(Form4-2)

JOINT RESEARCH PROJECT

FINAL REPORT
For Japan-Korea Joint Research Project

AREA	①. Mathematics & Physics 2. Chemistry & Material Science 3. Biology 4. Informatics & Mechatronics 5. Geo-Science & Space Science 6. Medical Science 7. Humanities & Social Sciences

1. Research Title:

Nucleosynthesis in Novae and X-ray bursts

2. Term of Research: From 2009/07/01 To 2011/06/30

3. Total Budget

a. Financial Support by JSPS: Total amount: 2400 thousand yen

1st Year 900 thousand yen 2nd Year 1200 thousand yen

3rd Year 300 thousand yen

b. Other Financial Support : Total amount: 0 thousand yen

4. Project Organization

a. Japanese Principal Researcher	
Name	Shigeru KUBONO
Institution / Department Position	The University of Tokyo/ Graduate school of Science Professor
b. Korean Principal Researcher	
Name	Chun Sik Lee
Institution / Department Position	Chung-Ang University/ Department of Physics Professor

c. List of Japanese-side Participants (Except for Principal Researcher)

Name	Institution/Department	Position
H. Yamaguchi	University of Tokyo/ Graduate school of science	Assist. Professor
H. Hashimoto	University of Tokyo/ Graduate school of science	Post doc.
T. Teranishi	Kyushu University/ Graduate school of science	Assoc. professor
N. Iwasa	Tohoku University/ Graduate school of science	Assoc. professor
S. Kato	Yamagata University/ Faculty of Science	Professor
T. Komatsubara	Tsukuba University/ Graduate school of science	Lecturer

d. List of Korean-side Participants (Except for Principal Researcher)

Name	Institution/Department	Position
Young Kwan Kwon	Chung-Ang University/Dept. of Physics	Research Professor
Ju Hahn Lee	Chung-Ang University/Dept. of Physics	Research Professor
Jun Young Moon	Chung-Ang University/Dept. of Physics	Postdoc
Hwa Youn Cho	Chung-Ang University/Dept. of Physics	PhD student
Hyo Soon Jung	Chung-Ang University/Dept. of Physics	PhD student
Nam Young Kim	Chung-Ang University/Dept. of Physics	Post Doc

5. **Number of Exchanges during the Final Fiscal Year***

a. from Japan to Korea *Japanese fiscal year begins April 1.

Name	Home Institution	Duration	Host Institution
For Final Fiscal Year(FY2011) Total: 0 persons		For Final Fiscal Year(FY2011) Total: 0 man-days	
Numbers of Exchanges during the past fiscal years			
FY2009: Total 2 persons FY2010: Total 2 persons			

b. from Korea to Japan

Name	Home Institution	Duration	Host Institution
Y. K. Kwon	Chung-Ang Univ	2011.6.19~6.25	CNS, Univ of Tokyo
H. S. Jung	Chung-Ang Univ	2011.5.8~5.19	CNS, Univ of Tokyo
For Final Fiscal Year(FY2011) Total: 2 persons		For Final Fiscal Year(FY2011) Total: 19 man-days	
Numbers of Exchanges during the past fiscal years			
FY2009: Total 3 persons FY2010: Total 7 persons			

