List of Figures

1.1 Coulomb-plus-nuclear potential and dynamics of the colliding nuclei. . 10

2.1 Schematic configurations of two (equal/ unequal) axially symmetric deformed, oriented nuclei, lying in the same plane and for various \( \theta_1 \) and \( \theta_2 \) values in the range 0° to 180°. .................................................... 33

2.2 An axially symmetric (quadrupole) deformed and oriented nucleus, showing the nuclear radius parameter \( R_1(\alpha_1) \) and the geometry associated with the principal radius of curvature \( R_{12}(\alpha_1) \). .................................................... 38

2.3 The geometry of the classical hydrodynamical model of Kröger and Scheid for calculating the mass parameter \( B_{mp} \). ............................ 42

2.4 A typical scattering potential, with characteristic quantities. . . . . . 45

2.5 The \( T \) and \( \ell \) dependent scattering potentials \( V(R) \), illustrated for \( ^{64}\text{Ni}+^{100}\text{Mo} \rightarrow ^{164}\text{Yb}^* \rightarrow ^{163}\text{Yb}+n \), at two different \( \ell \) and \( T \) (equivalently, \( E_{cm} \)) values under frozen approximation for the Skyrme force SIII (discussed later). The decay path, defined by \( V(R_a, \ell) \) for each \( \ell \) is shown to begin at \( R_a = R_1 + R_2 + \Delta R \) for the \( \ell_{\min} \)-value. The definition of “barrier lowering” \( \Delta V_B = V(R_a) - V_B \) is also shown in this figure for both the \( \ell_{\min} \) and \( \ell_{\max} \) values. ..................................... 53

2.6 The half-density radius \( R_0 \) and the surface thickness \( a \) in fm, plotted as a function of mass number \( A \) of nuclei, each fitted to a polynomial in \( A \). The data are from [63, 64]. ..................................................... 59

2.7 The Fermi density compared with HF, ETF and SM density distributions at \( T=0 \) for \( ^{208}\text{Pb} \) and \( ^{16}\text{O} \) nuclei. The HF and ETF calculations are from [53] and [60], respectively. ............................................ 61

2.8 Variation of the \( \ell \)-integrated cross-section summed up to the angular momentum \( \ell \) as a function of \( \ell \) itself for different (a) \( \Delta V_B^{emp} \)-values, and (b) \( \Delta \omega^{emp} \), for \( ^{64}\text{Ni}+^{100}\text{Mo} \) reaction at \( E_{cm} = 129.2 \text{ MeV}\), showing the minimum value of \( \Delta V_B^{emp} \) (or \( \Delta \omega^{emp} \)) (solid line) required to fit the data at an \( \ell_{\max} \)-value (a saturation condition is reached for the best fitted \( \Delta V_B^{emp} \) or \( \Delta \omega^{emp} \)). In (a) is also shown the failure of \( \Delta V_B^{emp}=0 \) value (dashed line) to reach the experimental cross-section, and its uniqueness by its failure again at a slightly above (dot-dashed line) and slightly below (dotted line) the exact \( \Delta V_B^{emp} \)-value fitting the data. ................................. 64
3.1 Scattering potentials $V(R, \ell)$ for $^{118}$Ba* → $^{12}$C+$^{106}$Sn at a fixed temperature $T=2.62$ MeV (equivalently, $E_{c.m.}=145.42$ MeV of experiments [15]) and different angular momentum $\ell$-values. The decay path, defined by $V(R_a, \ell)=Q_{eff}(T, \ell)$ for each $\ell$, is shown to begin at $R_a=C+\Delta R$, fixed for the $\ell = 0$ case. The $\Delta R$ and $\ell_{max}$-values are for the best fit to $^{12}$C data.

3.2 Preformation probability $P_0$ as a function of $\ell$ for the energetically favored even-mass fragments $A_L$, minimized in charge coordinate $Z_L$, calculated on DCM for the compound system $^{118}$Ba* at $E_{c.m.}=145.42$ MeV (equivalently $T=2.62$ MeV), using the fragmentation potentials $V(A_L)$ calculated at $R=R_a=C+\Delta R$, $\Delta R=1.16$ fm and $\ell_{max}=91 h$. Some light, odd-mass fragments are also shown.

