Isomeric cross section ratios for the reactions $^{86(87)}$Sr(α,n(2n))^{89mg}Zr

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Abstract. Calculations of the excitation functions of high-spin and low-spin isomeric states in one and the same nucleus as well as the respective isomeric cross section ratios (ICSR) are carried out for the reactions $^{86(87)}$Sr(α,n(2n))^{89mg}Zr.The reliability of advanced data-containing codes EMPIRE and TALYS are analyzed. The results of the measurements of isomeric cross section ratios themselves and comparison of these results with the ones calculated by the discussed codes are proved to be a promising test of the codes and their capability to reproduce angular momentum dynamics of the discussed and related reactions.

1. Introduction. ICSR as a tool for nuclear reaction studies

Excitation functions of various isotopes and energy dependences of ICSR obtained in typical α-induced nuclear reactions such as (α,n), (α,2n), etc. are presented in many papers, see, for example Refs. [1–11]. The calculations of the total excitation functions performed by use of modern computer codes demonstrate the similarity of the resulting curves and a reasonable agreement of the computed absolute values with the measured data. Various experimental and theoretical results reliably indicate that at least for near-barrier energies of the incident α-particle the compound nucleus mechanisms are dominating. In contrast to that behaviour of the ICSR curves is very different in accordance with spin characteristics of the initial, the intermediate and the final states. In many cases it turns out to be impossible to reproduce the ICSR in calculations if even a broad variety of starting assumptions is exploited. Thus some properties of the angular momentum dynamics in these reactions and spin dependence of nuclear level density are not disclosed yet.

Off-beam measurement of reaction product radiation is a popular method in studies of excitation functions and ICSR of various nuclear reactions. Distinctive features of this method are high efficiency and reliable recognition of radioactive residues. Experiments of such a type are rather convenient and labour-saving. At the same time analysis of the excitation functions of the isotope production and isomeric cross section ratios allows one to reveal reaction mechanisms of a residue production and properties of the intermediate states involved in the cascade. Indeed, usually the yield of the products strongly depends on the density of these states, particle capture and emission strength functions, discrete spectra of a nucleus under study, etc.

The isomeric cross section ratio which characterizes the relative yield of high- and low-spin isomers of one and the same isotope is determined to a large measure on spin distributions of the

intermediate products of the reaction as well as on the properties of gamma-cascade in a final residue. Thus the results of the measurements of the ICSR indicate the dynamics of distribution of angular momentum over the reaction products. In particular, ICSR observed in alpha-particle-induced reactions reveal the spin dependence of the alpha-cluster strength in the energy area under study.

Recently the analysis of the excitation functions and the ICSR is based on large-scale data-containing codes, for example, EMPIRE [12] and TALYS [13]. Codes of such a type allow one to take into account various reaction mechanisms as well as a large number of characteristics of nuclear reactions and nuclei involved in them. Thus the codes turn out to be beneficial in search for various associations of these characteristics with the results of the discussed measurements.

2. Results and conclusions

Two reactions producing one and the same isomeric pair: $^{86(87)}Sr(\alpha,n(2n))^{89mg}Zr$ at the energy ranges 13-29(27) MeV are analyzed. Experimental studies of ICSR produced by these reactions were carried out by us earlier [4] using off-beam measurements of induced activity of members of the isomeric pair.

