Direct measurement of the ^{19}F($p, \alpha\gamma$)^{16}O reaction in JUNA

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Abstract. The ^{19}F($p, \alpha\gamma$)^{16}O reaction is of crucial importance for Galactic ^{19}F abundances and CNO cycle loss in first generation Population III stars. Due to its extremely small cross sections, the ^{19}F($p, \alpha\gamma$)^{16}O reaction has not been measured in the low energy part of the Gamow window(70-200 keV). As a day-one campaign, the experiment was performed under the extremely low cosmic-ray-induced background environment of the China JinPing Underground Laboratory(CJPL), one of the deepest underground laboratories in the world. The γ-ray yields were measured over $E_{c.m.}$=72.4–344 keV, covering the full Gamow window for the first time. The direct experimental data will help people to expound the fluorine over-abundances, energy generation, as well as heavy-element nuclosynthesis scenario in asymptotic giant branch (AGB) stars, with the astrophysical model on the firm ground.

1 Introduction

Fluorine is one of the most interesting elements in nuclear astrophysics, its astrophysical origin is puzzling. ^{19}F can be produced in the convective zone triggered by a thermal pulse in asymptotic giant branch (AGB) stars [1, 2]. So far, however, the astronomically observed fluorine over-abundances cannot be understood by using current AGB models [3–6]. In AGB

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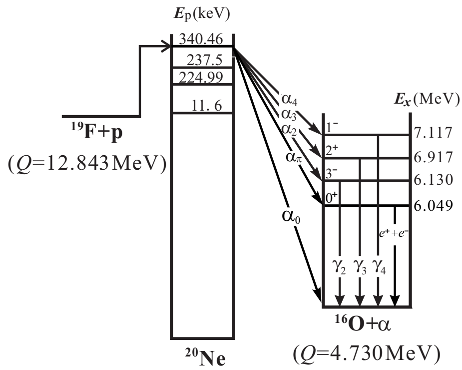

Figure 1. Level scheme of the ^{19}F$(p, \alpha)^{16}$O reaction. The total reaction rate is dominated by the (p, α_0) and $(p, \alpha\gamma)$ channel.

stars, ^{19}F is readily annihilated by hydrogen via the ^{19}F$(p, \alpha)^{16}$O reaction [3, 7, 8]. Given its importance, a precise and complete measurement of the total cross section appeared desirable. The ^{19}F$(p, \alpha)^{16}$O reaction occurs via three types of channels, i.e., (p, α_0), (p, α_π) and $(p, \alpha\gamma)$, as shown in Fig. 1. The total reaction rate is dominated by the (p, α_0) and $(p, \alpha\gamma)$ channel [3]. For the $(p, \alpha\gamma)$ channel, the energy range of $E_{c.m.} > 189$ keV has been studied which is much higher than the the low energy edge of the Gamow window(70-350 keV) [9, 10]. In this paper, we report on the progress of a direct measurement of the ^{19}F$(p, \alpha\gamma)^{16}$O reaction at Jinping Underground Nuclear Astrophysics experimental facility (JUNA). In the present work, the studies have been extended to $E_{c.m.}$=72.4-344 keV, the lowest to date. The results from present and previous work allow to calculate the reaction rates over a wide range of temperatures.

2 Experiment

The experiment was carried out on the JUNA accelerator at CJPL [11]. The experimental setup is similar to the one described in Ref. [2, 12]. The beam current was 1 mA for the low energy measurements. Two very strong and durable implanted ^{19}F targets were used [10, 12]. A 4π BGO detector array specially designed for the JUNA project [13] was equipped to detect the γ-rays, which was already used in previous work [12].

The γ-ray spectrum taken at a proton beam energy of E_p = 130 keV with the 4π BGO array was shown in Fig. 2. Two background peaks at 1460.8 keV (from ^{40}Ar) and 2614.5 keV (from ^{208}Tl) and the 6130 keV peak from the ^{19}F$(p,\alpha\gamma_2)^{16}$O reaction were used for energy calibration [2].

The γ-ray yield and hence the S Factors of the ^{19}F$(p,\alpha\gamma_2)^{16}$O reaction were determined by the integration of the 6130 keV peak of the spectrum(the red region in Fig. 2). The details can be found in Ref [2]. In conclusion, The present S Factors are much larger than the previous predictions. The thermonuclear ^{19}F$(p,\alpha\gamma_2)^{16}$O rate has been determined down to 0.05 GK

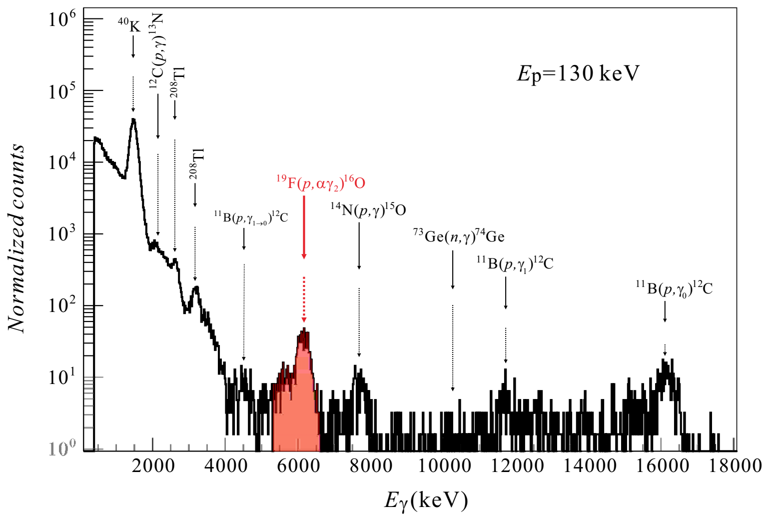

Figure 2. γ-ray spectrum of the ^{19}F+p experiments measured by a 4π BGO array at a proton energy of E_p = 130 keV [2].

and parameterized by the standard format of [14],

$$
\begin{aligned}
&N_A\langle\sigma v\rangle_{(p,\alpha\gamma)}\\
&= \exp(62.821 - \frac{0.022063}{T_9} - \frac{10.5347}{T_9^{1/3}} - 67.9612T_9^{1/3} + 50.592T_9 - 24.33T_9^{5/3} + 11.0325\ln T_9)\\
&+ \exp(30.5159 - \frac{0.097764}{T_9} + \frac{17.4599}{T_9^{1/3}} + 38.7519T_9^{1/3} - 134.383T_9 + 57.3453T_9^{5/3} + 37.5491\ln T_9)\\
&+ \exp(-18.6175 - \frac{0.349603}{T_9} + \frac{39.0245}{T_9^{1/3}} + 67.2527T_9^{1/3} - 116.029T_9 + 39.954T_9^{5/3} + 42.7072\ln T_9)\\
&+ \exp(-91.3551 - \frac{0.136527}{T_9} + \frac{0.16144}{T_9^{1/3}} + 21.6386T_9^{1/3} + 873.979T_9 - 1709.51T_9^{5/3} - 7.5102\ln T_9)
\end{aligned}
$$

with a fitting error of less than 1% over a temperature region of 0.01–1 GK [2].

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