Journal of Physics: Conference Series

PAPER • **OPEN ACCESS**

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Abstract. We discuss new results concerning the investigation of the ^{19}F(p,α_0)^{16}O reaction at very low energies (0.6-0.2 MeV). This reaction is important both in Nuclear Astrophysics, because it closes the CNOF cycle and it is an important fluorine destruction channel in hydrogen rich stellar environments, and in Nuclear Structure, because it allows to study the spectroscopy of the self-conjugated ^{20}Ne compound nucleus. Despite its importance, very few direct data have been published at low energies in the literature. Our work allowed to deduce the S-factor down to $\approx$ 0.2 MeV and to point out the role played by broad resonances at low energies. The experimental S-factor is $\approx$1.5-2 times larger than non-resonant extrapolations reported by NACRE with potentially important astrophysical consequences.

1. Introduction

The study of low energy ^{19}F(p,α_0) and ^{19}F(p,α_π) reactions represents a powerful tool to probe the structure of the self-conjugated ^{20}Ne compound nucleus [1, 2, 3, 4, 5], that can show important α-cluster structures [6, 7] near some N-α disintegration thresholds (e.g. 11.89 MeV for the ^{12}C+2α and 19.17 MeV for the 5α disintegration mode [8]). For this reason in past times several experimental efforts were done on the study of this reaction in order to highlight the existence of quartet excitations in ^{20}Ne [9]. Nevertheless, some ambiguities in the ^{20}Ne spectroscopy (mainly concerning the J$^\pi$ assignment of states and the determination of branching ratios $\frac{\gamma^2_{\alpha_\pi}}{\gamma^2_{\alpha_0}}$) are still persisting [8], especially in the lowermost energy region accessible with direct measurements (E_p <0.5 MeV).

Furthermore, the $p+^{19}F \rightarrow \alpha+^{16}O$ reaction plays an important role in Nuclear Astrophysics for two reasons. First, this reaction closes the CNOF cycle in the hydrogen-burning phase of massive stars [10]; second, it can be an important fluorine destruction channel in hydrogen-rich stellar environments [11, 12, 13]. Unfortunately, very few direct data-sets of the S-factor at

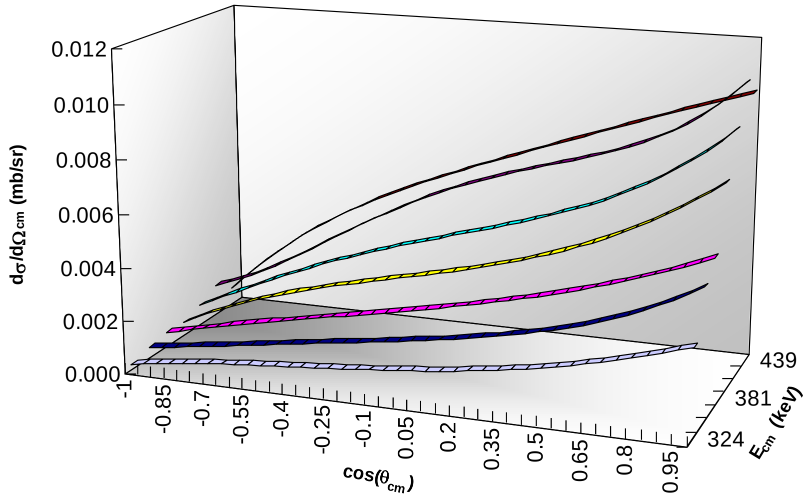

Figure 1. Evolution with the energy of the shape of angular distributions of the ^{19}F(p,α_0)^{16}O reaction. Curves are the results of Legendre Polynomial fits of experimental data in the 0.45-0.3 MeV center of mass energy domain. A noticeable forward anisotropy is observed.

$E_{cm} < 1$ MeV have been reported in the literature [1, 3, 14], and the reaction rate estimate at astrophysical energies is mainly based on extrapolation from high energy data [15]. Very interestingly, recent indirect data obtained with the Trojan Horse Method [16, 17] pointed out the important role played by a low energy resonance at 113 keV [12, 13]. Considering the importance of this reaction and taking into account the lack of data reported in the literature, we performed a new experiment at INFN - Laboratori Nazionali di Legnaro aimed at measuring excitation functions and angular distributions of the ^{19}F(p,α_0) reaction in the bombarding energy region E_p ≈0.6-0.2 MeV. The details of this experiment are widely discussed in Ref. [18]. In the following sections we report the main experimental findings obtained in this experiment.

2. Experimental apparatus

Low energy proton beams have been delivered by the AN2000 Van de Graaf accelerator of Laboratori Nazionali di Legnaro (Padua, Italy). The calibration procedure used in this experiment is described in details in Ref. [18]. The energy uncertainty was of the order of $\approx \pm$ 2.5 keV; the proton beam intensity was of the order of 0.3-0.9 μA. The used targets were CaF_2 layers 30 μg/cm^2 thick, evaporated onto a 20 μg/cm^2 carbon backing, and were frequently changed during the experiment. The detection array was constituted by 12 silicon detectors (300 μm thick) mounted at polar angles ranging from 20° to 160°. 8 μm aluminium absorbers were placed in front of the silicon detectors to stop scattered protons [1, 19, 20, 21, 22]. Beam current was measured by means of a Faraday cup (-300 V suppression voltage). A copper rod cooled to liquid nitrogen temperature was used inside the scattering chamber to reduce carbon build-up effects. The vacuum in the scattering chamber was better than 10^{-6} mbar. Due to the high Q-value (8.114 MeV), experimental spectra show clean peaks due to the ^{19}F(p,α_0)^{16}O reaction (see, e.g. Figure 1 of Ref. [18]). From α_0 particle yields it is possible to deduce angular distributions and excitation functions in the 0.2-0.6 MeV bombarding energy range.

