Excitation energy and nuclear dissipation probed with evaporation-residue cross sections

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Using a Langevin equation coupled with a statistical decay model, we calculate the excess of evaporation-residue cross sections over its standard statistical-model value as a function of nuclear dissipation strength for ^{200}Hg compound nuclei (CNs) under two distinct types of initial conditions for populated CNs: (i) high excitation energy but low angular momentum (produced via proton-induced spallation reactions at GeV energies and via peripheral heavy-ion collisions at relativistic energies) and (ii) high angular momentum but low excitation energy (produced through fusion mechanisms). We find that the conditions of case (ii) not only amplify the effect of dissipation on the evaporation residues, but also substantially increase the sensitivity of this excess to nuclear dissipation. These results suggest that, in experiments, to obtain accurate information of presaddle nuclear dissipation strength by measuring evaporation-residue cross sections, it is best to choose the heavy-ion-induced fusion reaction approach to yield excited compound nuclei.

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I. INTRODUCTION

In the last two decades, experimental challenges to probe the nature and magnitude of nuclear dissipation have been carried out by using heavy-ion fusion reactions [1–20]. In particular, the determination of the presaddle dissipation strength has been the focus of intense studies [21–31]. Although prescission particles have been suggested to be a principle observable of nuclear dissipation [19], they are a less-direct signature of presaddle effects because of the interference of postsaddle emission. Therefore, it is rather inaccurate to constrain the presaddle friction strength with light-particle multiplicity as tools. To extract reliable information of the presaddle dissipation strength, it is critical to employ those experimental signatures that are uniquely sensitive to presaddle dissipation. To this end, two alternative approaches (i.e., proton- [25] and antiproton-induced [24,27] spallation reactions as well as peripheral relativistic heavy-ion collisions [21,22,26]) have recently been used to yield compound systems, and the observables investigated are fission probabilities and widths of fission-fragment charge distributions. The compound nuclei (CNs) populated in these reactions have very large excitation energies E^*—up to 1 GeV—and low angular momenta, which is in sharp contrast with the situation of fusion reactions via which the formed CNs have high spin ℓ_c ($\sim 75\hbar$ [32]) but low excitation energy (<250 MeV). The motivation for choosing these new experimental avenues is based on the assumptions that high E^* can significantly increase the effects of dissipation on fission observables due to the shortened particle evaporation time and that low ℓ_c can reduce side effects associated with high angular momentum, which possibly favors a survey of transient effects arising from presaddle friction.

To facilitate the planning of new experiments and to gain a more complete and clear understanding for the role of excitation energy in probing presaddle nuclear dissipation strength, the present work compares two different types of initial conditions for the formed CNs; namely (high E^*, low ℓ_c) and (high ℓ_c, low E^*), with the aim of determining which condition (i.e., which type of experimental approach) is more favorable for revealing presaddle dissipation effects. Because evaporation-residue cross sections are considered to be the most sensitive indicator of the friction strength inside the saddle point [6,9], we will make a detailed computation and comparison for the sensitivity of evaporation residues to presaddle nuclear friction under the condition of (high E^*, low ℓ_c) and of (high ℓ_c, low E^*) within the framework of Langevin models. In the model, the dynamics associated with the fission degree of freedom is usually considered to be similar to that of a Brownian particle floating in a viscous heat bath. The heat bath in this picture represents all the other nuclear degrees of freedom, which are assumed to be in thermal equilibrium. The interaction between this large number of intrinsic degrees of freedom and the fission degree of freedom gives rises to a random force and, consequently, a dissipative drag on the dynamics of fission [33,34]. The stochastic model [33–40] has been employed to successfully reproduce a great number of experimental data on prescission particle multiplicities and evaporation-residue cross sections for a lot of compound systems over a wide range of excitation energy, angular momentum, and fissility. Furthermore, it was applied to survey fission dynamics at very high energy ($\sim$750 MeV) [30] and in regions of superheavy nuclei ($Z \sim 110$) [41,42].

This article is organized as follows: Section II briefly describes the Langevin model, our results are presented and discussed in Sec. III, and a summary and conclusion is given in Sec. IV.

