Dissipation during saddle to scission motion in fission

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Introduction

The evolution from equilibrium shape to scission is assumed to be adiabatic until fragments' identities are established during the approach towards scission. During this period and till final scission, actions such as exchange of energy (or angular or linear momentum) and nucleons cause *damping* that leading to energy and momentum *dissipations*. In induced fission, very *strong* damping is present in compound nuclear evolution till the saddle and slightly beyond, when collective motion is slow. The excitation energy brought in by the projectile quickly excites the internal degrees of freedom. Thereafter, as collective motions pick up, the nature of damping changes to *weak* damping and this phase continues till final scission. Weak damping allows elasto-plastic property such as giant vibrations for the nuclear matter. The weak damping phase is also called diabatic or non-adiabatic phase. In fission, the collective pre-scission kinetic energy is largely accumulated during this phase. The weak damping also allows other collective degrees to get generated.

Collective velocity versus strong or weak damping as discussed above brings up several questions. It is generally understood that damping forces are proportional to velocities. On which velocities do damping forces depend in fission? What moves and experiences frictional effects? Does damping effects depend strongly on deformation? Answers to such questions appear to be critical to find how much energy goes to fragment heat and how much to fragment collective motion.

Emergence of fragment spin bearing collective modes is a field of current interest. Spontaneous thermal generation of rotational modes arise near the scission stage where the nucleus is transformed into an excited di-nucleus under diabatic non-equilibrium conditions. Knowledge of pre-scission heat dissipation, particularly during the diabatic phase, is important to understand the emergence.

Formalism

A simple formalism was used for calculation of the pre-scission kinetic energy and fragment excitation energy using the following assumptions. It is known that the fissioning nucleus de-excites itself prior to the split by emission of particles if excess excitation energy is available initially. Therefore it is assumed that longitudinal motion in elongation coordinate gets initiated from a relatively cold nucleus, and as such, at an early stage like the saddle point, its magnitude is practically zero and the motion picks up only during the saddle to scission period.

An equation of motion for the elongation parameter R during this evolution is given by

$$M_{eff}\frac{d^2\bar{R}}{dt^2} = K\bar{R} \qquad (1)$$

where $\bar{R} = R - R_s$ where R_s is the distance parameter at the saddle point, and the effective mass M_{eff} can be approximated by the reduced mass of the fission fragments. The solution for the equation of motion with initial condition $\bar{R}$(t=0)=0 is given by

$$\bar{R} = c\ \sinh\lambda t, \qquad (2a)$$

$$\dot{\bar{R}} = c\lambda\ \cosh\lambda t \qquad (2b)$$

with constants c and λ determined from empirical considerations with the constant of proportionality

$$K = \lambda^2 M_{eff}\ . \qquad (3)$$

For the present system their values are c = 0.007 fm and $\lambda = 1.0(10^{-21}\ \text{s})^{-1}$[1].

The above is a one-dimensional model and the transverse motions are not taken into account. There are degrees of freedom present with transverse components; for example thermally generated rotational degrees and quadrupole and hexadecopole shape oscillations. To calculate their probability distribution the following method was adopted. As the system has weak damping properties, it necessitates the introduction of two nuclear temperatures, a collective temperature T_{coll} and an intrinsic temperature T_{int} [2]. By assuming that the longitudinal and transverse motions in collective excitations share the energy equally T_{coll} was calculated from half the energy available in the one-dimensional model.[Eq.(1-3)]. Detailed results will be presented in a future communication.

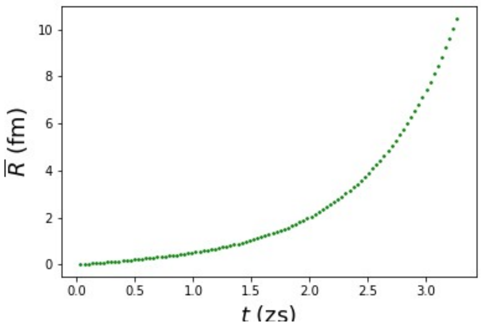

Fig.1. Elongation parameter $\bar{R} = R - R_s$as a function of time. R_s= 8 fm, is the elongation at the saddle.

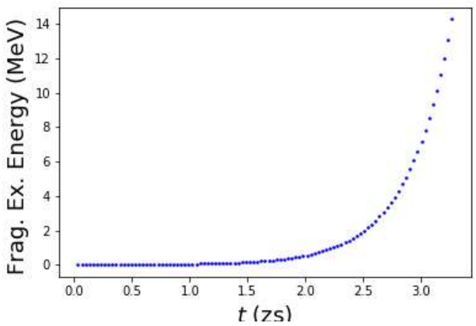

Fig.2. Fragment excitation energy generated during diabatic phase as a function of time since saddle crossing.

As a worked out example for the energy dissipated during the diabatic phase, fission of excited ^{236}U nucleus is considered. It is assumed that the available excitation is shared proportionally between the fragments in their mass ratio. The elongation parameter for symmetric fission as a function of time since saddle crossing (1zs = 10^{-21} s) is given in Fig.1. For the same case, the excitation energy in a fragment as a function of time since the saddle crossing is given in Fig.2. These results are comparable to the results of TDHF method presented in [3].

The overwhelming contribution to diabatically generated excitation in fragments comes from a narrow interval in the very last stage the fission process. An adiabatic description might be sufficient until this interval.

Discussion

Damping influences observables such as total kinetic energy and excitation energies of the fragments, broadening of fission fragment mass yields, thermal generation of angular momentum in the fragments, and near scission particle emission. We have reported recently experimental results on these topics[4-6] and supplementary new results are reported in the present symposium.

In the formation of super heavy elements, the heavy ion reactions face the damping of bombarding energy. If the damping is very strong at an early stage or midway of the reaction, too much energy will go into heat and too little to collective motion. There will be no collective drive left to put the reaction system to the fusion pocket in this case. So, the nature of dissipation discussed in the present work, though it is time reversed for heavy ion reactions, seems to be quite critical for super heavy element research.

References

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