A \((p, p'\gamma)\) Angular Correlation Study of an Intermediate Structure in the \(3^-\) Exit Channel of \(^{40}\text{Ca} + p\)

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Excitation functions of the \(^{40}\text{Ca}(p,p_2\gamma)\) triple angular correlations have been measured in the region of an intermediate structure centered at \(E_p = 6.25\) MeV, for 12 pairs of proton and gamma detector positions. The angular correlations are consistent with the spin \(5/2^+\) assigned for these resonances and have established the \(p_{1/2}\) partial wave as the main decay mode of the intermediate structure in the \(3^-\) inelastic channel. These results are strongly supporting the description of the structure observed in the \(3^-\) exit channel as consisting of \(2p - 1h\) doorway states in which a \(2p_{1/2}\) single-particle state weakly coupled to \(3^-\) excited core is split by residual interactions. An improved dynamical treatment, aimed to obtain the strength function of the \(2p_{1/2}\) single-particle state in the \(3^-\) channel, is suggested.

1. Introduction

Nuclei in the region of magic numbers are among the most suitable targets for studying weak coupling of states with simple structures. A well known example of such states in a region of high level density, manifesting themselves as intermediate structures, is given by the isobaric resonances. A group of pronounced resonances has been observed by Mittig et al. [1] in the excitation function of the inelastically scattered protons of the \(3^-\) level of \(^{40}\text{Ca}\) at \(3.73\) MeV, for bombarding energies between \(5.8\) and \(6.6\) MeV. These resonances are correlated at all angles in the \((p,p_2)\) inelastic channel while they are not correlated with the less pronounced structures present in the other channels. The authors of [1] conclude that this group of resonances form an intermediate structure due to the \(2p_{1/2}\) single-particle state coupled to the \(3^-\) state of \(^{40}\text{Ca}\) at a total spin and parity \(5/2^+\). The spin of the various components of the structure has been inferred from the angular distributions. On the other hand, the angular distributions alone did not allow to decide which of the two partial waves, \(p_{1/2}\) or \(p_{3/2}\), is the main decay mode in the \(3^-\) channel. The choice of the \(p_{1/2}\) wave has been made via weak coupling and shell model considerations. Since not many doorway states in the exit channel are thoroughly investigated, the aim of the present work is a detailed study of this intermediate structure in the \(^{40}\text{Ca} + p\) system by means of \((p,p'\gamma)\) angular correlations. The Goldfarb-Seyler method [2] has been used to infer the spin of the resonances, while the bulk of the correlation data allowed a rather accurate determination of the \(p_{3/2} - p_{1/2}\) amplitude mixing ratio in the exit channel.

The experimental method is presented in Sect. 2, the analysis and the results in Sect. 3, while the conclusions are drawn in the last section, where the need for a more complete theoretical treatment is emphasized too.

2. Experiment

The proton beam was delivered by the EN Tandem of Max-Planck-Institut für Kernphysik in Heidelberg.
It bombarded a natural Ca target (96.94% of Ca) having a thickness of about 40 keV at 6 MeV proton energy. The angular correlations set-up is shown in Fig. 1. The 160 mm diameter scattering chamber had 2 mm thick aluminium walls. By locating the beam dump 4 m from the scattering chamber, shielding it by 1 m thick concrete blocks and shielding with lead the beam defining slit, the gamma radiation background was kept to a minimum.

The angular correlations between 4 protons surface barrier silicon detectors and 3 gamma-ray NaI detectors were measured in 10 keV steps between 5.98 MeV and 6.55 MeV bombarding energy. Two proton detectors were placed in the scattering chamber plane (φ = 0) at θp = 131.5° and 89.3° relative to the beam direction, the third one perpendicular to this plane (φ = 90°) at θp = 88.8°, while the fourth proton detector was an annular one at 180°. The 7.5 cm diameter × 7.5 cm NaI crystals used for gamma ray detectors were optically coupled to XP 1021 photomultipliers, known to preserve their linearity at high counting rates (~ 10^5 s^-1). The gamma counters were set in the following positions: counter 1 at θγ = 90°, φ = π, counter 2 at θγ = 34°, φ = 0 and counter 3 at θγ = 60°, φ = π. On the maxima of the intermediate structure the proton detectors were kept fixed at the above mentioned angles, while the gamma counters were additionally moved to the following positions: counter 1 at θγ = 80° and 120°, φ = π; counter 2 at θγ = 45°, φ = 0, and counter 3 at θγ = 55° and 67.5°, φ = π. Thus, on resonance the number of proton–gamma angular combinations amounted 32 as compared to 12 combinations used off-resonance.

In the present experiment the Goldfarb-Seyler (GS) geometry is realized by the out-of-plane proton detector at θp = 88.8°, φ = π, together with all the above specified gamma counter positions. Part of these positions were chosen such as to increase the sensitivity in detecting an eventual term in the expansion of the angular correlation function proportional to cos(6θp) (see Eq. (1) below).

The relative normalization of the solid angles subtended by the proton detectors has been made by means of proton Rutherford scattering on gold at Ep = 6 MeV, while for gamma counters a radioactive source in the target place has been used.

The coincidence circuit is arranged around a fast coincidence circuit of typically 200 ns resolution time which enables time-to-pulse-height conversion. Further details can be found in [3]. The coincident signals were processed on-line and stored in list mode on tape.

Each point of the correlation function has been obtained by summing up the total absorption, first escape and double escape peak areas for the 3.734 MeV gamma transitions deexciting the 3° level in 40Ca, coincident with the protons inelastically scattered on this level. A coincident spectrum, con-