The results of the measurements and the calculations of ICSR in the framework of, EMPIRE and TALYS codes are presented in Figs. 1 and 2.
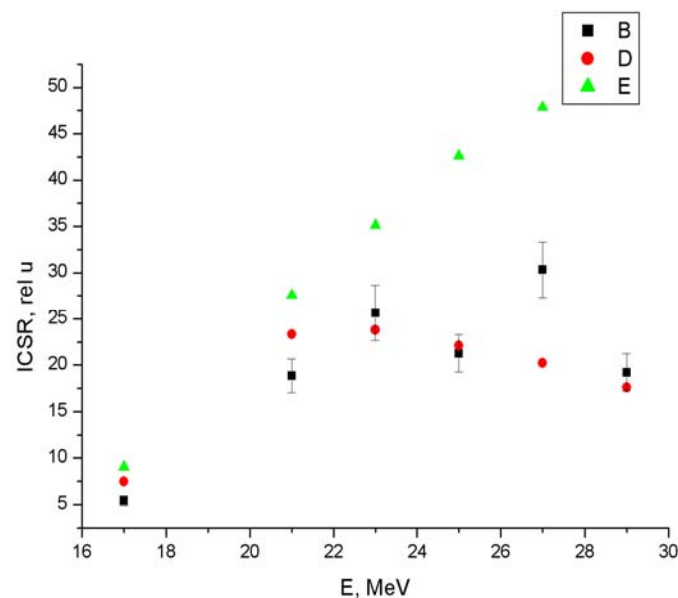
Figure 1. Values of the isomeric cross section ratios σ_g/σ_m ($9/2^+/1/2^-$) for the reaction $^{86}Sr(\alpha,n)$ ^{89mg}Zr: D – calculated by TALYS, E – calculated by EMPIRE-3.1, B – experiment.

These figures demonstrate both similarity and distinction in behaviour of ICSR of the respective reactions. On the one hand the values of ICSR of both reactions are very large and in this sense aresimilar. On the other hand the (α,n) reaction reveals unusual maximum of ICSR at an energy point of 27 MeV, while the ($\alpha,2n$) reaction demonstrates monotonic increasing of this value. TALYS code turns out to be preferable for description of the first reaction, at the same time both it and EMPIRE code fall short of the ideal in description of the second reaction. The analysis of some other ICSR data by these codes may result sometimes in a more drastic disagreement between the experimental and results (see, for example [11]). Such examples provide reasons to perform the more wide analysis of related experiments with the intent to upgrade the codes.
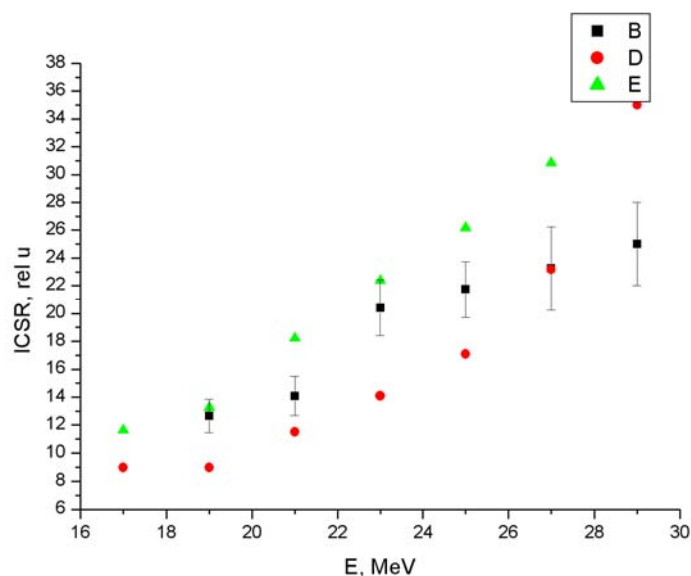
Figure 2. The came as in Fig. for the reaction ^{87}Sr(α,2n) ^{89mg}Zr: D – calculations by TALYS, E – calculated by EMPIRE–3.1, B – experiment.

In conclusion it should be emphasize that codes under discussion are constructed as a synthesis of more or less standard theoretical models and a broad spectrum of nuclear data. Nevertheless delicate properties of nuclear structure including, probably, properties of high-spin alpha-cluster states turn out to be lost in the input of these codes

The measurements of the isomeric cross-section ratios and comparison of the results with the ones obtained in the calculations seem to be a good test of the capability of nuclear reaction codes and a tool to demonstrate a manifestation on unusual properties of highly-excited states including their clustering.

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