Accurate estimation of the neutron and fission decay widths for hot fusion reactions

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Yanez *et al.* [Phys. Rev. Lett. **112**, 152702 (2014)] measured unusually high neutron decay width for the hot fusion reaction $^{25,26}Mg + ^{248}Cm$ compared to the theoretical estimations available till that date. Various theoretical models have been developed since then to upgrade our understanding of the phenomenon but good agreement is not yet achieved. We have made an attempt for the same, which is based on a modified back-shifted Fermi gas model that also includes the shell and pairing energy correction. Though it works well for the neutron decay, it needs a dissipative effect also to evaluate the fission decay width correctly. It predicts the neutron to total decay width ratio 0.82–0.89 for dissipation coefficients 15–22 and thus closed to the measured value 0.89 ± 0.13.

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I. INTRODUCTION

The last two decades have witnessed the synthesis of heavy and superheavy nuclei as an exciting research area of nuclear physics [1–4]. The field has made remarkable progress on the heavy-ion fusion reactions, that can be divided into two prototypical classes: "cold" and "hot" fusion reactions. In cold fusion reactions, one bombards Pb or Bi target nuclei with heavier projectiles (Ca-Kr) to form completely fused systems with low excitation energies ($E^* = 10$–15 MeV). Such reactions lead to a higher survival of the compound nucleus against fission but with a reduced fusion cross section because of the larger Coulomb repulsion in the more symmetric reacting system. This approach has been used in the synthesis of elements $Z = 104$–113. Whereas, in hot fusion reactions, one involves a lighter projectile and an actinide target nucleus to increase the fusion probability but leading to a highly excited completely fused system ($E^* = 30$–60 MeV) with a reduced probability of surviving against fission. This approach has been used to synthesize elements $Z = 108$–118. However, recently Yanez *et al.* [5] measured an unusually high value of the decay width ratio (survival probability) of a hot fusion reaction $^{25,26}Mg + ^{248}Cm$. It made the researchers very eager to understand the underlying fusion mechanisms. Though the survival probability of the heavy nuclei decreases linearly with the atomic number [6], however, that of the superheavy nuclei appears to be very different.

Here, we address this issue in view of the existing models and a proposed one. The existing models have been classified into two. In the first, we discuss the models developed prior to the experiment performed for a particular hot fusion reaction mentioned above [5] and in the second we describe the ones evolved in the post era of this same experiment. The models in the first category underestimate the observed neutron decay width to a high extent and the ones in the second category predict quite close to the observed value. Now, the present model prediction approaches the closest to the experimental figure.

II. THEORETICAL MODELS

A. Models prior to the experiment

The success in production of superheavy nuclei mainly depends on how strongly a hot compound nucleus is formed against the fission process in a fusion reaction. Thus, the survival probability ($W_{\rm sur}^{xn}$) is the probability that the completely fused system de-excite by x number of neutron emission rather than fissioning,

$$W_{\rm sur}^{xn} = P_{xn}(E^*)\prod_{x=1}^{x}\left(\frac{\Gamma_n}{\Gamma_n+\Gamma_f}\right)_{x,E^*,J} = P_{xn}(E^*)\prod_{x=1}^{x}\left(\frac{\frac{\Gamma_n}{\Gamma_f}}{1+\frac{\Gamma_n}{\Gamma_f}}\right)_{x,E^*,J}, \quad (1)$$

where $\frac{\Gamma_n}{\Gamma_f}$ is the ratio of decay width of neutron to that of fission. By considering constant temperature level density in Fermi-gas model, the $\frac{\Gamma_n}{\Gamma_f}$ is written as [7]

$$\frac{\Gamma_n}{\Gamma_f} = \frac{2TA^{2/3}}{K_0}\exp[(E_f - B_n)/T]. \quad (2)$$

Here, $K_0 = \hbar^2/2mr_0^2 \approx 10$ MeV, $T = \sqrt{\frac{E^*}{2a}}$, where E^* is the excitation energy and a is the level density parameter, E_f and B_n as defined in literature [7]. P_{xn} in Eq. (2) is the probability of evaporation of x neutrons from the compound nucleus [8],

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which is written as

$$P_{xn}(E^*) = I(\Delta_x, 2x-3) - I(\Delta_{x+1}, 2x-1), \quad (3)$$

where $I(z,n) =$ Pearson's incomplete gamma function $= (1/n!)\int_0^z x^n e^{-x}dx$ and $\Delta_x =$ the energy (in units of T) above threshold for the emission of x neutrons $= (E^* - \sum_1^x B_i)/T$. Here, B_i is the binding energy of the ith neutron.

