Probing Stellar Explosions with Radioactive Beams at ORNL*

Michael S. Smith
Physics Division, Oak Ridge National Laboratory
Oak Ridge, Tennessee, U.S.A.

Laboratory measurements of nuclear reactions using radioactive ion beams are being made at the Holifield Radioactive Ion Beam Facility (HRIBF) at Oak Ridge National Laboratory. The reactions under study include proton- and alpha-capture reactions on proton-rich radioactive nuclei occurring in stellar explosions such as novae and X-ray bursts. The experimental endstation for these measurements is centered on the Daresbury Recoil Separator (DRS), a 90-ton, 13-meter long device featuring two 1.2-meter long velocity filters, a 50 degree dipole magnet, and a series of focal plane detectors. The DRS will be used to measure capture reactions in inverse kinematics using a radioactive ion beam incident on a hydrogen or helium target. The DRS must separate beam particles passing through the target from the products of the capture reaction. These two groups of particles typically differ in intensity by a factor of a trillion but differ in mass and velocity only by a few percent, so separating these groups is very challenging. Details of the experimental equipment, including a new windowless, differentially-pumped gas target system and a new, large area focal plane detector (both under construction) will be presented. Results from a first DRS commissioning experiment - a measurement of $^{12}C(p,\gamma)^{13}N$ - will also be discussed.

Another important part of our experimental setup centers on the Silicon Detector Array (SIDAR) in the target chamber of the DRS. The SIDAR consists of up to 3 annular arrays of highly-segmented silicon detectors with corresponding high-density, low-noise electronics. The system, which can be configured to include more than 200 channels, is used for excitation function and angular distribution measurements of charged particles from transfer reactions such as (p,p) and (p,alpha) in inverse kinematics with radioactive heavy ion beams. The SIDAR has been used to better understand the $^{17}F(p,\gamma)^{18}Ne$ reaction that occurs in stellar explosions. The rate of this reaction was uncertain (by up to a factor of 100) because of an expected 3^+ state in ^{18}Ne that had not been conclusively observed despite nine previous experimental studies of the relevant excitation energy region. This state would provide a strong s-wave resonance in $^{17}F + p$ capture and, depending on its excitation energy, could dominate the $^{17}F(p,\gamma)^{18}Ne$ stellar reaction rate. We observed [1] this missing 3^+ state by measuring the $^{1}H(^{17}F,p)^{17}F$ excitation function with a radioactive ^{17}F beam produced with the isotope separator on-line (ISOL) technique at HRIBF. We find that the state lies at a center-of-mass energy of 599.8 ± 1.5 (stat) ± 2.0 (sys) keV and has a width of 18 ± 1.5 (stat) ± 2 (sys) keV. Our measurement significantly reduces the uncertainty in the reaction rate, changes the predicted production of some isotopes in novae by more than a factor of 1000, and shows that the 3^+ resonance dominates the capture rate at temperatures above 0.5 GK while the non-resonant direct capture dominates at lower temperatures. Details of the SIDAR, the $^{1}H(^{17}F,p)^{17}F$ measurement, and other radioactive beam experiments in progress will be discussed.

* Oak Ridge National Laboratory, managed by Lockheed Martin Energy Research Corp. for the U.S. Department of Energy under contract number DE-AC05-96OR22464.

Reference

[1] D. W. Bardayan, J. C. Blackmon, C. R. Brune, A. E. Champagne, A. A. Chen, J. M. Cox, T. Davinson, V. Y. Hansper, M. A. Hofstee, B. A. Johnson, R. L. Kozub, Z. Ma, P. D. Parker, D. E. Pierce, M. T. Rabban, A. C. Shotter, M. S. Smith, K. B. Swartz, D. W. Visser, and P. J. Woods, *Phys. Rev. Lett.* **83** (1999) 45.