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^{25}Al+p Elastic Scattering with CRIB

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The present rate of the ^{25}Al(p,γ)^{26}Si reaction suffers from significant uncertainties due to the lack of relevant structure information in the compound nucleus ^{26}Si. An ^{25}Al+p elastic-scattering experiment in inverse kinematics was performed using the CRIB facility at the CNS at the University of Tokyo, Japan, to try and improve current understanding. The ^{2}H(^{24}Mg,n)^{25}Al reaction was used to produce a 7.5 MeV/A ^{25}Al radioactive beam with intensities of $\sim 10^6$ pps at the secondary CH_2 target position. Protons were detected in silicon $E\Delta E$ telescopes and a center-of-mass energy range of 3 MeV was scanned, reaching up to about 8.5 MeV in excitation energy in ^{26}Si.

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1. Introduction

The origin of galactic ^{26}Al remains a long-standing question in nuclear astrophysics. Within the context of explosive hydrogen burning, the ^{25}Al(p,γ)^{26}Si reaction bypasses the production of ^{26}Al at lower temperatures found in novae, while the same reaction contributes indirectly to ^{26}Al production at higher temperatures. The present rate of the ^{25}Al(p,γ)^{26}Si reaction suffers from significant uncertainties due to the lack of relevant structure information in the compound nucleus ^{26}Si.

The recent detection of decaying ^{26g}Al ($t_{1/2} = (7.1 \pm 0.2) \times 10^5$ yr) via its characteristic 1.809 MeV γ-ray by the RHESSI and INTEGRAL satellites has furthered understanding of the production sites of this radioisotope [1, 2]. The COMPTEL all-sky map of the 1.809 MeV line [3] points to young, high-mass progenitors such as core collapse supernovae (CCSN) and Wolf-Rayet stars [4]. Though previous studies suggested that the measured 2.8 ± 0.8 M$_\odot$ [5] of ^{26g}Al in the galaxy could have been entirely produced in CCSN [6], these new results have suggested that CCSN may be a much less dominant component, and that other sources, likely Wolf-Rayet stars, must contribute [7].

Due to the long lifetime of ^{26g}Al, space-based γ-ray observatories such as INTEGRAL are unable to detect it from individual sources. Therefore, the likely primary progenitors can only be inferred from the galactic ^{26g}Al distribution. However, with a firm understanding of the ^{26g}Al(p,γ)^{27}Si and ^{25}Al(p,γ)^{26}Si rates, solid upper limits can be inferred for the nova contribution to galactic ^{26g}Al as a secondary source.

Classical novae are one potential source of ^{26g}Al and it has been shown that up to 0.4 M$_\odot$ of the galactic abundance could have been produced in these sites [8]. Of particular importance to the calculation of nova-synthesized ^{26g}Al abundances are the ^{25}Al(p,γ)^{26}Si and ^{26g}Al(p,γ)^{27}Si reaction rates, the former being the most uncertain.

At the highest temperatures in explosive hydrogen burning (e.g. in supernovae), s-wave resonances in the energy range E_x(^{26}Si) ∼6–8 MeV will dominate the reaction rate (see Figure 1). While some states in this energy region have been found, their level parameters are largely unknown. Furthermore, a comparison between the relevant energy regions in ^{26}Si and in ^{26}Mg reveals the presence of missing states in the former, some of which could be s-wave resonances in the ^{25}Al+p system and therefore important for the stellar reaction rate.

2. Experiment at CRIB

To address the uncertainties in the ^{25}Al(p,γ)^{26}Si reaction rate and obtain spectroscopic information on ^{26}Si, a ^{25}Al+p elastic-scattering experiment in inverse kinematics was performed recently, using the CNS radioactive ion beam separator (CRIB) facility at RIKEN. The experiment aims to improve upon a similar previous experiment performed using CRIB by having a purer ^{25}Al beam using a Wien filter and a higher beam intensity to increase the counting rate [12].

