Heavy ion reactions using universal function of Energy Density Formalism in semiclasical approach

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

Introduction

Recently [1] we obtained universal function for the nuclear potential in semiclassical extended Thomas-Fermi (ETF) approach. The universal function and the potential obtained reproduces the exact potential with in a difference of ~ 1 MeV. Here, the application of the parameterized universal functions is made to calculate the fusion cross-sections for various reactions from light, the light-heavy and the super-heavy compound systems for Skyrme forces SII, SIII, SIV, SVI and SkM* and compared with experimental data. Also a comparison is made for the cross-sections calculated with the proximate potential of Blocki and et al. [2].

Methods

The universal functions for spin density independent part of the interaction potential obtained in our recent work [1] in terms of dimensionless variable D ($= s/b$) is

$$\phi_P = \begin{cases} -\phi_P^0 \exp[-a(D-D_0)^{1.67}] \text{for } D \geq D_0 \\ -\phi_P^0 + b(D-D_0)^2 \quad \text{for} \quad D \leq D_0 \end{cases} \quad (1)$$

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 of interaction potential is

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

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

$$V_N(R) = 4\pi \bar{R} \gamma b \left[\phi_P(D) + \phi_J(D)\right]. \quad (3)$$

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 $\frac{Z_1 Z_2 e^2}{R}$ to Eq. 3 which gives the barrier height V_B and

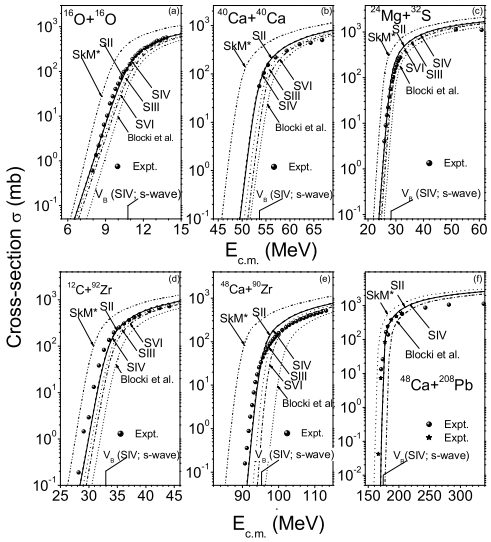

FIG. 1: The calculated fusion cross-sections using our [1] parameterized universal functions for Skyrme forces SII (dash dotted line), SIII (dashed line), SIV (solid line), SVI (dotted line), SkM* (short dashed line) and proximity pocket formula [2] (dash dot dot line), compared with experimental data of [4–9], data marked * is from [10] and the last two data points in reaction ^{24}Mg+^{32}S are taken from ref. [11]

*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. (1) and (2)], 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

position R_B. Using the above information on V_B, R_B in Wong's formula [3]

$$\sigma = \frac{\hbar\omega_0 R_B^2}{2E_{c.m.}} \ln\left(1 + \exp\left[\frac{2\pi}{\hbar\omega_0}(E_{c.m.} - V_B)\right]\right) \quad (4)$$

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 cross-section for various reactions for different mass regions, i.e., the light, the light-heavy and the super-heavy compound systems, calculated using our parameterized universal functions for Skyrme forces SII (dash dotted line), SIII (dashed line), SIV (solid line), SVI (dotted line), SkM* (short dashed line) and proximity pocket formula [2] (dash dot dot line), for the reactions ^{16}O+^{16}O, ^{40}Ca+^{40}Ca compared with data of [4], [5], for ^{24}Mg+^{32}S, ^{12}C+^{92}Zr with data of [6],[7], respectively, the last two data points in reaction ^{24}Mg+^{32}S are taken from [11]. For ^{48}Ca+^{90}Zr data is from [8], and for ^{48}Ca+^{208}Pb the data is of [9], [10], respectively, marked solid circle and marked *

The calculated fusion cross-sections using the parameterized universal functions, are in nice agreement with data, force SII and SIV being the closest. Apparently, the comparisons are somewhat better for the lighter systems than for the heavier ones. The comparison is also made with the fusion cross-sections calculated using the interaction potential $V_P(R)$ calculated with the proximity pocket formula of Blocki and et al. [2]. From the figure we find that the cross section calculations using $V_P(R)$ from proximity pocket formula is not reproducing the experimental data nicely.

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