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Spin assignments of ^{22}Mg states through a ^{24}Mg(p,t)^{22}Mg measurement

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The ^{18}Ne(α,p)^{21}Na reaction plays a crucial role in the (α,p) process, which leads to the rapid proton capture process in X-ray bursts. The reaction rate depends upon properties of ^{22}Mg levels above the α threshold at 8.14 MeV. Despite recent studies of these levels, only the excitation energies are known for most with no constraints on the spins. We have studied the ^{24}Mg(p,t)^{22}Mg reaction at the Oak Ridge National Laboratory (ORNL) Holifield Radioactive Ion Beam Facility (HRIBF), and by measuring the angular distributions of outgoing tritons, we provide the first experimental constraints on the spins of astrophysically-important ^{18}Ne(α,p)^{21}Na resonances.

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1. Introduction

An X-ray burst is characterized by repeated sudden increases of X-ray emission of only a few seconds' duration with a total energy of about 10^{39-40} ergs per burst. The recurrence time between single bursts can range from hours to days. The characteristics of X-ray burst phenomena are being studied extensively today using a number of space-based X-ray observatories such as RXTE, BeppoSAX, Chandra, HETE-2, and XMM/Newton. More than eighty galactic sources of X-ray bursts have been identified since their initial discovery in 1976. These bursts are explained as thermonuclear explosions in the atmosphere of an accreting neutron star in a close binary system [1]. When critical values for density and temperature are reached in the neutron star atmosphere, the freshly accreted hydrogen and helium ignites and burns via the hot CNO cycles at a constant rate. Depending on the strength of the ^{15}O(α,γ)^{19}Ne and ^{18}Ne(α,p)^{21}Na reactions, break-out from the hot CNO cycles will occur, fueling the rapid proton capture (rp)-process [2]. The rp-process converts the light element fuel into heavy elements from Fe-Ni up to Cd-Sn within only a few seconds. To understand the observed light curves of X-ray bursts and the subsequent heavy-element production in the rp-process, one must understand the rates of these breakout reactions.

The ^{18}Ne(α,p)^{21}Na reaction rate depends upon properties of ^{22}Mg levels above the α threshold at 8.14 MeV. Despite recent studies of these levels [3, 4], only the excitation energies are known for most with no constraints on the spins. We have studied the ^{24}Mg(p,t)^{22}Mg reaction, and by measuring the angular distributions of outgoing tritons, we could provide the first experimental constraints on the spins of astrophysically important ^{22}Mg levels.

2. Experimental setup

A search for the ^{22}Mg levels was performed by studying the ^{24}Mg(p,t)^{22}Mg reaction with 41- and 41.5-MeV proton beams at the ORNL HRIBF. The beam impinged on a 500 μg/cm^2 isotopically enriched ^{24}Mg foil. Recoiling tritons from the ^{24}Mg(p,t)^{22}Mg reaction were detected by a large area silicon detector array (SIDAR). The SIDAR [5] was configured with 100 μm detectors (ΔE) backed by 1000 μm detectors (E). Also, the SIDAR was arranged in "lampshade" configuration to cover a large angular range. The angles covered by SIDAR were: $18^\circ \leq \theta_{lab} \leq 48^\circ$ for E_{beam} = 41 MeV and $27^\circ \leq \theta_{lab} \leq 69^\circ$ for E_{beam} = 41.5 MeV. For the second beam energy, another ^{24}Mg target was placed at 3 inches further downstream so that triton energy ranges covered by SIDAR were roughly the same for both sets of runs. Owing to the angular range per strip for the second experimental setup, the energy resolution obtained from the E_{beam} = 41 MeV ($\Delta E_{c.m.}$ $\sim$70 keV) data was better than that from the E_{beam} = 41.5 MeV ($\Delta E_{c.m.}$ $\sim$95 keV) data. Therefore excitation energies were determined from 41 MeV data set.

