PROCEEDINGS OF SCIENCE

Resonances in ^{19}Ne with relevance to the astrophysically important ^{18}F(p,α)^{15}O reaction

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The main source of gamma ray emission from novae below 511 keV is likely to be associated with the β^+ decay of ^{18}F. The main uncertainty in the abundance of this nucleus comes from the ^{18}F(p,α)^{15}O reaction. In 2006, through microscopic techniques, two previously unseen energy levels in the compound ^{19}Ne nucleus, at 6 and 7.9 MeV were proposed by Dufour and Descouvemont. In light of this there have been two published attempts in the search for the higher of these states, by Murphy *et al.* and Dalouzy *et al.*. The aim of this work is to address the contradiction between these works and come to a conclusion as to the possible existence of this state. An experiment has taken place that utilised a 4 MeV/u ^{18}F beam, degraded to $\sim$1.9 MeV/u, incident upon a thick CH_2 target. The data has been analysed within the R-matrix formalism and preliminary results are presented here.

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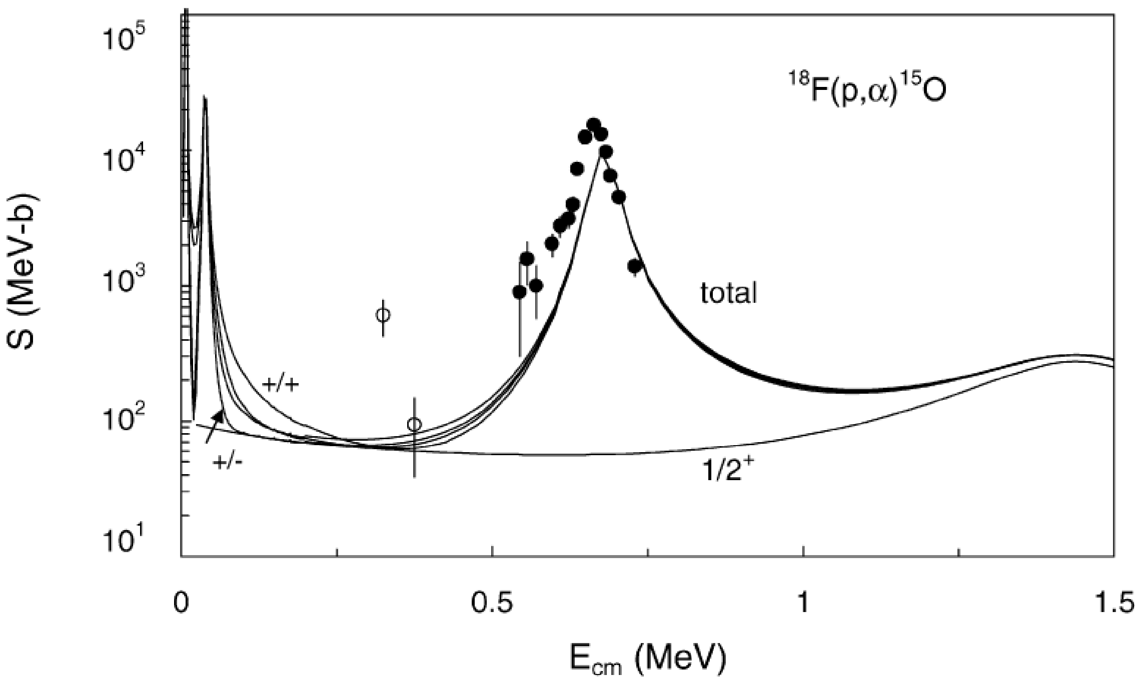

Figure 1: The predicted enhancement of the astrophysical *S*-factor of the ^{18}F(p,α)^{15}O reaction below 0.25 MeV due to the prdicted two broad $1/2^+$ states.

1. ^{18}F and Novae

Novae originate in binary stellar systems where hydrogen rich matter is accreted from a main sequence star to the surface of a white dwarf. Due to the electron degenerate environment, the bottom layer is compressed such that it heats rapidly to trigger hydrogen burning and eventually a thermonuclear runaway. This lifts the degeneracy and the outer layers are blown off in a nova explosion.

