Chapter 74
Spectroscopic Study on ^{39}Ca Using the ^{40}Ca(d,t)^{39}Ca Reaction for Classical Nova Endpoint Nucleosynthesis

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Abstract In classical novae simulations, the uncertainty in the reaction rate of ^{38}K(p,γ) has been shown to affect the abundances of endpoint nuclides significantly. To better understand the reaction rate, we have done a spectroscopic study on ^{39}Ca. The reaction ^{40}Ca(d,t)^{39}Ca at a beam energy of 22 MeV was used to populate excited states of ^{39}Ca. Tritons were momentum analyzed using a high resolution quadrupole-dipole-dipole-dipole (Q3D) magnetic spectrograph at 4 angles. Preliminary resonance energies for ^{39}Ca within the energetic region of interest for classical novae - 6.0–6.4 MeV - were determined.

74.1 Introduction

Classical novae occur in close binary systems with a white dwarf and a main sequence/red giant companion star. In these systems, the denser white dwarf siphons hydrogen rich material from its companion star, forming a layer of nuclear fuel on the surface of the white dwarf. Thermonuclear runaway ensues, causing a dramatic increase in temperature (T = 0.1–0.4 GK) and luminosity, eventually leading to a classical nova outburst. In this process, heavier nuclei are synthesized via pro-

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gressive proton capture reactions and subsequent β^+ decays. The endpoint of this nucleosynthesis occurs at approximately A $\sim$ 40.

Currently, observed elemental abundances of endpoint nuclides show enhancement compared to nova models by up to an order of magnitude [1, 2]. This difference could be caused by the treatment of clumping in the ejecta [3], or due to uncertainties in nuclear reaction rates. In a sensitivity study by Iliadis et al. [4] it was shown that the ^{38}K(p,γ)^{39}Ca reaction could change abundances of the endpoint nuclides in classical novae by up to 2 orders of magnitude if the reaction rate was varied within its uncertainty.

In temperatures typical of classical novae, the total reaction rate is dominated by three $\ell = 0$ resonances within the Gamow window. These occur at excitation energies in ^{39}Ca at 6157(10), 6286(10), and 6460(10) keV. This motivated the direct measurement of the ^{39}K(p,γ)^{39}Ca reaction by Lotay et al. [5] at the DRAGON facility in TRIUMF. In [5], the resonance at 6460(10) was instead observed at 6450^{+2}_{-1}(stat.) $\pm$1 (sys.) and the resonance strength was obtained. Upper limits were determined for the resonance strengths of the others. When the reaction rate was varied within its new uncertainties it was shown that the variations in abundances of these endpoint nuclides were reduced to one order of magnitude.

High resolution spectroscopic studies of ^{39}Ca were recommended by Lotay et al. [5] to probe for additional resonances corresponding to low ℓ capture resonances in the ^{38}K+p system. To that end we performed a spectroscopic study using the reaction ^{40}Ca(d,t)^{39}Ca not only to probe for new states, but to also to improve the precision on excitation energies of existing states.

74.2 Experimental Method

The experiment was performed at the Maier-Leibnitz Laboratory (MLL), a joint facility of the Technical University of Munich and Ludwig-Maximilians-Universität. The MP Tandem Van de Graff was used to accelerate a deuteron beam to 22 MeV, which was then impinged on the following targets: natural CaF_2 on carbon backing, a calibration target of ^{32}S implanted in carbon, and a background target of natural LiF on a carbon backing.

Tritons emerging from the reaction were momentum analyzed in a quadrupole-dipole-dipole-dipole (Q3D) magnetic spectrograph. Data were taken at spectrograh angle θ_{lab} = 15, 20, 25 and 30°. Gas filled proportional counters provided energy loss signals and precise position information from charges induced on the anode strips detector along the focal plane. A scintillator provided residual energy of the tritons, and thus a unique particle identification.

Positions of the tritons were determined, corresponding to the energies of those tritons.

Table 74.1 Preliminary resonance energies of ^{39}Ca determined in the current work compared to previously evaluated values

NDS evaluated energy (keV)	This work (keV) (±) stat
6.451(2)	6.4592(6)
6.432(2)	6.431(2)
6.405(10)	6.4003(4)
6.286(10)	6.289(1)
6.157(10)	6.1507(1)
6.094(10)	6.0869(5)

74.3 Results and Discussion

The background from ^{19}F(d,t)^{18}F was well characterized by a scaled spectrum produced by a LiF target, where a polynomial, featureless background from ^{7}Li(d,t)^{6}Li was assumed.

The peaks in the background subtracted triton position spectrum, corresponding to resonance states, were fitted using exponentially modified Gaussian functions; the asymmetry accounting for the energy straggling within the target. Centroid positions and full widths at half maximum of peaks were determined for the ^{40}Ca(d,t)^{39}Ca and the ^{32}S(d,t)^{31}S calibration spectrum.

The ^{40}Ca(d,t)^{39}Ca triton spectra were calibrated by relating the positions of isolated ^{32}S(d,t)^{31}S peaks with their respective energies from [6]. Through the SPlitpole ANalysis Code (SPANC) [7], a polynomial function of the energy vs. position was determined using these calibration peaks, which was then applied to the ^{40}Ca(d,t)^{39}Ca triton spectrum to determine the energy at each centroid position.

The preliminary results of a measurement at a spectrograph angle of 20° is reported in Table 74.1. The uncertainty is purely statistical, however the addition of systematic uncertainties is unlikely to cause the total uncertainty to exceed 2–5 keV [8]. Most of the preliminary energies agree with previously tabulated values, with the exception of the 6451(2) keV state.

74.4 Conclusion

A spectroscopic study of ^{39}Ca was performed at MLL using the reaction ^{40}Ca(d,t)^{39}Ca. Preliminary data generally agrees well with previously evaluated data, and will likely reduce uncertainties in excitation energies, however a discrepancy exists between the state suggested in [5] and this preliminary work.

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