The excited nuclei decay through emission of neutrons, photons, protons, or light particles like α particle and fission. The density of the levels in the transition state are from the excitation of all degrees of freedom other than the fission. The probability of fission gradually decreases with an increase in excitation energy. Yanez *et al.* [5] studied the first chance fission of ^{274}Hs by the level density parameter that is written as

$$a(A, E^*) = \tilde{a}\left[1 + \delta E\frac{1-\exp(-\gamma E^*)}{E^*}\right], \quad (4)$$

where $\tilde{a} = 0.073A + 0.095B_s\beta_2A^{2/3}$, δE is the shell corrections [9,10], and the shell damping parameter $\gamma = 0.0061$. The resultant $\Gamma_n/\Gamma_{\text{tot}}$ was found to be only 0.18 [5]. Employing the Lestone [11] correction for the effect of the fission barrier height and angular momentum on the fission probability as

$$\Gamma_f^{\text{Lestone}} = \Gamma_f^{BW}\frac{K_0\sqrt{2\pi}}{2J+1}erf\left(\frac{J+1/2}{\sqrt{2}K_0}\right), \quad (5)$$

where Γ_f^{BW} is the Bohr-Wheeler fission width [12] of the conventional transition state. At this instance, the $\Gamma_n/\Gamma_{\text{tot}}$ value is increased from 0.18 to 0.23.

The decay width of the neutron emission from the excited compound nuclei can be written as a function of angular momentum and excited energy as [13]

$$\Gamma_n(E^*, J) = \frac{2m_nR^2}{\pi\hbar^2}\int_0^{E^*-Sn}\frac{\rho(E^*-S_n-\epsilon_n, J)}{\rho(E^*, J)}\epsilon_n d\epsilon_n, \quad (6)$$

where m_n and S_n are the mass and separation energy of the neutron. The radius of the compound nucleus is $R = r_0A^{1/3}$ with $r_0 = 1.2$ fm, ϵ_n is the kinetic energy of the ith evaporated neutron, and $\rho(E^*, J)$ is the level density [14]. The fission width is evaluated using the Bohr-Wheeler formula [12] as

$$\Gamma_f(E^*, J) = \frac{1}{2\pi}\int_0^{E^*-B_f}\frac{\rho_{s.d}(E^*-B_f-\epsilon_f, J)}{\rho_{s.d}(E^*, J)}T_f(\epsilon_f)d\epsilon_f, \quad (7)$$

where B_f, $\rho_{s.d}$, ϵ_f, and $T_f(\epsilon_f)$ are the fission barrier, level density at the saddle point, kinetic energy of the emitting particle and transmission probability, respectively. Note that $\Gamma_f(E^*, J)$ is the same as the above mentioned Γ_f^{BW}. The level density $\rho(E, J; \beta_2)$ [15] is defined as

$$\rho(E, J; \beta_2) = K_{\text{coll}}(\beta_2)\frac{2J+1}{E^2} \times \exp(2\sqrt{a(A, E_{\text{int}})[E - E_{\text{rot}}(J)]}). \quad (8)$$

Here, $E = E^* - \delta$, $\delta = 0$, Δ, or 2Δ for odd-odd, odd-even, and even-even nuclei and $\Delta = 11/\sqrt{A}$ MeV. K_{coll} is the collective enhancement factor. The level density parameter is given by

$$a(A, E_{\text{int}}) = \tilde{a}\left[1 + \delta E\frac{1-\exp(-\gamma E_{\text{int}})}{E_{\text{int}}}\right], \quad (9)$$

where $\tilde{a} = 0.073A + 0.095B_s\beta_2A^{2/3}$ MeV^{-1}, surface energy B_s is a dimensionless quantity [16], and δE is the shell correction energy [9]. $E_{\text{int}} = E - E_{\text{rot}}(J)$ and $E_{\text{rot}}(J) = (\hbar^2/2\Im_{g.s})J(J+1)$. The term K_{coll} in Eq. (8) is given by

$$K_{\text{coll}}(\beta_2) = \frac{\Im_\perp T}{\hbar^2}\phi(\beta_2) + K_{\text{vib}}[1-\phi(\beta_2)]. \quad (10)$$