A ^{24}Mg^{8+} primary beam with an intensity of 1.6×10^{11} pps, produced by an ECR ion source, was accelerated by the RIKEN AVF cyclotron to an energy of 7.49 MeV/u. The shape of the ^{24}Mg beam was checked using a ZnS scintillator target at the F0 position and found to be well-contained within a 3×3 mm spot. The beam bombarded a ^{2}H gas target which was kept at a constant pressure

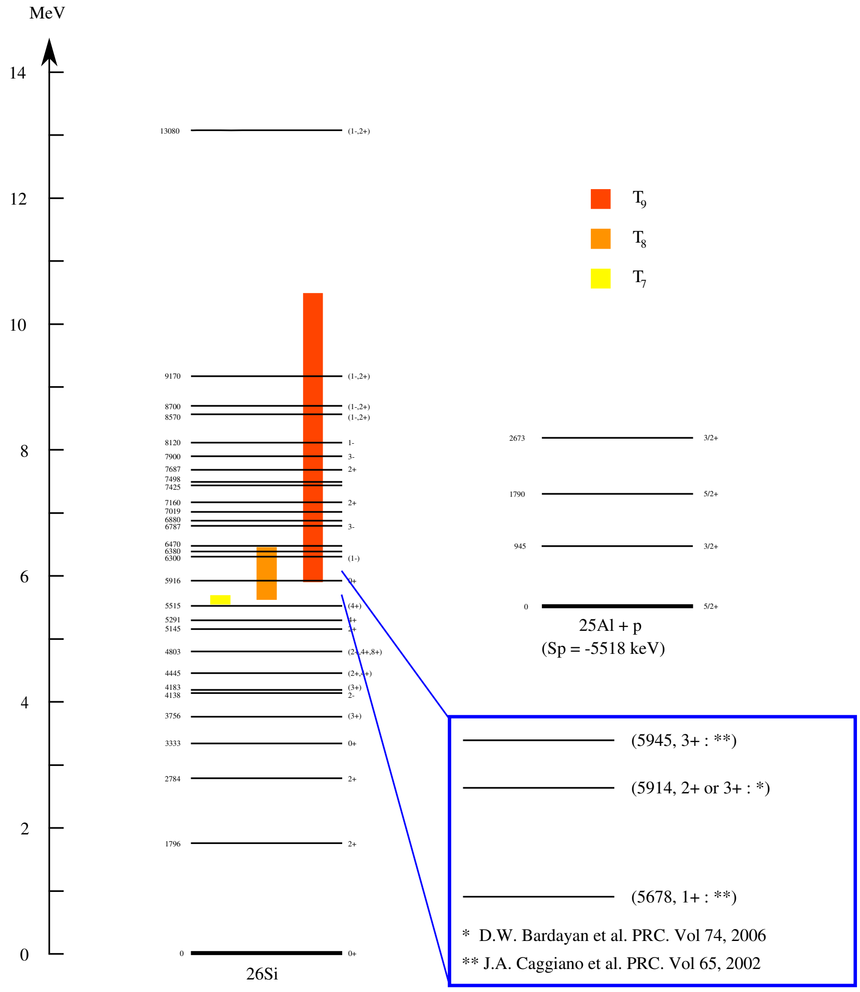

Figure 1: Astrophysically important energy levels in ^{26}Si and the ^{25}Al+p threshold [9, 10, 11].

of 760 Torr throughout the experiment. A primary beam reaction of ^{2}H(^{24}Mg,n)^{25}Al produced the desired secondary ^{25}Al^{13+} beam with an intensity of $2-5\times10^{5}$ pps. The current intensity was limited by the event-handling rate of the parallel-plate avalanche counters (PPACs) used for beam identification. The secondary beam was identified by using time-of-flight (TOF) (between the two PPACs on an achromatic focal plane at the F2 position), beam energy and TOF between the production target and a PPAC on the F2 plane (an example of secondary beam identification is shown in Figure 2).

The secondary beam impinged upon a thick polyethylene (CH_2) target of 6.5 mg/cm^2 in the F3 scattering chamber, where it was stopped. Three sets of silicon $E\Delta E$ telescopes were used to detect elastically scattered protons from ^{1}H(^{25}Al,p)^{25}Al. The telescopes consisted of a 75 μm thick position-sensitive silicon detector (PSD) backed by two 1500 μm surface-barrier silicon detectors (SSD) (an example $E\Delta E$ spectrum is shown in Figure 4). The detectors were installed at 0.0, 17.2 and 27.6°. The second SSD was added to each telescope to aid the background rejection of high-energy protons. Figure 3 shows the experimental configuration.

