SPECTROSCOPY IN RP-PROCESS NUCLEI WITH THE S800

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The rp-process is one of two major reaction sequences in hot stellar hydrogen burning [1]. It is a series of proton capture reactions, and β^+ decays that occurs between the valley of stability and the proton drip line. Many proton capture rates on stable nuclei in the sequence have not been experimentally determined, and the situation is much worse for unstable nuclei in the sequence.

The proton capture reactions can either be direct capture to the ground state of the resultant nucleus or capture into an excited state. If the level density in the resultant nucleus is sufficiently high, Hauser-Feschbach theoretical predictions have been used to determine rates where experimental information is missing.

However, if the level density is low, as is the case for lighter nuclei in the sequence and further from stability, then the reaction rate may be dominated by resonant capture through a single isolated resonance. Where experimental evidence is missing, various theoretical approaches are taken to deduce the nuclear level schemes[4]. These calculations have uncertainties of $\geq$100 keV on the excitation energies. Because the resonant capture proceeds at a rate $\propto exp(\frac{-E_r}{kT})$, this uncertainty can lead to orders of magnitude uncertainty in the reaction rates.

It is experimentally difficult to probe these nuclear levels directly because the coulomb barrier makes the (p,γ) cross sections at the energies of interest prohibitively small. Thus indirect study of the important levels is required. In some cases, heavy ion reactions have proven an effective way to probe these levels [2,3].

We have chosen to study two proton-rich nuclei which have significant impact on rp-process flow, ^{23}Al and ^{27}P. The Q-value for ^{22}Mg(p,γ)^{23}Al is 0.127 MeV, so an equilibrium can be reached between the photodisintegration of ^{23}Al and the proton capture on ^{22}Mg. In explosive events, there isn't time to reach equilibrium and there may be significant production of ^{23}Al, and hence a significant depletion of the gamma ray emitter ^{22}Na. The ^{23}Al level structure affects the ^{22}Mg(p,γ) capture rate, particularly in explosive events, and thus has a significant impact on the production of^{22}Na.

The ^{27}P level structure governs the destruction rate of the waiting point nucleus^{26}Si, which affects the amount of ^{26}Al and ^{26}Mg produced in an explosive event. Because of its long half life, gamma ray observations of ^{26}Al from explosive events can place tight constraints on the models for these events, provided its production can be accurately predicted. A shell model calculation [4] predicted a level at 1.18 MeV in ^{27}P, leading to a resonance energy of 0.32 MeV. This level had been previously supposed to exist below the proton threshold. Because of its proximity to the proton threshold, it can affect the ^{26}Si(p,γ)^{27}P reaction rate by up to 4 orders of magnitude at certain temperature and density conditions, so experimental verification of this level is desired.

A beam of 50 MeV/u ^{7}Li bombarded targets of 0.63 mg/cm^2 ^{24}Mg, 1.42 mg/cm^2 ^{nat}Si (92% ^{28}Si), and for calibration, 1.22 mg/cm^2 ^{9}Be and 0.34 mg/cm^2 ^{10}B. The ^{9}Be(^{7}Li,^{8}He)^{8}B populated the ground state of ^{8}B(mass uncertainty = 1.1 keV), as well as the 0.774(6) and 2.32(3) excited states. The ^{10}B(^{7}Li,^{8}He)^{9}C reaction only populated the ^{9}C ground state (mass uncertainty = 2.1 keV).

The spectrometer was operated in dispersion-matched, energy loss mode. The ^{8}He fragments from

Table 1: Preliminary locations of the excitated states in the nuclei ^{23}Al and ^{27}P as found in this experiment.

^{23}Al	^{27}P
0.57±0.03 MeV	1.16±0.03 MeV
1.82±0.05	1.58±0.05
2.65±0.05	
3.31±0.05	
3.85±0.05	

the reaction were identified by energy loss, total energy, and flight time in the focal plane detectors. The detectors consisted of two cathode readout drift chambers (CRDC) for measuring horizontal and vertical positions and angles, an ion chamber for measuring energy loss, and a 5cm plastic scintillator for measuring total energy; the flight time was measured relative to the cyclotron RF. The ^{8}He fragments were unambiguously identified using these measurements. Using ray-reconstruction techniques, the reaction scattering angles and energies of the ^{8}He fragments from the reaction were deduced.

Figure 1 shows preliminary energy spectra for the four reactions. The number of counts per 77 keV are plotted vs the relative energy (with respect to the central energy of the spectrometer) in the laboratory frame. Kinematic energy shifts were applied on an event-by-event basis to shift the energies of the ^{8}He ions to their zero degree value. Table 1 summarizes the preliminary excited state locations in the nuclei ^{27}P and ^{23}Al.