II. THEORETICAL MODEL

An account of the combined Langevin equation coupled with a statistical decay model (CDSM) [43,44] is given. The dynamic part of the CDSM is described by the Langevin equation that is expressed by entropy. We employ the following one-dimensional overdamped Langevin equation [43] to perform the trajectory calculations:

$$\frac{dq}{dt} = \frac{T}{M\beta}\frac{dS}{dq} + \sqrt{\frac{T}{M\beta}}\Gamma(t). \quad (1)$$

Here, q is the dimensionless fission coordinate and is defined as half the distance between the center of mass of the future fission fragments divided by the radius of the compound nucleus, M is the inertia parameter, and β is the dissipation strength. The temperature in Eq. (1) is denoted by T and $\Gamma(t)$ is a fluctuating force with $\langle\Gamma(t)\rangle = 0$ and $\langle\Gamma(t)\Gamma(t')\rangle = 2\delta(t-t')$. The driving force of the Langevin equation is calculated from the entropy:

$$S(q, E^*, A, Z, \ell) = 2\sqrt{a(q, A)[E^* - V(q, A, Z, \ell)]}. \qquad (2)$$

The entropy depends on the mass number A and charge number Z of the fissioning nucleus, which are changing due to particle evaporation during fission. The angular momentum ℓ due to rotation is also indicated. E^* is the total internal energy of the system. Equation (2) is constructed from the Fermi-gas expression with a finite-range liquid-drop potential $V(q)$ [45,46] in the $\{c, h, \alpha\}$ parametrization [47]. Since only symmetric fission is considered, the parameter describing the asymmetry of the shape is set to $\alpha = 0$. The q-dependent surface, Coulomb, and rotation-energy terms are included in the potential $V(q, A, Z, \ell)$ [43].

In constructing the entropy, the deformation-dependent level density parameter $a(q, A)$ is used [48,49]:

$$a(q, A) = a_1 A + a_2 A^{2/3} B_s(q). \qquad (3)$$

The values of the parameters $a_1 = 0.073$ MeV^{-1} and $a_2 = 0.095$ MeV^{-1} in Eq. (3) have been taken from the work of Ignatyuk *et al.* [49] and are consistent with the data [31,38,43]. B_s is the dimensionless surface area (for a sphere $B_s = 1$) which can be parametrized by the analytical expression [50]

$$B_s(q) = \begin{cases} 1 + 2.844(q-0.375)^2, & \text{if } q < 0.452 \\ 0.983 + 0.439(q-0.375), & \text{if } q \geqslant 0.452. \end{cases} \qquad (4)$$

In the CDSM, evaporation of prescission light particles along Langevin fission trajectories from their ground state to their scission point has been taken into account using a Monte Carlo simulation technique. Although particle emission is on a much faster time scale than fission, it will be affected by the latter because the intrinsic excitation energy $E^*_{\rm intr}[= E^* - V(q)]$ that is important in particle-emission width [see Eq. (5)] is a function of fission coordinate q. In addition, fission processes are also affected by particle evaporation because, after emission of a particle, the angular momentum, mass, charge, and energy remaining in the fissioning have changed. As seen, both influence each other; that is, particle evaporation is coupled to the motion of fission. The emission width of a particle of type ν $(= n, p, \alpha)$ is given by [51]

$$\Gamma_\nu = (2s_\nu + 1)\frac{m_\nu}{\pi^2\hbar^2\rho_c(E^*_{\rm intr})} \times \int_0^{E^*_{\rm intr}-B_\nu} d\varepsilon_\nu \rho_R(E^*_{\rm intr} - B_\nu - \varepsilon_\nu)\varepsilon_\nu\sigma_{\rm inv}(\varepsilon_\nu), \qquad (5)$$

where s_ν is the spin of the emitted particle ν and m_ν is its reduced mass with respect to the residual nucleus. The level densities of the compound and residual nuclei are denoted by $\rho_c(E^*_{\rm intr})$ and $\rho_R(E^*_{\rm intr} - B_\nu - \varepsilon_\nu)$, respectively. The intrinsic excitation energy is $E^*_{\rm intr}$, B_ν are the particle binding energies [45], ε is the kinetic energy of the emitted particle, and $\sigma_{\rm inv}(\varepsilon_\nu)$ is the inverse cross section [51].