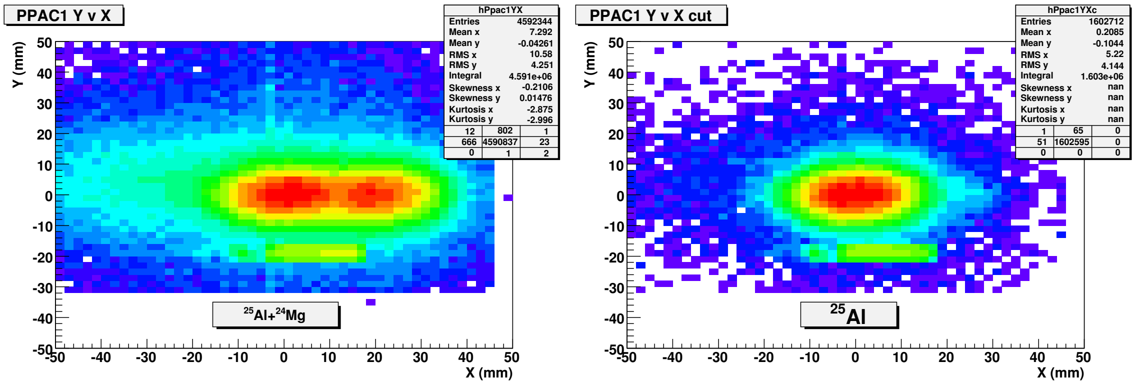

Figure 2: Ion species selection using a cut on RF timing.

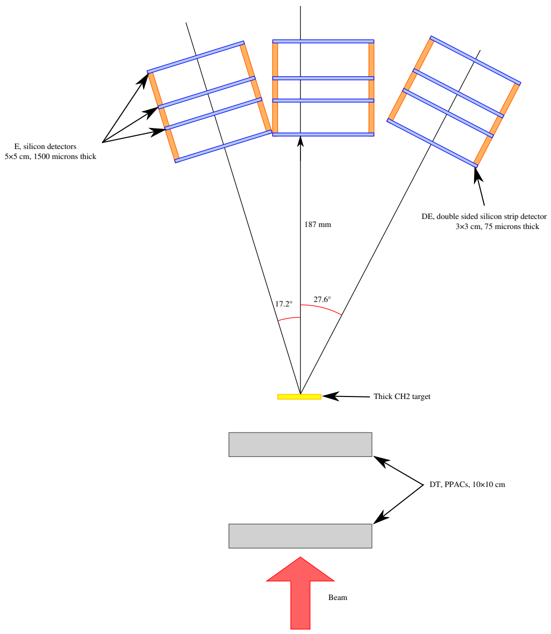

Figure 3: Detector configuration for the ^{25}Al(p,p')^{25}Al reaction. The PPACs were used for beam identification, the $E\Delta E$ telescopes for scattering product identification.

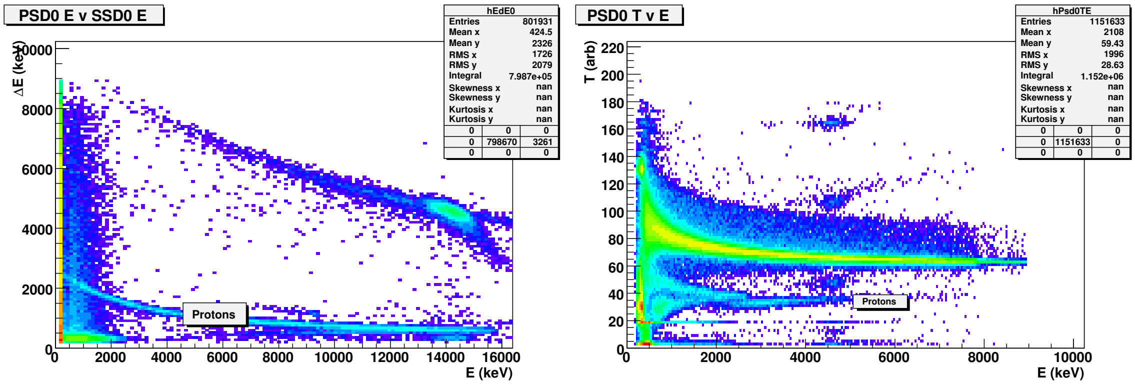

Figure 4: Example $E\Delta E$ spectrum. Protons are clearly separated from other ion species.

The ^{25}Al beam had an energy of 3.43 MeV/u, allowing a scan up to $\sim E_x = 8.5$ MeV in ^{26}Si. A ^{12}C target was used to obtain data for a background subtraction (due to a contribution by carbon contained in the CH_2 target) from the proton spectrum obtained with the CH_2 target. An array of 10 NaI scintillator detectors were used to monitor the inelastic contribution to the yield. These were positioned slightly upstream of and above the target position. Energy calibration was made with a proton beam at energies of 5, 9 and 14 MeV (as determined by the CRIB magnet settings).

3. Further Analysis

Analysis of the data is currently ongoing and is in preliminary stages.

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