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

W. Ye

Phys. Rev. C **83**, 044611 — Published 18 April 2011

DOI: 10.1103/PhysRevC.83.044611

Excitation energy and nuclear dissipation probed with evaporation residue cross sections

W. Ye

Department of Physics, Southeast University, Nanjing 210096, Jiangsu Province, People's Republic of China

Abstract

Using a Langevin equation coupled with a statistical decay model, we calculate the excess of evaporation residue cross sections over its standard statistical-model values as a function of nuclear dissipation strength for ^{200}Hg compound nuclei (CN) under two distinct types of initial conditions for the populated CN: (i) high excitation energy but low angular momentum (produced via proton-induced spallation reactions at a GeV energy regime 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 dissipation effects on the evaporation residues, but also increase the sensitivity of this excess to nuclear dissipation substantially. These results suggest that in experiments, to obtain accurate information of presaddle nuclear dissipation strength by measuring evaporation residue cross sections, it is optimal to choose heavy-ion induced fusion reaction approach to yield excited compound nuclei.

PACS numbers: 25.70.Jj, 25.70.Gh, 24.10.-i, 24.60.Ky

I. INTRODUCTION

Experimental challenges to probe the nature and magnitude of nuclear dissipation have been carried out by using heavy-ion fusion reactions in the last two decades [1–20]. In particular, the determination of presaddle dissipation strength is 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, recently 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 been used to yield compound systems, and the observables investigated are fission probabilities and widths of fission-fragment charge distributions. The compound nuclei (CN) 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 CN 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 dissipation effects on fission observables due to shorten 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 which arise from presaddle friction.

To facilitate to plan 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 is devoted to a comparative study of two different types of initial conditions for the formed CN, namely (high E^*, low ℓ_c) and (high ℓ_c, low E^*), with the aim of determining which type of conditions (i.e., which type of experimental approaches) is more favorable for revealing presaddle dissipation effects. Because evaporation residue cross sections are considered to be the most sensitive indicator for 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 the rest of 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 evaporation 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 at superheavy nuclei regions ($Z \sim 110$) [41, 42].

The article is organized as follows. Section II describes the Langevin model in brief. Our results will be presented and discussed in Sec. III. A summary and conclusion is contained 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 dynamical part of the CDSM model 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

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

Here q is the dimensionless fission coordinate and is defined as half of the distance between the center of mass of the future fission fragments divided by the radius of the compound nucleus, M 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 $< \Gamma(t) > = 0$ and $< \Gamma(t)\Gamma(t') >$ $= 2\delta(t - t')$. The driving force of the Langevin equation is calculated from the entropy

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

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 the rotation motion is also indicated. E^* is the total internal energy of the system. Eq.(2) is constructed from the Fermi gas expression with a finite-range liquid-drop potential [45, 46] $V(q)$ in the $\{c, h, \alpha\}$ parametrization [47]. Since only symmetrical 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]

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

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]

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

In the CDSM evaporation of prescission light particles along Langevin fission trajectories from its ground state to its 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^*_{intr} $[= E^* - V(q)]$ that plays an important role 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 a particle emission, the angular momentum, mass, charge, and energy remaining in the fissioning are changed. As seen, both are influenced each other; that is, particle evaporation is coupled to the motion of fission. The emission width of a particle of kind ν $(= n, p, \alpha)$ is given by [51]

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

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

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

After each emission act of a particle of kind ν the energy of the emitted particle is calculated by a hit and miss Monte Carlo procedure, using the integrand of the formula for the corresponding decay width as weight function. Then the intrinsic energy, the entropy, and the 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 leading to fission (or evaporation residue) events.