The present simulation allows for the discrete emission of light particles. The procedure is as follows: We calculate the decay widths for light particles at each Langevin time step τ. Then the emission of a particle is allowed by asking whether, along the trajectory at each time step τ, a random number ζ is less than the ratio of the Langevin time step τ to the decay time $\tau_{\rm dec} = \hbar/\Gamma_{\rm tot}$: $\zeta < \tau/\tau_{\rm dec}$ $(0 \leqslant \zeta \leqslant 1)$, where $\Gamma_{\rm tot}$ is the sum of light-particle decay widths. If this is the case, a particle is emitted and we ask for the particle type ν $(\nu = n, p, \alpha)$ by a Monte Carlo selection with the weights $\Gamma_\nu/\Gamma_{\rm tot}$. This procedure simulates the law of radioactive decay for the different particles.

After each act of emitting a particle of type ν, the energy of the emitted particle is calculated by a hit-and-miss Monte Carlo procedure that uses the integrand of the formula for the corresponding decay width as a weight function. Then the intrinsic energy, entropy, and temperature in the Langevin equation are recalculated and the dynamics is continued. The loss of angular momentum is taken into account by assuming that a neutron carries away $1\hbar$, a proton $1\hbar$, and an α particle $2\hbar$. As seen, Eq. (5) is calculated for each event (i.e., each trajectory simulating the fission motion) with time-dependent excitation energy, and then in CDSM the average is taken over those Langevin trajectories that lead to fission (or evaporation-residue) events.

A dynamic trajectory will either reach the scission point, in this case it is counted as a fission event, or, if the intrinsic excitation energy $E^*_{\rm intr}$ for a trajectory still inside the saddle $(q < q_{\rm sd})$ reaches a value $E^*_{\rm intr} < \min(B_f, B_\nu)$ (B_f is the height of the fission barrier and B_ν is the binding energy of the particle ν), then the event is counted as an evaporation-residue event. We do not follow the subsequent cooling of the evaporation residues which proceeds exclusively by γ-ray emission. When the dynamical description reaches a quasistationary region (i.e., fission probability flow over the fission barrier attains its quasistationary value), the decay of compound systems is described by the statistical part of the CDSM. When entering the statistical branch we calculate the decay widths Γ_ν again according to Eq. (5) and the fission width according to Ref. [33] and use a standard Monte Carlo cascade procedure which allows for multiple emissions of light particles and higher-chance fission. After each emission act we again recalculate the intrinsic energy and the angular momentum and continue the cascade until the intrinsic energy is $E^*_{\rm intr} < \min(B_f, B_\nu)$. In this case we count the event as evaporation residue and do not follow the deexcitation process further. Evaporation-residue cross sections are calculated by counting the number of corresponding evaporation-residue events registered in the dynamic and statistical branch of the CDSM.

For starting a trajectory, an orbit angular momentum value is sampled from the fusion spin distribution, which reads [33]

$$\frac{d\sigma(\ell)}{d\ell} = \frac{2\pi}{k^2}\frac{2\ell + 1}{1 + \exp[(\ell - \ell_c)/\delta\ell]}. \qquad (6)$$

The parameters ℓ_c and $\delta\ell$ are the critical angular momenta for fusion and diffuseness, respectively. The final results are weighted over all relevant waves; namely, the spin distribution is used as the angular momentum weight function. Note that the present model, which is based on the approximation of overdamped motion, applies to the case of $\beta \geqslant 2 \times 10^{21}\ \mathrm{s}^{-1}$ [50].

III. RESULTS AND DISCUSSION

Because the population of the evaporation residues depends only on the dissipation strength β inside the barrier, to better reveal the presaddle friction effects on the residues, dynamical calculations are performed herein considering different values of β, which are equal to 3, 5, 7, 10, 15, and $20 \times 10^{21}\ \mathrm{s}^{-1}$ throughout the whole fission process. To accumulate sufficient statistics, 10^7 Langevin trajectories are simulated.