3.3 Preformation probability $P_0$ as a function of fragment mass $A_L$, and for different $\ell$-values, calculated on DCM for the compound system $^{118}$Ba* at $E_{c.m.}=145.42$ MeV (equivalently $T=2.62$ MeV), using the fragmentation potentials $V(A_L)$ calculated at $R=R_a=C+\Delta R$, $\Delta R=1.16$ fm.

3.4 Fragmentation potential $V(A_L)$ for the compound system $^{118}$Ba* formed in $^{78}$Kr+$^{40}$Ca reaction at 5.5 MeV/A of bombarding energy, calculated on DCM for use of different $\Delta R$ (fm) and $\ell_{max}$ (h) values for different mass regions. The $\Delta R$ $(\ell_{max})$ values are 1.6 (52 h), 1.35 (66 h), 1.34 (74 h) and 1.27 (81 h), respectively, for LPs+IMFs, HMFs, nSF and SF. Since no data are available for LPs, for simplicity, we have taken them together with light IMFs.

3.5 The $\ell$-summed (summation over $\ell_{max}$) fragment preformation factor $P_0$, the penetrability $P$ and the decay cross-section $\sigma$ as a function of light mass fragment $A_L$, for the decay of $^{118}$Ba*. The $\ell_{max}$-values for each region are given in the figure caption of Fig. 3.4.

3.6 The calculated cross-sections $\sigma_{CN}$ are compared with the measured ones [15] as a function of the charge $Z_L$ of the light fragment, for the $^{118,122}$Ba* decays at incident laboratory energy of 5.5 MeV/A. Since only the charges of fragments are measured in experiments, the calculated yields for each charge are summed over the energetically favored masses of fragments. In (a) we further make the comparison with the statistical model calculations of Bonnet et al. [15] for $^{122}$Ba*, based on BUSCO and GEMINI codes, and also add the non-compound nucleus contribution $\sigma_{NCN}$, calculated on DCM($P_0=1$) for $Z_L=8-15$ fragments only. Note that at the $T$-values of experiments (T>2 MeV) the pairing strength $\delta=0$ in the liquid drop model used here in DCM calculations. The role of non-zero pairing strength ($\delta >0$) is illustrated in (b) for $^{118}$Ba*, using $\delta=16.7$ MeV, fitted to $^{12}$C data.
3.7 The ratio $\sigma_{^1_{18}Ba}/\sigma_{^1_{22}Ba}$ as a function of $Z_B$ for experiments [15], compared with the predictions of GEMINI code and the DCM calculations (for two different pairing strengths $\delta=0$ and $\delta>0$). $\delta=16.65$ and 16.15 MeV, respectively, for $^{118}$Ba and $^{122}$Ba, for a similar best fit to the $^{13}$C data. Note that a similar DCM calculation for $\delta=0$ case is published in [26], which is preliminary and hence differs somewhat from the present results.

4.1 The spin-orbit density independent function $\phi_p(D)$ and spin-orbit density dependent function $\phi_s(D)$ calculated on semiclassical ETF approach for various pairs of colliding nuclei (scattered points), and the corresponding parameterized universal functions of proximity, Eqs. (4.1) and (4.2), shown as solid lines for (a) SII, (b) SIII, (c) SIV and (d) SkM* Skyrme forces.

4.2 Same as for Fig. 4.1, but for (a) SLy4, (b) SKa, (c) MSK1 and (d) SGII Skyrme forces.

4.3 The two contributing terms $V_p(R)$ and $V_j(R)$ of nucleus-nucleus interaction potential $V(R) = V_p(R) + V_j(R)$ for an illustrative reaction $^{32}$S+$^{40}$Ca, using various Skyrme forces, calculated by using the “exact” integrals, Eqs. (2.90) and (2.88), and the parameterized universal functions, Eqs. (4.1) and (4.2).

4.4 The total interaction potential $V(R)$ for $^{64}$Ni+$^{54}$Ni reaction for the cases of “exact” and parameterized universal functions, using the empirically determined parameters $R_{01} = R_{02} = R_0$ and $a_{01} = a_{02} = a_0$ (thick solid and dashed lines) and ones fitted to data on cross-sections (thin solid and dashed lines) for SIV Skyrme force.

4.5 The fusion cross-section for the reaction $^{64}$Ni+$^{54}$Ni, using Skyrme force SIV, calculated for the cases of “exact” and parameterized universal functions, using the empirically determined parameters $R_{01} = R_{02} = R_0$ and $a_{01} = a_{02} = a_0$ (thick solid and dashed lines) and ones fitted to data on cross-sections (thin solid and dashed lines), compared with experimental data [13].

