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Is there incomplete fusion mechanism beyond 100A MeV?

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Abstract

Presented is a universal description of the generalized fusion excitation function which indicates that the fusion reaction mechanism should vanish at center-of-mass energy per nucleon of about 13 MeV/nucleon independently of the specific heavy-ion reaction system. Placing reliance on this result and comforted by semiclassical transport model simulations we suggest that the proposed persistence of the incomplete fusion cross sections in the measurement of the ^{14}N induced reactions on heavy targets at beam energies between 100A and 155A MeV should be attributed to a geometrical participant-spectator-like reaction mechanism.

Keywords: Heavy-ion reactions; Intermediate energies; Fusion excitation function; Vanishing of fusion; Semiclassical transport model; Geometrical participant-spectator picture

1. Introduction

Fusion reaction mechanism is related to the formation of a fully equilibrated nuclear system which may be either the result of amalgamating all the nucleons into a compound nucleus (complete fusion, CF) or of only a part of the total reaction system (incomplete fusion, IF). According to the strong absorption picture of nuclear processes the fusion, or more generally

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the total reaction cross section, may be approximated by a simple schematic relation between center-of-mass energy $E_{c.m.}$, reaction threshold barrier V and an effective interaction radius R:

$$\sigma(E) = \pi R^2 \left(1 - \frac{V}{E_{c.m.}}\right). \tag{1}$$

Each empirical model, from the first one by Bass [1], intended to describe the fusion cross section σ_{fus} relies on the above functional form. According to Eq. (1), σ_{fus} expressed as a function of $1/E_{c.m.}$ increases linearly with increasing energy. Such a behavior characterizes the so-called fusion region I.

At E_{inc} several times higher than the barrier the fusion starts to compete not only with transfer, inelastic and quasi-elastic processes but progressively with strongly damped processes which do not lead to compound-nucleus formation. Fusion is still the dominant reaction mechanism but σ_{fus} stagnates. This region is referred to as the fusion region II. With the further rise of energy sequential and simultaneous fragmentation processes open. In addition, the reaction system is exposed to conditions at which energetic particles may leave the composite system at the early collision stage and, thus, reduce the mass of the eventually formed compound nucleus. One is dealing with the fusion region III in which both CF and IF are present. Although the IF mechanism after opening increases, in the region III the total σ_{fus} steadily decreases with the rise of E_{inc}, quickly ceases to be a dominant reaction mechanism and ends by vanishing. A recent review on heavy-ion reaction mechanisms may be found in Ref. [2] and specifically on the fusion reactions in Ref. [3].

In a recent publication [4] we have demonstrated that the fusion region III cross sections reduced by the reaction cross section $\sigma_{red} = \sigma_{fus}/\sigma_{reac}$ as a function of the center-of-mass energy per nucleon, i.e. the so-called (system) available energy

$$E_{avail} = \frac{E_{c.m.}}{A_{sys}} = \frac{E_{lab}}{A_p} \frac{A_p A_t}{(A_p + A_t)^2}, \tag{2}$$

follows a universal homographic functional dependence

$$\sigma_{red} = a + \frac{b}{E_{avail} + c}. \tag{3}$$

This relation is derived by a direct application of the strong absorption model (1) to both σ_{fus} and σ_{reac} [4] while its universality is an outcome of the above energy scaling given by Eq. (2). In Eq. (2) A_p and A_t stand for projectile and target mass numbers, respectively, whereas incident energy reads $E_{inc} = E_{lab}/A_p$.

A fit with the homographic probe-function (3) presented in Ref. [4] has been carried out over the evaporation-residue σ_{fus} data only. A fit result over the full evaporation-residue and fusion–fission data set will be presented in Ref. [5] together with a fit over the portion of the full data set associated with the fusion region III. The latter consists of the 256 σ_{fus} data values belonging to 78 reaction systems whose fit coefficients are displayed in Table 1. The data span the mass asymmetry parameter $\mu = |A_t - A_p|/(A_t + A_p)$ between 0.0 and 0.886. The above fit function, within experimental errors, provides a common description of the fusion excitation function for an overwhelming amount of σ_{red} values and reaction systems [4,5]. In particular, from the relation (3) and Table 1 it follows that the fusion process completely disappears at $E_{avail} = 13 \pm 1$ MeV/nucleon whatever the system characteristics are, regarding its mass, mass asymmetry or isospin content [4,5]. The two homographic functions [4] and [5] differ markedly less than their rather small uncertainties (cf. Table 1 and the orange background band around the