A dynamical trajectory will either reach the scission point, in this case it is counted as a fission event, or if the intrinsic excitation energy E^*_{intr} for a trajectory still inside the saddle $(q < q_{sd})$ reaches a value $E^*_{intr} < \min(B_f,\, B_\nu)$ (B_f is the height of the fission barrier and B_ν the binding energy of the particle ν) 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 quasi-stationary region (i.e. fission probability flow over the fission barrier attains its quasi-stationary 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 $E^*_{intr} < \min(B_f,\, B_\nu)$. 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 countering the numbers of the corresponding evaporation residue events registered in the dynamical and statistical branch of the CDSM.

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

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

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. It needs to be mentioned that the present model based on the approximation of overdamped motion applies to the case of $\beta \geq 2 \times 10^{21} s^{-1}$ [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, in this paper dynamical calculations are performed considering different values of β, which is 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. So the amplitude of the deviation is extremely sensitive to the strength of nuclear dissipation. A study of the deviation can thus provide a method of determining 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,

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

Figure 1 shows dissipation effects on the ER excess (σ_{ER}^{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 σ_{ER}^{excess}. The reason is that particle evaporation time becomes short at high E^*, which enhances the dissipation effects on the particle emission prior to saddle and hence increases ER survival, as expected.

In Fig.2, we compute the σ_{ER}^{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, σ_{ER}^{excess} is greater in the latter case. The picture is distinct from Fig.1(a) where high E^* yields a larger σ_{ER}^{excess}. We note that when the conditions of case (ii) are used in solving the Langevin equation, except a difference in ℓ_c with that used by symbols $\triangle$ 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 fission barrier, making CN stay a longer time inside the barrier which is more favorable for ER survival. But σ_{ER}^{excess} is found to be greater in case (ii). Considering that CN undergoing fission or surviving as an ER are decided mainly within the saddle point, the picture seen in Fig.2 thus suggests that there should exist other crucial factors that affect the ERs, apart from the known excitation energy and friction strength. As fission rates turn out to be sensitive to the coordinate dependence of the level density parameter [43, 53], it implies a significant effect of the level density parameter on the amplitude of fission probability, that is, the ratio of level-density parameters at saddle point to that at ground state, a_f/a_n, is also a vital factor in influencing the competition between fission and evaporation channels.

Calculations of the ratio a_f/a_n within the framework of CDSM are as follows. First, entropy S is related to the level density parameter $a(q, A)$ by Eq.(2). In this way information concerning the $a(q, A)$ 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, 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 (at which $B_s = 1$, as it is assumed in CDSM that the fissioning nucleus is in a spherical shape at the potential bottom), a_n, are worked out. So the ratio a_f/a_n is obtained.

Because of the importance of the parameter a_f/a_n in CN decays, 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 the ℓ, the smaller the 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 position [43]. Owing to the shape dependence of the level density parameter [see Eq.(3)], consequently, the magnitude of a_f/a_n has an evident difference at $\ell = 10\hbar$ and $60\hbar$.

The second feature is that a_f/a_n is also a function of E^*. The cause for it 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 bare potential $V(q)$ but entropy $S(q, E^*, \ell)$. So 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 of the stationary position of the saddle point configuration and correspondingly, the change of the level density parameter at this point. It is worth mentioning 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 de-excitation process the decaying CN have lower a_f/a_n values in case (ii) than those in case (i); for instance CDSM predicts that the value of 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 opposite contributions that high a_f/a_n and friction make to the magnitude of fission probability (or its complementary quantity, i.e. ER survival probability), the difference in a_f/a_n means that a greater influence arising from a high ratio a_f/a_n [for case (i)] on the survival probability weakens the influence of friction on it more strongly as compared to the situation of a low ratio 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 σ_{ER}^{excess} vs. β, which reflects the sensitivity of the ER excess to the variation of the friction strength, has an appreciable difference for the two cases. Specifically, as β changes from $3\times10^{21}s^{-1}$ to $20\times10^{21}s^{-1}$, σ_{ER}^{excess} increases by 35.61% for case (i), which is far over that for case (ii), where the increase is only 6.42%. The physical mechanism giving rising to different sensitivities of ERs in the two cases to presaddle friction is the counterbalanced effects of friction and level density parameters on the amplitude of ER survival probability. A rise of a_f/a_n is in favor of fission rather than ER survival, in contrast with the role of friction. Consequently, the large a_f/a_n value 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 CN via a fusion mechanism can substantially improve the sensitivity of the evaporation residues to nuclear dissipation.

