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*Afanasyeva N.V., Burkova N.A., Jumasheva A.B., Yerzhanova A.M.

Physical-Technical department, al-Farabi Kazakh National University, Almaty, Kazakhstan
*e-mail: n.v.afanasyeva@gmail.com

Cluster analogies for nuclei with a=6, 7, 9

Abstract. The systematization of cluster analogies for nuclei with A=6, 7, 9 is given. The isobar ^{6}He – ^{6}Li – ^{6}Be triplets and ^{7}Li–^{7}Be doublet have been considered. The total cross-sections of neutrons radiative capture in channels ^{6}Be (n, $\gamma_{0,1}$)^7 Be with transition to both the ground and the first excited states of ^{7} Be nucleus have been calculated at ultralow astrophysical energies ($E_{cm} \geq 1$ MeV). On the basis of obtained results for the total cross-sections the corresponding reaction yields for ^{6}Be (n, $\gamma_{0,1}$)^7 Be process have been calculated. All these calculations have been done with taking into account $\{\alpha pp\}$ configuration of ^{6}Be in a three-body model with realistic nuclear forces. The obtained theoretical data for ^{6}Be (n, $\gamma_{0,1}$)^7 Be reaction have been compared with corresponding data for ^{6}Li (n, $\gamma_{0,1}$)^7 Li process.

Key words: cluster model, astrophysical applications, cluster channels, radiative neutron channel, reaction rates.

Introduction

The idea of "cluster analogies" can be explained more transparently by comparison of deuteron with ^{6}Li nucleus in the binary $\{\tau t\}$ cluster representation, where ^{3}He is associated with *heavy* proton, but ^{3}H is associated with *heavy* neutron. Within this analogy the energy dependence of $\Sigma(E_\gamma;90^0)$ asymmetry of secondary particles angular distribution in $d(\vec{\gamma},p)n$ and $^6\mathrm{Li}(\vec{\gamma},\tau)t$ processes of photodisintegration by linearly polarized photons can be predicted and explained, and it was confirmed experimentally.

Another variant of analogies is *isobar* analogies. In [1,2] within the dynamic potential cluster model the investigation and comparative analysis of characteristics of the photonucleon channels for ^{7}Li and ^{7}Be nuclei such as ^{6}Li+n→^{7}Li+γ, ^{6}He+p→^{7}Li+γ, ^{6}Be+n→^{7}Be+γ, ^{6}Li+p→^{7}Be+γ, have been performed. These channels are interesting due to the several reasons: first of all these channels are isobar-analogous, and investigation of isobar-analogous nuclei (in our case ^{6}He–^{6}Li–^{6}Be, ^{7}Li–^{7}Be) is of interest from the point of view of charge independence of nuclear forces. In addition, within the isobar multiplets some features of the nuclei structure can be revealed [3].

Structural analogies can be retraced by using the methods of the dynamic potential cluster model in the case of investigation of ^{6}Li(n,γ)^{7}Li, ^{6}He(p,γ)^{7}Li and ^{8}Li(p,γ)^{9}Be photonucleon reactions in the region of low and ultralow energies ($E_{cm} \leq 1$ MeV). Also one should mention the role of these reactions in context of evaluation of their contribution in the elements synthesis problem solving in the case with A=8. The calculation of these reactions yields at low astrophysical energies is presented in [2,4].

Radiative neutron capture at astrophysical energies

In this work within the dynamic potential cluster model the total cross-sections of ^6Be *(n,* $\gamma_{0,1}$*)*^7Be reaction with formation of ^7Be nucleus in both the ground (J^π, T = 3/2$^-$, 1/2) and the first (J^π, T = 1/2$^-$, 1/2) excited states at low astrophysical energies ($E_{cm} \leq 1$ MeV) have been calculated. The results of the total cross-sections calculations are presented in figure 1. Figure 1 shows that the cross-section of ^6Be *(n,* $\gamma_{0,1}$*)*^7Be process with formation of ^7Be in the ground state is about two times more than for ^6Be *(n,* $\gamma_{0,1}$*)*^7Be process. Also it should be noted that the basic contribution in the cross-section is caused by E1 transition, the contribution of E2 transition is negligibly small.

