Determination of the $^{17}F(p,\gamma)^{18}Ne$ reaction rate using the neutron transfer reaction $^{13}C(^{17}O,^{18}O)^{12}C$

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It is believed that the abundance of ^{18}F can be influenced by the $^{17}F(p,\gamma)^{18}Ne$ reaction. Its reaction rate at astrophysical energies has been determined for the first time through measurements of the ANCs in the mirror nuclear system. The peripheral $^{13}C(^{17}O,^{18}O)^{12}C$ reaction was performed using the MDM spectrometer. The elastic scattering for $^{17}O+^{13}C$ and $^{18}O+^{12}C$ were also measured to obtain the OMPs that give the best description of the input and exit channels of the $^{13}C(^{17}O,^{18}O)^{12}C$ reaction [1]. The radiative capture reaction $^{17}F(p,\gamma)^{18}Ne$ is dominated by the direct capture to the first and second 2^+ states in ^{18}Ne due to the $s_{1/2}$ component in their wave functions. The angular distributions for the transfer to the states $J^\pi = 0_1^+$, 2_1^+, 4_1^+, and 2_2^+ in ^{18}O are shown in Fig. 1. In our transfer calculations, the 2^+ states result

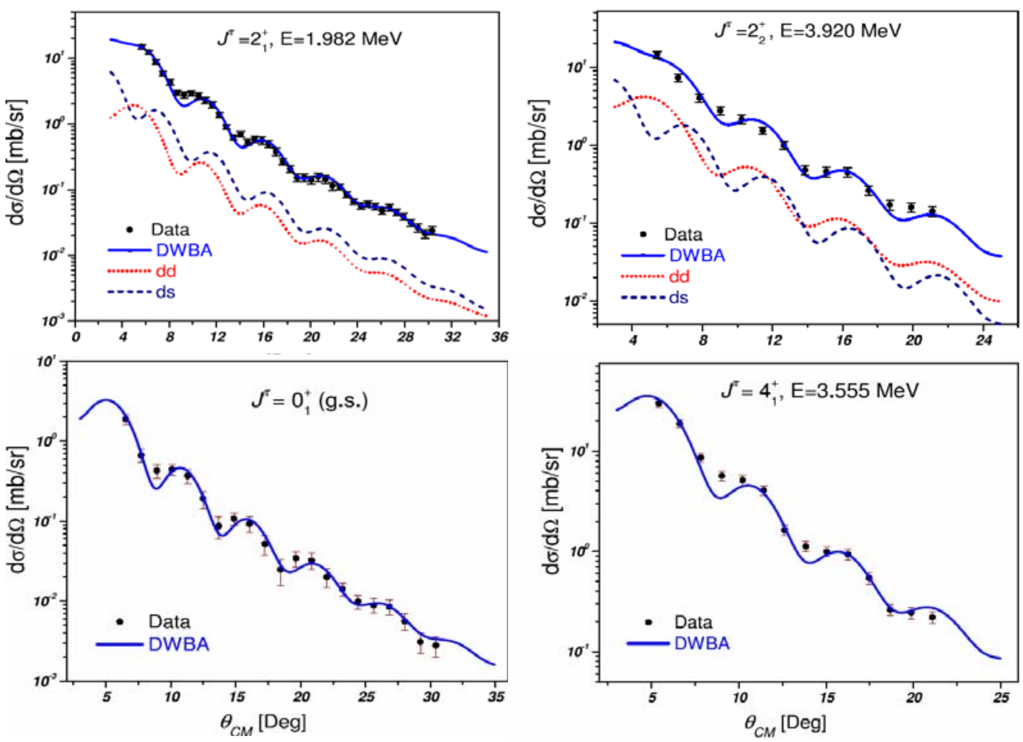

Figure 1. The angular distribution for the neutron transfer to the low-lying states in ^{18}O, $J^\pi = 0_1^+$, 2_1^+, 4_1^+, and 2_2^+, populated in the $^{13}C(^{17}O,^{18}O)^{12}C$ reaction. The solid lines represent the DWBA fit taking into account the shell model configurations for each state.