Because a_f/a_n plays a pivotal role in the previous analysis for the difference in the results of case (i) and case (ii) (see Fig.2), in order 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 firstly 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 raising 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 CN produced by heavy-ion fusion can reach a high-spin value, an obvious difference in the sensitivity of σ_{ER}^{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 of probing presaddle friction, namely, it can place a more stringent constraint on the determination of the presaddle friction strength.

Another calculation is carried out at even high energy. Although CN formed in spallation reactions and peripheral relativistic heavy-ion collisions have a very high excitation energy ($\sim$ 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. Because of the reason our calculations are restrict to the energies below 500 MeV. Figure 3 shows that when E^* rises from 300 MeV to 500 MeV the value of a_f/a_n at $\ell_c = 10\hbar$ is much reduced, and its difference with the 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 σ_{ER}^{excess} at ($E^* = 500$ MeV, $\ell_c = 10\hbar$) is over that at ($E^* = 180$ MeV, $\ell_c = 70\hbar$) for $\beta \leq 5 \times 10^{21} s^{-1}$. But it is below the σ_{ER}^{excess} at ($E^* = 225$ MeV, $\ell_c = 70\hbar$) independent of β. Moreover, one can see from Fig.4 that the rate of the change of the ER excess with the variation of β in case (ii) is still greater than that in case (i); for example σ_{ER}^{excess} changes by 31.85% at ($E^* = 180$ MeV, $\ell_c = 70\hbar$) and by 35.18% at ($E^* = 225$ MeV, $\ell_c = 70\hbar$) as β varies from $3 \times 10^{21} s^{-1}$ to $10 \times 10^{21} s^{-1}$, whereas at ($E^* = 500$ MeV, $\ell_c = 10\hbar$) it changes by 10.69%. The numerical comparison clearly indicates an enhanced sensitivity of the ER excess to β under the conditions of case (ii). Taken together, we can conclude that populating CN through heavy-ion fusion is more preferable for investigation of dissipation strength.

Because a rather small variation in the ratio a_f/a_n could result in a prominent change of the competition between fission and evaporation [24, 59, 60], many authors (e.g., those in [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] has 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 be dependent on the excitation energy in agreement with the prediction by CDSM.

Various magnitudes of the friction coefficient have been reported. An analysis of emitted prescission particles indicates that the magnitude of presaddle β is (5−8) $\times 10^{21}$ [66], (3−10) $\times 10^{21}$ [67], and 5 $\times 10^{21}$ [36] (s^{-1}). From the data of giant dipole resonance γ-ray decay and evaporation residue cross sections, the β value extracted is (4−6) $\times 10^{21}$ [6], $\leq$ 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 $\times 10^{21} s^{-1}$ [31]. Studies on the mass- and kinetic-energy distributions of fission fragments give a friction value of 5.5 $\times 10^{21} s^{-1}$ [68]. No significant transient effects is seen from the data of fission probabilities [25]. By reproducing prescission neutrons and fragment kinetic energies, the value of β is determined as around 20 $\times 10^{21} s^{-1}$ [34], which is comparable to the predication by one-body dissipation model. Based on a survey for fission-fragment charge distributions, β is suggested to be (2−5) $\times 10^{21} s^{-1}$ [22, 26]. The diverse estimate [from 2 $\times 10^{21} s^{-1}$ to 20 $\times 10^{21} s^{-1}$] on the magnitude of the friction coefficient indicates 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 have 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 increased substantially as well. Because case (ii) is the characteristics of compound nuclei populated by fusion reactions and not by spallation and peripheral relativistic heavy-ion reactions, our results therefore 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 heavy-ion induced fusion approach to yield excited compound nuclei.