This is the first experimental report of a state in ^{27}P at 1.16 MeV. Because of its proximity to the proton threshold, this greatly enhances the ^{26}Si(p,γ)^{27}P reaction rate in a stellar environment. A state has been previously observed at 1.66 MeV by Benenson et al.[5], close to the presently observed one at 1.58 MeV. This is also the first time the first excited state in ^{23}Al has been resolved from the ground state. Previously reported values were consistent with the present value of 0.570 MeV [3,6].

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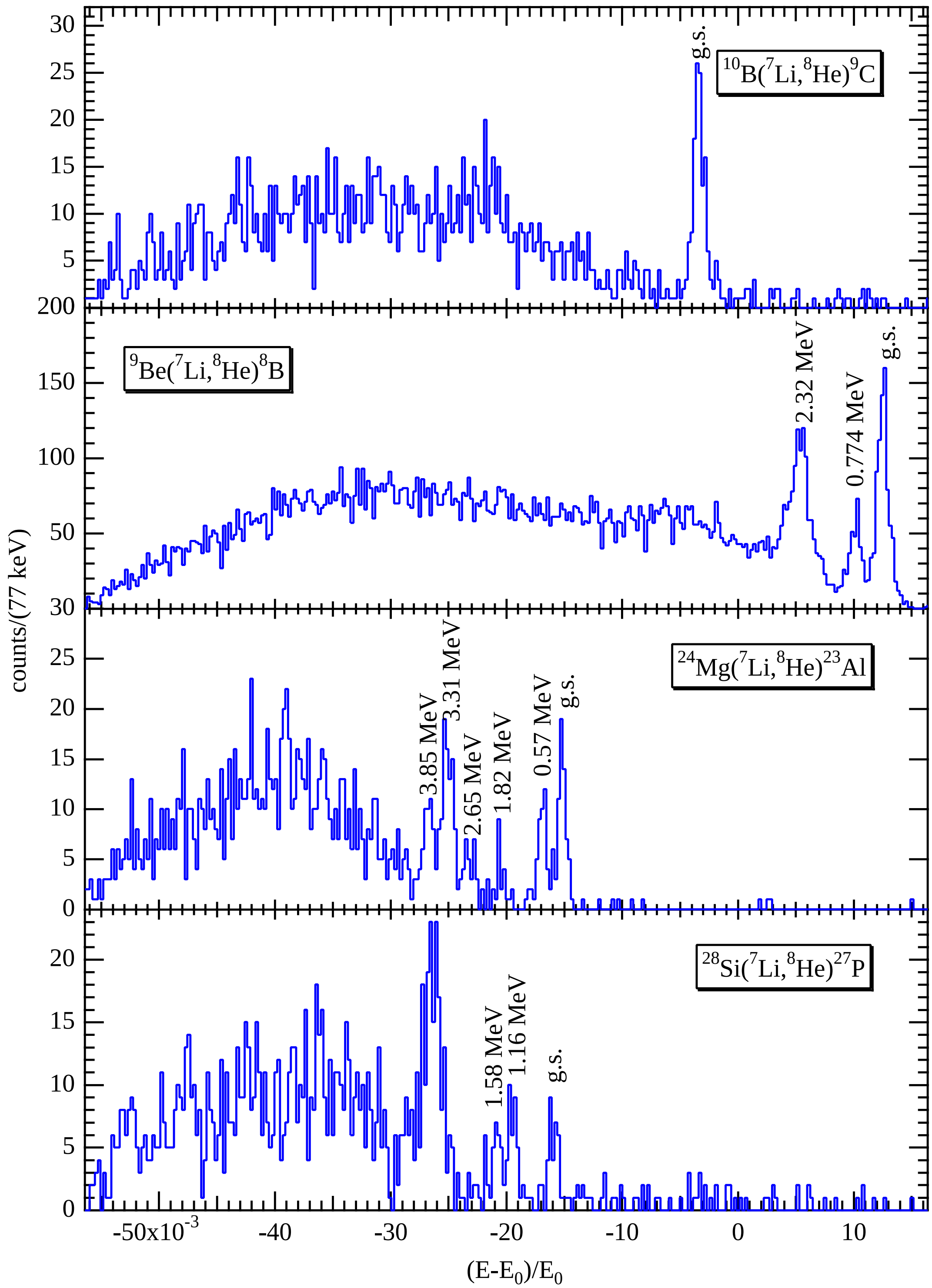

Figure 1: Preliminary energy spectra of the emitted ^{8}He ions from the listed reactions. Clear separation of the ground state and first excited state in ^{23}Al (570 keV) is achieved, as well as separation of the first two excited states in ^{27}P. Four new states were identified in the ^{23}Al nucleus (Table 1).