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Microscopic Study of the ^{6}Li(p, α)^{3}He Reaction at Low Energies

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Abstract. The ^{6}Li(p, α)^{3}He reaction important for nuclear astrophysics is studied in the framework of a microscopic approach based on a multichannel algebraic version of the resonating group model. Astrophysical *S*-factor for the reaction is calculated at low energies. The obtained result is compared with experimental data and other theoretical calculations.

1 Introduction

Reactions responsible for production and destruction of lithium isotopes are of great interest to nuclear astrophysics [1, 2]. Cross sections (astrophysical *S*-factors) for these reactions at low energies are required for understanding Big Bang nucleosynthesis and for solving, in particular, so-called "lithium depletion" problem in galactic stars including the Sun. Experimental measurements of these cross sections at astrophysically important energies as a rule meet principal difficulties due to the sizeable Coulomb barrier. That is why theoretical calculations based on microscopic approaches become a very important source of knowledge of these cross sections.

The aim of the present work is to calculate the ^{6}Li(p, α)^{3}He astrophysical *S*-factor at low energies, using a multichannel algebraic version of the resonating group model (AVRGM) [3]. This reaction plays an important role in nuclear astrophysics as the process of the ^{6}Li nuclei destruction during the primordial and stellar nucleosynthesis.

2 Brief description of the multichannel AVRGM

In the framework of the multichannel AVRGM, the total wave function of a system considered is written in the form of an expansion [4]

$$\Psi = \sum_{J^\pi M i l_i s_i \nu_i} C^{(i)}_{J^\pi M l_i s_i \nu_i} \Psi^{(i)}_{J^\pi M l_i s_i \nu_i} \tag{1}$$

in series of the AVRGM basis functions

$$\Psi^{(i)}_{J^\pi M l_i s_i \nu_i} = \mathrm{A}\left\{ \sum_{m_i+\sigma_i=M} C^{JM}_{l_i m_i\ s_i \sigma_i} \left[\varphi^{(1)_i}_{s_{1i}} \varphi^{(2)_i}_{s_{2i}} \right]_{s_i \sigma_i} f_{\nu_i l_i m_i}(\mathbf{q}_i) \right\}. \tag{2}$$

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Here A is the antisymmetrization operator; i is the number of the cluster channel characterized by the specified cluster structure (all the channels are assumed to be two-cluster ones); l_i, s_i, m_i, and σ_i are respectively the relative orbital momentum, the channel spin, and their projections in the ith cluster channel; J, M, and π are the total angular momentum, its projection, and the parity respectively (they are integrals of the motion and have identical values for all the cluster channels); $\varphi^{(1)_i}_{s_{1i}\sigma_{1i}}$ and $\varphi^{(2)_i}_{s_{2i}\sigma_{2i}}$ are respectively the internal wave functions for the first $(1)_i$ and second $(2)_i$ clusters with spins s_{1i}, s_{2i} and their projections σ_{1i}, σ_{2i} in the ith channel (these functions are assumed to be fixed and are chosen, as a rule, in the form of the translationally invariant oscillator shell model wave functions for the lowest states compatible with the Pauli exclusion principle); $C^{JM}_{lm\,s\sigma}$ is the Clebsch–Gordan coefficient; $f_{\nu lm}(\mathbf{q})$ is the oscillator function, ν is the number of oscillator quanta, $\mathbf{q}$ is the Jacobi vector.

Unknown quantities in the AVRGM approach are the expansion coefficients $C^{(i)}_{J^\pi M l_i s_i \nu_i}$ of the total wave function (1) over AVRGM basis functions (2). These coefficients for an expansion of a continuum wave function are found by solving a set of linear inhomogeneous algebraic equations, so-called the AVRGM equations set for continuum [4]. The solution of this set gives not only expansion coefficients but also elements of the scattering matrix $S^{J^\pi}(E_{\text{c.m.}})$ (S-matrix), which are required to calculate cross section for a transfer reaction

$$\sigma_{i\to f}(E_{\text{c.m.}}) = \frac{\pi}{k^2}\sum_{J^\pi}\frac{2J+1}{(2s_1+1)(2s_2+1)}\sum_{l_i l_f s_i s_f}\left|S^{J^\pi}_{f l_f s_f, i l_i s_i}(E_{\text{c.m.}})\right|^2, \qquad (3)$$

where indices i and f denote the initial and final channels of the reaction respectively; s_1 and s_2 are the spins of the colliding nuclei in the entrance channel, k and $E_{\text{c.m.}}$ are the wave number and the energy of their relative motion in the center-of-mass system respectively.

3 Discussion of the results. Conclusions

The present study of the ^{6}Li(p, α)^{3}He reaction is first of all a benchmark for the implemented approach based on the multichannel AVRGM. It allows to demonstrate capability of the approach to describe charged-particle induced reactions involving p-shell nuclei. Two cluster configurations ^{6}Li + p and α + ^{3}He were adopted in the calculations. Consideration of the reaction at low energies makes possible to be restricted only to the s-waves in the entrance channel ^{6}Li + p.

