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Isomeric ^{26}Al beam production with CRIB

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Abstract. We performed an experiment to measure proton resonant elastic scattering of a mixed $^{26\mathrm{m,g}}$Al beam with a thick target in inverse kinematics by using CNS RI beam separator, located at RIKEN Nishina Center. It aimed to search for strong proton resonances and determine level properties of low spin-parity states in ^{27}Si. Diagnosis of the $^{26\mathrm{m}}$Al purity of the beam by annihilation radiation are discussed.

1 Introduction

Galactic abundance of the ^{26}Al radionuclide provides a unique window to the ongoing nucleosynthesis in the Milky Way. ^{26}Al is known as the first detected specific radioactivity that decays along with its characteristic β-delayed γ-ray and it has been directly observed by astronomical telescopes [1]. Despite a lot of effort over the past three decades, particular sites of galactic ^{26}Al are still poorly understood, and there is a discrepancy between observations and theories on estimations of its abundance.

However, this problem is complicated by its isomer, $^{26\mathrm{m}}$Al, which has a low spin $J^\pi = 0^+$ and a short lifetime $T_{1/2} = 6.35\ s$ compared with $T_{1/2} = 0.72$ Myr and $J^\pi = 5^+$ of ground state, and thus it directly decays to a stable state without emitting γ-ray. It is proposed that the ground state of ^{26}Al can communicate with the isomeric state through thermal excitations under high temperature environment such as core-collapse supernovae [2], therefore the reactions of the isomer might play an important role in the production of ^{26}Al in our Galaxy. Though the isomeric state of ^{26}Al might be a key to solve the discrepancy, only a little experimental information on the isomer has been published and theoretical calculations based on Hauser-Feshbach theory are used in the reaction networks so far. For

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this reason, the production of $^{26\mathrm{m}}$Al beam is a useful experimental approach for measuring nuclear properties and cross-sections as inputs to calculations of stellar reaction rates.

2 Production of $^{26\mathrm{m}}$Al

We performed an experiment with the Center for Nuclear Study low-energy RI Beam separator, CRIB, which is located at RIBF of the RIKEN Nishina center.

2.1 RI beam production with CRIB

A primary beam of ^{26}Mg^{8+} was supplied by an azimuthally varying field (AVF) cyclotron with radio frequency at 65 MHz and the kinetic energy of 172.9 MeV (6.65 MeV$/u$) and typical primary intensity of 20 – 50 pnA. A cryogenic hydrogen gas target system was used as a proton target to induce the ^{26}Mg$(p,n)^{26}$Al reaction in inverse kinematics. The secondary beam was bent by two dipole magnets, and by selecting the beams with a slit which is placed at the momentum-dispersive focal plane between two dipole magnets, the beam was purified according to the magnetic rigidity $B\rho$ and the slit width. The beam spot as well as the number of particles was measured by parallel plate avalanche counters at dispersive-focal plane after that. The isotopes in the beam were identified by energy versus time-of-flight plot, shown in Fig. 1. Through the Wien-Filter, ^{26}Al^{13+} was purified to more than 90% at the experimental target position, and typical intensity was around 1.5×10^5 pps, and typical energy was 114–120 MeV. However, because the ground state and the isomeric state of ^{26}Al have only a small mass difference (228 keV), they could not be distinguished event-by-event by the CRIB separator. By varying the secondary beam production target, H_2 gas pressure, several conditions of $^{26\mathrm{m}}$Al beam were produced during the experiment. Since CRIB uses a in-flight method and has a typical fight time of ^{26}Al on the order of 500 ns, the second excited state of ^{26}Al (417 keV) decays enroute to the traget, contributing to the yield of $^{26\mathrm{g}}$Al.

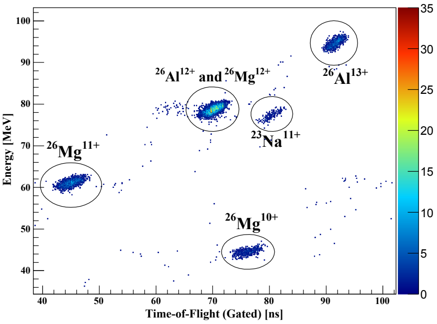

Figure 1. RI species identified at focal plane after the dipole magnets

2.2 Determing purity of the isomers

To obtain the absolute purity of the isomers, the beam was in a pulsing mode with a cycle of 24 s for implantation, where the beam was on for 12 s for implantation and off for 12 s independent from scattering measurement. The RI beam was implanted into several targets such as CH_2 film and thick blocks, and when the beam was off, the radiation was measured by 10 NaI scintillators placed above the center of the target, in order to measure annihilation radiation from ^{26m}Al. The half life of the radiation at 511 ± 60 keV, where 60 is about 3σ of the energy resolution of the detectors, was measured to be 6.359 ± 0.150 s (cf. known $T_{1/2}$ of ^{26m}Al is 6.35 s). Therefore it is confirmed that almost all of the decay events originated from ^{26m}Al.

As ^{26}Al decays, positrons emitted from the inside target isotropically can escape to all the surrounding material and made a precise counting annihilation radiation difficult. To estimate such complicated situation, we defined the intrinsic efficiency η of the detectors as η = (511 keV counts)/(^{26m}Al decays) which depends on solid angle of detectors, quantum efficiency and geometry of the experimental chamber, and the Monte-Carlo simulation framework, Geant4, was used to evaluate it. By comparing simulation results and experimental data, the validity of the simulation was confirmed within an uncertainty of 5%.

2.2.1 Result of the decay measurement

Using the value of η from the simulation, the isomeric purities determined are tabulated in Tab. 1 under several conditions. These differences will be used to evaluate the contribution of ^{26g}Al to the cross section of the resonant scattering.

Table 1. Result of the isomeric purities under the different situations labeled as #1–#5, where #3 and #5, #2 and #4 are somewhat similar conditions respectively.

RI beam label	#1	#2	#3	#4	#5
Isomeric Purity (%)	48.3 ± 2.9	43.0 ± 2.5	56.4 ± 3.4	43.9 ± 2.4	52.7 ± 2.4

3 Conclusion

The isomeric RI beam ^{26m}Al was produced by CRIB with the purity of at maximum 56.4% and at minimum 43.0% according to the evaluation with the Monte-Carlo simulation. The energies of RI beams can cover the region of interest of high temperature environments such as core-collapse supernovae. With these isomeric ^{26}Al beams, proton elastic scattering was measured with a thick target in inverse kinematics method, in order to encompass the uncertainty of recent ^{26}Al problem connected with the observation of the γ-ray and the reaction networks of nuclear astrophysics.

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