Resonance States in Proton Rich Nuclei and Reaction Rates in the rp-Process.

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The explosive nuclear burning of hydrogen at high temperatures and densities on the surface of accreting white dwarfs and neutron stars gives rise to a number of observable phenomena like Novae or X-ray bursts. To interpret the observational data and to find answers to open questions requires an understanding of the nuclear processes during the explosive events and therefore information on the structure of unstable, proton rich nuclei.

Network model calculations show that the dominant burning processes are the hot CNO cycles, the rp process, and at sufficiently high temperatures, the 3α reaction and the αp process [1, 2, 3]. However, the proton and α induced reaction rates in these reaction sequences are very sensitive to the structure of the nuclei involved - especially in cases of low level density in the compound nucleus when statistical model predictions of reaction rates cannot be applied. The precision of shell model predictions is often not good enough to decide if reaction rates are sufficient to favor or disfavor specific reactions paths.

One of the physics motivations for the construction of radioactive beam facilities is to obtain the needed experimental data which cannot be measured with present equipment and to understand these important astrophysical scenarios.

Existing experimental facilities, however can provide crucial information with readily available techniques. A recent experiment [4] using the IUCF high-resolution spectrometer K600 in a 0° experiment provided, for the first time, measured energies of excited states in the ^{28}Si(^{4}He,^{8}He)^{24}Si reaction and found that previous shell model predictions of the excitation energy of the second excited state, which plays a role in determining the astrophysically relevant proton capture ^{23}Al(p,γ)^{24}Si reaction rate, were high by 179 keV.

While the (^{4}He,^{8}He) reaction with cross sections as small as a few nb/sr is difficult to measure, the (^{4}He,^{6}He) and the (^{3}He,^{6}He) reactions with significantly larger cross section can provide much needed experimental information for realistic network calculations.

For this purpose we conducted a feasibility study using the high resolution Grand Raiden Spectrometer [5] with two new beam stops (see Fig. 1) inside dipole magnet D1. These beam stops are required to stop the beam of the above mentioned reactions. The magnetic rigidities of the α-beam at about 200 MeV is of the order of 7 - 15 % lower compared to the reactions products, depending on energy and reaction Q-value. The beam stop labeled ^{6}He and ^{8}He Faraday Cup are used for the (^{4}He,^{6}He) and the (^{4}He,^{8}He) reaction, respectively. The latter is also suitable for the (^{3}He,^{6}He) reaction.

Fig. 2 shows a spectrum of the ^{24}Mg(^{4}He,^{6}He)^{22}Mg reaction at 0°. This reaction allows to independently verify resonance states in ^{21}Na(p,γ)^{22}Mg and provides information complementary to the proposed ^{21}Na radioactive experiment at ISAC. The levels above the α-threshold of 8.14 MeV are relevant for the ^{18}Ne(α,p)^{21}Na reaction rates which control the

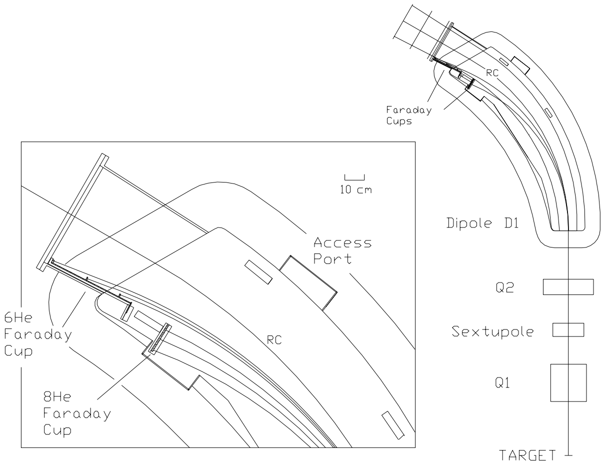

Figure 1: Two new Faraday cups inside Grand Raiden dipole D1. For details see text.

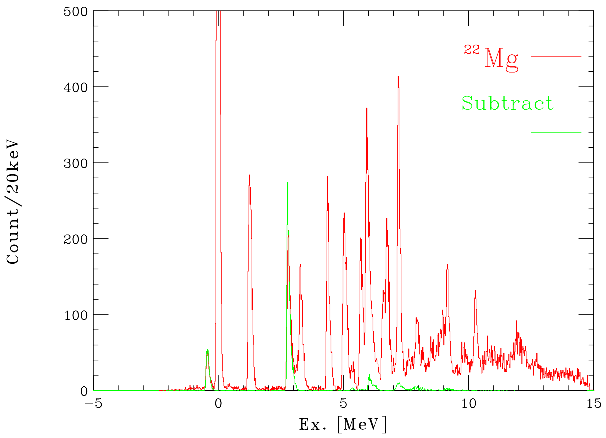

Figure 2: Energy spectrum of the ^{24}Mg(^{4}He,^{6}He)^{22}Mg at 205 MeV reaction and contamination spectra (Subtract) are shown.

break-out from the hot CNO cycles at X-ray burst conditions.

The beam energy was 205 MeV with a current of approximately 40 pnA. The solid angle was the full acceptance of the spectrometer of ±20 mrad horizontally and ±50 mrad vertically. The resolution was approximately 95 keV mainly due to target effects from the 1.8 mg/cm^2 thick target which consisted of enriched ^{24}Mg. In order to determine contributions of ^{12}C and ^{16}O contaminations spectra were also measured on a carbon and Mylar target. Normalization was made using the well separated peaks of the ground states of ^{16}O and ^{12}C. It can be seen that the background (Subtract) at higher excitation energies is rather small. Using peak fitting procedures the energies of many new levels could be determined with a standard deviation of 12 keV.

In a more recent experiment the following improvements were achieved. The beam current could be increased to 100pnA and the resolution of 70 keV was achieved using a thinner 0.7 mg/cm^2 target of ^{24}Mg. This resolution is probably limited by the large Q-value not considered in the present dispersion matching procedure. This issue is under investigation. We have also shown that the over-focus mode is possible, allowing to extract angular distributions in the angular range particular important for measurements at 0°. This helps to determine the angular momentum for the newly determined energy levels.

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