Characteristics of ^{6}Li Nucleus Cluster Photodisintegration Reactions

Zhusupov M.A.[1], Zhaksybekova K.A.[1] and Kabatayeva R.S.[1,2]

[1] IETP, al-Farabi Kazakh National University, Almaty, Kazakhstan

[2] International Information Technology University, Almaty, Kazakhstan
raushan.kabatayeva@gmail.com

Abstract. On the base of potential theory the characteristics of Lithium nuclei cluster photodisintegration reactions are considered in the range of very low and intermediate energies. At low energies the important role of E1-multipole and its interference with E2-multipole were considered. The essential point is the different character of interference of E1- and E2-amplitude for the direct and inverse reactions. If for the direct reaction the interference at scattering in forward semisphere has a constructive character, then in backward semisphere the interference of E1- and E2-amplitudes – is destructive one. For the inverse reaction the interference has an opposite character: in forward semisphere it is destructive, and in backward semisphere it is constructive. In the energy range above several MeV the E2-multipole becomes dominating.

Keywords: Cluster Photodisintegration, Photonuclear Reaction, Potential Theory, E1-multipole, E2-multipole.

E1-transitions at low energies

The processes of two-particle photodisintegration of light self-conjugated (N=Z) nuclei with formation of particles with zero isotopic spin like ^{4}He(γ,d)d, ^{6}Li(γ,d)α and etc. are of peculiar interest for the theory of photonuclear reactions. The cross sections of the reactions are unusually small because according to selection rules by isotopic spin the E1-transitions in case $\Delta T = 0$ are strongly suppressed and the E2-multipoles begin to play the determining role.

The reaction $\alpha d \to {}^6Li\gamma$ represents peculiar interest as a unique source of formation of ^{6}Li nuclei in the Big Bang [1]. Its study is important for thermonuclear applications as well. However the E1-transitions in the reaction $\alpha d \to {}^6Li\gamma$ are strongly suppressed due to selection rules by isospin a violation of symmetry of angular distribution of γ-quanta with respect to angle $\theta = 90^0$, characteristic for the case of "pure" E2-transitions, shows the noticeable interference of these multipoles at low energies [2]. That is why there appears a natural question about which reasons lead to appearance of E1-multipole.

We think that in this case the reason for appearance of E1-multipole is connected to a clearly pronounced αd-structure of ^6Li nucleus as a consequence of which for subsystems the center of the charge does not coincide with the center of mass of a system. For a nucleus consisting of subsystems a and b the dipole operator can be presented in form of a sum dipole operators acting in each of the subsystems and $\vec{d}_\rho = e\vec{\rho} \cdot m_a m_b / (m_a + m_b) \cdot (Z_a / m_a - Z_b / m_b)$, here $\vec{\rho}$ – is a coordinate of relative motion of clusters *a* and *b*. Applying this formula for calculation of the reaction $\alpha+d \rightarrow {}^6Li+\gamma$ one finds that in αd-system because of the fact that $m_\alpha - 2m_d \neq 0$ the dipole moment $d_\rho = 4.3 \cdot 10^{-4} \cdot e\rho$ appears and it gives the appearance of E1-multipole [3]. The wave function of the ground state of ${}^6Li$ nucleus was chosen in αnp-model [4]. When constructing the wave function of αd-scattering a deep potential with forbidden states was used [3].

One can observe the E1-transition in angular distributions of processes ${}^6Li\gamma \leftrightarrow \alpha d$ in the interference with E2-multipole. In fig. 1 there are our calculations in cluster model. As it is seen in fig. 1b the theoretical calculation agrees qualitatively with experimental data [2]. Note the different character of interference of E1- and E2-amplitudes for direct ${}^6Li\gamma \rightarrow \alpha d$ and inverse $\alpha d \rightarrow {}^6Li\gamma$ reactions. If for the direct reaction the interference at scattering in the forward semisphere (until $\pi/2$) has a constructive character, then in the backward semisphere the interference of E1- and E2-amplitudes – is destructive. For the inverse reaction the interference has opposite character. Concerning the reaction $\alpha d \rightarrow {}^6Li\gamma$ the region lower than 700 keV is still important. In this region only data obtained as a result of coulomb dissociation of lithium nuclei in the field of a heavy nucleus (Pb) is available that is using the method of virtual photons [**5**].

