

The ${}^3\text{H}(\alpha, \gamma){}^7\text{Li}$ and ${}^3\text{He}(\alpha, \gamma){}^7\text{Be}$ Radiative Capture Reactions in a Wide Energy Range

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Abstract. The mirror ${}^3\text{H}(\alpha, \gamma){}^7\text{Li}$ and ${}^3\text{He}(\alpha, \gamma){}^7\text{Be}$ reactions are considered from the microscopic viewpoint within a developed approach based on the multiscale algebraic version of the resonating group model. The total astrophysical S factors and the branching ratios for these reactions are calculated at low and intermediate energies covering the lowest resonances of the final fused nuclei. The results from the calculations are in an agreement with data from experiments.

1 Introduction

The ${}^3\text{H}(\alpha, \gamma){}^7\text{Li}$ and ${}^3\text{He}(\alpha, \gamma){}^7\text{Be}$ mirror radiative capture reactions have a great importance for astrophysical applications. In particular, both reactions are of interest to study Big Bang nucleosynthesis. The latter reaction is also important to study stellar nucleosynthesis, especially in the Sun. Despite a long story of experimental and theoretical investigations of these reactions (see references cited in works [1, 2]), the required precision has not been achieved yet. As a result, the problems still remain.

The aim of the present work is to demonstrate the energy dependences of the total astrophysical S factors and the branching ratios R obtained for the considered reactions in a wide energy range from a microscopic approach based on the multiscale algebraic version of the resonating group model (AVRGM). This approach was proposed in Ref. [1] and developed in Ref. [2].

2 Results

Formalism and details of the multiscale AVRGM approach can be found in work [1]. In order to describe the nuclear interaction, the modified Hasegawa–Nagata potential is used [3]. The intensities of the central Majorana force g_c and the spin-orbit interaction g_{ls} involved in this potential as adjustable parameters are equal to 0.977 and 3.469 respectively. These values were set to describe nuclear phase shifts of elastic scattering in the entrance channels of the reactions [2].

The total astrophysical S factor and the branching ratio R are defined by

$$S(E_{c.m.}) = E_{c.m.} \exp\left(\sqrt{E_G / E_{c.m.}}\right) \sigma(E_{c.m.}), \quad (1)$$

$$R(E_{c.m.}) = \sigma_1(E_{c.m.}) / \sigma_0(E_{c.m.}), \quad (2)$$

where E_G is the Gamow energy of the colliding nuclei, $E_{c.m.}$ is their relative energy in the center-of-mass system, σ_0 and σ_1 are the total cross sections related to the captures to the ground and first excited states of the final nucleus respectively, and σ is the total cross section of the reaction [2].

2.1 The ${}^3\text{He}(\alpha, \gamma){}^7\text{Be}$ total astrophysical S factor and branching ratio

The total astrophysical S factor calculated for the ${}^3\text{He}(\alpha, \gamma){}^7\text{Be}$ radiative capture within the multiscale AVRGM approach is shown in Fig. 1. References to experimental data denoted by the symbols in this figure are given in Ref. [2].

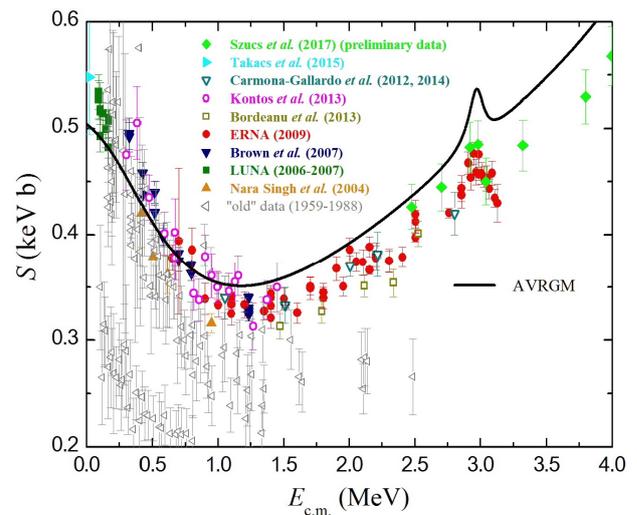


Fig. 1. Energy dependence of the ${}^3\text{He}(\alpha, \gamma){}^7\text{Be}$ total astrophysical S factor.

The obtained curve agrees reasonably well with the modern data up to vicinity of the $7/2^-$ resonance. The calculation reproduces the position of this resonance

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(2.98 MeV) but the calculated values of the astrophysical S factor in vicinity of the corresponding peak are slightly overestimated compared to the experimental ones.

The ${}^3\text{He}(\alpha, \gamma){}^7\text{Be}$ branching ratio from the multiscale AVRGM approach is drawn in Fig. 2. The presented curve agrees adequately with the data. These data were extracted from direct measurements only.

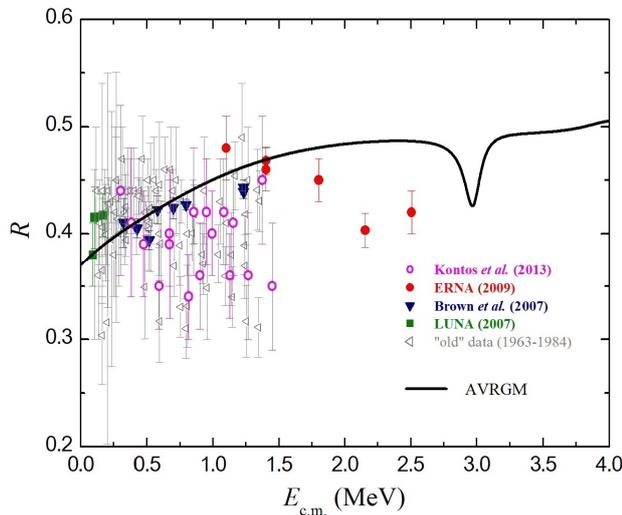


Fig. 2. Energy dependence of the ${}^3\text{He}(\alpha, \gamma){}^7\text{Be}$ branching ratio.