For comparison and investigation of cluster analogies there is the total cross-section for ^{6}Li (n, $\gamma_{0,1}$)^{7} Li radiative capture with transition into both the ground and the first excited states of ^{7}Li nucleus in figure 2.

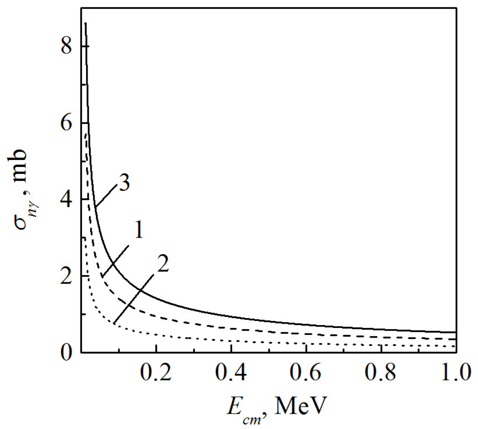

Figure 1 – The cross-section for ^{6}Be (n, $\gamma_{0,1}$)^{7} reaction: *1* – the cross-section for ^{6}Be (n, γ_0)^{7}; *2* – the cross-section for ^{6}Be (n, γ_1)^{7}; *3* – the total cross-section

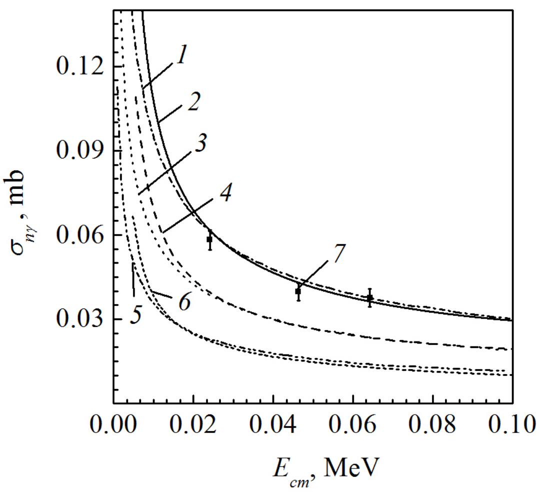

Figure 2 – ^{6}Li (n, $\gamma_{0,1}$)^{7} Li radiative capture cross-section: *1* – the total cross-section [5]; *2* – the total cross-section [2]; *3* – ^{6}Li (n, γ_0)^{7} Li cross-section [5]; *4* – ^{6}Li (n, γ_0)^{7} Li cross-section [2]; *5* – ^{6}Li (n, γ_1)^{7} Li cross-section [5]; *6* - ^{6}Li (n, γ_1)^{7} Li cross-section [2]; *7* – experimental data [6]

It can be seen from figures 1 and 2 that shape of the curves is analogous that can be caused by isobar analogy of ^{7}Li – ^{7}Be nuclei. In addition in this case also the structural analogies are observed, because these two processes ^{6}Be (n, $\gamma_{0,1}$)^{7} and ^{6}Li (n, $\gamma_{0,1}$)^{7} Li relate to so called dynamical type of nuclei clusterization and occur with restructuring of one of the clusters in the final channel. In ^{6}Be (n, $\gamma_{0,1}$)^{7} process the destruction and restructuring of τ cluster takes place, but in ^{6}Li (n, $\gamma_{0,1}$)^{7} Li *t* cluster is destructed.

Let's make an analysis of the wave functions of ^{7}Be {ατ} used in calculations and mentioned above. The second variant of this wave function [9] is more exact than the first one [8], because according to [9] in the second variant for the construction of this wave function more exact parameters of ^{3}He ^{4}He interaction potentials were used. These parameters have been selected to reproduce the experimental data for ^{7}Be energy levels [10] with maximum possible accuracy. In the whole this little changing of ^{3}He ^{4}He potentials parameters relative to the results of [8] practically has no impact on the behavior of scattering phases, but it allows to reproduce exactly the levels energies in cluster channels, that plays the vital role in the case of calculation of astrophysical S-factors for energies of the order 1-10 keV.

