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The level structure of ^{18}Ne

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We have measured levels in ^{18}Ne by the ^{16}O(^{3}He,n) reaction at the FN tandem accelerator of University of Notre Dame in order to measure the rate of the waiting point reaction ^{14}O(α,p) in the hot CNO cycle. This is one of the breakout reaction in the CNO cycle where the signatures are that the temperatures are high enough to bypass the beta decay of the waiting points breaking out of the hot CNO cycle by a thermonuclear runaway in some explosive environments like Novae and X-ray bursts. One of the two paths to breakout of the hot CNO cycle is the reaction chain ^{14}O(α,p)^{17}F(p,γ)^{18}Ne(α,p). The starting (α,p) reaction on the waiting point nucleus ^{14}O proceeds through resonant states above α-decay threshold in ^{18}Ne. The rate of this reaction is therefore very sensitive to the partial and total widths, excitation energies and spins of the resonances in ^{18}Ne. We studied the relevant states in ^{18}Ne using an array of liquid scintillators with time-of-flight and pulse-shape-discrimination techniques to measure the neutrons while decaying charged particles were detected by a silicon detector array. Coincidences of n-p/α were used to measure α and proton decay branching ratios. DWBA calculations were carried out to constrain the possible spins of the new states. We will include this new information in reaction network calculations to determine the impact of this breakout path on the nuclear energy generation and nucleosynthesis in explosive hydrogen burning environments.

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The level structure of ^{18}Ne is shown in figure 1. The charged particle threshold of ^{18}Ne is of great interest in explosive astrophysical scenarios since the reaction path ^{14}O(α,p)^{17}F(p,γ)^{18}Ne(α,p) is one of the two breakout paths of the hot CNO cycle [1], [2].

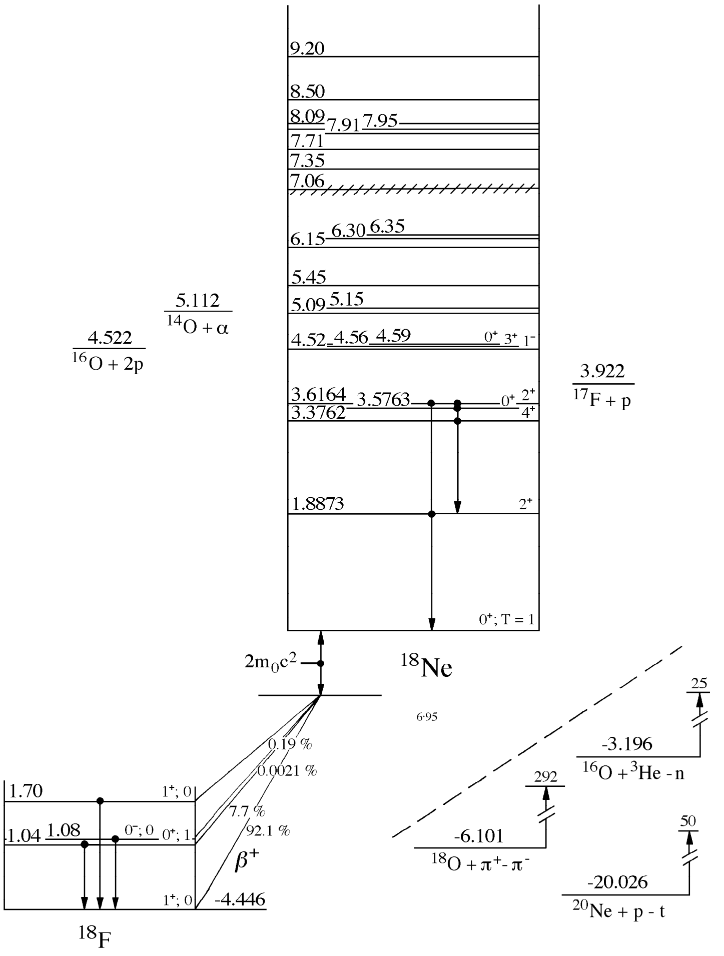

Figure 1: Energy level diagram of ^{18}Ne.