6. Objective of Research

Elemental abundance is one of the keys in astronomical observations that enable us to clarify the evolution of the universe as well as various astronomical phenomena. The mechanism that produces such elements, i.e., stellar nuclear reactions, is a crucial theme to understand the universe from the basic point of view. Of course, the anomalous energies, which are produced by nuclear reactions and are the main energy source for the stars, are also an important clue for the study. This collaborative project includes experimental investigation on such nuclear reactions. We studied key nuclear reactions, which are not known yet because they involve unstable nuclei that are not present on the earth. Specifically, we studied the stellar nuclear reactions in explosive hydrogen burning process like in novae and X-ray bursts. This burning process could be relevant to the mysterious observation of abundant long-lived isotope of ^{26}Al by gamma ray observatories on satellites in the last decades. The stellar nuclear reaction ^{26}Si(p,γ)^{27}P which is crucial to understand the origin of cosmic radioactive nucleus ^{26}Al, was investigated using an RI beam of ^{26}Si. Although there have been recent efforts on the ^{26}Si(p,γ)^{27}P reaction, there are still large uncertainties in the cross sections at the energies of interest. Caggiano et al. measured the ground state mass excess of ^{27}P to be -0.670(41) MeV and observed the first excited state at E_x=1.199(19) MeV in ^{27}P for the first time by the ^{28}Si(^{7}Li,^{8}He)^{27}P reaction. Another two excited states also were observed at E_x=1.615 and 3.453 MeV in ^{27}P. Togano et al. determined the gamma decay width of the first excited state in ^{27}P by the Coulomb dissociation method. The transition between the first excited state ($3/2^+$ from mirror nucleus, ^{27}Mg) and the ground state ($1/2^+$) has M1 and E2 components. However, the Coulomb dissociation is highly sensitive to the E2 component compared with the M1 transition. Therefore, they estimated the total (M1+E2) gamma decay width by combining the experimental result and a shell model calculation. In 2005, we have studied the proton elastic resonant scattering of ^{26}Si as a by-product of ^{25}Al+p measurement. In spite of low statistics, several candidates for new resonant states have been observed above the proton threshold. Especially, resonant states at E_x=3.084 and 3.253 MeV, which may affect the ^{26}Si(p,γ)^{27}P reaction rate at higher temperatures have been observed for the first time. The primary aim of this project is to confirm those new resonances, and determine the property (excitation energies, spin-parities and proton partial widths). These results from the proposed experiment could be an important information to determine accurately the ^{26}Si(p,γ)^{27}P reaction rate. The experiment was performed using the low-energy ^{26}Si at the low-energy RI beam separator CRIB, which is one of the most powerful low-energy RI beam facilities in the world.

7. Methodology

A measurement of ^{26}Si+p elastic scattering was performed at the CRIB facility (Fig.1), by bombarding the ^{26}Si radioactive ion beam onto a H_2 gas target in inverse kinematics, and detecting recoiled protons using silicon detectors of ΔE-E telescope. We applied the thick-target method to scan the energy range of interest. The excitation function were obtained from the recoiled proton energy spectrum by a de-convolution process. The astrophysically important $^{26}Si(p,\gamma)^{27}P$ reaction proceed through resonances above the ^{26}Si+p threshold ($Q_{p\gamma}$= 0.859 MeV). This measurement allowed us to identify new resonances by determining proton widths, spin-parities and excitation energies of important resonant states above the proton threshold.

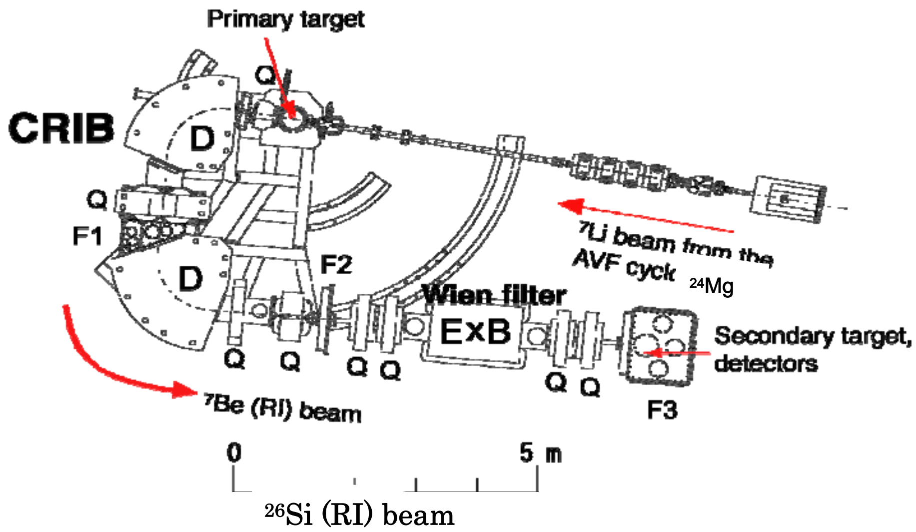

Fig. 1 Schematic plane view of CRIB (CNS radioactive ion beam separator) which is based on in-flight method and operated by CNS (center for nuclear study), University of Tokyo, installed at RIKEN.

