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Experimental Study Of The Key Astrophysical ^{18}Ne(α, *p*)^{21}Na reaction

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The ^{18}Ne(α, *p*)^{21}Na reaction is thought to be one of the key breakout reaction from the hot CNO cycle to the *rp*-process in X-ray bursts. We investigated the resonant properties of the compound nucleus ^{22}Mg by measuring the resonant elastic scattering of ^{21}Na+*p*. An 89 MeV ^{21}Na radioactive beam was produced by CRIB and then bombarded a 93-µm-thick polyethylene target. The ^{21}Na beam intensity was about 2×10^5 pps, with a purity of about 70% on the target. The recoiled protons were measured by three sets of ΔE-E telescope respectively. A wide excitation energy range of 5.5-9.2 MeV in ^{22}Mg was scanned with a thick-target method. Some preliminary results are shown.

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1. Introduction

A nuclear astrophysics experiment was performed at CRIB (CNS low-energy Radioactive-Ion Beam separator) on Mar. 2011. The goal of this experiment was to study the reaction rate of a stellar ^{18}Ne(α, *p*)^{21}Na reaction, which might be a key breakout reaction from the hot CNO cycle to the rp-process in X-ray bursts. Yet, the reaction rate is not well understood.

Explosive hydrogen burning is thought to be the main source of energy generation and a source of nucleosynthesis in X-ray burst [1,2]. In X-ray burst, for example, at the typical temperature of 0.4-2 GK, the hydrogen burning occurs via the hot CNO cycle:

$$^{12}\mathrm{C}(p,\gamma)^{13}\mathrm{N}(p,\gamma)^{14}\mathrm{O}(e+\nu)^{14}\mathrm{N}(p,\gamma)^{15}\mathrm{O}(e+\nu)^{15}\mathrm{N}\,(p,\alpha)^{12}\mathrm{C},$$

where the ^{13}N(e+ ν)^{13}C decay in the CNO cycle is bypassed by the ^{13}N(p, γ)^{14}O reaction. The temperature of the accretion disk increases as the compressing and exothermic nuclear reactions going on. When the temperature reaches about 0.4 GK, the second hot CNO cycle becomes dominant:

$$^{12}\mathrm{C}(p,\gamma)^{13}\mathrm{N}(p,\gamma)^{14}\mathrm{O}(\alpha,p)^{17}\mathrm{F}(p,\gamma)^{18}\mathrm{Ne}(e+\nu)^{18}\mathrm{F}(p,\alpha)^{15}\mathrm{O}(e+\nu)^{15}\mathrm{N}(p,\alpha)^{12}\mathrm{C}$$

It is predicted [1,2] that the ^{18}Ne waiting point in the second hot CNO cycle can be bypassed by the ^{18}Ne(α, *p*)^{21}Na reaction at T ~ 0.6 GK, and subsequently, the reaction chain breaks out to the rp-process. Hence it is very important to study this reaction rate.

2.Experiment

An 89 MeV ^{21}Na radioactive beam was produced and separated by CRIB (CNS low-energy Radioactive-Ion Beam separator, located at RIKEN). It bombarded a 90-µm-thick polyethylene target with intensity about 2×10^5 pps and purity about 70%. In this study, we mainly focused on determining the resonance properties above the α-threshold in the compound ^{22}Mg nucleus.

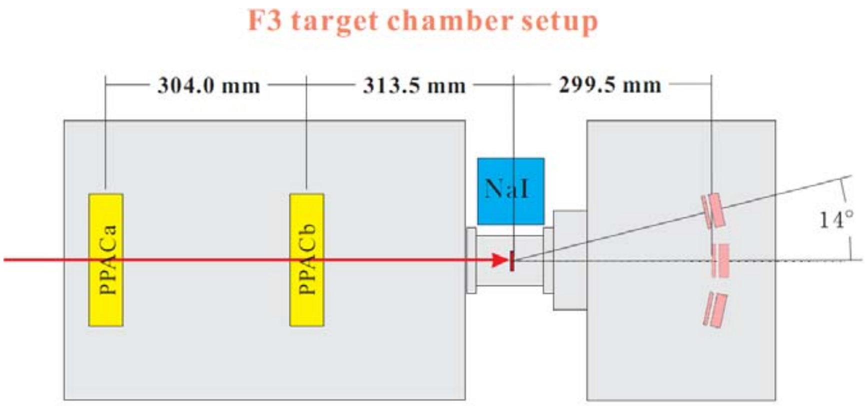

FIGURE 1. Schematic view of the detector setup at F3 focal plane of CRIB.

Two PPACs (Parallel-plate avalanche counter) were used to monitor the beam, $[CH_2]_n$ and carbon targets were used in the experiment. Each telescope consist a position and energy sensitive ΔE detector and an energy sensitive E detector.