2.2 The ${}^3\text{H}(\alpha, \gamma){}^7\text{Li}$ total astrophysical S factor and branching ratio

For the ${}^3\text{H}(\alpha, \gamma){}^7\text{Li}$ radiative capture, the total astrophysical S factor and the branching ratio obtained in the framework of the multiscale AVRGM approach are depicted in Fig. 3 and Fig. 4 respectively. Experimental data are also marked in these figures (see Ref. [2] for references). The calculated curves are in a very good agreement with the data [4] in the whole energy range. The obtained $7/2^-$ resonance position (2.11 MeV) is also very close to its experimental value (2.18 MeV). Unfortunately, experimental data on the ${}^3\text{H}(\alpha, \gamma){}^7\text{Li}$ total astrophysical S factor in vicinity of the peak corresponding to the $7/2^-$ resonance are quite absent.

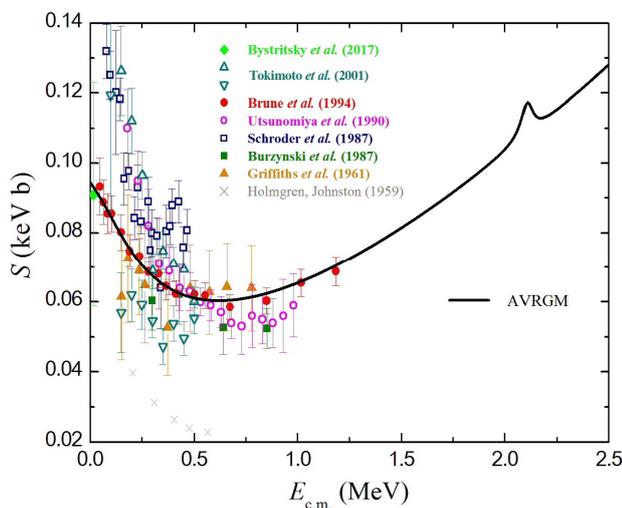


Fig. 3. Energy dependence of the ${}^3\text{H}(\alpha, \gamma){}^7\text{Li}$ total astrophysical S factor.

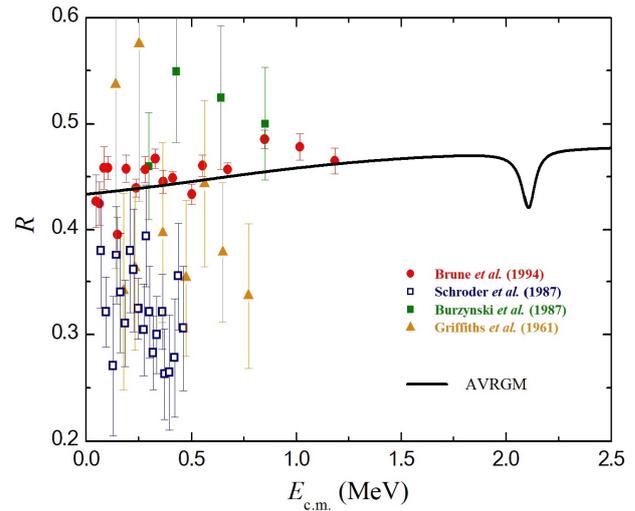


Fig. 4. Energy dependence of the ${}^3\text{H}(\alpha, \gamma){}^7\text{Li}$ branching ratio.

3 Conclusions

The multiscale AVRGM approach enables one to describe a wide enough set of the data on the mirror ${}^3\text{H}(\alpha, \gamma){}^7\text{Li}$ and ${}^3\text{He}(\alpha, \gamma){}^7\text{Be}$ reactions simultaneously in the unified way. In particular, the energy dependences of the calculated total astrophysical S factors and the branching ratios for both reactions agree with the data well. Moreover, the calculated nuclear phase shifts for the elastic scattering in the entrance channels of the reactions together with the calculated electromagnetic properties of the final fused nuclei are in a good correspondence with data extracted from experiments (see Ref. [2] for details).

On the whole, the presented curves cover a wide enough energy region, including the lowest $7/2^-$ resonances of the ${}^7\text{Li}$ and ${}^7\text{Be}$ nuclei. In the calculations, all allowed E1, E2, and M1 transitions from the partial s , p , d , and f waves of the entrance channels of the reactions to the ground and first excited states of the final nuclei were taken into account. Undoubtedly, the E1 captures play the dominating role at all considered energies. However, the peaks in the energy dependences of the total astrophysical S factors are caused by the E2 transition from the $7/2^-$ partial f wave to the final ground state. The M1 transitions turn out to be negligible.

Finally, the approach capabilities demonstrated in this work for ${}^3\text{H}(\alpha, \gamma){}^7\text{Li}$ and ${}^3\text{He}(\alpha, \gamma){}^7\text{Be}$ could be considered as the essential reasons for further development and applications of this approach.

References

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