ACKNOWLEDGMENTS

The author is grateful to the anonymous referee for his comments and suggestions that have led to an improved version of the article. This work is supported by National Natural Science Foundation of China under Grant No. 11075034.

[1] H.Singh et al., Phys. Rev. C **80**, 064615 (2009); *ibid.* **78**, 024609 (2008).

[2] J.U.Andersen et al., Phys. Rev. C **78**, 064609 (2008).

[3] P.D.Shidling et al., Phys. Rev. C **74**, 064603 (2006).

[4] K.Ramachandran et al., Phys. Rev. C **73**, 064609 (2006).

[5] J.P.Seitz et al., Nucl. Phys. A **750**, 245 (2005).

[6] I.Diószegi et al., Phys. Rev. C **63**, 014611 (2000); *ibid.* **61**, 024613 (2000).

[7] N.P.Shaw et al., Phys. Rev. C **61**, 044612 (2000).

[8] S.K.Hui et al., Phys. Rev. C **62**, 054604 (2000).

[9] B.B.Back et al., Phys. Rev. C **60**, 044602 (1999).

[10] G. van't Hof et al., Nucl. Phys. A **638**, 613 (1998).

[11] C.R.Morton et al., J. Phys. G **23**, 1383 (1997).

[12] D.J.Hofman, B.B.Back, and P.Paul, Phys. Rev. C **51**, 2597 (1995).

[13] D.Fabris, G.Viesti, E.Fioretto, M.Cinausero, N.Gelli, K.Hagel, F.Lucarelli, J.B.Natowitz, G.Nebbia, G.Prete, and R.Wada, Phys. Rev. Lett. **73**, 2676 (1994).

[14] K.T.Brinkman et al., Phys. Rev. C **50**, 309 (1994).

[15] P.Paul and M.Thoennessen, Annu. Rev. Nucl. Part. Sci. **44**, 55 (1994).

[16] K.Siwek-Wilczynska, J.Wilczynski, H.K.W.Leegte, R.H.Siemssen, H.W.Wilschut, K.Grotowski, A.Panasiewicz, Z.Sosin, and A.Wiesoch, Phys. Rev. C **48**, 228 (1993).

[17] M.Thoennessen and G.F.Bertsch, Phys. Rev. Lett. **71**, 4303 (1993).

[18] R.Butsch et al., Phys. Rev. C **44**, 1515 (1991).

[19] D.Hilscher and H.Rossner, Ann. Phys. (Paris) **17**, 471 (1992).

[20] D.J.Hinde et al., Phys. Rev. C **45**, 1229 (1992).

[21] C.Schmitt et al., Phys. Rev. C **81**, 064602 (2010).

[22] C.Schmitt, P.N.Nadtochy, A.Heinz, B.Jurado, A.Kelic, and K.H.Schmidt, Phys. Rev. Lett. **99**, 042701 (2007).

[23] J.Benlliure et al., Phys. Rev. C **74**, 014609 (2006).

[24] B.Lott et al., Phys. Rev. C **63**, 034616 (2001).

[25] V.Tishchenko et al., Phys. Rev. Lett. **95**, 162701 (2005).

[26] B.Jurado et al., Phys. Rev. Lett. 93 (2004) 082501.

[27] U.Jahnke et al., Phys. Rev. Lett. **83**, 4959 (1999).

[28] J.Sadhukhan and S.Pal, Phys. Rev. C **79**, 064606 (2009); *ibid.* **78**, 011603(R) (2008).

[29] V.V.Sargsyan, Yu.V.Palchikov, Z.Kanokov, G.G.Adamian, and N.V.Antonenko, Phys. Rev. C **76**, 064604 (2007).

[30] I.I.Gontchar and N.E.Aktaev, Phys. Rev. C **80**, 044601 (2009).