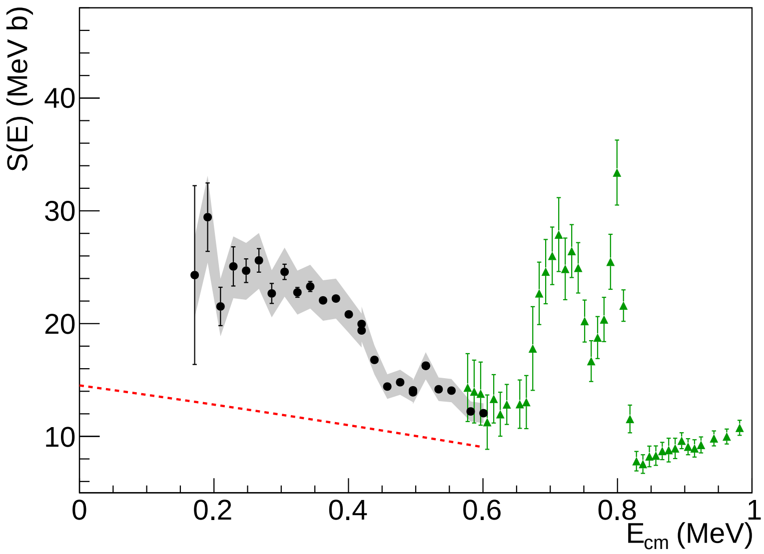

Figure 2. S-factor of the ^{19}F(p,α_0)^{16}O reaction at low energies ($\lesssim$ 1 MeV). Black full dots: experimental data obtained in this work (error bars: statistical errors; light grey band: non-statistical errors). Green triangles: data reported in Ref. [19]. Dashed line: non-resonant extrapolation reported by NACRE in Ref. [15].

3. Experimental results

Figure 1 shows the shape of the present experimental angular distributions as a function of the energy in the $E_{cm} \approx$ 0.3-0.45 MeV domain. A pronounced forward asymmetry can be observed; this effect characterizes the whole E_p=0.2-0.5 MeV region and could be attributed either to the interference between adjacent resonances with opposite parities [1, 3, 14] (in fact, in this case, the R-matrix theory predicts non vanishing contributions due to odd terms in the Legendre polynomial expansion of angular distributions [23]) or to the onset of direct processes at very low energies, that could reflect some cluster structure in the target nucleus [24, 25]. The analysis of experimental angular distributions in terms of cosine polynomials [1, 3], discussed in details in Ref. [18], reveals that both processes co-exist. In particular, the overall trend of angular distribution seems to be consistent with the presence of a direct contribution in the E_p=0.3-0.5 MeV region, together with the excitation of a broad 2^+ state in ^{20}Ne (E_{cm}=0.251 MeV, E_x=13.095 MeV, Γ=162 keV [8]).

The ^{19}F(p,α_0)^{16}O cross section $\sigma(E)$ has been obtained by integrating experimental angular distributions over 4π. From the $\sigma(E)$ data we deduced the astrophysical S-factor, that is shown in Figure 2 as black dots. Vertical bars represent statistical errors, while the band represents non-statistical errors, estimated as discussed in Ref. [18]. In Figure 2 we also report the recent data of Ref. [19] as green triangles, obtained in a previous experiment performed at the TTT3 tandem accelerator in Naples at higher energies, and the non-resonant S-factor extrapolation by the NACRE collaboration [15] (red dashed line). Results obtained in the present experiment agree well with the lowermost energy data of Ref. [19]. The analysis of the low energy part of Figure 2 reveals a behaviour of the S-factor that can be attributed to the sum of a direct component and of various resonances of the compound nucleus. For example, we can see a resonant contribution due to the broad 2^+ state at 0.251 MeV (E_x=13.095 MeV, Γ=162 keV), in agreement with the considerations on the angular distributions made before. This broad resonance leads to an increase of the low energy S-factor with respect to the non-resonant case.

At low energy, the S-factor is ≈1.5-2 times larger than the corresponding NACRE evaluation based on the non-resonant extrapolation of high energy data. As a consequence, also the reaction rate is well larger than the NACRE predictions (for further details on the reaction rate calculation see Ref. [18]). This larger reaction rate could lead to a more efficient ^{19}F destruction in extra-mixing phenomena. This seems in agreement with recent experimental observations of fluorine abundance in metal-poor AGB stars [11, 26] and could contribute to improve the description of fluorine nucleosyntesis in stars [27].

4. Summary

In these proceedings we briefly discuss new direct experimental measurements of the ^{19}F(p,α_0)^{16}O S-factor at $E_{cm} \approx 0.2$ - 0.6 MeV. More details on the experimental procedures and results can be found in Ref. [18]. The investigated reaction is interesting for (a) the study of the spectroscopy of natural parity states in ^{20}Ne and (b) the astrophysical implication of the ^{19}F(p,α)^{16}O reaction rate on fluorine nucleosynthesis in AGB stars. We point out for the first time the contribute of the low-energy 0.251 MeV resonance in ^{20}Ne to the experimental S-factor, that is well larger than the currently adopted extrapolations reported by NACRE. The presence of low-energy resonant contributions is in agreement with results of recent experiments with the Trojan Horse method. These findings could help to improve our knowledge of ^{19}F nucleosynthesis by reaction rate reassessments [28, 29].

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