from the coupling of $1d_{5/2}$ or $2s_{1/2}$ neutron to the $d_{5/2}$ ground state of ^{17}O, while the 0_1^+ and 4_1^+ states can be obtained from adding a $1d_{5/2}$ neutron to the $1d_{5/2}$ core configuration. Therefore, the asymptotic normalization coefficients for each 2^+ state are obtained by

$$\frac{d\sigma}{d\Omega}=\frac{C_{p_{1/2}}^{2}\left({}^{13}\mathrm{C}\right)}{b_{p_{1/2}}^{2}\left({}^{13}\mathrm{C}\right)}\left\{C_{\frac{5}{2},\frac{5}{2}}^{2}\left({}^{18}\mathrm{O}\right)\frac{\sigma_{\frac{5}{2},\frac{5}{2}}^{\mathrm{DWBA}}}{b_{\frac{5}{2},\frac{5}{2}}^{2}\left({}^{18}\mathrm{O}\right)}+C_{\frac{5}{2},\frac{1}{2}}^{2}\left({}^{18}\mathrm{O}\right)\frac{\sigma_{\frac{5}{2},\frac{1}{2}}^{\mathrm{DWBA}}}{b_{\frac{5}{2},\frac{1}{2}}^{2}\left({}^{18}\mathrm{O}\right)}\right\}.$$

The ANCs for 0_1^+ and 4_1^+ are extracted using a similar relation, but without the second term on the right hand side. The ANCs are listed in Table I. The astrophysical *S*-factor calculations for each

Table I. The binding energies (B.E.) and the ANCs of the low-lying levels in ^{18}O and its mirror ^{18}Ne.

J^π	Proton Orbital	^{18}O B.E. [MeV]	^{18}O $C_{\ell j}^2$ [fm^{-1}]	^{18}Ne B.E. [MeV]	^{18}Ne $C_{\ell j}^2$ [fm^{-1}]
0_1^+	$d_{5/2}$	8.04	7.33 ± 0.73	3.92	10.76 ± 0.97
2_1^+	$d_{5/2}$	6.06	2.06 ± 0.21	2.04	2.17 ± 0.24
	$s_{1/2}$		6.55 ± 0.69		14.29 ± 1.71
4_1^+	$d_{5/2}$	4.48	1.05 ± 0.11	0.54	2.17 ± 0.22
2_2^+	$d_{5/2}$	4.12	0.49 ± 0.06	0.31	2.69 ± 0.32
	$s_{1/2}$		4.47 ± 0.54		127 ± 17

(ℓ, j) configuration of the table were done depending on their related ANCs, as shown in Fig. 2, where the *S* factors for the 2_1^+ and 2_2^+ states are the sum of their (*dd*) and (*ds*) components. The figure shows

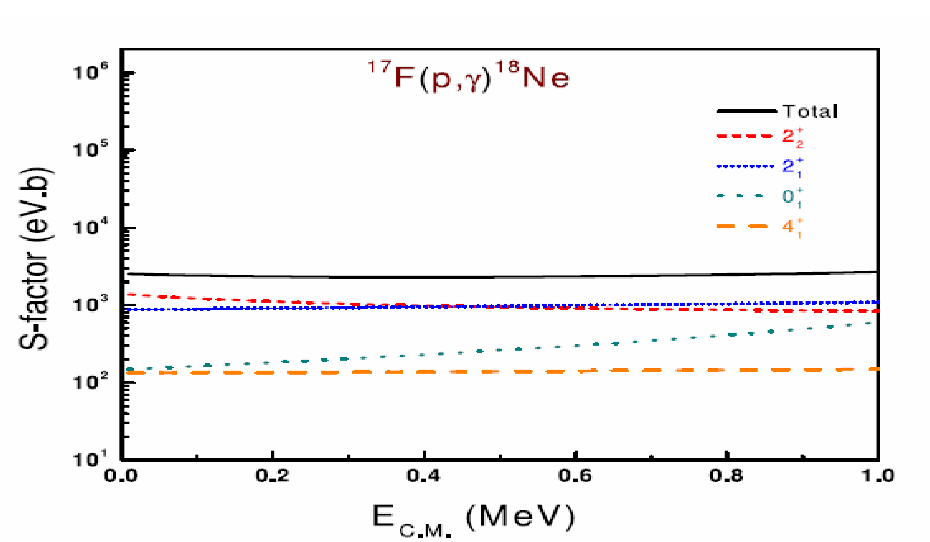

Figure 2. The *S*-factor components of the ^{17}F(p,γ)^{18}Ne reaction. *S(0)* of the $J^\pi = 2_2^+$ state makes the major contribution to the reaction rate, and it is almost 50% larger than the $J^\pi = 2_1^+$ contribution. The other components are one order of magnitude smaller than the major one. The total $S_{1\text{-}17}(0) = 2.5\pm0.4$ keVb..