[31] W.Ye, H.W.Yang, and F.Wu, Phys. Rev. C **77**, 011302(R) (2008).

[32] L.Fiore et al., Nucl. Phys. A **620**, 71 (1997).

[33] P.Fröbrich, I.I.Gontchar, and N.D.Mavlitov, Nucl. Phys. A **556**, 281 (1993); *ibid.* A **563**, 326 (1993).

[34] T.Wada, Y.Abe, and N.Carjan, Phys. Rev. Lett. **70**, 3538 (1993).

[35] Y.Abe, S.Ayik, P.G.Reinhard, and E. Suraud, Phys. Rep. **275**, 49 (1996).

[36] W.Ye, Z. Phys. A **359**, 385 (1997); *ibid.* Phys. Rev. C **81**, 054609 (2010).

[37] K.Pomorski, J.Bartel, J.Richert, and K.Dietrich, Nucl. Phys. A **605**, 87 (1996).

[38] P.N.Nadtochy, G.D.Adeev, and A.V.Karpov, Phys. Rev. C **65**, 064615 (2002).

[39] S.M.Mirfathi and M.R.Pahlavani, Phys. Rev. C **78**, 064612 (2008).

[40] E.G.Ryabov et al., Phys. Rev. C **78**, 044614 (2008).

[41] K.Pomorski et al., Nucl. Phys. A **679**, 25 (2000).

[42] Y.Arimoto, Nucl. Phys. A **780**, 222 (2006).

[43] P.Fröbrich and I.I.Gontchar, Phys. Rep. **292**, 131 (1998).

[44] P.Fröbrich, Nucl. Phys. A **787**, 170c (2007).

[45] W.D.Myers and W.J.Swiatecki, Nucl. Phys. **81**, 1 (1966); Ark. Fys. **36**, 343 (1967).

[46] H.J.Krappe, J.R.Nix, and A.J.Sierk, Phys. Rev. C **20**, 992 (1979); P.Möller, W.D.Myers, W.J.Swiatecki, and J.Treiner, At. Data & Nucl. Data Tables **39**, 225 (1988).

[47] M.Brack, J.Damgaard, A.S.Jensen, H.C.Pauli, V.M.Strutinsky, and C.Y.Wong, Rev. Mod. Phys. **44**, 320 (1972).

[48] R.Balian and C.Bloch, Ann. Phys. **60**, 401 (1970).

[49] A.V.Ignatyuk et al., Sov. J. Nucl. Phys. **21**, 612 (1975).

[50] I.I.Gontchar, L.A.Litnesvsky, and P.Fröbrich, Comput. Phys. Commun. **107**, 223 (1997).

[51] M.Blann, Phys. Rev. C **21**, 1770 (1980).

[52] A.Yu.Lazarev, I.I.Gontchar, and D.N. Mavlitov, Phys. Rev. Lett. **70**, 1220 (1993).

[53] G.Chaudhuri and S.Pal, Eur. Phys. J A **18**, 9 (2003).

[54] I.I.Gontchar, P.Fröbrich, and N.I.Pischasov, Phys. Rev. C **47**, 2228 (1993).

[55] H.J.Krappe, Phys. Rev. C **59**, 2640 (1999).

[56] J.P.Lestone and S.G.McCalla, Phys. Rev. C **79**, 044611 (2009); S.G.McCalla and J.P.Lestone, Phys. Rev. Lett. **101**, 032702 (2008).

[57] J.Tõke and W.Udo Schröder, Phys. Rev. Lett. **82**, 5008 (1999); *ibid.* Phys. Rev. C **72**, 031601(R) (2005); L.G.Sobtaka, R.J.Charity, J.Tõke, and W.Udo Schröder, Phys. Rev. Lett. **93**, 132702 (2004).

[58] W.Ye, J.Tõke, and W.Udo Schröder, Phys. Lett. B **676**, 193 (2009).