The high tempertures in the explosion trigger the hot CNO cycle which produces and destroys ^{18}F through a series of hydrogen burning reactions. The destruction of this nucleus through the ^{18}F(p,α)^{15}O reaction is the focus of this work.

There is significant interest in the abundance of ^{18}F present in the nova explosion due to its lifetime of approximately 110 minutes. This is slow enough so that the nova envelope has become transparent to the associated γ-rays while not exhausting the decay in the meantime. Significant efforts are being made to observe these γ-rays, such as the European Space Angency's INTEGRAL satellite, although as yet they have not been observed

The nuclear uncertainty in the ^{18}F(p,α)^{15}O reaction was the subject of a microscopic study of the ^{19}Ne energy spectrum by Dufour and Descouvement in 2007 [1]. This work suggested the existence of two broad states; one just below the ^{18}F+p threshold and one $\sim$1.5 MeV above. The lower state could significantly enhance the rate of the ^{18}F(p,α)^{15}O reaction as shown by the astrophysical *S*- factor in Figure 1.

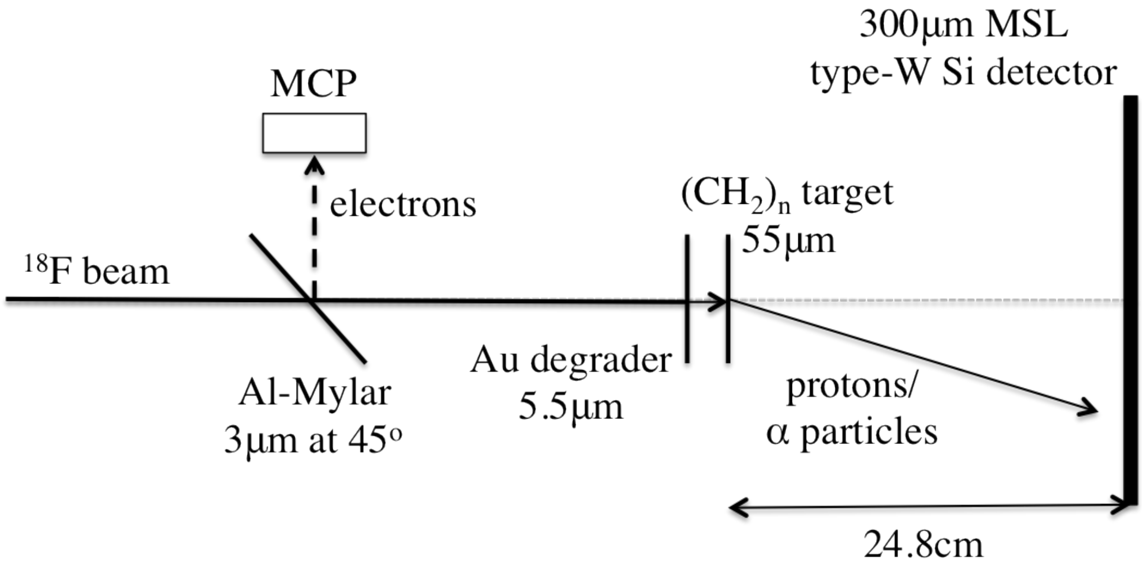

Figure 2: Experimental setup for the direct measurement of the ^{18}F(p,α)^{15}O reaction at GANIL in 2010.

2. Previous Work and the Experiment

A comprehensive review of observed states in ^{19}Ne has been carried out by Nesaraja *et al.* [4] and the reader is directed there for a summary. However, two previous works have focussed on the observation of the resonant state at 1.5 MeV. Murphy *et al.* [2] carried out an experiment to study the direct reaction at a center of mass energy of ∼1.6 MeV, seeing no candidates exhibiting the properties predicted. On the contrary, Dalouzy *et al.* [3] obesrved the broad state with $J^{\pi} = 1/2^{+}$ via the study of inelastic ^{19}Ne scattering.

To address this inconsistency, a direct measurement was carried out at the SPIRAL facility at GANIL with the experimental setup shown in Figure 2. The facility provided a 4 MeV/u ^{18}F beam which was degraded by a 5.5(3) μm thick gold foil to an energy of ∼2 MeV/u, corresponding to 1.9 MeV in the center of mass.

