Competition between fusion and quasi-fission in a heavy fusing system within a quantum-statistical theory

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Outline

1. Introduction
   - Current models for compound nucleus formation
   - Motivation

2. Theory and numerical results
   - Dynamical collective Potential Energy Surface
   - Evolution of compact nuclear shapes
   - Observables

3. Remarks and conclusions
1 Introduction
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3 Remarks and conclusions
Current models for compound nucleus formation

MACROSCOPIC DYNAMICAL MODEL

Melting of the nuclei along the radius

DINUCLEAR SYSTEM MODEL

Nucleon/cluster transfer at the contact radius

Motion in mass asymmetry coordinate

$$\eta = \frac{A_1 - A_2}{A_1 + A_2}$$
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Motivation

- To reconcile the current conflicting models for compound nucleus formation.

- To incorporate the multi-particle quantum nature of the fusing system, rather than assuming a continuous macroscopic fluid.
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Dynamical collective Potential Energy Surface

Diabatic collective Potential Energy Surface: $^{256}$No

$V_{\text{diab}}$ (MeV) \hspace{1cm} \eta_0 = 0.0

$V_{\text{diab}}$ (MeV) \hspace{1cm} \eta_0 = 0.2

$V_{\text{diab}}$ (MeV) \hspace{1cm} \eta_0 = 0.625

$V_{\text{diab}}$ (MeV) \hspace{1cm} \eta_0 = 0.8
Entrance capture barrier: $^{256}$No
Entrance driving potential: $^{256}$No

The figure illustrates the potential energy $V$ (in MeV) as a function of the parameter $\eta$ for different values of $\eta_0$. The potential energy curves are labeled for $\eta_0 = 0.0$, $\eta_0 = 0.2$, $\eta_0 = 0.625$, and $\eta_0 = 0.8$. The inset shows a zoomed-in view of the potential energy at $\eta$ values from $-1$ to $1$.
Adiabatic collective Potential Energy Surface: $^{256}\text{No}$
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Evolution of compact nuclear shapes

(\nu \text{ refers to a nuclear shape})

\[
\frac{dP_\nu(t)}{dt} = \sum_{\mu \neq \nu} [\Lambda_{\nu\mu}(t)P_\mu(t) - \Lambda_{\mu\nu}(t)P_\nu(t)],
\]

where

\[
\Lambda_{\nu\mu}(t) = \lambda_{\nu\mu}^0(t) \cdot \exp[\sqrt{aE_\nu^*(t)} - \sqrt{aE_\mu^*(t)}],
\]

\[
\lambda_{\nu\mu}^0(t) \sim \exp\left\{ -\frac{(q_{\mu} - q_{\nu})^2}{\bar{\sigma}_{\nu}^2} \right\},
\]

\[
E_\nu^*(t) = E_{c.m.} - \frac{\hbar^2 J(J + 1)}{2\Theta_\nu} - V^\nu_{dyn}(t) \geq 0,
\]

\[
V^\nu_{dyn}(t) = V^\nu_{adiab}(\epsilon^*_\nu(t)) + \Delta V^\nu_{diab}(t),
\]
Evolution of compact nuclear shapes

\[ \Delta V_{\text{diab}}^\nu(t) = \sum_\alpha e_\alpha^{\nu,\text{diab}} \cdot n_\alpha^{\nu,\text{diab}}(t) - \sum_{\alpha'} e_{\alpha'}^{\nu,\text{adiab}} \cdot n_{\alpha'}^{\nu,\text{adiab}}(e_F, \epsilon_\nu^*), \]  

(6)

\[ \frac{d n_{\alpha}^{\nu,\text{diab}}(t)}{dt} = -\tau_\nu^{-1}(t) \cdot [n_{\alpha}^{\nu,\text{diab}}(t) - n_{\alpha}^{\nu,\text{adiab}}(e_F, \epsilon_\nu^*)], \]  

(7)

\[ \tau_\nu^{-1}(t) = \frac{\sum_\alpha n_{\alpha}^{\nu,\text{diab}}(t) \cdot \Gamma_\nu^\nu(e_F, \epsilon_\nu^*)}{\hbar \sum_\alpha n_{\alpha}^{\nu,\text{diab}}(t)}, \]  

(8)

Intrinsic excitation energy:

\[ \frac{d \epsilon_\nu^*(t)}{dt} = \begin{cases} -\frac{\partial \Delta V_{\text{diab}}^\nu(t)}{\partial t}, & E_\nu^*(t) \geq 0 \\ 0, & E_\nu^*(t) < 0 \end{cases}, \]  

(9)
Method of solution of the equations of motion
Probability distribution of the nuclear shapes:
$^{48}\text{Ca} + ^{208}\text{Pb} \rightarrow ^{256}\text{No}$

$t = 0.5 \times 10^{-22} \text{ s}$

$t = 2 \times 10^{-22} \text{ s}$

$t = 7 \times 10^{-22} \text{ s}$

$t = 20 \times 10^{-22} \text{ s}$
Intrinsic excitation energy of the nuclear shapes: $^{48}\text{Ca} + ^{208}\text{Pb} \rightarrow ^{256}\text{No}$
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Dependence of observables on incident energy (top), angular momentum (middle) and entrance channel (bottom)
Diabatic and shell corrections effect on $P_{CN}$
Remarks

- Preliminary calculations using a limited set of basis states.
- This is a model in development.
- Other important physical effects like deformation and orientation of the nuclei as well as the stages of capture and decay of the compound nucleus are being incorporated into the theory.
Conclusions

- The *dynamical* collective potential energy surface partially reconciles conflicting aspects of the current models for compound nucleus formation.

- The model suggests that diabatic effects play a very important role in the onset of fusion hindrance for heavy systems.

- Remaining ground-state shell corrections to the collective potential energy surface can be very important in establishing the value of the probability for compound nucleus formation.

- Very asymmetric reactions induced by closed shell nuclei seem to be the best suited to form the heaviest compound nuclei.