Dissipation hinders fission, resulting in a deviation of the measured evaporation-residue (ER) cross sections from that predicted by the standard statistical model. Thus, the amplitude of the deviation is extremely sensitive to the strength of nuclear dissipation. A study of the deviation can thus provide a method to determine β. For this study, we adopt a definition similar to that suggested by Lazarev, Gontchar, and Mavlitov [52] and define the relative excess of evaporation residues calculated by taking into account the dissipation and fluctuations of collective nuclear motion over its standard statistical-model (SSM) value:

$$\sigma_{\mathrm{ER}}^{\mathrm{excess}} = \frac{\langle \sigma_{\mathrm{ER}}^{\mathrm{dyn}} \rangle - \langle \sigma_{\mathrm{ER}}^{\mathrm{SSM}} \rangle}{\langle \sigma_{\mathrm{ER}}^{\mathrm{SSM}} \rangle}. \tag{7}$$

Figure 1 shows dissipation effects on ER excess ($\sigma_{\mathrm{ER}}^{\mathrm{excess}}$) of Hg compound nuclei at the same ℓ_c but at two different E^*. Obviously, symbols ■ are above △ for any β, meaning that a higher E^* leads to a larger influence of β on $\sigma_{\mathrm{ER}}^{\mathrm{excess}}$. The reason is that particle evaporation time becomes short at high E^*, which enhances the effects of dissipation on particle emission prior to the saddle and hence increases ER survival, as expected.

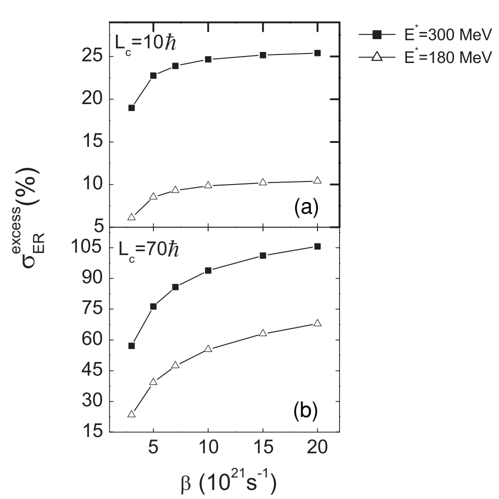

FIG. 1. Comparison of excess of evaporation residues over standard-statistical values versus dissipation strength β for ^{200}Hg nuclei between case (i) $E^* = 300$ MeV, $\ell_c = 10\hbar$, $70\hbar$ and case (ii) $E^* = 180$ MeV, $\ell_c = 10\hbar$, $70\hbar$.

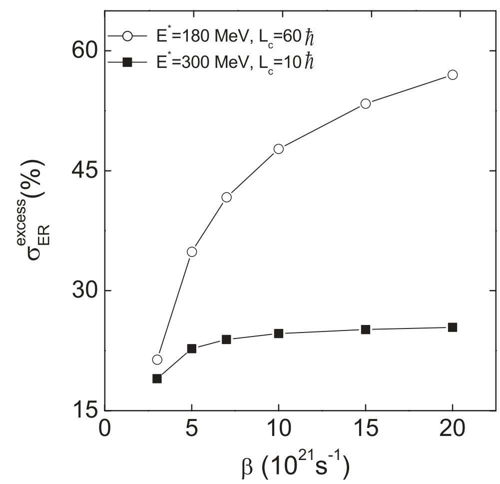

FIG. 2. Comparison of excess of evaporation residues over standard-statistical values versus dissipation strength β for ^{200}Hg nuclei between case (i) $E^* = 300$ MeV and $\ell_c = 10\hbar$ and case (ii) $E^* = 180$ MeV and $\ell_c = 60\hbar$.

In Fig. 2, we compute $\sigma_{\mathrm{ER}}^{\mathrm{excess}}$ as a function of β for two cases: (i) ($E^* = 300$ MeV, $\ell_c = 10\hbar$) and (ii) ($E^* = 180$ MeV, $\ell_c = 60\hbar$). As seen, $\sigma_{\mathrm{ER}}^{\mathrm{excess}}$ is greater in the latter case. The picture is distinct from that of Fig. 1(a) where high E^* yields a larger $\sigma_{\mathrm{ER}}^{\mathrm{excess}}$. We note that, when the conditions of case (ii) are used in solving the Langevin equation, except for a difference in ℓ_c with that used by symbols △ in Fig. 1(a), other conditions such as E^* and β are the same. Moreover, a low ℓ_c in case (i) can raise the height of the fission barrier, making the CNs remain longer inside the barrier, which is more favorable for ER survival. However, $\sigma_{\mathrm{ER}}^{\mathrm{excess}}$ is found to be greater in case (ii). Considering that whether CN undergoes fission or survives as ER is decided mainly within the saddle point, the picture seen in Fig. 2 suggests that there should exist other crucial factors that affect the ERs, apart from the known excitation energy and friction strength. Because fission rates turn out to be sensitive to the coordinate dependence of the level density parameter [43,53], it implies that the level density parameter significantly affects the amplitude of fission probability; that is, the ratio of level density parameters at the saddle point to that at the ground state, a_f/a_n, is also a vital factor in the competition between fission and evaporation channels.