The degraded ^{18}F beam was then delivered onto a 55(4) μm thick polyethylene target. The thickness of the target was chosen in order to stop the impinging beam. Protons and alpha particles from the resulting ^{18}F(p,p)^{18}F and ^{18}F(p,α)^{15}O reactions were detected in a 1 mm thick double sided silicon strip detector.

Employing an energy vs time of flight plot allowed proton, alpha particle and carbon ion events (from the ^{18}F(^{12}C,^{12}C)^{18}F reaction) to be well discriminated.

3. Preliminary Results

Knowing the detected energy and angle for each proton or alpha particle event allows a projection of excitation functions in the center of mass frame for the ^{18}F(p,p)^{18}F and ^{18}F(p,α)^{15}O reactions, as shown in Figure 3.

Table 1: Tabulation of the resonance parameters extracted from the present data when all resonances, apart from resonance A, are allowed to vary within the minimisation procedure.

Resonance	E_{CM} (MeV)	J^{π}	Γ_p (keV)	Γ_α (keV)
A	0.665	$\frac{3}{2}^+$	15.2	23.8
B	0.759(20)	$\frac{3}{2}^+$	1.6(5)	2.4(6)
C	1.096(11)	$\frac{5}{2}^+$	3(1)	54(12)
D	1.160(34)	$\frac{3}{2}^+$	2.3(6)	1.9(6)
E	1.219(22)	$\frac{3}{2}^-$	21(3)	0.1(1)
F	1.335(6)	$\frac{3}{2}^+$	65(8)	26(4)
G	1.455(38)	$\frac{1}{2}^+$	55(12)	347(92)
H	1.571(13)	$\frac{5}{2}^+$	1.7(4)	12(3)

There are 7 clear structures identified in the spectra and each of these states are reported by at least one of Murphy *et al.*, Dalouzy *et al.* and Nesaraja *et al.*, [2, 3, 4]. Table 1 summarizes the states identified through the experiment discussed here. The most well-known of these is the 0.655 MeV $J^{\pi} = 3/2^+$ resonance (resonance A in table 1), hence, this resonance was used for normalization and the associated parameters are taken as reported by [4].

In addition to resonant structures, the presence of carbon in the target could give a possible contribution from fusion-evaporation reactions. To investigate this, data were taken with the CH_2 target replaced with a thick natural carbon target. The resulting yield of both protons and alpha particles was found to be small and insufficient to make a significant contribution to any of the proposed resonant structures.

Given this information, the additional strength underlying the structure in the region of ∼1.3-1.7 MeV is of particular interest. While not accounting for this in some way has a large detrimental effect on the fit in this region, the addition of a broad $1/2^+$ state well-describes the strength.

By using measurements of the resonances labelled as B-F and H in Table 1 (as given by [2, 3, 4]) and by using the predicted paramters of G [1], the *R*-Matrix formalism was implemented to calculate the cross section over the energy range. Searching for a minimum $\bar{\chi}^2$ by allowing the parameters of all states (except the constrained state, A) to vary in the calculation, gives the parameters in Table 1.

The structure of particular interest in this work, resonance G is found to best reproduce the data with a tentaive assignment of $J^{\pi} = 1/2^+$. It is found to have significantly different partial widths to the prediction [1], however it is consistent in total strength with the prediction and the previous observation of Dalouzy *et al.* [3].

4. Conclusion

This work allowed to obtain new data in the direct study of the astrophysically important ^{18}F(p,α)^{15}O reaction, and to produce the excitation functions for both ^{18}F(p,p)^{18}F and ^{18}F(p,α)^{15}O reactions. Using the *R*-Matrix formalism, a candidate for a predicted $1/2^+$ state has been found which is consistent with the prediction and a previous measurement. The existence of a sub-