The astrophysical S-factor for the ^{6}Li(p, α)^{3}He reaction calculated within the multichannel AVRGM, using the modified Hasegawa–Nagata potential [5] for description of nuclear interaction, is shown in Fig. 1 by solid line. Symbols in Fig. 1 are the experimental data (see [2] for references and [6–8]). The obtained result is seen to be in a reasonable enough agreement with the data. The calculation was performed without including any screening effects. That is why the energy behavior of the calculated astrophysical S-factor somewhat differs qualitatively from that of the experimental data below 100 keV, which are affected by the electron screening effects in this energy range [6] and consequently have values larger than those of the calculation at very low energies.

It should be noted that the ^{6}Li(p, α)^{3}He reaction was already considered on the basis of microscopic approaches, for example, in works [9, 10] (see Fig. 1 for curves). The former provides the RGM description of the considered reaction (dashed line) while the latter is based on a three-cluster model (dash-dotted line). In both the works, the Minnesota potential [11] as central part and the Reichstein–Tang spin-orbit interaction [12] as noncentral component of nuclear forces were utilized.

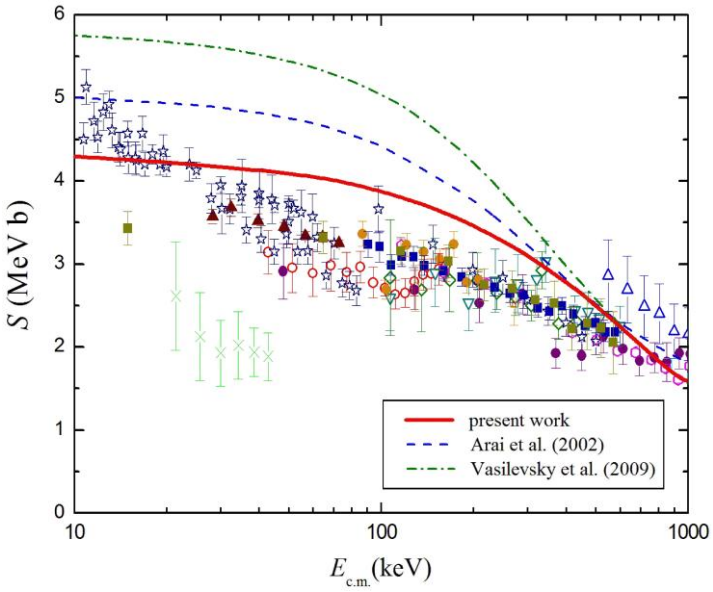

Fig. 1. Energy dependence of astrophysical *S*-factor for the ^{6}Li(p, α)^{3}He reaction.

The screening effects are also not included in the calculations [9, 10]. The results of these works qualitatively agree with each other and with ours but all three calculations differ quantitatively from each other at low energies. The calculation [10] gives the largest overestimation of the data compared to the others.

There are several ways to improve our study: using more complicated internal cluster wave functions, taking into account more cluster channels, inclusion of the screening effects, consideration of high energy range covering the resonance observed in the data near 1.6 MeV [2], etc. Most likely, these improvements will allow to refine the implemented AVRGM approach and to increase reliability of the obtained theoretical results.

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References

1. E.G. Adelberger, A. García, R.G.H. Robertson et al., Rev. Mod. Phys. **83**, 195 (2011)
2. Y. Xu, K. Takahashi, S. Goriely et al., Nucl. Phys. A **918**, 61 (2013)
3. G.F. Filippov, I.P. Okhrimenko, Phys. Atom. Nucl. **32**, 480 (1980)
4. S.Yu. Igashov, Bull. Russ. Acad. Sci.: Phys. **65**, 817 (2001)
5. H. Kanada, T. Kaneko, S. Nagata, M. Nomoto, Prog. Theor. Phys. **61**, 1327 (1979)
6. S. Engstler, G. Raimann, C. Angulo et al., Z. Phys. A **342**, 471 (1992)
7. L. Lamia, C. Spitaleri, R.G. Pizzone et al., Astrophys. J. **768**, 1 (2013)
8. J.J. He, S.Z. Chen, C.E. Rolfs et al., Phys. Lett. B **725**, 287 (2013)
9. K. Arai, D. Baye, P. Descouvemont, Nucl. Phys. A **699**, 963 (2002)
10. V.S. Vasilevsky, F. Arickx, J. Broeckhove, T.P. Kovalenko, Nucl. Phys. A **824**, 37 (2009)
11. D.R. Thompson, M. LeMere, Y.C. Tang, Nucl. Phys. A **286**, 53 (1977)
12. I. Reichstein, Y.C. Tang, Nucl. Phys. A **158**, 529 (1970)