Low-energy ^{7}Li$(n,\gamma_0)^8$Li and ^{7}Li$(p,\gamma_0)^8$Be cross sections

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(Received 3 September 1996)

The lack of p-wave strength in a recent measurement of the low-energy ^{7}Li$(n,\gamma_0)^8$Li cross section, as compared with significant strength found in the ^{7}Li$(p,\gamma_0)^8$Be reaction, may be attributed to the qualitatively different low-energy behaviors of penetration factors for neutron and charged-particle channels. [S0556-2813(97)05001-2]

PACS number(s): 25.40.Lw, 27.20.+n

Blackmon *et al.* [1] recently measured the ^{7}Li$(n,\gamma_0)^8$Li cross section for $E_n = 1.5-1340$ eV, in part to look for evidence of p-wave contributions. They found none. Earlier a ^{7}Li$(p,\gamma_0)^8$Be measurement by Chasteler *et al.* [2] at $E_p = 70$ keV had indicated substantial p-wave strength, of uncertain origin. Chasteler *et al.* pointed out that such strength could significantly reduce the zero-energy astrophysical S factor obtained by assuming pure s waves, and that a similar phenomenon might be present in the ^{7}Be$(p,\gamma)^8$B reaction, which is of importance in the solar neutrino problem and to which ^{7}Li$(n,\gamma_0)^8$Li is the mirror reaction. Here we show that the difference in the observed low-energy p-wave strengths may be attributed to the qualitatively different low-energy behaviors of penetration factors for neutron and charged-particle channels.

The ℓ-wave contributions to the low-energy cross sections for the three reactions ^{7}Li$(n,\gamma_0)^8$Li, ^{7}Li$(p,\gamma_0)^8$Be, and ^{7}Be$(p,\gamma)^8$B are proportional to the penetration factors P_ℓ in the initial channels ^{7}Li + n, ^{7}Li + p and ^{7}Be + p, respectively. We are particularly interested in the ratio P_1/P_0. For the charged-particle channels, the low-energy penetration factors are determined mainly by the Coulomb potential, which extends to larger distances than either the centrifugal potential or the nuclear interaction. Since the Coulomb potential is ℓ independent, the ratio of the P_ℓ for different ℓ values tends to a constant as the energy tends to zero. With the penetration factor defined as in R-matrix theory [3],

$$P_\ell = \rho/(F_\ell^2 + G_\ell^2),$$

where F_ℓ and G_ℓ are the regular and irregular Coulomb functions evaluated at the channel radius a, and $\rho = ka$, the formulas in Ref. [4] lead to

$$[P_\ell/P_{\ell-1}]_{E=0} = [K_{2\ell-1}(x)/K_{2\ell+1}(x)]^2,$$

where $K_n(x)$ is a Bessel function [5] and $x = (8\rho\eta)^{1/2}$, with η the Sommerfeld parameter. For neutron channels, however, the ℓ-dependent centrifugal potential dominates at large distances, and at low energies one has

$$P_\ell/P_{\ell-1} = \rho^2/(2\ell-1)^2,$$

which tends to zero as E tends to zero.

For the conventional value of the channel radius, $a = 1.45(7^{1/3}+1)$ fm$=4.22$ fm, the ratio P_1/P_0 has the zero-energy values 0.034 and 0.048 for ^{7}Li$+p$ and ^{7}Be$+p$, respectively, and increases with energy. For ^{7}Li + n, P_1/P_0 has the values 1.2×10^{-6} and 4.7×10^{-4} at $E_n = 1.78$ eV and 721 eV, the average energies for the extreme bins in the measurement of Blackmon *et al.* [1].

Chasteler *et al.* [2] obtained fits to their ^{7}Li$(p,\gamma_0)^8$Be data with (18–95)% p-wave strength and found that these could reduce the zero-energy S factor by (7–38)%. By attributing the p-wave strength to the tails of known 1^+ levels of ^{8}Be, Barker [6] found acceptable fits to the data of Chasteler *et al.* with $\lesssim 9\%$ p-wave strength. Suppose that there were appreciable p-wave strength in ^{7}Li$(p,\gamma_0)^8$Be, say 10%. If all relevant quantities except penetration factors are assumed the same for ^{7}Li$(n,\gamma_0)^8$Li as for ^{7}Li$(p,\gamma_0)^8$Be, then the different values of the ratio P_1/P_0 would imply p-wave strengths in ^{7}Li$(n,\gamma_0)^8$Li of 3.8×10^{-4}% and 0.15% at 1.78 and 721 eV, respectively. The uncertainties in the measurement of Blackmon *et al.* [1] are, however, only sufficient to limit the p-wave strength to less than about 30%. Similarly, this measurement would not impose any significant restriction on possible low-energy p-wave strength in the ^{7}Be$(p,\gamma)^8$B reaction.

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