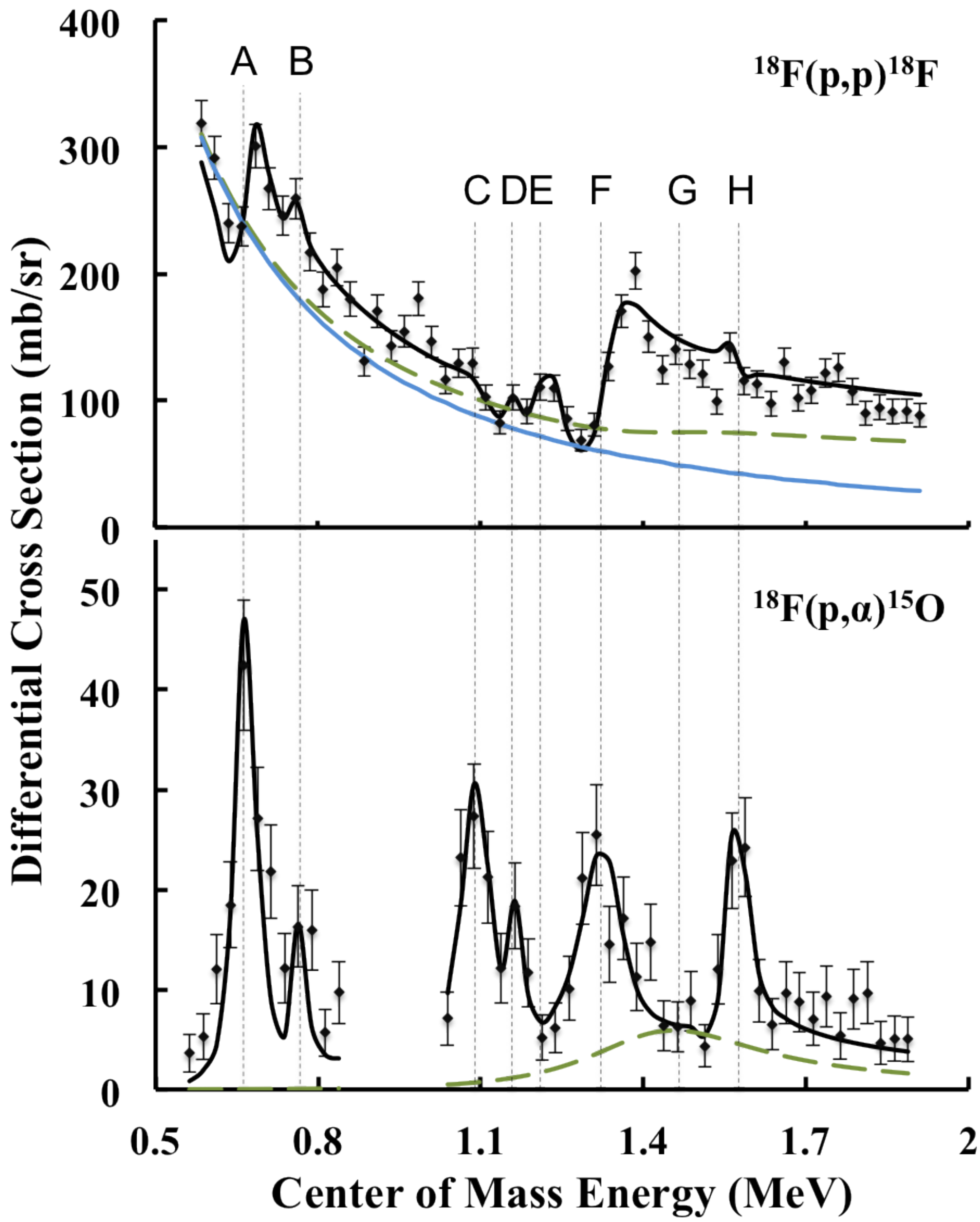

Figure 3: Excitation functions of the ^{18}F(p,p)^{18}F and ^{18}F(p,α)^{15}O reactions. The solid black lines show the simultaneous R-Matrix fits to the data. The $1/2^{+}$ contribution is shown in long dashed and the pale line is the Coulomb contribution to the ^{18}F(p,p)^{18}F reaction.

threshold partner to this state could significantly enhance ^{18}F destruction in nova explosions, thus reducing the yield of 511 keV γ-rays observed from such events.

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[2] A.St J. Murphy *et al.*; *Simultaneous measurement of the ^{18}F(p,p)^{18}F and ^{18}F(p,α)^{15}O reactions: Implications for the level structure of ^{19}Ne, and for ^{18}F production in novae*, *Phys. Rev. C*, **79**, 058801,(2009).

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