that the transitions to these states dominate the direct capture reaction over the other contributions. We find $S_{1-17}(0) = 2.5 \pm 0.4$ keV b. The total direct capture rate is plotted in Fig. 3. The uncertainty in the reaction rate is related to the 20% overall uncertainty of the extracted ANCs. The resonant contribution through a proton capture to the resonance state $J^{\pi} = 3^{+}\left[E_r = 600 \text{ keV}, \Gamma_{\gamma} = (2.5 \pm 1.6) \times 10^{-5} \text{ keV}\right]$ [2] in ^{18}Ne is calculated and plotted in the same figure to compare it with the direct capture reaction rate. The present results show that the thermonuclear reaction rate is dominated by the direct capture component by a factor up to 10^4 over the resonant contribution for $T_9 = 0.2 - 0.4$. The resonant contribution is more significant for temperatures in excess of $T_9 \approx 0.5$ that characterize X-ray bursts or neutron stars.

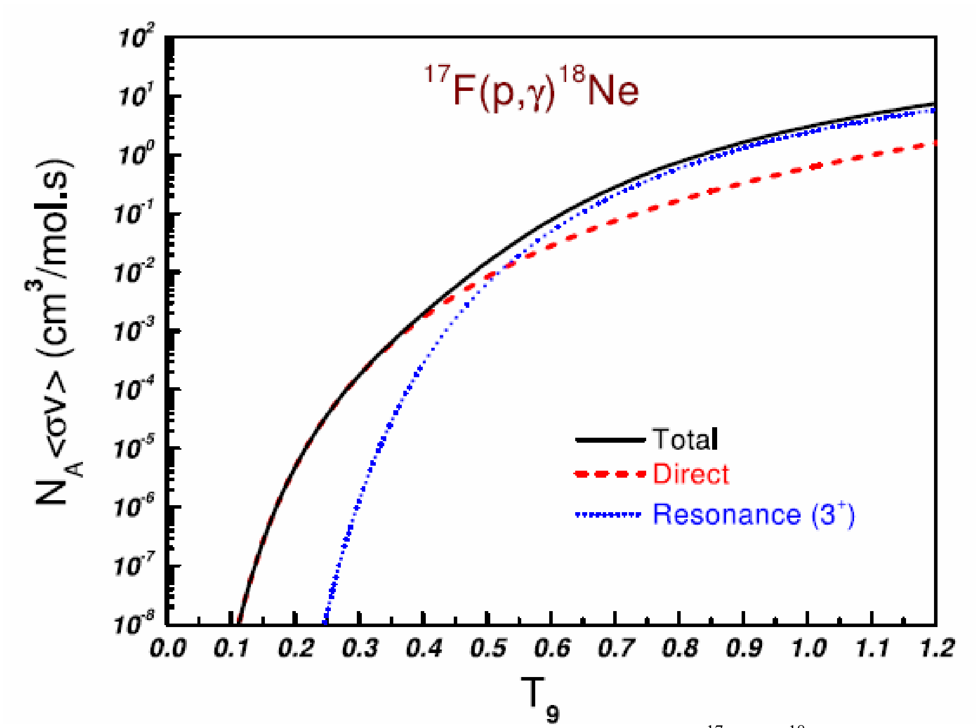

Figure 3. The (black) solid line represents the total rate for the ^{17}F(p,γ)^{18}Ne reaction. The direct capture reaction, (red) dashed line, is evaluated using the extracted ANCs for the low-lying levels in ^{18}Ne and the determined *S*-factors, while the (blue) dotted line shows the contribution from the resonant 3^+ state in ^{18}Ne.

[1] T. Al-Abdullah, *et al.*, *Progress in Research*, Cyclotron Institute, Texas A&M University (2005-2006), p. I-13.

[2] D. W. Bardayan, *et al.*, Phys. Rev. Lett. **83**, 45 (1999).

[3] A. Garcia, *et al.*, Phys. Rev. C **43**, 2012 (1991).