The angular range was chosen to probe energy levels in ^{22}Mg from the ground state to above the ^{18}Ne + α threshold at E_x = 8.142 MeV. Beam was continuously monitored by measuring beam current from a graphite beam stop placed downstream of the target chamber for normalization. A schematic diagram of the experimental setup is shown in Figure 1.

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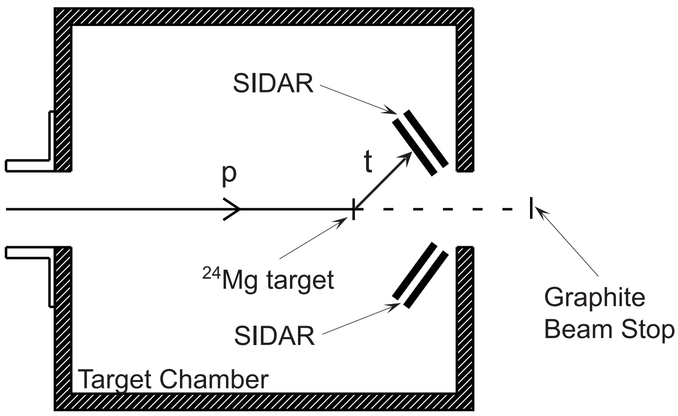

Figure 1: A schematic diagram of the experimental setup is shown.

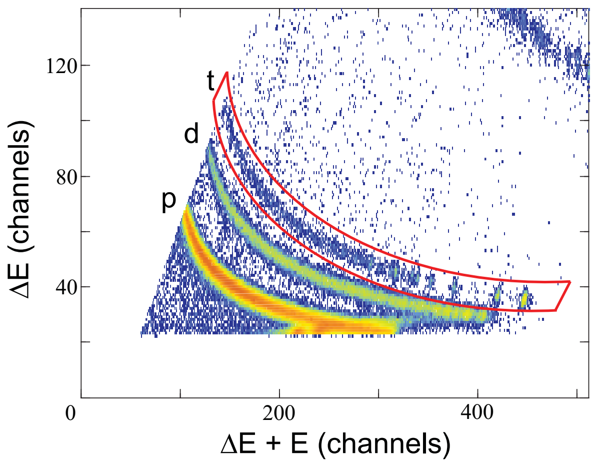

Figure 2: Particle identification of tritons from the ^{24}Mg(p,t)^{22}Mg reaction.

3. Results

The tritons from the ^{24}Mg(p,t)^{22}Mg reaction were identified by standard energy loss techniques. A typical particle-identification plot from the current experiment at θ_{ab}=37.6° ($\theta_{c.m.}$=41.6°) is shown in Figure 2. The triton yields were clearly identified as shown in the figure without significant evidence for contamination from other charged particle groups.

An example of energy spectra for the tritons gated on the $\Delta E - E$ spectrum at θ_{ab}=37.6° ($\theta_{c.m.}$=41.6°) is shown in Figure 3. Internal energy calibrations were performed at each angle using the levels at 1247, 3308, 4402, and 7810 keV. The excitation energies of these levels were precisely determined before [3, 6, 7].

Angular distributions of the differential cross section were compared with Distorted Wave Born Approximation (DWBA) calculations using the finite range computer code DWUCK5 [8] with previously determined optical model parameters [9]. Angular distributions for six strongly-populated states and DWBA calculations best fitting the observed angular distributions are shown in

