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Impact of reaction cross section on the unified description of fusion excitation function

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Abstract

A systematics of over 300 complete and incomplete fusion cross section data points covering energies beyond the barrier for fusion is presented. Owing to a usual reduction of the fusion cross sections by the total reaction cross sections and an original scaling of energy, a fusion excitation function common to all the data points is established. A universal description of the fusion excitation function relying on basic nuclear concepts is proposed and its dependence on the reaction cross section used for the cross section normalization is discussed. The pioneering empirical model proposed by Bass in 1974 to describe the complete fusion cross sections is rather successful for the incomplete fusion too and provides cross section predictions in satisfactory agreement with the observed universality of the fusion excitation function. The sophisticated microscopic transport DYWAN model not only reproduces the data but also predicts that fusion reaction mechanism disappears due to weakened nuclear stopping power around the Fermi energy.

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Keywords: Heavy-ion reactions, Intermediate energies, Fusion excitation function, Vanishing of fusion, Reaction cross sections

1. Introduction

The complex interplay between the one body (nuclear mean field) and the two-body (elementary nucleon-nucleon (NN) collisions) degrees of freedom governs the rich zoo of nuclear reaction mechanisms observed in the transition Fermi-energy region. Understanding the role of these two origins of energy dissipation in the course of heavy-ion reactions (HIR) is a long standing challenge put to nuclear models. Study of the fusion excitation function, both complete (CF) and incomplete (IF), and in particular shedding some light onto conditions of fusion disappearance, may be a useful tool to constrain the ingredients entering theoretical models used to describe HIR in this energy range. The modern dynamical models such as Sky3D by Maruhn et al. (2014), TDHF3D by Simenel (2012) or DYWAN by

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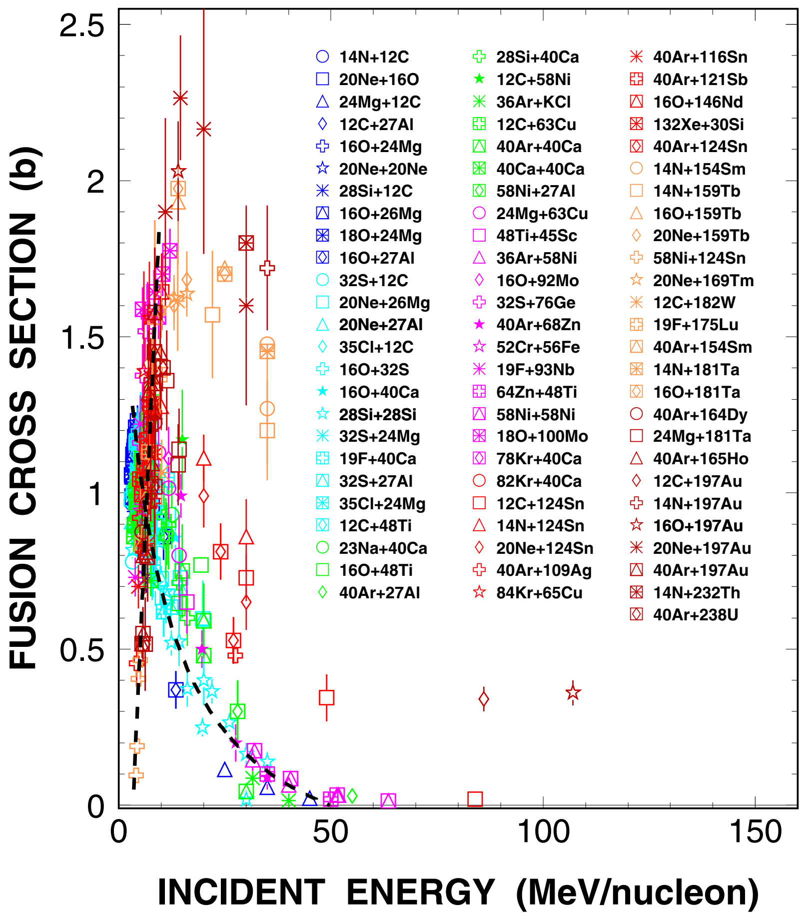

Fig. 1. Raw fusion cross sections σ_f plotted as a function of E_{inc}. The inventoried systems are distinguished among them by symbols and a color code. The same symbols and the color code are used in Eudes et al. (2014-a) where an interested reader may find detailed information on energies, σ values, and references to original works. The dashed line and the dashed curve are intended to guide the eye only.

Sébille et al. (2007) offer the promising theoretical frameworks to resolve above questions especially in selecting the most appropriate effective interaction, see e.g. Dutra et al. (2012), and an improved modeling of the NN collisions.

In two recent papers we have presented a systematic study of both CF and IF fusion cross sections σ_f in the incident energy $E_{\text{inc}} = E_{\text{lab}}/nucleon$ range of $\sim 3A - 155A$ MeV, see Eudes et al. (2013, 2014-a). In total, from the literature published during the past 40 years, we have collected 382 CF and CF+IF σ_f data points belonging to 81 reaction systems with a vast variety of projectile–target pairs, system mass asymmetry, system isospin content as well as in the large range of covered system masses $A_{\text{sys}} = 26 - 278$ nucleons.

2. Scaling of fusion cross sections

Discarding those σ_f data points for which we have strong indication that the σ_f value suffers from a non-fusion contribution, cf. in Eudes et al. (2013, 2014-a), or that other reaction mechanism has been erroneously identified as fusion, Eudes et al. (2014-b), one ends with 76 systems and 316 CF+IF σ_f data points. These data, as a function of E_{inc}, are displayed in figure 1. Clearly, most of these raw σ_f data points gather in a narrow domain of the σ_f vs E_{inc} plane although the lighter systems (blue, cyan, and green symbols) gather along an arclike structure (see the dashed curve) while the heavier ones (pink, red, and orange symbols) follow a line which sharply rises with E_{inc} (see