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# Exchange effects in the radiative capture reactions $^3$H$(\alpha,\gamma)^7$Li and $^3$He$(\alpha,\gamma)^7$Be

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**Abstract**

The mirror $^3$H$(\alpha,\gamma)^7$Li and $^3$He$(\alpha,\gamma)^7$Be reactions have been considered using the algebraic versions of the resonating group model and of the orthogonality conditions model. Exchange effects in interaction of the colliding nuclei and influence of the corresponding exchange terms in matrix elements of the interaction potential on calculated astrophysical $S$-factors for the reactions have been studied.

At the present time one of the most important aims of nuclear reaction theory is to build so called *ab initio* approaches to description of nuclear reactions, which use realistic NN-potentials and exactly account for all exchange effects caused by the antisymmetry of a wave function of nuclear system. Such approaches are in continuous progress but, nevertheless, turn out to be very complicated procedures, which are, in fact, unrealizable for sufficiently heavy colliding nuclei. Though, there are alternative approaches suitable for heavier systems. They are based on the resonating group model (RGM) [1] or its algebraic version (AVRGM) [2] with effective NN-potentials and, as above mentioned approaches, rigorously allow for the exchange effects. However, complexities rapidly grow even in such approaches at increasing system mass. Thus, a development of reliable approximations within the existing microscopic approaches is rather topical problem of nuclear reaction theory. Such approximations will allow to simplify the calculations significantly and even to make ones realizable for sufficiently complicated systems.

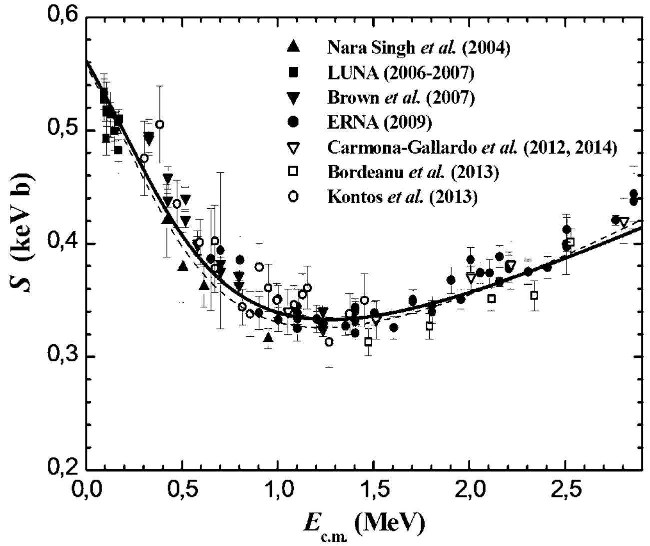

Figure 1: Astrophysical $S$-factor for the $^3\mathrm{He}(\alpha,\gamma)^7\mathrm{Be}$ reaction.

One of approximations originating from the RGM consists in the exchange term neglect in the matrix elements of Coulomb and nuclear potentials of microscopic Hamiltonian. The approximation based on such simplified treatment of the exchange effects is known as the orthogonality conditions model (OCM) [3]. The same assumption done in the framework of the AVRGM leads to the algebraic version of the OCM (AVOCM) [4]. So, the main aim of the present work is to study the role of the discussed exchange effects in the radiative capture reactions $^3\mathrm{H}(\alpha,\gamma)^7\mathrm{Li}$ and $^3\mathrm{He}(\alpha,\gamma)^7\mathrm{Be}$ using the AVRGM and the AVOCM, as well as to consider a possibility of the exchange term neglect at the radiative capture description.

It should be noted, that radiative capture reactions at low energies play very significant role in nuclear astrophysics [5]. It is a reason for permanent interest to this type of reactions, in general, and to the $^3\mathrm{H}(\alpha,\gamma)^7\mathrm{Li}$ and $^3\mathrm{He}(\alpha,\gamma)^7\mathrm{Be}$ reactions, in particular.