Although some new spin-parities were tentatively made in a previous similar experiment [3], our new experiment will put stronger constraints on J^{π} assignment with much better statistics. In this work, the resonant properties (such as J^{π}, and Γ_p) of the compound ^{22}Mg nucleus were studied by measuring the ^{21}Na+*p* resonant elastic/inelastic scattering. As shown in Fig. 1, we used two PPACs for monitoring beam counts and directions, and used three sets of ΔE-E silicon telescope for measuring the energy and scattering angle of the recoiled particles. A NaI array surrounded the target for detecting the γ-rays. Several runs with a carbon target were performed for background evaluation.

The recoiled particles (mainly α, *p*) were identified by ΔE-E and TOF-E methods. Fig. 2 shows a typical particle identification plot. Where, ΔE and E signals were given by the silicon telescope, TOF was the time of flight between PPACb and ΔE. The high energy particles which penetrated ΔE detector were identified by using ΔE-E method, and the E-TOF method was mainly used to identify the low-energy particles stopped in ΔE detector. It shows that the proton and α particles can be clearly identified.

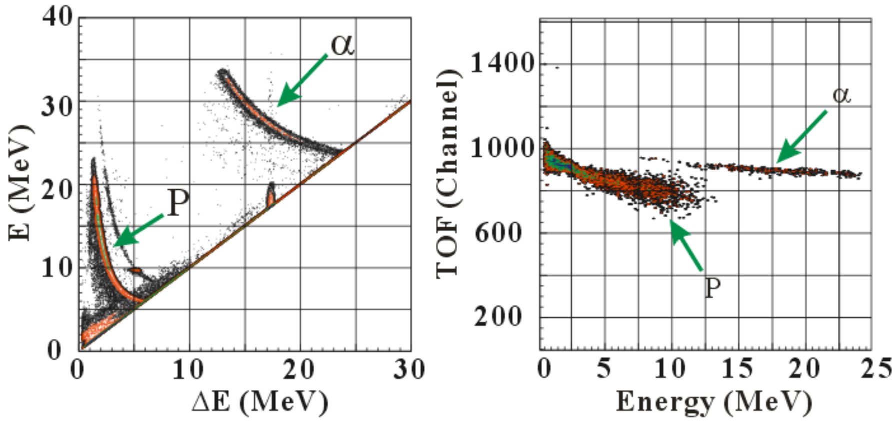

FIGURE 2. Particle identification plots for the ΔE-E and E-TOF methods. The start TOF signal is given by PPACa, and the stop signal is given by ΔE.

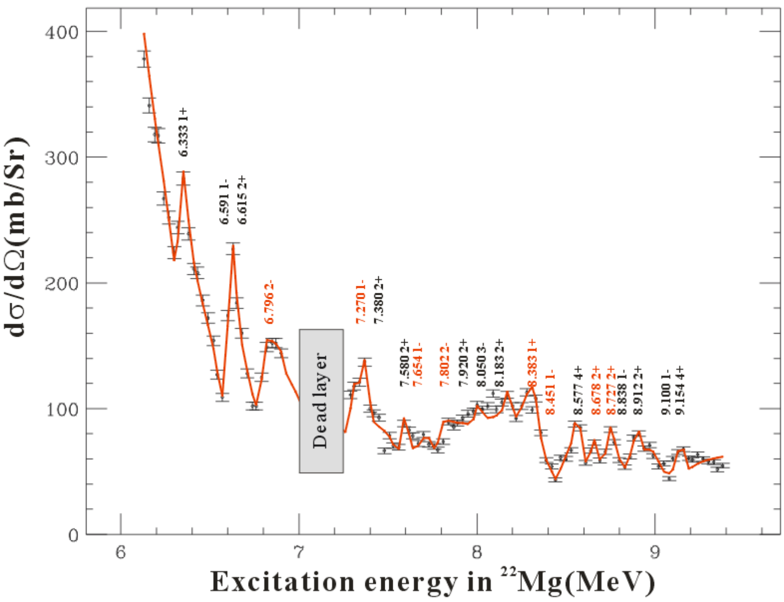

FIGURE 3. Elastic-scattering proton spectrum with a typical R-matrix fitting (Preliminary).

3.Preliminary results

In this work, totally 21 levels in ^{22}Mg were observed, and their spin-parities and proton widths have been determined by fitting the ^{21}Na+*p* elastic-scattering data with an R-matrix code MULTI[4]. The doublet at 8.451 and 8.577 MeV is confirmed, and new spin-parity assignments for states above the α threshold, *i.e*., 8.383, 8.451, 8.678 and 8.727 MeV, were given based on the present R-Matrix analyses. Fig. 3 shows a typical R-matrix fitting for the c.m. differential cross section of the resonant elastic scattering of ^{21}Na+*p* measured at $\theta_{c.m.} \approx 175^{\mathrm{o}}$. The data within the dead-layer region (between ΔE and E) are removed from the figure. The levels labeled in red refer to the ones which have new spin-parity assignments. The data analysis is still going on. The impact of our new J^{π} values on the ^{18}Ne(α, *p*)^{21}Na reaction rate, as well as on the nucleosynthesis in X-ray burst will be reported in a forthcoming publication.

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