5.1 Interaction potential for $^{40}$Ca+$^{238}$U system at $E_{c.m.}=193.57$ MeV (equivalently, $T=1.091$ MeV) using nuclear proximity potential of Blocki, taking $\theta=90^\circ$ and $\ell=0, 15$ and 30 h.

5.2 Interaction potentials for the $^{40}$Ca+$^{238}$U system at various $\theta$ values of $^{238}$U for $\ell=0$ case of $E_{c.m.}=181.92$ MeV using nuclear proximity potential of Blocki.

5.3 (a) Nuclear proximity potentials $V_N(R)$ calculated under sudden and frozen approximations, using Skyrme force SIII, for $\ell=0$ case and two $\theta$, values, for coplanar nuclei in $^{64}$Ni+$^{54}$Ni reaction at a given $E_{c.m.}$.

(b) Same as for (a), but for total interaction potential $V(r)$. (c) Same as for (b), but for $^{40}$Ca+$^{238}$U reaction at another $E_{c.m.}$.
5.4 Total interaction potentials $V_\ell(R)$, calculated under sudden and frozen approximations, for $\ell=0$ case of fixed $\theta_i$ and $T$ values, usingSkyrme force $\text{SIII}$, in (a) $^{58}\text{Ni}+^{58}\text{Ni}$, $^{64}\text{Ni}+^{64}\text{Ni}$, and $^{64}\text{Ni}+^{100}\text{Mo}$, and (b) $^{48}\text{Ca}+^{238}\text{U}$, $^{48}\text{Ca}+^{244}\text{Pu}$, and $^{48}\text{Ca}+^{248}\text{Cm}$ reactions. .......................... 107

5.5 Interaction potentials calculated for $\ell=0$ case of $^{64}\text{Ni}+^{100}\text{Mo}$ reaction at a fixed $E_{\text{c.m.}}$ and fixed orientations $\theta_i$, using various Skyrme forces in frozen density approximation. .......................................................... 109

5.6 Fusion-evaporation cross-sections as a function of $E_{\text{c.m.}}$, calculated by using the $\ell$-summed extended-Wong model, integrated over $\theta_i$, for Skyrme forces $\text{SIII}$, $\text{SV}$, $\text{SkM}^*$ and $\text{GSkI}$, under frozen approximation, and compared with experimental data for $^{58}\text{Ni}+^{58}\text{Ni}$ [18], $^{64}\text{Ni}+^{58}\text{Ni}$ [1] and $^{64}\text{Ni}+^{100}\text{Mo}$ [2] systems. ...................................................... 110

5.7 Same as for Fig. 5.6, but for deduced maximum angular momentum $\ell_{\text{max}}$. The $\ell_{\text{max}}$-values deduced [18] from the measured fusion-evaporation cross-sections for $^{58}\text{Ni}+^{58}\text{Ni}$ are also shown. The lines are only for the guide of eye. ............................................................... 111

5.8 Same as for Fig. 5.6, but for capture cross-sections for the systems $^{48}\text{Ca}+^{238}\text{U}$, $^{244}\text{Pu}$ and $^{248}\text{Cm}$. The experimental data is from Ref. [6]. Also shown here is the extrapolation of calculations (dot-dash line) for $\text{GSkI}$ force to a high, above-barrier energy where the sharp cut-off approximation is valid. Sharp cut-off model calculations ("stars") are made for $\theta_2=90^0$ orientation of deformed reaction partners, whereas the same for $\ell$-summed extended-Wong model are integrated over $\theta_i$. For the case of $^{48}\text{Ca}+^{248}\text{Cm}$, the calculated extended-Wong model point ("triangle") at the near-barrier energy in (c) is for the interpolated $\ell_{\text{max}}$-value from Fig. 5.9(c). ............................................. 112

5.9 Same as for Fig. 5.7, but for $^{48}\text{Ca}+^{238}\text{U}$, $^{244}\text{Pu}$ and $^{248}\text{Cm}$ systems. At the above-barrier energy, the $\ell_{\text{max}}$ value is obtained in $\ell$-summed extended-Wong model for the estimated cross-section in Sharp cut-off model, using $\text{GSkI}$ force (shown as "stars", and joined by solid lines), and an interpolation in (c) to near-barrier energy (dot-dash line) is carried out for the case of $^{48}\text{Ca}+^{248}\text{Cm}$, with $\ell_{\text{max}}$ value shown by a "triangle". ............................................. 113