In explosive hydrogen burning environments such as Novae and X-ray burst, ^{14}O is produced by successive proton captures on ^{12}C and ^{13}N. At temperatures of T_9>0.1, the relatively slow beta decay of ^{14}O ($t_{1/2}$=71 s) can be bypassed by the reaction ^{14}O(α,p)^{17}F which proceeds through resonant states in ^{18}Ne. This reaction is followed by ^{17}F(p,γ)^{18}Ne, going again through resonant states in ^{18}Ne, opening one of the two paths to breakout from the hot CNO cycle into the rp process where some of the heavier elements are made [3]. These reaction rates are very important in the understanding of such explosive astrophysical events because they can be linked to observables like isotopic ratios and energy production [4], providing important constraints in the theoretical models. Experimental information on the level structure of ^{18}Ne above the α decay threshold is scarce, the ^{14}O(α,p)^{17}F reaction is very sensitive on the excitation energies, spins and partial and total widths of the relevant resonances in ^{18}Ne, there have been various attempts to provide better experimental information and estimate such important reaction rates [5] [6], but the direct measurements of the reactions are still very difficult due to the radioactive nature of the isotopes involved. This work provides new information on the structure of ^{18}Ne that will be used to make a better estimation of these important reactions rates.

The ^{18}Ne resonant states were populated through the ^{16}O(^{3}He,n) reaction. The experiment was carried out at the Institute for Structure and Nuclear Astrophysics at University of Notre Dame. A 15 MeV bunched ^{3}He beam was used to bombard a 100 μg/cm^2 SiO target. An array of silicon detectors was placed inside the reaction chamber to detect charged particles from the decay of ^{18}Ne, the array consists of 4 identical 300 μm thick silicon-pad detectors, each of which has 4 strips and an area of 4×4 cm^2, covering an angular range of 90° to 150°. An array of 16 liquid scintillation neutron detectors located at 3.6 m from the reaction chamber and covering an angular range of 11° to 39° was used to identify states in ^{18}Ne using both Time-of-Flight and Pulse-shape-discrimination techniques. The experimental setup is shown in figure 2. A typical Time-of-Flight spectrum is shown in figure 3. The charged particles detected in the silicon detectors were measured in coincidence with the neutrons detected in the liquid scintillation detectors, allowing for a direct measurement of the branching ratios for each specific level populated in ^{18}Ne.

Figure 2: Array of 16 neutron detectors located at 3.6 meters away from reaction chamber. The insert in the lower right shows the reaction chamber with the silicon detector array.

A source of background was produced by the interaction of ^{3}He with Si in the SiO target. To subtract those background events, a measurement with a pure Si target was also performed.

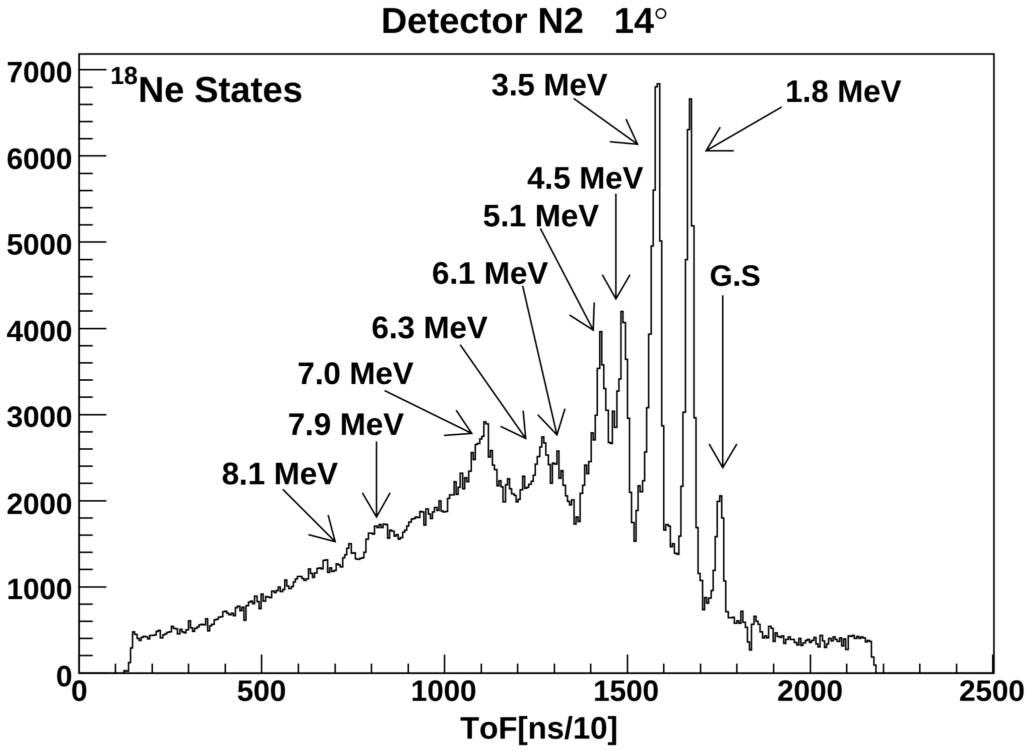

Figure 3: Typical ToF spectrum in the neutron detectors after Si background subtraction. The different levels corresponding to ^{18}Ne are indicated.

