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Level Structure of ^{19}Ne from studies of the ^{17}O(^{3}He, n)^{19}Ne Reaction

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The astrophysically-relevant region of the level structure of ^{19}Ne around the proton threshold remains incomplete when considering that analogs for several states in the mirror nucleus ^{19}F have not yet been identified in ^{19}Ne. This structure is particularly important to understanding the eventual fate of the long-lived radioisotope ^{18}F in explosive environments like novae and x-ray bursts, where rates of proton-induced reactions on ^{19}F depend critically on the properties of ^{19}Ne excited states above threshold. To study this system, a measurement of the ^{17}O(^{3}He, n)^{19}Ne reaction has been performed at Ohio University's Edwards Accelerator Laboratory, which features a 4.5-MV tandem Van de Graaff accelerator. Utilizing pulsed beams and neutron time-of-flight techniques, this experiment has been conducted at forward angles with a ^{3}He beam energy of 4.2 MeV. This energy has been chosen such that the compound reaction model is the dominant mechanism, which should ensure that this reaction will in principle populate all excited states including any newly observed ones. In addition to precisely determining the excited energies for individual levels, this measurement will provide experimental differential cross sections for individual states that can be compared to calculations employing the Hauser-Feshbach statistical model in an attempt to extract information on the spins of the excited states. The observed ^{19}Ne level structure from this reaction will be presented.

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1. Introduction

Determining the rates of proton-induced reactions on the long-lived radioisotope ^{18}F will improve our understanding of the role that it plays in annihilation gamma-ray emission from novae and in possible heavier-element nucleosynthesis in x-ray bursts. For temperatures in the range of (1-4)$\times 10^8$ K, the rates of the ^{18}F$(p,\alpha)^{15}$O and ^{18}F$(p,\gamma)^{19}$Ne reactions depend critically on individual ^{19}Ne resonances above the proton threshold($Q_{p\gamma} = 6.411$ MeV) [1].

Unfortunately, there remains considerable uncertainty in the level structure of ^{19}Ne, where as many as seven levels in the excitation energy range of interest (6.4-7.4 MeV) appear to be missing with respect to analog states of the corresponding mirror nucleus ^{19}F (see Figure 1). This dilemma leads to large uncertainties in the reaction rate calculations [2]. As a result, a considerable effort has been undertaken over the past decade to study this system. Indeed, a variety of laboratory experiments utilizing an array of different stable- and radioactive-beam studies (for a partial list, see references cited in Ref. [2]) have been conducted to search for excited states of ^{19}Ne and to identify their properties.

The Edwards Accelerator Laboratory is ideally suited for performing neutron time-of-flight measurements with its 30-meter tunnel in conjunction with the swinger magnet assembly and pulsed beams supplied by the 4.5-MV Tandem. With these capabilities, a measurement of the $(^3\mathrm{He},n)$ reaction on ^{17}O was determined to be a useful tool for conducting studies of the level structure of ^{19}Ne. This reaction has a Q value of 4.299 MeV with respect to the ^{19}Ne ground state, which enables the use of low-energy ^{3}He beams to readily access the excitation energy range of interest, while producing optimal neutron energies with respect to energy resolution and detection efficiency. Moreover, the study of this reaction at low beam energies will ensure that it is dominated by the compound nuclear mechanism. As such, the particularly nice feature of this study, unlike many others which preferentially access only certain spin states, will in principle be the population of all ^{19}Ne excited states.

2. Experimental Approach

Targets of tantalum oxide, Ta_2O_5, on tantalum plates were fabricated via an monodic oxidation technique [5] using a sample of water enriched to 76.7% in ^{17}O. A group of three large (5-in diameter, 2-in thick) NE213 and BC501A liquid scintillator detectors were used for the measurements and were located at a distance of 8.7 meters from the target, at an angle of $\theta = 20^\circ$. The use of these detectors enables the implementation of pulse-shape discrimination (PSD) techniques to separate neutrons from gamma-rays, which constitute a significant albeit almost entirely random background in the experiment. The absolute efficiencies of the neutron detectors have been determined via a measurement of the $^{27}\mathrm{Al}(d,xn)$ reaction ($E_d = 7.44$ MeV, $\theta_{lab} = 120^\circ$) with a stopping target, the neutron yield of which has been normalized to a fission chamber [6].