Calculating the ratio a_f/a_n within the framework of CDSM proceeds as follows: First, the entropy S is related to the level density parameter $a(q, A)$ by Eq. (2). In this way information concerning $a(q, A)$ is introduced into the equation of motion [Eq. (1)]. Second, dynamical calculations are performed to search for the stationary point (related to the saddle point configuration) of the entropy by comparing the magnitude of $S(q)$ at different q following the method given in [54]. As a result, the deformation coordinate of the saddle point configuration, q_{sd}, is determined. Third, by using Eq. (3), the values of the level density parameter $a(q, A)$ at the saddle point deformation q_{sd}, a_f, and at the ground state (where $B_s = 1$, because it is assumed in CDSM that the fissioning nucleus is spherical in shape at the bottom of the potential), a_n, are worked out. Thus, the ratio a_f/a_n is obtained.

Because of the importance of the parameter a_f/a_n in the decay of CNs, we evaluate its dependence on angular momentum and excitation energy within the framework of CDSM. The result is displayed in Fig. 3, from which two features are noticed. First, a_f/a_n is a function of angular momentum ℓ. The higher is ℓ, the smaller is a_f/a_n. The dependence of a_f/a_n on ℓ is because a change in CN spin modifies the location of the saddle point [43]. Owing to the shape dependence of the level density parameter [see Eq. (3)], the magnitude of a_f/a_n is clearly different at $\ell = 10\hbar$ and $60\hbar$.

The second feature is that a_f/a_n is also a function of E^*. The reason for this is that the driving force of a hot system is not simply the negative gradient of the conservative potential but should contain a thermodynamical correction, as pointed out in Refs. [44,55,56]. Therefore, the crucial quantity adopted in our dynamical calculations is not the bare potential $V(q)$ but the entropy $S(q, E^*, \ell)$. Thus, the saddle point position is defined by the stationary point of entropy and not, as in the conventional approach, by the potential energy [54]. Furthermore, because the entropy changes with E^*, this leads to a shift in the stationary position of the saddle point configuration and, correspondingly, to a change in the level density parameter at this point. Note that the excitation energy dependence of a_f/a_n and its angular momentum dependence are treated simultaneously in the CDSM.

Our calculations show that, throughout the deexcitation process, the decaying CNs have lower a_f/a_n in case (ii) than in case (i). For instance, CDSM predicts that a_f/a_n is 1.012 at ($E^* = 180$ MeV, $\ell_c = 60\hbar$) and 1.026 at ($E^* = 300$ MeV, $\ell_c = 10\hbar$). Given the opposing contributions that high a_f/a_n and friction make to the magnitude of fission probability (or its complementary quantity, the ER survival probability), the difference in a_f/a_n means that a greater influence arising from a high a_f/a_n [for case (i)] on the survival probability weakens the influence of friction on it more strongly than does a low a_f/a_n [for case (ii)]. This demonstrates that, when ER cross sections are employed as a tool to reveal presaddle dissipation effects, it is optimal to adopt fusion reactions to yield excited compound systems.

In addition, we observe from Fig. 2 that the steepness of $\sigma_{\rm ER}^{\rm excess}$ vs. β, which reflects the sensitivity of the ER excess to variations in friction strength, is appreciably different between the two cases. Specifically, as β changes from 3×10^{21} s^{-1} to 20×10^{21} s^{-1}, $\sigma_{\rm ER}^{\rm excess}$ increases by 35.61% for case (i), which is far more than that for case (ii), where the increase is only 6.42%. The physical mechanism giving rising to the different sensitivities to presaddle friction of the ERs in the two cases is the counterbalanced effects of friction and level density parameters on the amplitude of ER-survival probability. A rise in a_f/a_n favors fission rather than ER survival, in contrast with the role of friction. Consequently, the large a_f/a_n in case (i) reduces the sensitivity of the ER excess to friction more significantly. Therefore, the feature appearing in Fig. 2 also illustrates that, on the experimental side, forming CNs via a fusion mechanism can substantially improve the sensitivity of the evaporation residues to nuclear dissipation.