[59] D.Jacquet and M.Morjean, Prog. Part. Nucl. Phys. **63**, 155 (2009).

[60] J.O.Newton, Sov. J. Part. Phys. **21**, 349 (1990).

[61] D.Mancusi, R.J.Charity, and J.Cugnon, Phys. Rev. C **82**, 044610 (2010).

[62] A.L.Caraley, B.P.Henry, J.P.Lestone, and R.Vandenbosch, Phys. Rev. C **62**, 054612 (2000).

[63] B.J.Fineman, K.T.Brinkmann, A.L.Caraley, N.Gan, R.L.McGrath, and J.Velkovska, Phys. Rev. C **50**, 1991 (1994).

[64] R.J.Charity, L.G.Sobotka, J.Cibor, K.Hagel, M.Murray, J.B.Natowitz, R.Wada, Y.EMaasri, D.Fabris, G.Nebbia, G.Vieste, M.Cinausero, E.Fioretto, G.Prete, A.Wagner, and H.Xu, Phys. Rev. C **63**, 024611 (2001).

[65] R.J.Charity, Phys. Rev. C **82**, 014610 (2010).

[66] E.Strumberger et al., Nucl. Phys. A **529**, 522 (1991).

[67] G.R.Tillack et al., Phys. Lett. B **296**, 296 (1992).

[68] A.V.Kapov et al., Phys. Rev. C **63**, 054610 (2001); P.N.Nadtochy et al., Phys. Rev. C **72**, 054608 (2005); M.V.Borunov et al., Nucl. Phys. A **799**, 56 (2008).