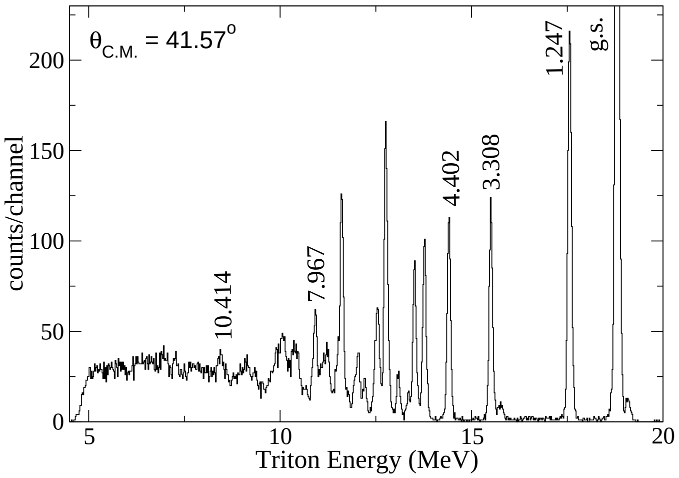

Figure 3: The number of counts per channels versus tritons energy plot at θ_{lab}=37.6° ($\theta_{c.m.}$=41.6°).

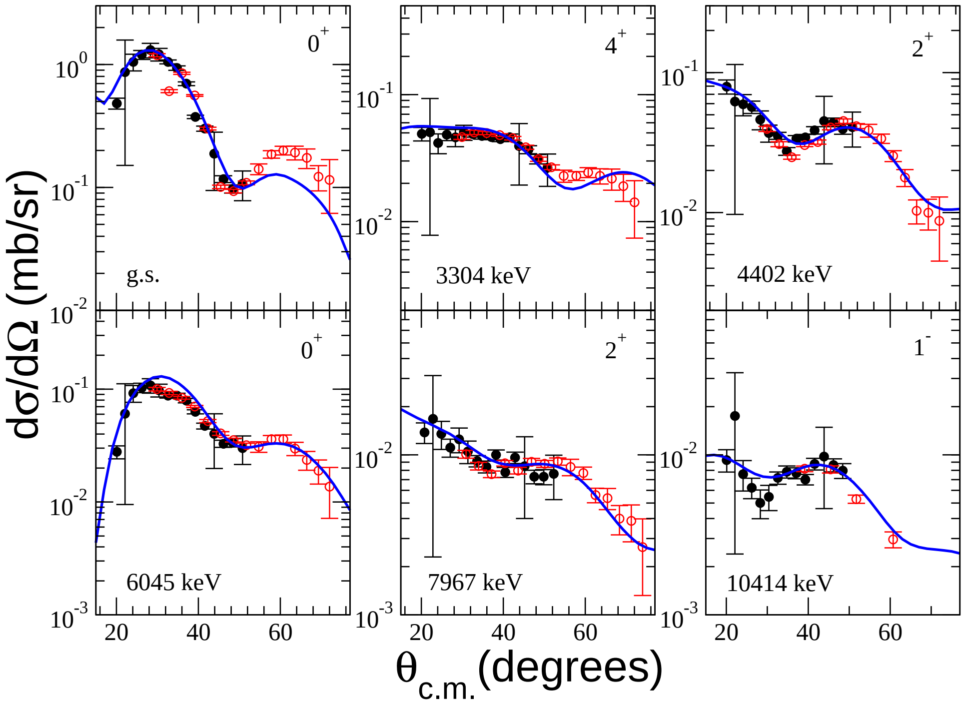

Figure 4: The angular distribution of tritons from the ^{24}Mg(p,t)^{22}Mg reaction for six levels are shown. The filled and empty circles are from E_{beam}=41 MeV and E_{beam}=41.5 MeV, respectively.

Figure 4. The filled and empty circles are from E_{beam}=41 MeV and E_{beam}=41.5 MeV, respectively.

By comparing the calculated angular distributions with observed differential cross sections we could make or confirm the following spin and parity assignments: ground state - 0^+, E_x=3304 keV - 4^+, E_x=4402 keV - 2^+, E_x=6045 keV - 0^+, E_x=7967 keV - 2^+, E_x=10414 keV - 1^-. The J^π assignments for 7967- and 10414-keV levels were made for the first time. In the future, we will make J^π assignments for more of the observed levels and improve the calculated ^{18}Ne(α,p)^{21}Na reaction rate above the α threshold.

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