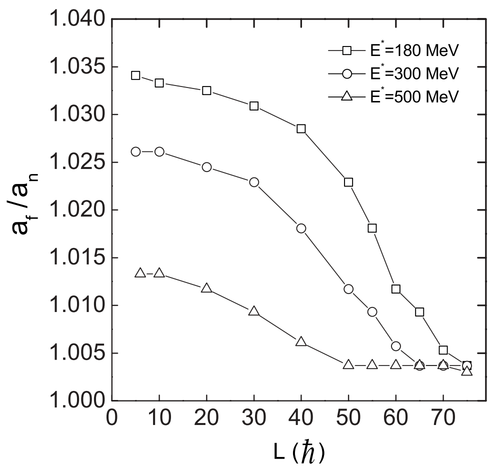

FIG. 3. Ratio of level density parameters at saddle to that at ground-state configurations, a_f/a_n, as a function of angular momentum ℓ for excitation energy $E^* = 180$, 300, and 500 MeV.

Because a_f/a_n plays a pivotal role in the previous analysis for the difference in the results of cases (i) and (ii) (see Fig. 2), to test the conclusion, further comparisons are made by altering the amplitude of the difference of a_f/a_n for the two comparative cases. For this purpose we perform two additional calculations. We first show in Fig. 4 the calculation at ($E^* = 180$ MeV, $\ell_c = 70\hbar$) (denoted by $\triangle$). As seen in Fig. 3, a_f/a_n drops with rising ℓ. According to the explanation given previously, it can be expected that this will yield a more significant sensitivity to friction at $\ell_c = 70\hbar$ than at $\ell_c = 60\hbar$. The expectation is justified in Fig. 4. Because CNs produced by heavy-ion fusion can reach a high-spin value, the obvious difference in the sensitivity of $\sigma_{\rm ER}^{\rm excess}$ vs. β found for the two ℓ_c further exhibits that exciting compound systems by using a fusion approach can provide more favorable conditions to probe presaddle friction; namely, it can place a more stringent constraint on the determination of the presaddle friction strength.

Another calculation is carried out for even higher energies. Although CNs formed in spallation reactions and peripheral relativistic heavy-ion collisions have very high excitation energies (~1 GeV), when $E^* > 500$ MeV other phenomena occur, such as nuclear expansion [57] and multifragmentation [58], which are not accounted for in the CDSM framework. For this reason our calculations are restricted to energies below 500 MeV. Figure 3 shows that, when E^* rises from 300 to 500 MeV, a_f/a_n at $\ell_c = 10\hbar$ is much reduced, and its difference with a_f/a_n at ($E^* = 180$ MeV, $\ell_c = 60\hbar$) also becomes small. In addition, with increasing E^* the speed of particle emission is faster than fission [30,43]. The two aspects cause a rise of the ER excess at an excitation energy of 500 MeV. As a result, the $\sigma_{\rm ER}^{\rm excess}$ at ($E^* = 500$ MeV, $\ell_c = 10\hbar$) is greater than that at ($E^* = 180$ MeV, $\ell_c = 70\hbar$) for $\beta \leqslant 5 \times 10^{21}$ s^{-1}, but it is below the $\sigma_{\rm ER}^{\rm excess}$ at ($E^* = 225$ MeV, $\ell_c = 70\hbar$), independent of β. Moreover, one can see from Fig. 4 that the rate of change of ER excess with variation in β in case (ii) is still greater than that in case (i); for example, $\sigma_{\rm ER}^{\rm excess}$ changes by 31.85% at ($E^* = 180$ MeV, $\ell_c = 70\hbar$) and

