E414

Stellar neutron sources: exploring the properties of resonances using the ($\vec{d}$,p) reaction

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Running Time: A total of 6 days running time is requested of which 2 days are needed for cyclotron optimization (momentum spread), beam line matching, and spectrometer setup, 3 days for production runs (including the time needed for mode changes) and background measurements and one day for deuteron elastic scattering.

Beam Line: Dispersive WS beam line and Grand Raiden Spectrometer in three modes (0° mode, Faraday cups behind Q1 and in scattering chamber).

Beam Requirements: Particle type and energy: vector polarized deuterons of 56 MeV
beam intensity: a maximum of 100 nA is required,
beam energy spread: of the order of 100 keV or better.

Other requirements: Halo-free beam, fully dispersion-matched beam on GR target.

Special Equipment required: A new 0° Faraday cup for the ($\vec{d}$,p) reactions with 2 electrical feedthroughs, standard GR, and focal plane equipment are needed.

Target Budget: Highly enriched ^{25}Mg target with a thickness of 1 mg/cm^2 (¥ 150000).
A ^{24}Mg target is available from a previous experiment.

INTRODUCTORY REMARKS

We propose to study levels in ^{26}Mg above the alpha threshold using the ($\vec{d}$,p) reaction with polarized deuteron beam. This experiment was originally presented to the previous B-PAC (E414) together with a high resolution study of the ^{22}Ne(^{6}Li,d) reaction (E415) to explore the same excitation range in ^{26}Mg. Aim of both experiments was to obtain detailed information about states in ^{26}Mg within the first 1 MeV above the alpha threshold. These states are potential resonances in the ^{22}Ne(α,γ) and ^{22}Ne(α,n) reactions. The effectiveness of the (α,n) reaction as neutron source during the core He burning phase of massive stars depends on the absolute strength of the stellar reaction rate of the (α,n) reaction as well as the ratio of both reactions.

Because of the lengthy shutdown of the RCNP cyclotron laboratory, a large number of experiments were submitted to the previous B-PAC. For this reason the B-PAC decided to approve only one of these two experiments even though both received positive evaluations. While the (^{6}Li,d) experiment (E415) was approved, the ($\vec{d}$,p) experiment (E414) was suspended. At this point we want to reactivate E414. The present proposal is nearly identical to the one originally submitted. We have added a short section discussing the influence of the rate uncertainties on the s-process nucleosynthesis in massive stars. The only other change is that Yingying Chen has replaced Rashi Talwar as spokesperson. Mrs. Talwar is presently finishing her PhD thesis and this experiment will become part of the PhD thesis of Mrs. Chen.

The ^{22}Ne(^{6}Li,d) experiment was performed at the end of October 2013. While these data are still presently analyzed at Notre Dame, it is already clear that we could not observe weakly populated states. The main reasons are that the cross section at the chosen beam energy is significantly lower than anticipated and the beam intensity was reduced by the poor transmission of the dispersion matched beam in the WS beam line. The feasibility of this experiment will be reevaluated again, once the analysis is finalized including the measured elastic scattering. However, the data of a lower resolution study of this reaction (E379) are available.

For this reason the importance of the proposed ($\vec{d}$,p) experiment is increased. This reaction is well suited to populate the states of interest with high energy resolution. This was demonstrated by previous experiments which unfortunately did not provide any information about states above 10 MeV excitation energy. The energy range between alpha- and neutron-threshold is only poorly studied (mainly via the (p,p') reaction) and the (d,p) reaction might reveal a number of presently unobserved states. In contrast the energy range above the neutron threshold is well studied, mainly by (n,n) and (n,γ) experiments. However, these reactions are mainly sensitive to s- and p-wave neutron capture and not well suited to study resonances with l_n>1 whereas e.g. s-wave resonances in ^{22}Ne+alpha require l_n=2.

During the last B-PAC there was a discussion about the energy resolution because this proposal strives for a resolution of better than 15 keV. In the meantime A. Tamii and collaborators performed a (p,d) experiment at a beam energy of 65 MeV using the AVF cyclotron only and achieved an achromatic resolution of 23 keV. For this reason be believe that a resolution of ≤15 keV is realistic for the proposed ($\vec{d}$,p) experiment.

1 Summary of the Proposal

• **Proposed Experiment**: Measurement of the ($\vec{d}$,p) reaction on ^{25}Mg with astrophysical motivation is proposed using the WS course and Grand Raiden(GR). The vector polarized deuteron beam of 56 MeV will be provided by the cyclotron facility with an intensity of 100 nA. GR will be used in three Faraday cup modes including the 0° mode with a Faraday cup inside dipole D1. This experiment is part of an ongoing astrophysics program at RCNP. It aims at resonance states above the α-threshold at excitation energies around 11 MeV (^{26}Mg) and is only possible with a high-resolution spectrometer since a resolution of ≤15 keV is required to resolve high-lying excited levels in the final nucleus. Part of this experiment will be combined with the results of E370 (^{26}Mg(α,α')) and of E379 (^{22}Ne(^{6}Li,d)) to obtain improved stellar reaction rates for the ^{22}Ne(α,γ/n) reactions.

• **Targets**: An isotopically enriched ^{25}Mg target with a thickness of 1 mg/cm^2 will be ordered from Oak Ridge. The energy losses for the 56 MeV deuteron beam and the ≈53 MeV protons from the reaction are 16 keV and 10 keV, respectively. This will result in a differential energy loss of 6 keV for the outgoing protons . A ^{24}Mg target (available from a previous experiment) as well as polystyrene and Mylar foils will be used for background measurements.

• **Apparatus and Beam Properties**:
The WS course in dispersive mode and the Grand Raiden spectrometer with the standard VDC focal plane detector system will be used. An existing set of 5 mm and 10 mm thick plastic scintillators will be used to provide energy loss and timing information for particle identification.

• **Beam time Request**:
The total beam time request of 6 days will be used as follows:
a) 2 days for beam preparation, detector and particle identification verifications, ion-optical setup and dispersion matching as well as energy calibration of the focal plane.
b) 3 days for production runs (including the time needed for mode changes) and background measurements.
c) 1 day to measure deuteron elastic scattering at angles ≥ 6°.

2 Scientific Motivation

Potential stellar neutron sources for the s-process in massive stars are associated with α-capture reactions on light nuclei, such as ^{13}C and ^{22}Ne. The reaction ^{22}Ne(α,n) is of particular importance for the neutron production in massive Red Giant stars during core helium burning and in AGB stars during helium shell burning. The cross section of this reaction at stellar energies as well as of the competing capture reaction ^{22}Ne(α,γ) are dominated by the contribution of low energy, natural parity resonances [1]. Considerable effort has been made in the past to measure the low