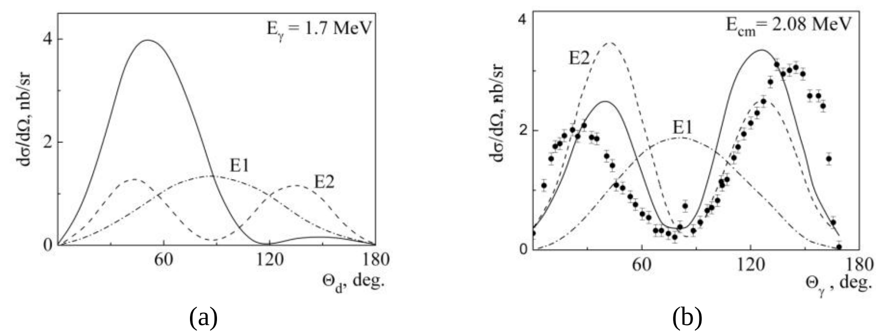
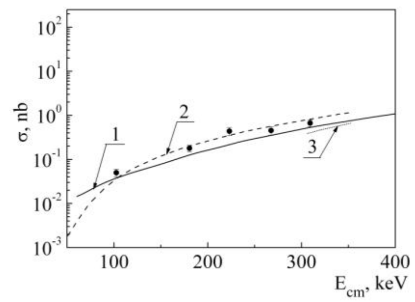
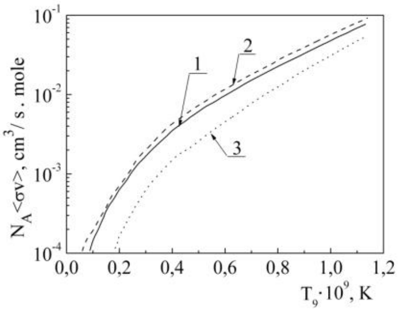


Fig. 1. Angular distributions in processes: a – ${}^6Li\gamma \rightarrow \alpha d$; b – $\alpha d \rightarrow {}^6Li\gamma$. Dashed – pure E2-transition, dash-and-dot – E1-transition, solid curve – total result accounting E1- and E2-multipoles. Experiment – [2].

To answer the question about the role of E1-multipole it is necessary along with the angular distributions of deuterons to measure the total cross sections. Calculations in works [6] and [7] reproduce the experimental data on total cross sections and astrophysical factor approximately in the same way (Fig. 2). The result in work [6] is a theoretical prediction since it had been obtained before the authors got acquainted with the experimental work [5].



(a)



(b)

Fig. 2. Total cross sections (a) and astrophysical rates (b) of $\alpha d \rightarrow {}^6Li\gamma$ process. Experiment – [8]. Theory: (a) 1 – calculation [6]; 2 – [7]; 3 – [8]; (b) 1 – calculation [6]; 2 – [9]; 3 – [8].

Conclusion

The cluster E1-transition appears due to large difference in masses $2m_d$ - m_α, that is because of large binding energy of α-particle in *dd*-channel which is equal to 24.5 MeV. Because of the difference in penetrability of potential barrier the E1-multipole appears in astrophysical region where the interference effects of E1 and E2 multipoles in the angular distributions of particles are the strongest. In such a case the character of interference of E1- and E2-multipoles in the direct and inverse photonuclear reactions is different.

The work was financially supported by the Grant №AP05132952.

References

1. Schramm, D.N., Wagoner, R.V.: Element Production in Early Universe. Ann. Rev. Nucl. Sci. 27, 37-74 (1997).
2. Robertson, R.G.H. et al.: Observation of the capture reaction H-2(Alpha-Gamma)Li-6 and its role in production of Li-6 in the Big-Bang. Phys. Rev. Lett. 47, 1867–1870 (1981).
3. Burkova, N.A. et al.: Is it possible to observe an isoscalar E1-multipole in Li-6-Gamma-Reversible-Alpha-D reactions. Phys. Lett. B. 248, 15–20 (1990).
4. Kukulin, V.I. et al.: Detailed study of the cluster structure of light-nuclei in a 3-body model. 1. Ground state of Li-6. Nucl. Phys. A. 417, 128–156 (1984).
5. Kiener, J. et al.: Measurements of the Coulomb dissociation cross-section of 156 MeV Li-6 projectiles at extremely low relative fragment energies of astrophysical interest. Phys. Rev. C 44, 2195–2208 (1991).
6. Zhusupov, M.A. et al.: One particle spectroscopic characteristics of Li-6 and Be-9 in the three particle models. Izv. Akad. Nauk Kaz. SSR. Ser. Fiz. 5(62), 985–990 (1998).
7. Igamov, S.B., Yarmukhamedov, R.K.: Analysis of the nuclear astrophysical reaction Alpha-D – Li-6+Gamma. Phys. At. Nucl. 58, 1317–1319 (1995).
8. Langanke, K.H.: Microscopic potential model studies of light nuclear capture reactions. Nucl. Phys. A 457, 351–366 (1986).
9. Caughlan, G.R., Fowler, W.A.: Thermonuclear reaction rates. At. Data Nucl. Data Tables 40, 283–334 (1988).