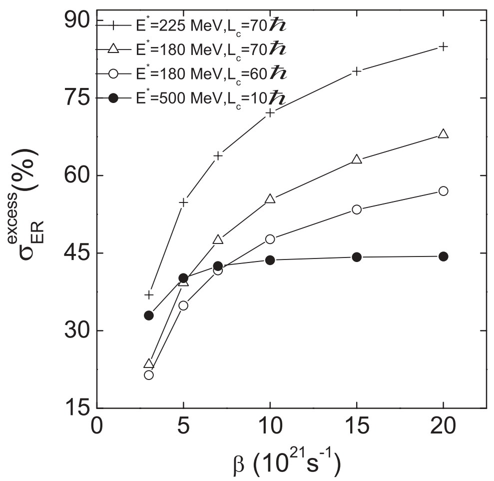

FIG. 4. Comparison of excess of evaporation residues over standard-statistical values versus dissipation strength β for ^{200}Hg nuclei between case (i) $E^* = 500$ MeV, $\ell_c = 10\hbar$ and case (ii) $E^* = 180$ MeV, $\ell_c = 60\hbar$, $70\hbar$; $E^* = 225$ MeV, $\ell_c = 70\hbar$.

by 35.18% at ($E^* = 225$ MeV, $\ell_c = 70\hbar$) as β varies from 3×10^{21} s^{-1} to 10×10^{21} s^{-1}, whereas at ($E^* = 500$ MeV, $\ell_c = 10\hbar$) it changes by 10.69%. The numerical comparison clearly indicates an enhanced sensitivity of ER excess to β under the conditions of case (ii). Taken together, we can conclude that populating CNs through heavy-ion fusion is preferable for investigating dissipation strength.

Because a rather small variation in the a_f/a_n could result in a prominent change in the competition between fission and evaporation [24,59,60], many authors (e.g., Refs. [23,61]) applied statistical models to reproduce measured ER cross sections and other types of fission data by slightly adjusting the magnitude of a_f/a_n. But in the present study a_f/a_n is not a free parameter—it is completely governed by the dynamics of presaddle fission. In addition, a number of studies [62–65] have shown that, at higher excitation energies, smaller values of the level density parameter are needed to reproduce the kinetic energy spectra of evaporated particles, suggesting that level density parameters must depend on the excitation energy, in agreement with the prediction by the CDSM.

Various magnitudes of the friction coefficient have been reported. An analysis of emitted prescission particles indicates that the magnitude of presaddle β is 5 to 8×10^{21} [66], 3 to 10×10^{21} [67], and 5×10^{21} [36] s^{-1}. From the data of giant dipole-resonance γ-ray decay and evaporation-residue cross sections, the β value extracted is 4 to 6×10^{21} [6], $\leqslant 10 \times 10^{21}$ [9], and $<8 \times 10^{21}$ [10] s^{-1}. A best fit for measured evaporation-residue spin distributions reveals a presaddle β of 5×10^{21} s^{-1} [31]. Studies on the mass- and kinetic-energy distributions of fission fragments give a friction value of 5.5×10^{21} s^{-1} [68]. No significant transient effects are seen from the data of fission probabilities [25]. By reproducing prescission neutrons and fragment kinetic energies, the value of β is determined to be around 20×10^{21} s^{-1} [34], which is comparable to the predication by the one-body dissipation model. Based on a survey for fission-fragment charge distributions, β is suggested to be 2 to 5×10^{21} s^{-1} [22,26]. The diverse estimates (from 2×10^{21} s^{-1} to 20×10^{21} s^{-1}) for the magnitude of the friction coefficient indicate that, to obtain a precise β, related research on which conditions can improve the sensitivity of fission observables on presaddle friction is very urgent.

IV. SUMMARY AND CONCLUSIONS

In summary, we used the dynamical Langevin model to investigate the role of excitation energy in probing presaddle friction with evaporation-residue (ER) cross sections for two comparative cases: (i) high excitation energy and low angular momentum and (ii) low excitation energy and high angular momentum. The ER excess over its standard statistical-model value originates from dissipation effects. We find that, under the conditions of case (ii), the effect of nuclear dissipation on the ER excess is enhanced appreciably and the sensitivity of this excess to nuclear friction is also increased substantially. Because case (ii) incorporates the characteristics of compound nuclei populated by fusion reactions and not by spallation and peripheral relativistic heavy-ion reactions, our results suggest that, in experiments, to accurately determine the strength of presaddle dissipation through the measurement of evaporation-residue cross sections (or fission cross sections), it is best to choose a heavy–ion-induced fusion approach to yield excited compound nuclei.

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