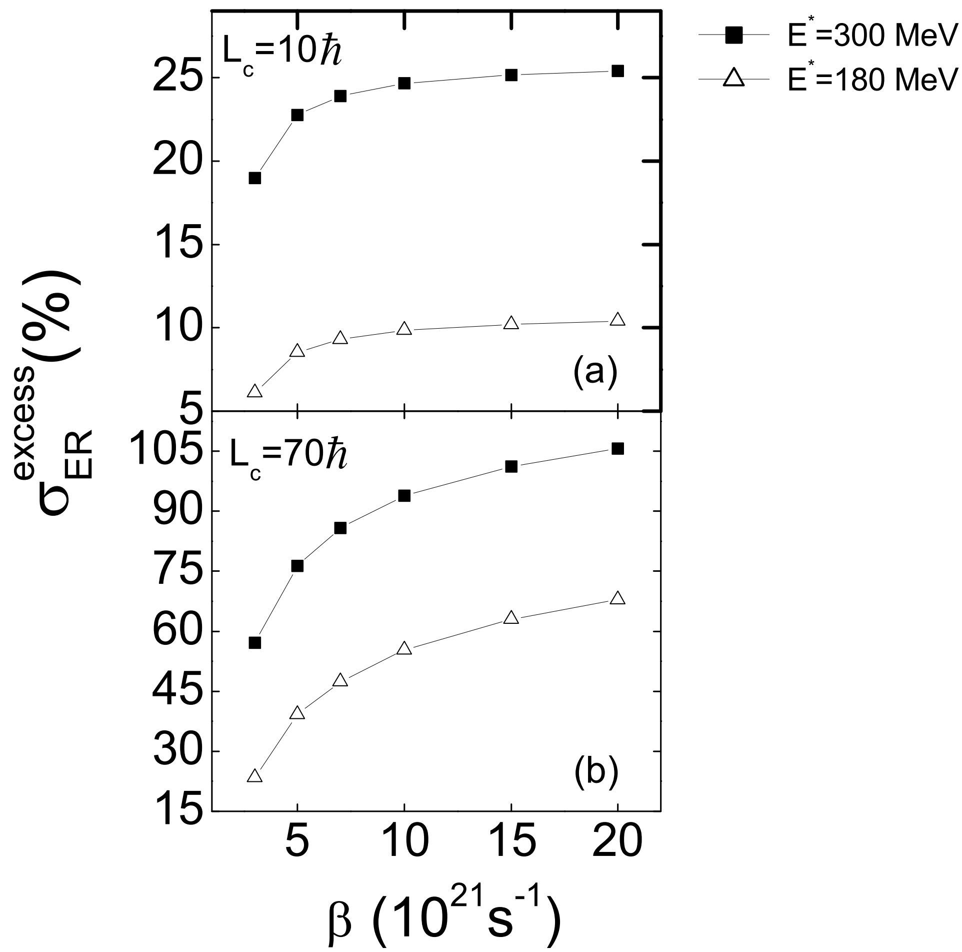

FIG. 1: Comparison of the excess of the evaporation residues over its standard-statistical values versus the dissipation strength β for ^{200}Hg nuclei between case (i) $E^* = 300$ MeV, $\ell_c = 10\hbar$, $70\hbar$ and case (ii) $E^* = 180$ MeV, $\ell_c = 10\hbar$, $70\hbar$.

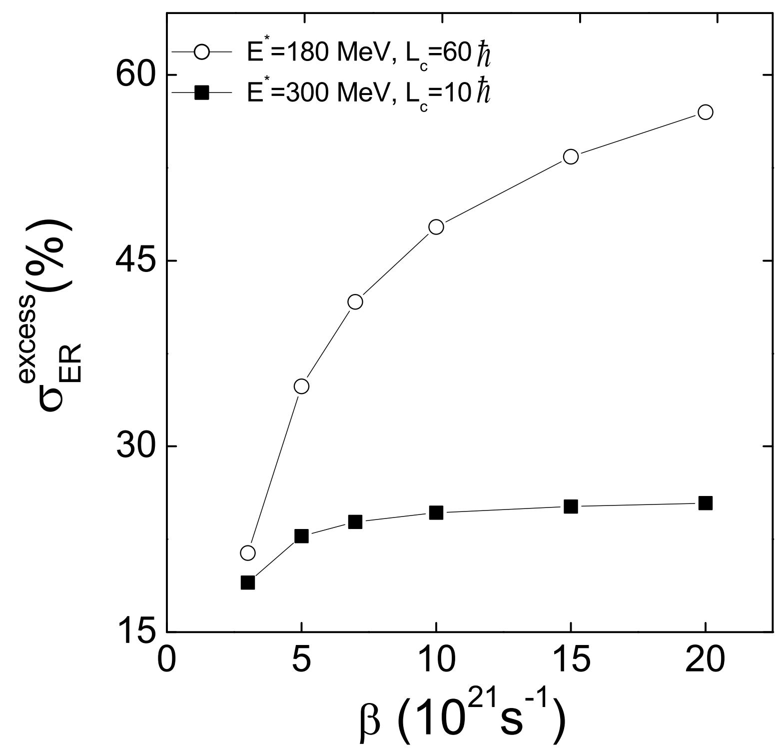

FIG. 2: Comparison of the excess of the evaporation residues over its standard-statistical values versus the dissipation strength β for ^{200}Hg nuclei between case (i) $E^* = 300$ MeV and $\ell_c = 10\hbar$ and case (ii) $E^* = 180$ MeV and $\ell_c = 60\hbar$.

