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Modified r-matrix analysis of the ^{19}F$(p,\alpha)^{16}$O HOES reaction

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The ^{19}F$(p,\alpha)^{16}$O reaction is an important fluorine destruction channel in the proton-rich outer layers of asymptotic giant branch (AGB) stars and it might also play a role in hydrogen-deficient post-AGB star nucleosynthesis. So far, available direct measurements do not reach the energy region of astrophysical interest ($E_{cm} \sim 300$ keV), because of the hindrance effect of the Coulomb barrier. The Trojan Horse (TH) method was thus used to access this energy region, by extracting the quasi-free contribution of the ^{2}H(^{19}F,α^{16}O)n reaction. The TH measurement has been devoted to the study of the α_0 channel, which is the dominant one at such energies. It has shown the presence of resonant structures not observed in direct measurements that cause an increase of the reaction rate at astrophysical temperatures up to a factor of 1.7, with potential important consequences for stellar nucleosynthesis.

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1. Introduction

Fluorine is a key isotope for astrophysics as its abundance is used to probe hotly-debated nucleosynthesis scenarios, as it is very sensitive to the physical conditions within stars [1]. Three are the most likely environments where its production could have taken place in the Milky Way, namely ν-process just above the collapsing core of a Type II supernova [2], Wolf-Rayet stars [3] and in the convective zone generated by a thermal pulse in AGB stars [4]. Recently, fluorine overabundances have been observed in R-Coronae-Borealis stars by factors of $800-8000$ [5]. Such overabundances are evidence for the synthesis of fluorine in these hydrogen-deficient supergiants. In spite of its key importance, a thorough view of fluorine abundance and nucleosynthesis is not at hand yet.

Regarding AGB stars, which are considered the major contributors to the Galactic fluorine supply [6], the largest observed fluorine overabundances could not be explained with standard AGB models and required additional mixing [7]. A possible lack of proper accounting for C-bearing molecule (i.e., CH, CN, CO, and C2) contribution might provide an explanation in the case of Population II stars [8], providing a renormalization of the observed abundances, though the understanding of F production in the case of metal-poor AGB stars is far from satisfactory [1]. An alternative explanation could be given by a reassessment of the nuclear reaction rates intervening in fluorine production and destruction. Deep mixing phenomena in AGB stars can alter the stellar outer-layer isotopic composition due to proton capture nucleosynthesis at relatively low temperatures ($T_9 < 0.04$), affecting the transported material [9, 10, 11]. In this environment, the ^{19}F$(p,\alpha)^{16}$O reaction at $E_{cm} \sim 27-94$ keV (corresponding to the Gamow window [12]) would represent the main fluorine destruction channel, possibly modifying F surface abundance.

2. Extraction of the astrophysical S(E)-factor through the Trojan Horse Method

The ^{19}F$(p,\alpha)^{16}$O reaction has been investigated by applying the Trojan Horse Method to the ^{2}H(^{19}F,α^{16}O)n reaction [17], thus allowing to estimate the low-energy resonance contribution to the ^{19}F$(p,\alpha)^{16}$O S(E)-factor at astrophysical energies. Therefore, the γ_p and γ_{α_0} reduced widths were extracted from the ^{2}H(^{19}F,α^{16}O)n TH data by means of the modified R-matrix approach, as discussed in [17]. These parameters were then used to evaluate the resonance contribution to the on-energy-shell (OES) ^{19}F$(p,\alpha_0)^{16}$O astrophysical S(E)-factor, parametrized by standard R-matrix formulas. This is possible as in the modified R-matrix approach the same reduced widths appear as in the OES S(E)-factor, the only difference being the absence of any Coulomb or centrifugal penetration factor. The OES S(E)-factor calculated with the reduced widths γ_p and γ_{α_0} given in [17] is shown in Fig.1. Since the TH cross section provided the resonance contribution only, the non-resonant part of the S(E)-factor has been taken from [16]. The curve evaluated from the best fit parameters is demonstrated by the middle red line. The red band accounts for the errors introduced in the present calculations (statistical + normalization).

The main result of the present work is the estimate of the contribution of the 12.957 MeV ^{20}Ne level to the total astrophysical factor, as it is responsible of the resonance at 113 keV, well inside the energy range of astrophysical interest. Moreover, a lower limit has been established for the contribution of the 13.222, 13.224 and 13.226 MeV ^{20}Ne states, to satisfy the condition set by

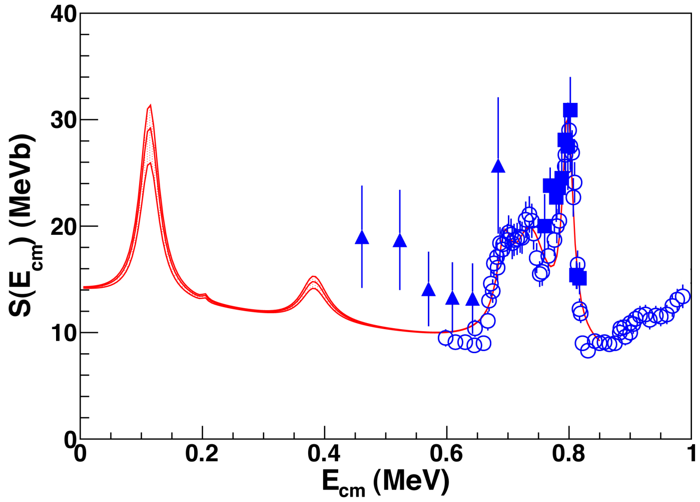

Figure 1: R-matrix parameterization of the $^{19}\mathrm{F}(p,\alpha_0)^{16}\mathrm{O}$ astrophysical factor. Above 0.6 MeV, the reduced partial widths are obtained through a R-matrix fit of the available direct data (open circles [13], blue squares [14], blue triangles [15]). Below 0.6 MeV, the resonance parameters are obtained from the modified R-matrix fit of the $\mathrm{d}^2\sigma/\mathrm{d}E_{cm}\mathrm{d}\Omega_n$ TH cross section, normalized to the direct data in the $0.6-0.9$ MeV range. The non-resonant contribution is taken from [16]. The best fit is demonstrated by the middle line, the red band highlighting the region allowed by the uncertainties (statistical + normalization) on the fitting parameters (compare [17]).

[18, 19, 20], namely the dominance of direct reaction mechanism in the $0.14-0.6$ MeV energy range. These levels yield resonances at ~ 0.4 MeV, thus their role is marginal at astrophysical energies (below 0.3 MeV).

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4. Acknowledgments

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