Extended-Wong model for ^{12}C+^{93}Nb using Skyrme forces

Sahila Chopra* and Raj K. Gupta
Department of Physics, Panjab University, Chandigarh-160014, INDIA

Introduction

Recently, we applied [1] the dynamical cluster-decay model (DCM) to an experiment [2] for studying the decay of compound nuclear system ^{105}Ag* formed in ^{12}C+^{93}Nb reaction. A nice fitting of data on evaporation residue plus intermediate mass fragments (ER+IMFs) cross-sections was obtained, but that the fitting required a large contribution of the non-compound nucleus (nCN) component at below and near barrier energies. In DCM, the nCN contribution is calculated as quasi-fission (qf) or capture process where the incoming channel does not loose its identity (the preformation probabililty P_0=1), and then the DCM(P_0=1) becomes similar to the extended-Wong model of Gupta and collaborators [3], but with a difference that, in DCM, we calculate the penetrability P differently and for *each decay channel* whereas the same in Wong is calculated for the *entrance channel* only. In other words, compared to DCM where the data for each decay channel is of interest, the Wong or extended-Wong model deals only with the capture/ qf or total reaction cross-section.

In this paper, we study the same reaction on extended-Wong model [3], using the Extended Thomas Fermi (ETF) method based on Skyrme energy density formalism (SEDF) [4]. This method has the advantage of using different Skyrme forces, giving different barrier characteristics, to fit the available data on either ER or ER+IMFs cross-sections, σ_{ER} or $\sigma_{ER+IMFs}$, at different center-of-mass energies $E_{c.m.}$. Data are available [2] for both ER (2≤A≤4) and IMFs (A=5-13) decay products. Calculations are made with effects of deformations and orientations of nuclei included.

*Electronic address: chopra.sahila@gmail.com

Methodology

The semiclassical Extended Thomas Fermi (ETF) model: The ETF defines the nucleus-nucleus interaction in SEDF,

$$V_N(R) = E(R) - E(\infty) = \int H(\vec{r})d\vec{r} - \left[\int H_1(\vec{r})d\vec{r} + \int H_2(\vec{r})d\vec{r}\right] \quad (1)$$

where H is the Skyrme Hamiltonian density, a function of nucler, kinetic-energy, and spin-orbit densities, the later two themselves being the functions of the nucleon/ nuclear density, written in terms of, so-called, the Skyrme force parameters, obtained by fitting to ground-state properties of various nuclei. There are many such forces, both old and new, and we choose an old SIII and a new GSkI force, the later having an additional tensor coupling term with spin and gradient, fitted also to isospin-rich nuclei. The nuclear density is the T-dependent, two-parameter Fermi density, and for the composite system, densities are added in frozen densities approximation.

Adding to V_N, the Coulomb and angular momentum ℓ-dependent potentials V_C and V_ℓ, we get the total interaction potential $V(R,\ell)$, characterized by barrier height V_B^ℓ, position R_B^ℓ and curvatur $\hbar\omega_\ell$, each being ℓ-dependent.

The extended-Wong model: According to Wong [5], in terms of ℓ partial waves, the fusion cross-section for two deformed and oriented nuclei, colliding with $E_{c.m.}$, is

$$\sigma(E_{c.m.},\theta_i) = \frac{\pi}{k^2}\sum_{\ell=0}^{\ell_{max}}(2\ell+1)P_\ell(E_{c.m.},\theta_i) \quad (2)$$

with $k=\sqrt{\frac{2\mu E_{c.m.}}{\hbar^2}}$ and μ, the reduced mass. P_ℓ is the transmission coefficient for each ℓ, describing the penetration of barrier $V(R,\ell)$

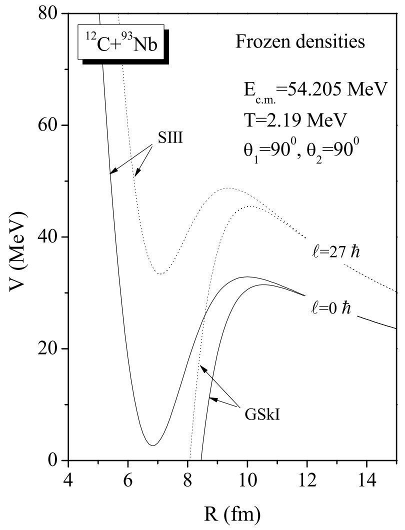

FIG. 1: Interaction potential at two ℓ-values for $^{12}C+^{93}Nb$ at a fixed $E_{c.m.}$ and fixed θ_i, using Skyrme forces in frozen density approximation.

