Applications of Skyrme parameterized universal function of nuclear proximity in dynamical cluster decay model

Dalip Singh*

Physics Department, Government College Bassa, District Mandi (Himachal Pradesh) - 175029, INDIA

Introduction

Heavy ion induced, low energy reactions have provided valuable insight in to the nature of both the reaction dynamics and decay mechanism. The investigation of sub-barrier fusion has created renewed interest in the study of cross sections for fusion of heavy ions near and below the Coulomb barrier. So far, the dynamical cluster-decay model (DCM) [1] is used to study the decay of hot and rotating compound nuclei (CN) in medium, heavy and super-heavy mass regions, formed in the low-energy heavy ion reactions with the nuclear proximity potential of Blocki and et al. [2]. Here, we used the DCM to study the fusion cross-sections for the compound nucleus formed in $^{32}S +^{24} Mg \rightarrow^{56} Ni^{*}$ reaction with the universal function of nuclear proximity potential obtained [3] for the Skyrme nucleus-nucleus interaction in semiclassical extended Thomas-Fermi (SETF) approach.

Methods

The dynamical cluster-decay model is a non-statistical, dynamical description for the emission of both the light particles (LPs) and intermediate mass fragments (IMFs) from hot and rotating compound systems. In this model, the dynamical collective clusterization process is an alternative of the fission process. Both the LPs and IMFs are considered as the dynamical mass motion of preformed fragments or clusters through the barrier. In terms of barrier picture, a cluster decay process is in fact a fission process with structure effects of CN also included via the preformation of fragments, but without any phase space arguments. This model successfully re-

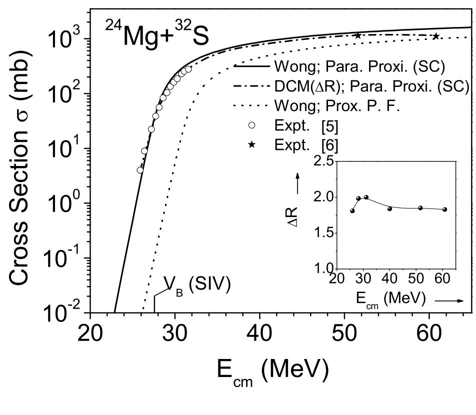

FIG. 1: The calculated fusion excitation functions using DCM with parameterized universal function of proximity potential [3] dash dot line, Wong's formula with parameterized proximity potential and proximity pocket formula [2], respectively with solid and dotted line, compared with the data of [5](open circle, ∘) and [6](star, ⋆).

produces the experimental data within one parameter description, the neck length parameter △R. The coordinates of model are the mass and charge asymmetries $\eta = (A1-A2)/(A1+A2)$ and $\eta_z = (Z1-Z2)/(Z1+Z2)$ and the relative separation R. DCM define the fusion cross section as

$$\sigma = \sum_{\ell=0}^{\ell_c} \sigma_\ell = \frac{\pi}{k^2}\sum_{\ell=0}^{\ell_c}(2\ell+1)P_0P; k=\sqrt{\frac{2\mu E_{c.m.}}{\hbar^2}} \quad (1)$$

where, the preformation probability P_0 refers to η-motion and the penetrability P to R-motion. The $\mu = [A_1A_2/(A_1+A_2)]m = \frac{1}{4}Am(1-\eta^2)$ is the reduced mass, ℓ_c, the critical (or maximum) angular momentum and m is the nucleon mass. The nuclear potential is

*Electronic address: dalipverma2003@yahoo.co.in

TABLE I: Constants obtained for the parameterized universal functions of spin-density independent part ϕ_P and spin-density dependent part ϕ_J [Eqs. (2) and (3)], using different Skyrme forces.

Force	ϕ_P^0	D_0	a	b	ϕ_J^0	c	d	e	f	g
SII	1.28	.35	.46	0.80	.164	.43	.012	.139	.049	.005
SIII	1.28	.30	.44	1.00	.259	.44	.029	.263	.092	.009
SIV	1.37	.26	.43	0.80	.289	.44	.013	.220	.079	.008
SkM^*	1.40	.14	.35	0.55	.313	.44	.052	.346	.121	.012
$SLy4$	1.40	.15	.41	0.45	.249	.46	.018	.222	.077	.008
SKa	1.40	.18	.40	0.60	.236	.44	.014	.196	.069	.007
$MSK1$	1.35	.14	.39	0.60	.312	.50	.052	.409	.142	.014
SGII	1.20	.18	.38	0.50	.209	.50	.017	.211	.074	.008

obtained using the universal functions [3], for spin density independent part, in terms of dimensionless variable D ($= s/b$), is

$$\phi_P = \begin{cases} -\phi_P^0 \exp[-a(D-D_0)^{1.67}] \text{for } D \geq D_0 \\ -\phi_P^0 + b(D-D_0)^2 \quad \text{for} \quad D \leq D_0 \end{cases} \quad (2)$$

where $b = 0.99$ fm is the surface width, $s(= R - R_{01} - R_{02})$ is the separation between two nuclear surfaces with nuclear radii R_{01}, R_{02} and R is separation of the center of two nuclei. The spin-orbit density dependent part is

$$\phi_J = \begin{cases} \phi_J^0 - dD - eD^2 - fD^3 - gD^4 \text{for} D \leq 0 \\ \phi_J^0 \exp[-cD^2] \quad \text{for} \quad D \geq 0 \end{cases} \quad (3)$$

The constants ϕ_P^0, D_0, a, and b of $\phi_P(D)$ and ϕ_J^0, c, d, e, f and g of $\phi_J(D)$ for different Skyrme forces used are given in Table I. Thus, the nuclear interaction potential becomes

$$V_N(R) \;=\; 4\pi\bar{R}\gamma b\left[\phi_P(D) + \phi_J(D)\right]. \quad (4)$$

with $\gamma = 0.9517\left[1 - 1.7826\left(\frac{N-Z}{A}\right)^2\right]$ MeV fm^{-2}, the nuclear surface energy constant, $\bar{R} = R_{01}R_{02}/(R_{01}+R_{02})$ is the mean curvature radius defining the geometry of the system. The total interaction potential can be obtained by adding Coulomb potential $\frac{Z_1Z_2e^2}{R}$ to Eq. 4, which gives the barrier height V_B and position R_B. Using the above information on V_B, R_B in Wong's formula [4]

$$\sigma = \frac{\hbar\omega_0 R_B^2}{2E_{c.m.}} \ln\left(1 + \exp\left[\frac{2\pi}{\hbar\omega_0}(E_{c.m.} - V_B)\right]\right) (5)$$

to get the cross-sections as a function of the center of mass energy E$_{c.m.}$ and $\hbar\omega_0$ is obtained for an inverted harmonic oscillator fit to the curvature in $V_T(R)$ at the top of the barrier.

Calculations and results

Figure 1 shows the fusion excitation function for reactions $^{24}Mg + ^{32}S \rightarrow ^{56}Ni^*$ at different $E_{c.m.}$ using (i) Wong's formula, Eq. (5) with the potential of Eq. (4) for Skyrme force SIV (solid line) (ii) DCM, Eq (1) with the potential of Eq. (4) dash dot line and for △R as a function of $E_{c.m.}$, shown in the inset (iii) Wong's formula, Eq. (5) with the potential of Blocki et al. [2] (dotted line). From the figure we find that the Wong's formula and the DCM with △R is taken as a function of $E_{c.m.}$ reproduces the data [5, 6] nicely with the parameterized proximity potential nicely while with the potential of Blocki et al. [2] in Wong's formula is not reproducing the data nicely.

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