The $^{17}\mathrm{O}(^3\mathrm{He},n)^{19}$Ne measurement was accomplished with a 4.2-MeV beam of $^3\mathrm{He}^{++}$ ions incident on a 64.25 μg/cm^2 (25-keV) thick target. The beam was chopped and bunched, thereby producing beam pulses of 3-4 ns width (FWHM) and spaced 800 ns apart. The beam current on target was typically 10-25 pnA and data were accumulated over the course of approximately 10 days including time spent studying some additional targets to better understand background

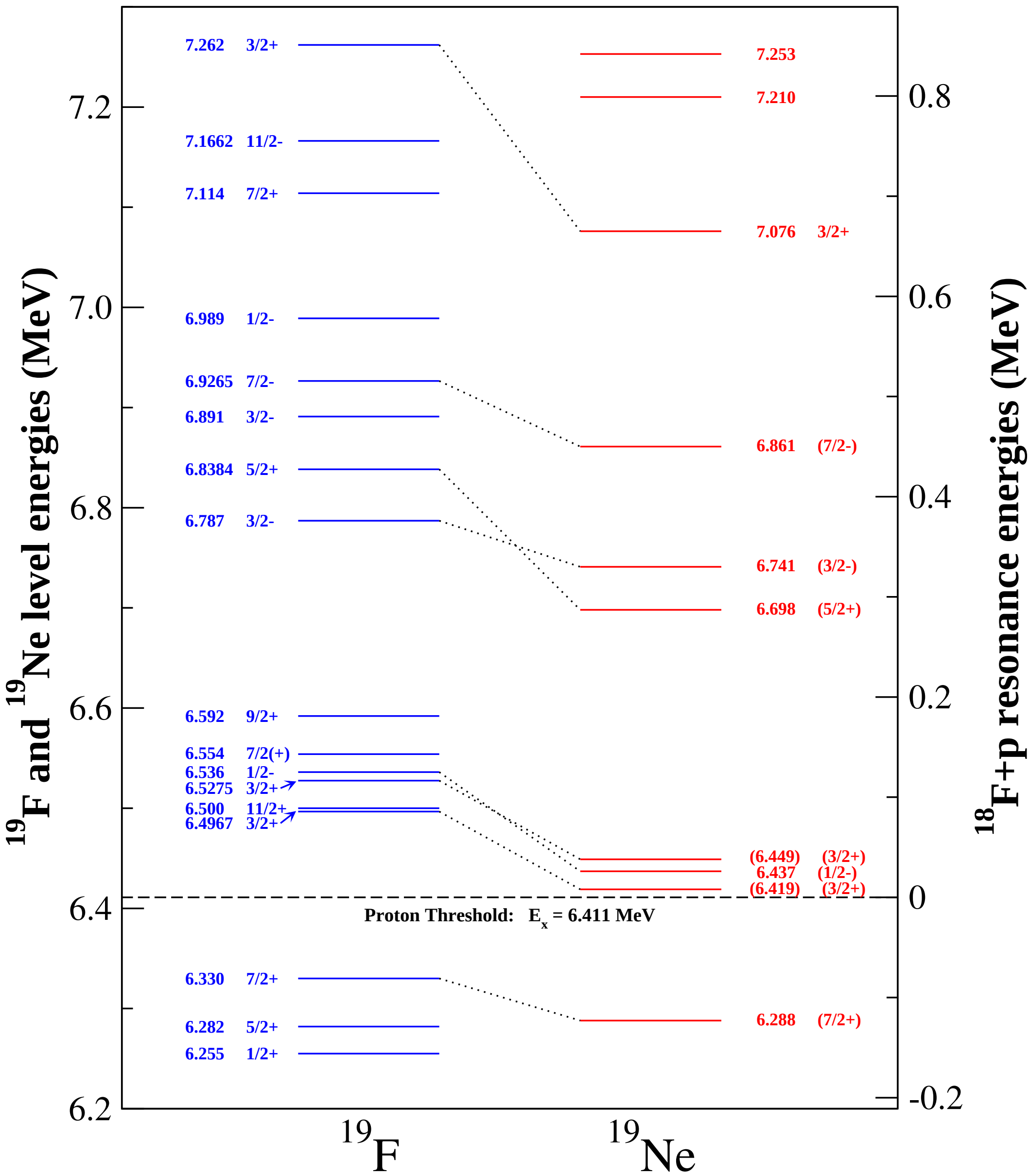

Figure 1: Level scheme for ^{19}F and ^{19}Ne, taking into account some recent results (e.g., Refs. [3, 4]). Dashed lines represent putative mirror states.

contributions. For example, time was spent studying a blank tantalum plate, as well as ^{12}C and ^{13}C targets used to study backgrounds associated with buildup over the course of the experiment of carbon on the tantalum oxide target. This effect was minimized as much as possible by frequent repositioning of the tantalum oxide targets with respect to the beam spot.