Availability of the AVRGM to description of energy dependence of astrophysical $S$-factors for the radiative capture reactions as well as its high efficiency were demonstrated in [6, 7]. All details of the model, which are necessary for the calculations, can be found in [2, 6, 7]. Details of the AVOCM are presented in [4]. It should be emphasized, that in the AVOCM exchange terms connected only with the permutations of nucleons between different clusters are neglected in the matrix elements of interaction poten-

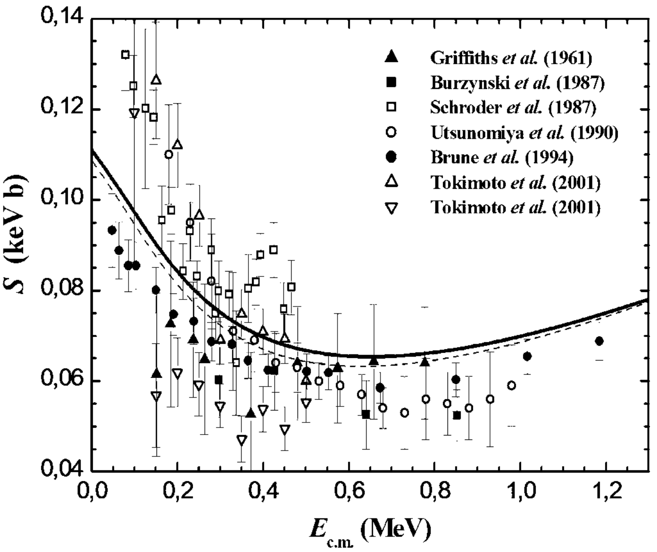

Figure 2: Astrophysical $S$-factor for the $^3\mathrm{H}(\alpha,\gamma)^7\mathrm{Li}$ reaction.

tial only. At the same time, all exchange terms are taken into consideration in matrix elements of all other operators (exchange normalization kernel, kinetic energy, *etc*). This character feature distinguishes the AVOCM from the potential cluster model that excludes all exchange terms.

Astrophysical $S$-factor for reaction induced by charged particles is related to cross section $\sigma$ in the following conventional way

$$S(E_{\mathrm{c.m.}}) = E_{\mathrm{c.m.}}\,\sigma(E_{\mathrm{c.m.}})\exp(2\pi\eta), \tag{1}$$

where $E_{\mathrm{c.m.}}$ is the relative motion energy of colliding nuclei in center-of-mass system, $\eta$ is Coulomb parameter. At sub-barrier energies the behavior of astrophysical $S$-factor looks smoother than cross section and, therefore, is more suitable for the analysis. Astrophysical $S$-factors for the mirror $^3\mathrm{He}(\alpha,\gamma)^7\mathrm{Be}$ and $^3\mathrm{H}(\alpha,\gamma)^7\mathrm{Li}$ reactions are shown in figs. 1 and 2 respectively. Solid lines are the AVRGM-calculation including all exchange terms. Curves obtained by the AVRGM-calculation without the Coulomb exchange terms practically coincide with the solid curves in the figs. Dashed lines are the AVRGM-calculation without the nuclear exchange terms. Curves calculated within approach combining the AVRGM and the AVOCM, *i.e.* without the exchange terms, simultaneously, in matrix elements of the Coulomb and nuclear interactions between colliding nuclei, almost do not differ from dashed lines in the figs. Only two adjustable parameters were used in the calculations. The first one is intensity of the central Majorana forces $g_{\mathrm{c}}$ entering into the modified Hasegawa–Nagata potential [8] employed to describe nuclear interaction. The second one is oscillator radius $r_0$ involved in the internal wave functions of the colliding clusters, which are chosen in form of the translationally invariant oscillator shell model lowest states eigenfunctions compatible with the Pauli exclusion principle. All the calculations are performed with the unified set of the parameter values: $r_0 =$ 1.22 fm, $g_{\mathrm{c}} = 1.035$. As it can be seen from the figs. 1 and 2, all curves are in good agreement with the experimental data (see refs. cited in [6, 7]).

Thus, the nuclear exchange terms affect the energy dependence of the astrophysical $S$-factors stronger than the Coulomb ones. For example, the nuclear exchange term neglect slightly decreases values of the astrophysical $S$-factors for the $^3\mathrm{H}(\alpha,\gamma)^7\mathrm{Li}$ and $^3\mathrm{He}(\alpha,\gamma)^7\mathrm{Be}$ reactions at low energies. But influence of the exchange matrix elements of the Coulomb and nuclear interactions between the colliding nuclei on the form of the curves, as a whole, turns out to be unessential enough. Consequently, approximations typical for the AVOCM allow to describe the radiative capture reactions and it makes opportunities for further applications of this model to perform calculations in the case of more complicated systems, when fully microscopic approaches become unrealizable at all.

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