Using the obtained results for the total cross-section for ^{6}Be (n, $\gamma_{0,1}$)^{7} the calculation of this reaction yield has been done. The corresponding results are shown in figure 3. The dot-dashed curve in this figure describe the yield of reaction occurring with formation of ^{7}Be in the first excited state, the dashed curve corresponds to ^{6}Be (n, $\gamma_{0,1}$)^{7} reaction yield, and the solid curve corresponds to the total reaction yield. The total reaction yield has maximum at temperature T = 35 keV, for ^{6}Be (n, $\gamma_{0,1}$)^{7} and ^{6}Be (n, γ_1)^{7} processes this maximum is observed at T = 36 keV and T = 33 keV correspondingly.

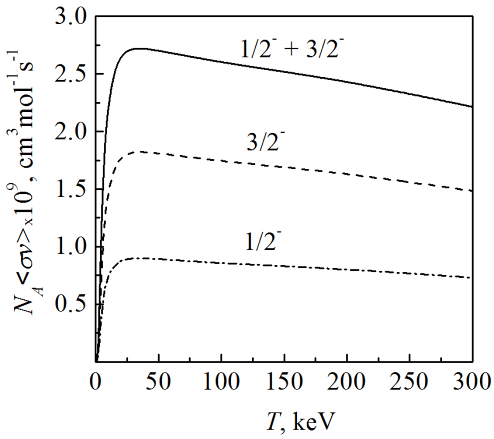

Figure 3 – ^{6}Be (n, $\gamma_{0,1}$)^{7} reaction yield: dashed curve – for ^{6}Be (n, γ_0)^{7}; dot-dashed curve – for ^{6}Be (n, γ_1)^{7}; solid curve – the total reaction yield

In figure 4 the results of calculation of ^{6}Li (n, $\gamma_{0,1}$)^{7} Li reaction yield given in [2] are presented for comparison. Figure 4 shows that ^{6}Li (n, $\gamma_{0,1}$)^{7} Li reaction yield has a maximum at T = 150 keV. As it is seen from figures 3 and 4 in the whole there is also the cluster and structure analogies of ^{7}Li – ^{7}Be.

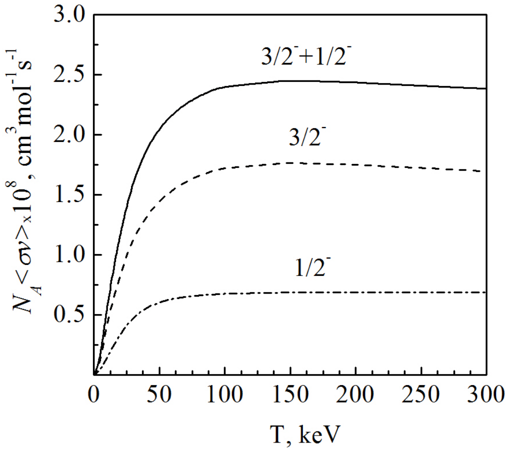

Figure 4 – ^{6}Li (n, $\gamma_{0,1}$)^7 Li reaction yield: dashed curve – for ^{6}Li (n, γ_0)^7 Li; dot-dashed curve – for ^{6}Li (n, γ_1)^7 Li; solid curve – the total reaction yield

Conclusion

Thus in the present paper new theoretical data of the investigation of $^7Be_{g.s}$→^{6}Be+n and $^7Be_{exs.}$→^{6}Be+n fragmentation channels: the cross-sections and reaction yields at low astrophysical energies are presented. These data in particular based on the semi-microscopic few-body approach and so may be regarded as reliable *proposal* for new experimental investigations.

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