The primary ^{24}Mg beam at 7.5 MeV/u with an intensity of 1.6 eμA extracted from the AVF cyclotron bombarded a ^{3}He gas production target, which was at 550 Torr and 90 K. A Secondary beam of ^{26}Si was produced by the $^{3}He(^{24}Mg,^{26}Si)$ reaction and was separated in the CRIB. The ^{26}Si beam had a well-defined energy of 132.78 MeV. The intensity and the purity were 1.2×10^4 pps and 23.2 %, respectively after the Wien-filter, which is set downstream of the two dipole magnets, as can be seen in Fig.1, and provides further purification of the RI beam by the velocity selection. With these techniques, the CRIB facility can produce intense and good-quality RI beam. Figure 2 shows particle identification on a contour plot of Time-Of-Flight(TOF) and Energy.

The detection system consisted of two Parallel Plate Avalanche Counters (PPACs) for beam tagging and silicon detectors for detecting the recoiled protons in the F3 chamber, as shown in Fig. 3. A PPAC called PPACb, placed at the entrance to the experimental target chamber was used for beam identification with TOF-E. The other PPAC called PPACa placed at the entrance of F3 together with PPACb were used to

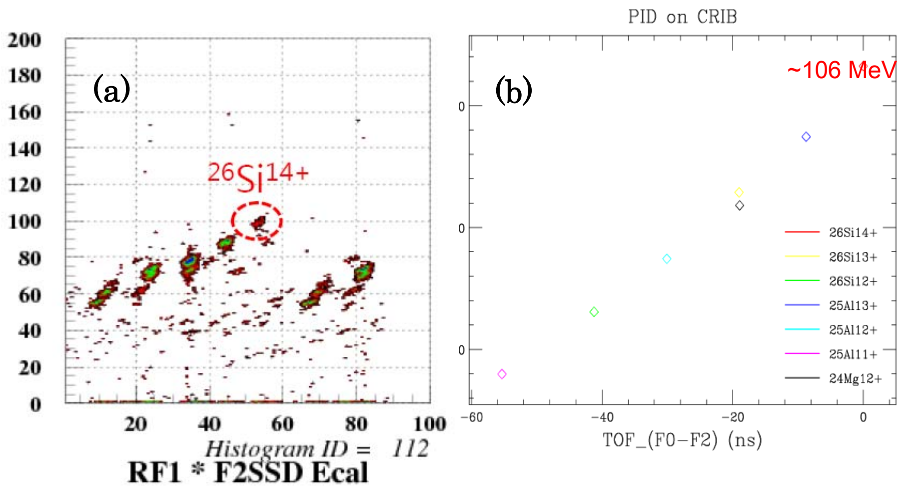

Fig. 2 Contour plot of TOF and Energy of the RI beams at F3 (a), compared with prediction (b).

determine the beam particle trajectory. The effective thickness of the Mylar foil was about 9.5 μm. The position resolution of PPACs is about 1 mm both for horizontal and vertical directions. The hydrogen gas was filled in a 300 mm diameter hemisphere like gas chamber, sealed by a thin (2.5 μm) Havar foil for the beam entrance window and a thin (25 μm) Mylar foil for the exit window, respectively. The hydrogen gas was set to 330 Torr at 293 K, giving an effective thickness of 1.09 mg/cm^2. The measurements of the resonant elastic protons were made using silicon detector ΔE-E telescopes located at θ_{lab} = 0^o and 15^o, which consisted of 75-μm-thick double-sided Silicon detectors (DSSD) and 1.5 mm thick Si detectors.

In this experiment, we planned to detect recoiled protons below 11.04 MeV in the laboratory system (equivalent to 3.0 MeV in the center-of-mass system). Therefore, up to a level at 3.0 MeV above the proton threshold (0.859 MeV) were measured. This excitation energy range corresponds to a Gamow window at temperatures up to T_9 ~ 8. Recoiled protons from the known state at E_x=1.199 MeV [5], should have E_{lab} = 1.1 MeV (or $E_{c.m.}$ = 0.3 MeV). However, these protons cannot penetrate even a thin ΔE counter of 20 μm.

In general, since the energy resolution of the detection system is limited, the resonance proton widths can be determined only for states with a few keV of larger. Thus, the present method is sensitive to resonances at certain energies and above. In fact, the present measurement covers the range of excitation energy range of E_x = 2.4 MeV ~ 3.8 MeV in ^{27}P.