6.1 The potential $V(A)$, defined by Eq. (2.17), for the energetically favored fragmentation of the compound system $^{58}\text{Yb}^*$, formed in $^{64}\text{Ni}+^{100}\text{Mo}$ reaction at a fixed temperature $T=2.0$ MeV (equivalently, $E_{\text{c.m.}}=158.8$ MeV) and $\Delta R=1.11$ fm under frozen approximation for the Skyrme force $\text{SIII}$. For mass 2, 3 and 4 fragments, the binding energy of the energetically favored fragment $^2H$, $^3H$, and $^4H$ is replaced by that of the observed $2n$, $3n$ and $4n$ fragments respectively (for example, refer to Fig. 6.2(a) for mass 4 fragment). .......................... 122

6.2 Same as for Fig. 6.1, but for charge fragmentation potential $V(Z_2)$ and preformation probability $P_0(Z_2)$, for fixed mass $A_2=4$. .......................... 123
The preformation probability $P_q$ as a function of angular momentum $\ell$ for the LPs and some light mass IMFs, calculated for the compound system $^{164}$Yb by using the fragmentation potentials of Fig. 6.1. For $\ell_{\text{max}}$ and for $\sigma_{\text{err}}(\ell) > 10^{-9}$ mb. .................................................. 124

Same as for Fig. 6.3, but for penetrability $P$. $\ell_{\text{min}}=40 \ h$ for $P_\infty(\ell) > 10^{-9}$. .......................................................... 125

Contributions of different LP channels, the $x_n$, to the total cross-section $\sigma_{\text{err}}(\ell)$ at different $E_{\text{c.m.}}$'s: (a) at $E_{\text{c.m.}}=141.1$ MeV and (b) $129.2$ MeV. .......................................................... 126

The cross-section $\sigma_\ell$ as a function of $\ell$ for LPs ($x_n, x=1-4$) calculated at energy $E_{\text{c.m.}}=141.1$ MeV for $\ell$ value up to $\ell_{\text{max}}$. The $\ell$-summed $\sum_\ell \sigma_\ell^{\text{LP}}$ are given in Table 6.1 as $\sigma_{\text{err}}^{\text{LP}}$. The inset shows the same calculation for $E_{\text{c.m.}}=129.2$ MeV. .......................................................... 127

Calculated fusion-evaporation cross-section for $^{64}$Ni+$^{100}$Mo$\rightarrow^{164}$Yb reaction under frozen approximation with Skyrme force SIII and GSkI, as a function of center-of-mass energy $E_{\text{c.m.}}$, compared with experimental data [1]. .......................................................... 129

(a) The variation of the neck-length parameter $\Delta R$ with $E_{\text{c.m.}}$ obtained for the best fit to fusion-evaporation data [1] with Skyrme forces SIII and GSkI, taking LPs as $x_n (x=1-4)$ (solid circles with solid line), and to fusion-fission CASCADE data [1] (open circles with solid line). (b) deduced $\ell_{\text{max}}$ for the Skyrme force SIII (hollow circle, solid line) and GSkI (plus symbol, dashed line). .......................................................... 130

The $\ell$-summed fragment preformation probability $P_\infty$, the penetrability $P$ and the decay cross-section $\sigma$ as a function of the light fragment mass number $A_2$ for compound system $^{164}$Yb* at $E_{\text{c.m.}}=158.8$ MeV for Skyrme force SIII. .......................................................... 131

Same as for Fig. 6.7, but for the fusion-fission cross-section, in Table 6.1. Note, that here only SFs contribute to $\sigma_f$ cross-section and is compared with CASCADE data. The CASCADE code data is from Refs. [1]. .......................................................... 132

(a) The barrier lowering $\Delta V_b$ in DCM, as defined by Eq. (2.73), deduced by fitting the cross-section, as a function of temperature $T$ for In for the nuclear proximity potential obtained from SEDF with Skyrme forces SIII (hollow circle, solid line) and GSkI (hollow triangle, dashed line) for the case of $\ell = \ell_{\text{max}}$. Comparison is also shown with the calculations that used Blocki’s formula (hollow square, dotted line). (b) same as part (a), but for outgoing channel, same as incoming channel $^{64}$Ni$+^{100}$Mo. .......................................................... 133