# Data from the $^{13}C+\alpha$ interaction for the studies of the cluster structure and for astrophysics

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Our knowledge of the $\alpha$-cluster structure in atomic nuclei is mainly based on the investigation of self-conjugate 4*N* nuclei, like $^{8}$Be, $^{12}$C, $^{16}$O, and so on (for the most recent review see [1]). The available data on the $\alpha$-cluster states in neutron rich nuclei are scarce [2–6], but they give indications for the developed cluster structures with very large moments of inertia. The study of non-self-conjugate nuclei has an additional advantage in that one can investigate isobaric analog states in mirror systems. Comparison of the results for the mirror systems can bring new spectroscopic information. The Coulomb energy differences can be used to get reliable estimations for the radii of the cluster states.

It is well known that reactions induced by α particles play an important role in the development of stars. The reaction $^{13}C(\alpha,n)^{16}O$ is considered to be the main source of neutrons for the *s* process at low temperatures in low mass stars in the asymptotic giant branch (AGB) [1]. About half of all elements heavier than iron are produced in a stellar environment through the *s* process, which involves a series of subsequent neutron captures and $\alpha$ decays. Two factors determine the efficiency of this reaction: the abundance of $^{13}$C and the rate of the $^{13}C(\alpha,n)^{16}O$ reaction (see [2], and references therein). The rate of the $^{13}C(\alpha,n)^{16}O$ reaction at temperatures of ~$10^8$ K is uncertain by ~300% [3] due to the prohibitively small reaction cross section at energies below 300 keV, therefore the nuclear models are helpful to make the theoretical predictions.

Therefore, even if astrophysical reactions involving helium do not proceed through strong $\alpha$-cluster states (because of their high excitation energy), the properties of the $\alpha$-cluster states can provide for the knowledge to the region of astrophysical interest through configuration mixing. Teams of the Cyclotron Institute and Nazyrbaeyev University (Astana) develop a joint program of the study of the $\alpha$-cluster states in $N \neq Z$ light nuclei which can be of interest for their nuclear structure and for astrophysics. A new DC-60 Astana cyclotron accelerating heavy ions up to energies of 1.75 MeV/A appeared to be a useful instrument in these studies.

The resonance elastic $^{13}C+\alpha$ elastic scattering was studied by Thick Target Inverse Kinematics method [10] at the $^{13}$C initial beam energy of 1.75 MeV/A. The excitation functions were obtained at different angles in the forward hemisphere (including zero degrees) and at cm energies down to 1.5 MeV. The details are given in [11]. At present we are close to finishing the complete R-matrix analysis of the $^{13}C+\alpha$ elastic scattering with information on over 25 levels in $^{17}$O (the example of the fit for the zero degrees data ($180^0$ cm) is given in Fig.1). The parameters obtain in this fit are used to describe the $^{13}C(\alpha,n)^{16}O$ and $^{13}O(n,n)^{16}O$ data. Then we plan to test the parameters in the description of the available $^{16}O(p,\alpha)^{13}N$ and $^{16}O(p,p)$ data. The found parameters together with recent ANC measurements[12] for the $^{17}$O resonances close to the threshold for decay to $^{13}$C+$\alpha$, should provide for very exact knowledge of the data needed calculation of the *s* process in stars.

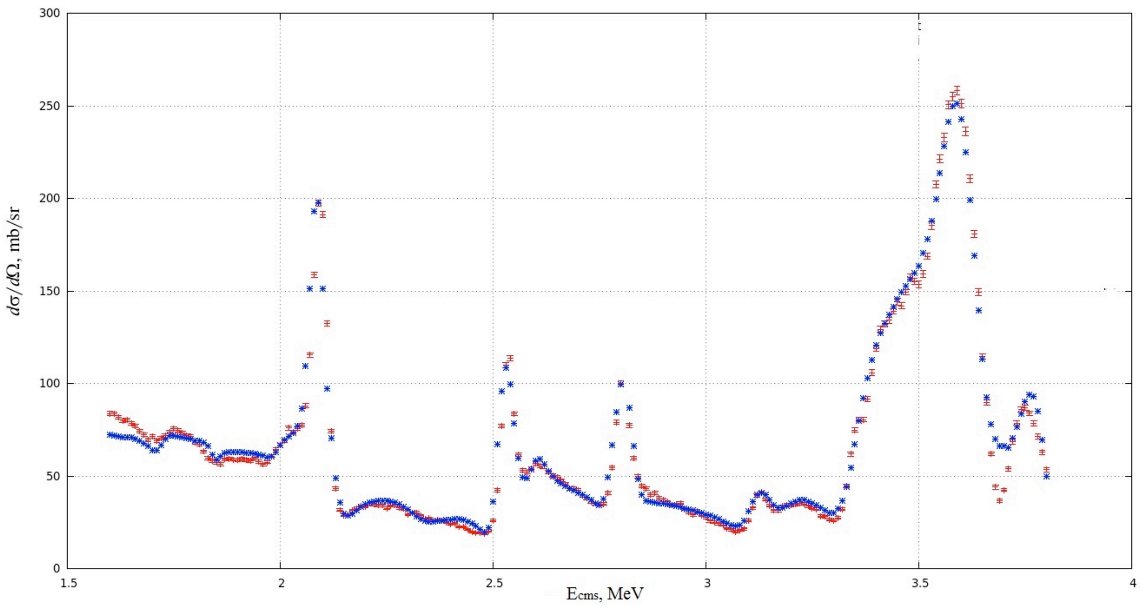


**FIG. 1.** Excitation function for the $^{13}$C+$\alpha$ elastic scattering at $180^0$ degrees cm. Blue points -*R* matrix fit, red points-experimental data.


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