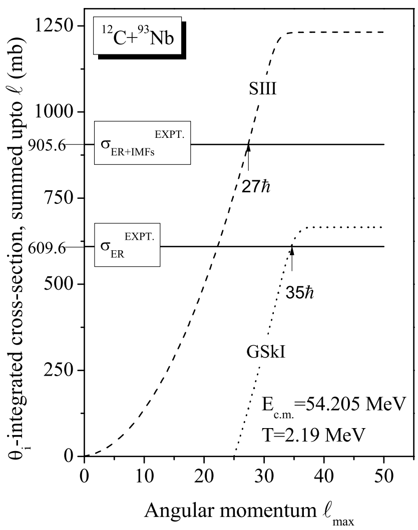

FIG. 2: θ_i-integrated, ℓ-summed cross section as a function of ℓ_{max} itself, compared with experimental data for $^{12}C+^{93}Nb$ at $E_c.m.$=54.205 MeV.

in Hill-Wheeler approximation, as

$$P_\ell = \left[1 + \exp\left(\frac{2\pi(V_B^\ell(E_{c.m.}, \theta_i) - E_{c.m.})}{\hbar\omega_\ell(E_{c.m.}, \theta_i)}\right)\right]^{-1}. \quad (3)$$

Wong carried out the ℓ-summation approximately, using only the ℓ=0 barrier.

Noting the importance of ℓ-dependent barriers, Gupta and collaborators [3] carried out the ℓ-summation explicitly, determining ℓ_{max} empirically for a best fit to the measured cross-section. Thus, the angles θ_i integrated fusion cross-section is given as

$$\sigma(E_{c.m.}) = \int_{\theta_i=0}^{\pi/2} \sigma(E_{c.m.}, \theta_i) sin\theta_1 d\theta_1 sin\theta_2 d\theta_2. \quad (4)$$

Calculations and Results

Fig. 1 shows our calculated $V(R, \ell)$ for $^{12}C+^{93}Nb$ reaction at $E_{c.m.}$=54.205 MeV, and fixed θ_i values, using Skyrme forces SIII and GSkI in frozen density approximation. Notice that the two forces have different barrier characteristics, suitable for attempting to fit the observed σ_{ER}, $\sigma_{ER+IMFs}$ or both, as is done in Fig. 2, where the θ_i-intgrated, ℓ-summed cross-section is plotted against the ℓ_{max} value itself. We notice that GSkI force could fit only the σ_{ER} at ℓ_{max}=35 $\hbar$, whereas SIII force fits not only the σ_{ER} (at a smaller ℓ_{max}-value) but also the $\sigma_{ER+IMFs}$ data at some what lower ℓ_{max}=27 $\hbar$ value.

Concluding, the extended-Wong moodel is suitable for accounting for the measured total cross-section $\sigma_{ER+IMFs}$ for $^{12}C+^{93}Nb$ reaction in terms of a Skyrme force with proper barrier properties, thereby justifying a large nCN component in the data of this reaction.

Acknowledgment

Part of calculations were carried out by using the Physics Department High Performance Computing Cluster (HPCC) facility.

References

[1] S. Chopra, M. Bansal, M. K. Sharma, and R. K. Gupta, Phys. Rev. C**88** (2013) 014615.

[2] T. Ahmad, I. A. Rizvi, A. Agarwal, R. Kumar, K. S. Golda, and A. K. Chaubey, Int. J. Mod Phys. E **20**, 645 (2011).

[3] R. Kumar, M. Bansal, S. K. Arun, and R. K. Gupta, Phys. Rev. C**80** (2009) 034618.

[4] R. Kumar, M. K. Sharma, and R. K. Gupta, Nucl. Phys. A**870-871** (2011) 42.

[5] C. Y. Wong, Phys. Rev. Lett. **31** (1973) 766.