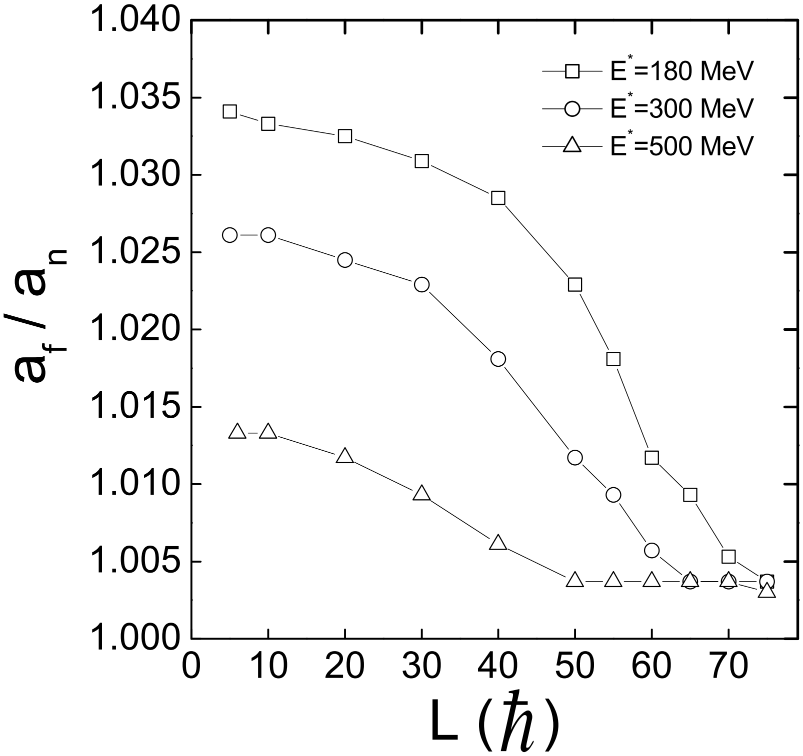

FIG. 3: The ratio of level density parameters at saddle to that at ground-state configurations, a_f/a_n, as a function of angular momentum ℓ for excitation energy $E^* = 180$, 300 and 500 MeV.

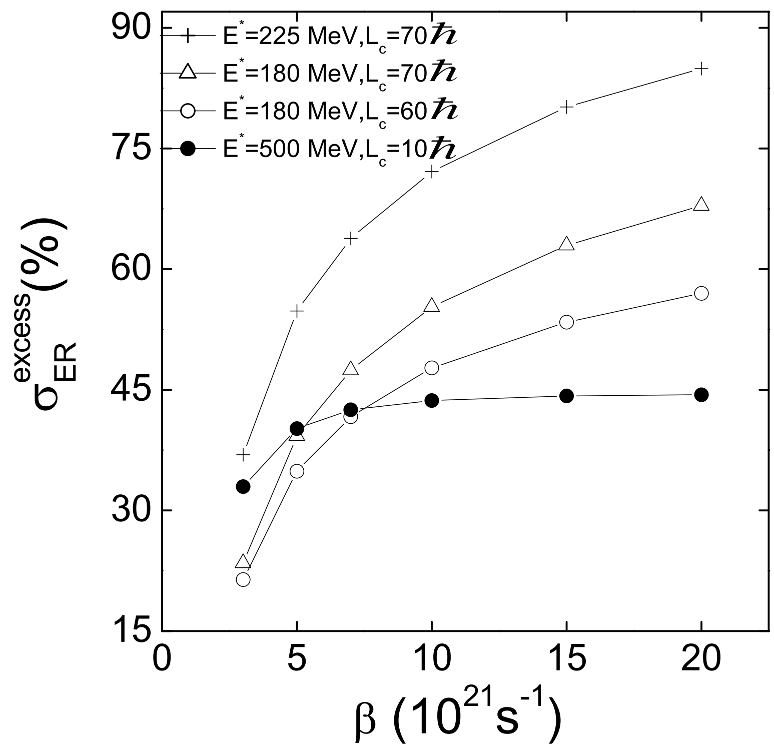

FIG. 4: Comparison of the excess of the evaporation residues over its standard-statistical values versus the dissipation strength β for ^{200}Hg nuclei between case (i) $E^* = 500$ MeV, $\ell_c = 10\hbar$ and case (ii) $E^* = 180$ MeV, $\ell_c = 60\hbar$, $70\hbar$; $E^* = 225$ MeV, $\ell_c = 70\hbar$.