Astrophysical S-factor for ^{9}Be$(p,\gamma)^{10}$B

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The reaction ^{9}Be$(p,\gamma)^{10}$B plays an important role in primordial and stellar nucleosynthesis of light elements in the $1p$-shell [1, 3]. There are two previous measurements of the astrophysical factor $S(E)$ for this reaction at low energies [2, 3] and one measurement of the analyzing power [4]. The energy dependence of this capture reaction over the range important to nuclear astrophysics is quite complex because it includes contributions from direct capture and several resonances, and they interfere with each other. Even though near the resonance peaks the resonance terms dominate, the weight of the direct part turns out to be very important, especially as $E \to 0$ Furthermore, the ^{9}Be$(p,d)^8$Be and ^{9}Be$(p,\alpha)^6$Li channels are both open at threshold, complicating theoretical efforts to construct the low-energy ^{9}Be + p optical potential required to calculate the direct capture contribution. These effects have made a detailed understanding of $S(E)$ quite difficult.

Recently, as part of our program to determine the ^{7}Be$(p,\gamma)^8$B direct capture rate at stellar energies [5], we have measured the asymptotic normalization coefficients (ANC's) for the virtual decay of the ground and low-lying excited states of ^{10}B into the channel ^{9}Be + p [6]. The simple relationship between ANC's and direct capture rates that exists for ^{7}Be$(p,\gamma)^8$B is not applicable to direct capture in ^{9}Be$(p,\gamma)^{10}$B because of the relatively tight binding energy of the last proton in ^{10}B ($\varepsilon = 6.586$ MeV). Nonetheless, it is interesting to investigate how well one can predict the ^{9}Be$(p,\gamma)^{10}$B direct capture rate from the measured ANC's, in order to test the relationship between them under adverse circumstances.

The R-matrix approach relates a direct capture rate to a radial integral which is taken from the channel radius to ∞, so only the peripheral part of the channel overlap function is needed. The absolute normalization of the peripheral part of this overlap function is specified by the corresponding ANC [6] making the R-matrix method an appropriate tool for this test. We analyze the existing ^{9}Be$(p,\gamma)^{10}$B experimental data within the framework of the R-matrix method taking into account all four low-lying resonances in ^{10}B and the direct capture contribution. We find results that are comparable to those in [3, 4]. However, unlike [3, 4], our fit is also consistent with the ^{10}B resonance parameters that have been extracted from other complementary reaction studies such as reaction ^{6}Li$(\alpha,\gamma)^{10}$B. The best fit is found for a channel radius $r_0 = 3.1$ fm. The result of the fit is shown in Fig. 1. The parameters of the fit are taken from reference [7] except for the γ width of the first resonance which is from reference [8]. The calculated relative γ-ray branching ratios at $E =$ 83 keV are compared to previous measurements [2, 4] and calculations [4]. Our fit slightly overestimates the relative transition rate to the ground state and underestimates the relative transition rate to the first excited state. It agrees with experiment quite well for transitions to the second and third excited states. We note once more that the relative contributions of the direct transitions to the different bound states in our cal-

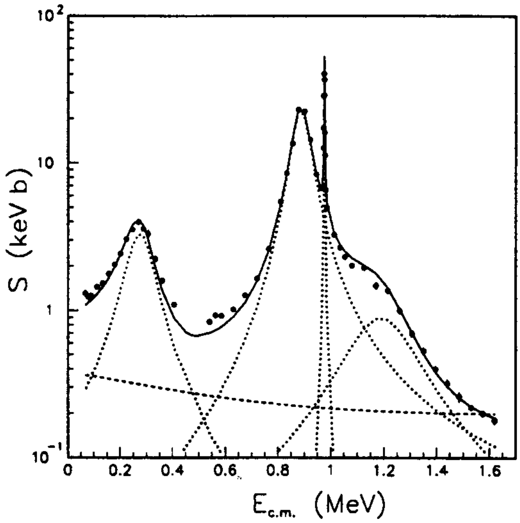

Figure 1: The $S(E)$-factor for the reaction ^{9}Be$(p,\gamma)^{10}$B, together with our fit $S(E)$ (solid curve), the direct capture part (dashed curve), and the four resonances (dotted curves).

culations are entirely determined by the ANC's extracted from the independent measurements of the ^{9}Be(^{10}B,^{9}Be)^{10}B reaction.

Using the fitted parameters from ^{9}Be$(p,\gamma)^{10}$B, we can calculate the cross section for ^{6}Li$(\alpha,\gamma)^{10}$B in the peak corresponding to the first resonance in ^{9}Be + p. We find $\sigma = 1.76\ \mu$b, in good agreement with experiment. The width of this resonance is $\Gamma_1 = 140$ keV, which coincides with the apparent width extracted from the (p,γ) excitation function and is close to that inferred from the (α,γ) excitation function. Thus, our fit gives reasonable agreement with the data from both radiative capture reactions simultaneously. Our results demonstrate that the ANC approach, coupled to the R-matrix method, can provide a reasonable determination of direct radiative capture rates, even when the captured proton is tightly bound in the final nuclear state.

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