It should be pointed out that special care was paid to understanding the time-of-flight spectrum. For example, periodic measurements of the time calibration (time per channel) of the TAC/ADC system were made and compared to a random spectrum taken after completion of the experiment. This information is essential to acquiring an accurate calculation of the energy of a given neutron

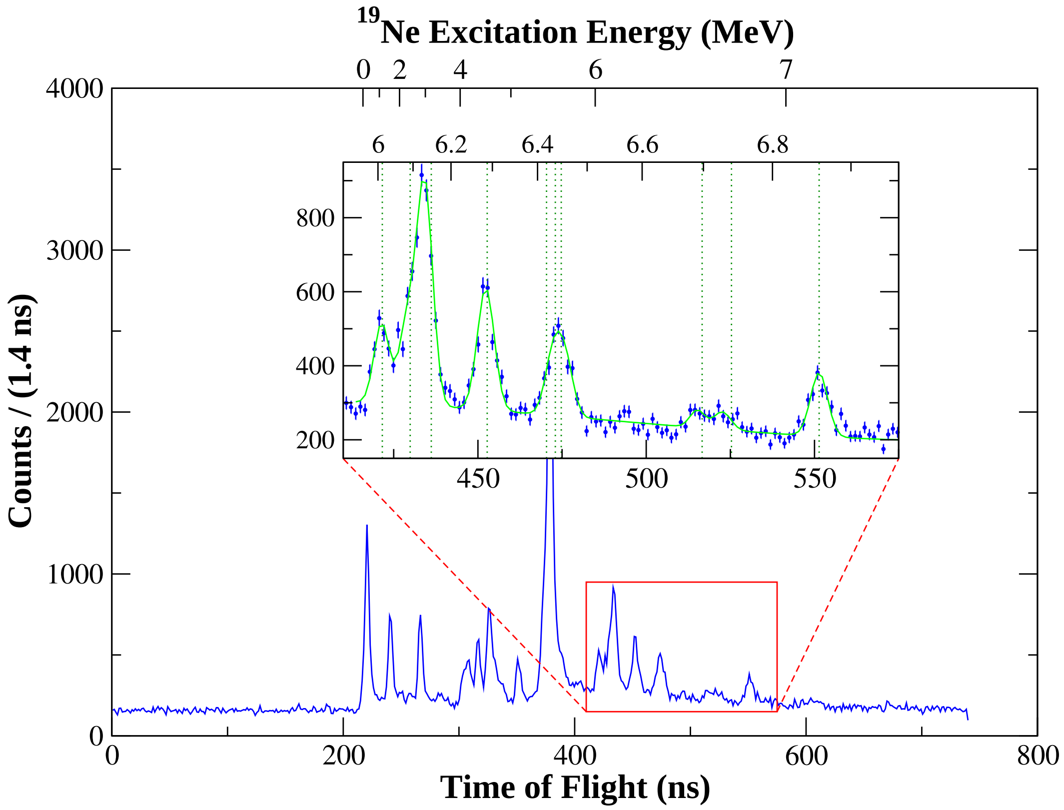

Figure 2: Neutron time-of-flight spectrum for the ^{17}O(^{3}He,n)^{19}Ne reaction measurement at E(^{3}He) = 4.2 MeV at $\theta = 20°$. The inset shows a preliminary MINUIT fit to a portion of the spectrum in the region of interest, where known levels are indicated by the vertical dashed lines.

group. In addition, the timing characteristics of the beam pulsing and bunching were frequently monitored and retuned to maintain consistency and correct for drift. Finally, a peak associated with prompt gamma-ray emission from the target is used as a reference point to establish the true neutron time of flight.

3. Results and Conclusions

A preliminary analysis of the data has been performed, and the combined data set from all three detectors is plotted in Figure 2. A few general observations can be made from a brief analysis of the spectrum. First of all, the neutron spectrum sits atop a flat, uniform background resulting from random gamma rays and cosmic-induced or otherwise scattered neutrons. Secondly, aside from one major background peak – that associated with the ground state of ^{14}O due to reactions on ^{12}C – the rest of the visible peaks in the spectrum are associated with states in ^{19}Ne. Generally speaking, the widths of the peaks are consistent with the expected experimental widths, taking into account time, distance and angle uncertainties, beam energy uncertainties and target energy loss.

One interesting note is that there is no overwhelming evidence of any newly-observed states. However, there are some hints of potentially interesting features that will be explored in more detail, once the data have been fitted with MINUIT. The final results from this analysis are expected to be completed in the near future.

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