In order to identify the charged particles decaying from ^{18}Ne, a full kinematics calculation was done for all the 16 neutron detectors and the 16 strips of silicon detectors, taking into account all possible open channels: proton decay (p) to ground state of ^{17}F, proton decay (p') to the first exited state (0.4953 MeV) of ^{17}F, two proton decay to ground state of ^{16}O and α decay to the ground state of ^{14}O. In the case of the two proton decay, we consider just the case of a di-proton system where the 2 protons decay together as a single particle. The spectra of the charged particle decays coming from a specific level of ^{18}Ne were obtained by gating on the identified levels in the neutron Time-of-Flight spectra and looking for the coincidences in the silicon detectors. The identification of the decays in the silicon detectors was done comparing the spectra coming from the 16 silicon strips with the kinematics calculation. After the identification of the decay channels for each level of ^{18}Ne, we performed an event by event reconstruction to add all the 16 stripes of silicon detectors. In this way, we obtained the spectrum shown in figure 4 from which we can extract directly the branching ratios of the 5.15 MeV level.

The cross section of the levels of interest in ^{18}Ne was extracted from the 16 neutron detectors, tentative spin assignments will be made in comparison with zero range DWBA calculations. The new information will be used to better estimate the reaction rates of interest and evaluate its impact in energy generation and nucleosynthesis that occurs in these stellar explosive environments. Analysis is in progress.

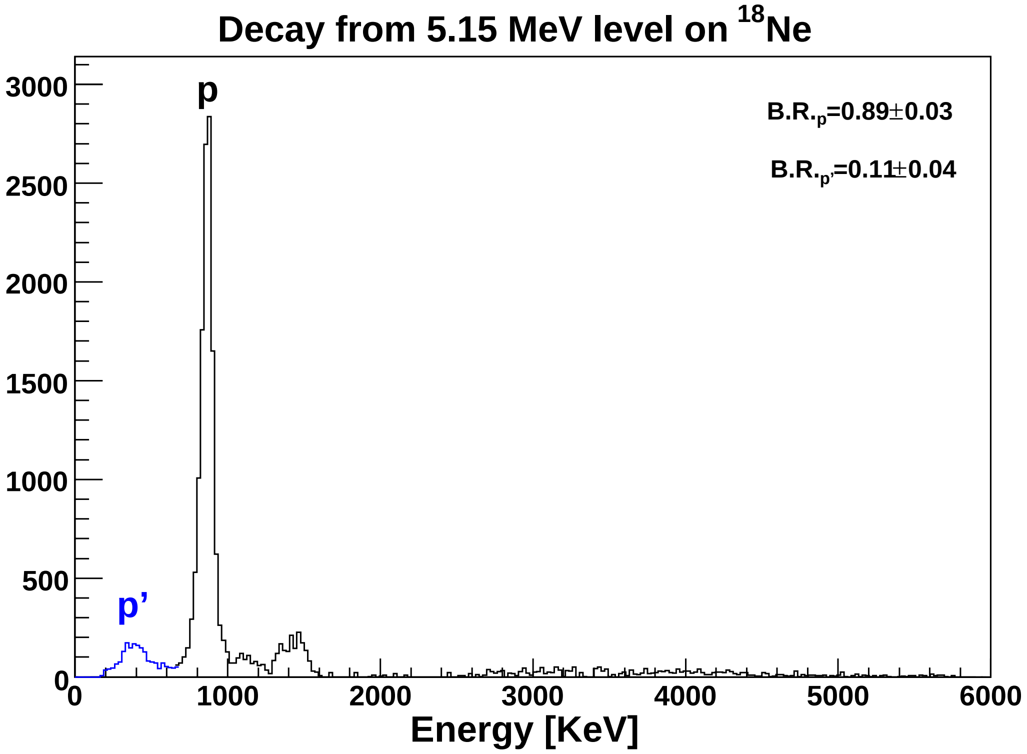

Figure 4: Decay from 5.15 MeV level on ^{18}Ne. The main decay channel is by proton emission to the ground state of ^{17}F, there is also a significant decay to the 1^{st} exited state of ^{17}F that is 0.4953 MeV above the ground state.

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