Contribution ID: **30** Type: **Contributed Oral/Poster**

Study of the ^{30}P(d,n)^{31}S reaction to probe astrophysical resonance strengths

Tuesday, 12 July 2016 14:10 (15 minutes)

The ^{30}P(p,γ)^{31}S proton capture reaction is a bottleneck for nucleosynthesis towards heavier nuclei during nova outbursts. This reaction is inaccessible experimentally in the relevant energy region, but its reaction rate can be probed using the ^{30}P(d,n)^{31}S transfer reaction. By determining the energies and spin assignments of low lying states in ^{31}S populated by this transfer reaction, one can recover the resonance strength for the desired ^{30}P(p,γ)^{31}S proton capture. This resonance strength is a key component of determining the reaction rate at astrophysical temperatures. There is, however, wide disagreement regarding spin assignments for these resonance states, including recent shell model calculations which indicate negative parity states should dominate the reaction rate in the Gamow window [1].

The ^{30}P(d,n)^{31}S experiment was carried out at the National Superconducting Cyclotron Laboratory at Michigan State University, where a radioactive beam of ^{30}P with E=30 MeV/u impinged on a thick, deuterated target. The resonances were identified by their γ decays with the high resolution GRETINA detector. These gamma decays were measured in coincidence with ^{31}S detections in the S800 Spectrograph. This method allows for high energy resolution and angle-integrated cross sections, which can be compared to reaction theory predictions.

This new method has been successfully employed to analyze the ^{26}Al(d,n)^{27}Si reaction. Comparison to theoretical calculations for this reaction reached good agreement and resonance strengths were extracted for the astrophysically relevant ^{26}Al(p,γ)^{27}Si reaction [2]. This indicates that it is a reliable method for estimating resonance strengths for similar reactions.

For the ^{30}P(d,n)^{31}S reactions we calculated total cross sections using the framework of the Adiabatic Distorted Wave Approximation (ADWA) which explicitly takes deuteron breakup into account to all orders [3]. The calculations were done using TWOFNR [4] and FRESCO [5]. The theoretical (d,n) cross sections can be used in the analysis of the data to produce experimental spectroscopic factors.

Reaction calculations for similar systems with low lying resonances have used a bound state approximation which artificially binds the resonant state by a few eV, but the accuracy of this approximation had not been tested rigorously. During our investigation we explored the limits of this approximation and discovered that the approximation was not valid for some cases, yielding percent differences of more than 10% for states of ^{31}S with low angular momentum. When our approximation did not hold, we introduced a resonance at the experimental energy and constructed a bin wave function to account for these states.

Another source of uncertainty in these calculations is the optical potential, in this case neutrons on ^{30}P, protons on ^{30}P, and protons on ^{31}S. The optical potentials we use are derived from fits to stable target data sets at different energies and mass number and then extrapolated. We make different choices for the optical potentials used in our calcutions to gauge the uncertainty in the calculated cross sections.

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Track Classification: Theoretical developments of direct reactions