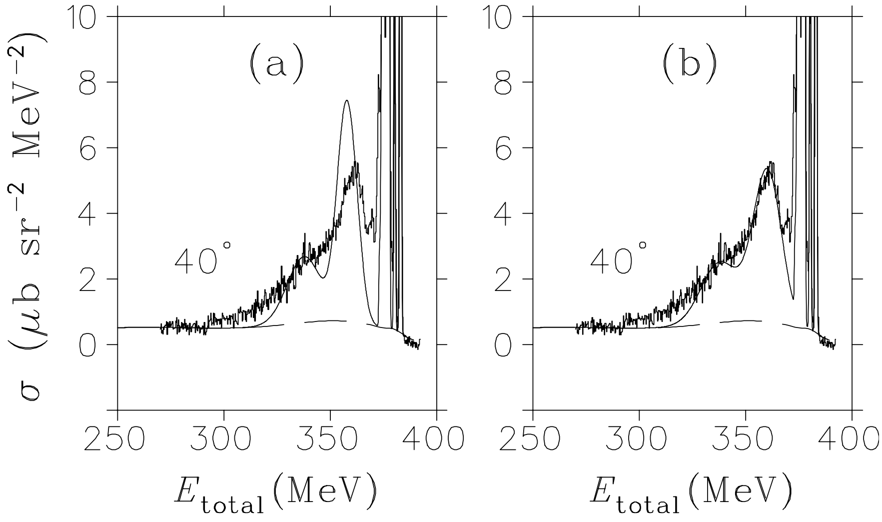

Figure 1: Binding energy spectra. The continuous theoretical curve shown in Fig. 1a applies to widths and positions of the $1s$- and $1p$-states taken from the experimental work of Volkov *et al.* [8] wheras Fig. 1b is a display if these quantities are adjusted for better agreement with our data. The calculated rescattering background is shown as dashed curves.

Relative spectroscopic factors for the initial knockout process were based on the single particle shell model spectroscopic sum rule limit, except for the $1f_{7/2}$-state, which had to be scaled to experimental results of Doll *et al.*[7]. The overall spectroscopic strength was subsequently adjusted to give a fair representation of the cross sections observed for knockout to discrete valence states in this work. This procedure then fixes the absolute magnitude of the initial interaction that serves as a source reaction to the rescattering process of the struck nucleon.

The agreement between the calculated and experimental knockout binding energy spectra for the $(p, 2p)$ reaction to discrete states was found to be satisfactory. However, as is shown in Fig. 1, for the deep-lying $1s$- and $1p$- hole states, superimposed on the background calculated to result from the $(p, p'p'')$ mechanism, the widths and positions needed to be adjusted slightly compared to the experimental work of Volkov *et al.* [8] for better agreement with our experimental data.

Final comparisons between the experimental coincident cross sections and an incoherent sum of the theoretical $(p, p'p'')$ and $(p, 2p)$ values, are shown in Fig. 2. Clearly the theoretical treatment reproduces the experimental coincidence spectra accurately. Results are plotted as a function of the energy of the proton observed in the large acceptance spectrometer for various secondary angles. It should be noted that the cross section units and scale are appropriate for the central momentum corresponding to 220 MeV in primary proton energy and momentum acceptance equivalent to an energy range of 20 MeV.

Our calculations indicate that at LAS angles of 80° and larger, discrete knockout is a negligible contribution, and the yield then represents only the rescattering mechanism. The absolute magnitude corresponds to a knockout strength that agrees to within 30% of the expected value, which is reasonable. Furthermore, it is significant that the cross section of the secondary $(p, p'p'')$ reaction scales exactly with the value of the $(p, 2p)$ source reaction, which is a prerequisite for the good agreement between the theory and experimental data.

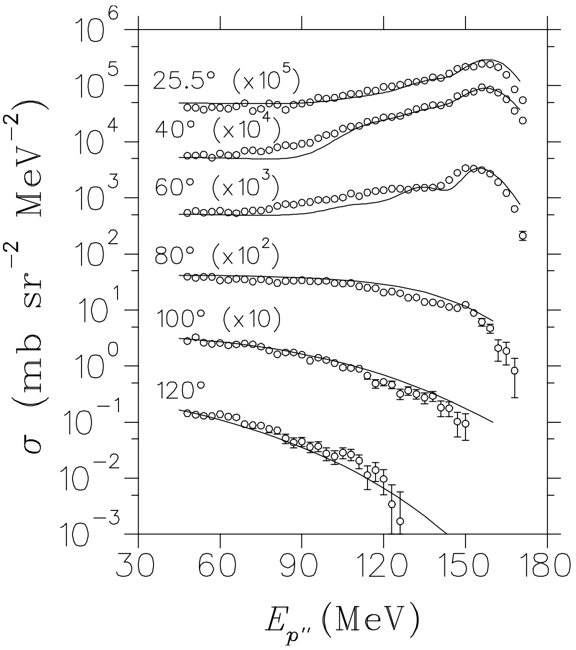

Figure 2: Differential cross sections for coincident protons emitted in the reaction of 392 MeV protons with ^{40}Ca at a primary angle of 25.5° and at various secondary angles as indicated. The cross section units and scale are appropriate for an average primary proton energy of 220 MeV and over a range of 20 MeV. Experimental data are shown with statistical error bars where these exceed the symbol size.

This work shows that a major part of the rescattering process in knockout reactions is understood reasonably well. However, aspects such as the apparent increase of the widths of knockout from the deeper-lying states compared to $(p, 2p)$ measurements at higher energy need to be investigated further.

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