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Cross sections for the production of superheavy nuclei

V.I. Zagrebaev [a], W. Greiner [b]

[a] *Flerov Laboratory of Nuclear Reactions, JINR, Dubna, Moscow Region, Russia*
[b] *Frankfurt Institute for Advanced Studies, J.W. Goethe-Universität, Frankfurt, Germany*

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Abstract

Production and studying properties of superheavy (SH) nuclei meet significant experimental difficulties owing to extremely low cross sections of their formation in heavy ion fusion or multinucleon transfer reactions. Accurate predictions of these cross sections along with the corresponding excitation functions are quite desirable for planning and performing experiments of such kind. Study of these cross sections (their dependence on projectile–target combination and energy dependence) gives us an opportunity to investigate complicated dynamics of low-energy heavy ion collisions as well as decay properties of excited SH nuclei.

Keywords: Synthesis of superheavy elements; Cross sections; Fusion reactions; Multinucleon transfers

1. Introduction

There are three methods for the production of transuranium elements, namely, a sequence of neutron capture and β^- decay processes, fusion of heavy nuclei, and multinucleon transfer reactions. The neutron capture process is an oldest (and natural) method for the production of new heavy elements. Strong neutron fluxes might be provided by nuclear reactors and nuclear explosions under laboratory conditions and by supernova explosions in nature. The so-called "fermium gap", consisting of the short-living fermium isotopes $^{258-260}$Fm located at the beta stability line and having very short half-lives for spontaneous fission, impedes the formation of

E-mail address: zagrebaev@jinr.ru (V.I. Zagrebaev).

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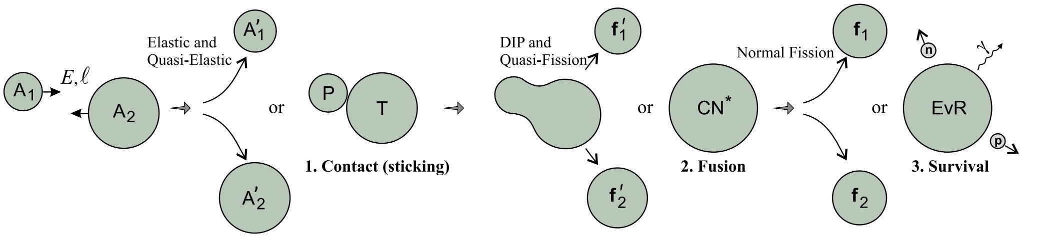

Fig. 1. Scenario of SH nucleus formation in heavy ion fusion reactions. Notations are quite evident, otherwise see the text.

nuclei with Z > 100 by the weak neutron fluxes realized in existing nuclear reactors. In nuclear and supernova explosions (fast neutron capture) this gap may be bypassed, if the total neutron fluence is high enough. Theoretical models predict also another region of short-living nuclei located at Z = 106–108 and A ∼ 270. A macroscopic amount of long-living SH nuclei located at the island of stability might really be produced in the pulsed nuclear reactors of the next generation, if their neutron fluence per pulse is increased by about 3 orders of magnitude (i.e. up to 10^{20} neutrons/cm^2), that is sufficient to bypass the both gaps of instability. Detailed consideration of the neutron capture process (including a possibility for the production of SH elements in nature) can be found in [1]. Here we restrict ourselves by analysis of the fusion and multinucleon transfer reactions for the production of SH nuclei.

The corresponding cross sections are extremely low (around one picobarn, i.e., 10^{-36} cm^2). Moreover, energy dependence of the cross sections for the formation of SH nuclei in fusion reactions is rather narrow (few MeV, see below). This significantly complicates planning and conducting experiments on production and studying properties of SH nuclei. In experiments based on heavy ion fusion reactions target material is irradiated by heavy ions during several weeks (sometime, several months). Incorrect choice of the beam energy (deviation by a few percents from the optimal value) may lead to a total loss of required events. Accurate predictions of the corresponding cross sections (or knowledge them from the previous experiments) are very desirable to perform experiments of such kind.

Cross sections for the production of SH nuclei both in fusion and transfer reactions are themselves of great interest. Their measurements allow one to study complicated dynamics of low-energy heavy ion collisions and decay properties of excited heavy nuclei formed in such processes (competition of light particle evaporation, γ emission, and fission).

2. Formation of superheavy nuclei in fusion reactions

Formation process of SH residual nucleus B(g.s.), which is the product of light particle evaporation and γ emission from an excited compound nucleus C, formed in fusion reaction of two heavy nuclei $A_1 + A_2 \to C \to B + n, p, \alpha, \gamma$, can be decomposed in the 3 reaction stages shown schematically in Fig. 1.

In the first reaction stage colliding nuclei overcome the Coulomb barrier and come in close contact with overlapped nuclear surfaces. This process competes with elastic and quasi-elastic scattering (including few nucleon transfers) with formation of projectile-like and target-like nuclei. This competition strongly depends on collision energy and impact parameter (angular momentum of relative motion). At sub-barrier energies the probability for nuclei to form the contact configuration is small even at zero angular momentum.

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