Dynamical description of nuclear dissipation through decay of ^{248}Cf using one-dimensional Langevin dynamical model

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Introduction

Fission dynamics is necessary in many areas of physics such as nuclear astrophysics applications and studies related to the production of superheavy nuclei. A comprehensive understanding of this process is still missing due to the complex nature of the nuclear interactions. The time evolution of a fissioning nucleus can only be realized once the associated theoretical model is validated with the measured data. The measurement of the prescission particle multiplicities and giant dipole resonance (GDR) γ-ray multiplicities are important observables to investigate fission dynamics. Moreover, pre-scission neutron multiplicity is also used as a clock to measure fission lifetime [1].

The pre-scission neutron multiplicity was measured for the reaction ^{16}O+^{232}Th populationg the compound nucleus (CN) ^{248}Cf, measured earlier by Saxena *et al.* [2], and systematic analaysis of the pre-scission neutron multiplicity was carried out. It was observed that the formation delay depends on the entrance channel mass asymmetry relative to the Businaro−Gallone point. The statistical model study of the decay of ^{248}Cf is already done by Banerjee *et al.* [3]. Since the dynamical effects play a crucial role in the fission process, we, therefore, want to study the nuclear dissipative properties through decay of ^{248}Cf by using a one-dimensional Langevin dynamical model. The dynamical model calculation has been performed for the reaction ^{16}O+^{232}Th at three excitation energies 49.5, 55.2, and 60.8 MeV, for which the experimental data of pre- scission neutron multiplicity (ν_{pre}) is already measured [2].

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Dynamical Model Calculations

The time evolution of the compound nuclei is studied by using a one-dimensional Langevin dynamical model governed by the Langevin equations,

$$\frac{dp}{dt} = \frac{p^2}{2}\frac{d}{dc}\left(\frac{1}{\mathcal{M}}\right) - \frac{dF}{dc} - \frac{\eta}{\mathcal{M}}p + g\Gamma(t),$$
$$\frac{dc}{dt} = \frac{p}{\mathcal{M}}, \quad (1)$$

where c is the collective coordinate defining the deformation of a fissioning nucleus, and p is the collective momentum conjugate to c.

The shape-dependent collective inertia $\mathcal{M}(c)$ is calculated by employing the Werner-Wheeler prescription. $F(c)$ represents the Helmholtz free energy and it is calculated from the double-folding Yukawa-plus-exponential potential $V(c)$ by relation $F(c) = V(c) - (a(c) - a(0))T^2$. Here, $a(c)$ is the shape dependent level density parameter and $a(0)$ being its value for the spherical shape ($c = 1$)[4]. T is the Fermi-gas temperature corresponding to the spherical shape represented as $T = \sqrt{E^*/a(0)}$. The strength of the random force $g(c)$ is related to the dissipation coefficient $\eta(c)$ through the fluctuation-dissipation theorem: $g(c) = \sqrt{\eta(c)T}$. The time-dependent part of the random force follows the time correlation property: $\langle\Gamma(t)\Gamma(t')\rangle = 2\delta(t - t')$. A Langevin trajectory is considered as a fission event when c reaches the scission configuration, i.e., $c = 2.01$, and the corresponding time is called the fission-time τ_f.

Results and Discussion

The experimental values of the ν_{pre} are reproduced with different choices like the chaos−weighted wall friction and wall+window friction (WF) with different values of the reduction factor k_s, which is shown in Fig. 1. The chaos−weighted wall friction was not able to reproduce the experimental value of ν_{pre} at any excitation energy. The wall + window friction with reduction factor k_s = 0.5 has reproduced the experimental value of ν_{pre} at excitation energy of 49.5 MeV, and reduction factor k_s = 0.75 is required at 55.2 MeV excitation energy. We were not able to reproduce the experimental value of ν_{pre} at 60.8 MeV excitation energy with wall + window fiction description.

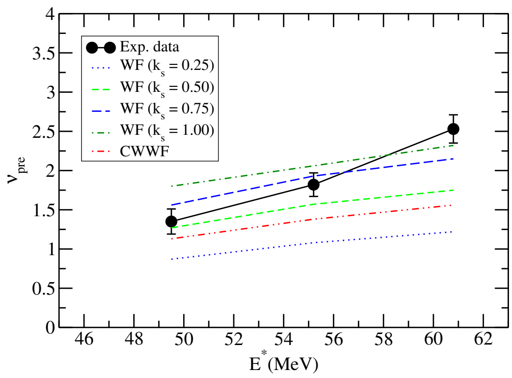

FIG. 1: Experimental values of ν_{pre} are compared with corresponding dynamical results for different type of dissipation strength.

Further, we performed calculations with the shape independent reduced dissipation β ($\beta = \eta/\mathcal{M}$) as a free parameter, which is shown in Fig. 2. As shown in Fig. 2(a), β = 4 MeV/$\hbar$ provides good agreement with the experimental data at excitation energy 49.5 MeV, and for the excitation energies 55.2 and 60.8 MeV the values of the β are 5 and 8 MeV/$\hbar$ respectivaly. Figure 2(b) shows the variation of the shape independent reduced dissipation β with respect to the excitation energy, required to reproduce the experimnatal value of ν_{pre} at a particular excitation energy.

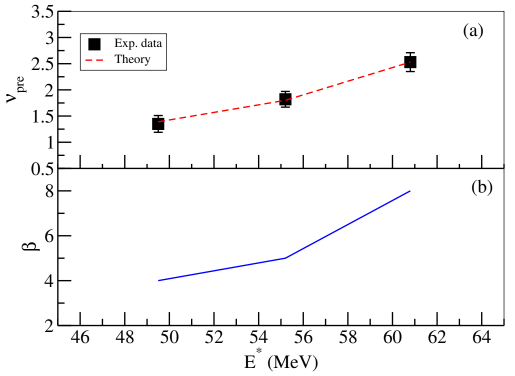

FIG. 2: (a) Experimental values of ν_{pre} (squares), and calculated ν_{pre} for ^{16}O+^{232}Th (dashed lines). The β used for the dynamical model calculations is shown in (b) for each energy point.

In the present study, the dynamical decay of the ^{248}Cf is studied considering chaos−weighted wall friction, wall+window friction (WF), and shape independent reduced dissipation. The wall+window friction (WF) with different values of the reduction factor k_s was able to reproduce the experimental data of ν_{pre}, while chaos−weighted wall friction was not able to reproduce the experimental value of ν_{pre}. It has also been observed that the shape independent reduced dissipation β is energy dependent for the present study.

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