Using the above set of equations, the Γ_n/Γ_{tot} is found to be about 0.19. The level density from the Fermi-gas model without considering the effect of collective enhancement factor [17] is given by

$$\rho(E^*, J) = \frac{2J+1}{24\sqrt{2}\sigma^3a^{1/4}(E^*-\delta')^{5/4}} \times \exp\left[2\sqrt{a(E^*-\delta')} - \frac{(J+1/2)^2}{2\sigma^2}\right], \quad (11)$$

where $\delta' = 0$, $12/\sqrt{A}$ and $-12/\sqrt{A}$ MeV for odd-even, even-even, and odd-odd nuclei. $\sigma^2 = 6\bar{m}^2\sqrt{a(E^*-\delta')/\pi^2}$, $\bar{m}^2 \approx 0.24A^{2/3}$. The value obtained from this approach is 0.25.

The level density with collective enhancement factor [18] is defined as

$$\rho(E^*, J) = K_{\text{vib}}K_{\text{rot}}(E^*)\frac{2J+1}{24\sqrt{2}\sigma_{\text{eff}}^3[a(A, E^*-E_c)(E^*-E_c)]^{1/4}} \times \exp\left[2\sqrt{a(A, E^*-E_c)(E^*-E_c)^5} - \frac{(J+1/2)^2}{2\sigma_{\text{eff}}^2}\right], \quad (12)$$

where E_c is the condensation energy [18] and σ_{eff} is

$$\sigma_{\text{eff}}^2 = \begin{cases}\Im_\perp^{2/3}\Im_\parallel^{1/3}\sqrt{E^*} - E_c)/a & \text{for deformed nuclei}\\ \Im_\parallel\sqrt{(E^*} - E_c)/a & \text{for spherical nuclei.}\end{cases} \quad (13)$$

The term rotational coefficient is defined as

$$K_{\text{rot}} = \begin{cases}\Im_\perp\sqrt{(E^*} - E_c)/a & \text{for deformed nuclei}\\ 1 & \text{for spherical nuclei,}\end{cases} \quad (14)$$

and the vibrational term is

$$K_{\text{vib}} = \exp[0.0555A^{2/3}(E^* - E_C)^{4/3}/a^{4/3}]. \quad (15)$$

The perpendicular and parallel moment of inertia are evaluated using the equation $\Im_\perp = \frac{2}{5}m_0r_0^2A^{5/3}(1+\frac{1}{3}\epsilon_0)$ and $\Im_\parallel = 6\bar{m}^2\sqrt{a(E^*-E_c(1-\frac{2}{3})/\pi^2}$, where $\epsilon_0 = \frac{3}{2}\sqrt{(5/4\pi)}\beta_2/(1+\frac{1}{2}\sqrt{(5/4\pi)}\beta_2)$. The level density parameter $a(A, E^*-E_c)$ takes the shell effects into consideration as follows:

$$a(A, E^*-E_c) = \tilde{a}(A)\left[1 + \frac{1-\exp[-(E^*-E_c)/E_D']}{E^*-E_c}\delta E\right]. \quad (16)$$

Here, E_D' is the inverse damping parameter taken as $E_D' = 0.4A^{4/3}/\tilde{a}$ and $\tilde{a} = 0.114A + 0.162A^{2/3}$, where A is the mass

TABLE I. Comparing the experimental $\frac{\Gamma_n}{\Gamma_{tot}}$ with different theories available till the experiment was conducted.

		Γ_n/Γ_{tot}					
		Exp.	Theo.				
Reaction	E^* (MeV)	[5]	[5]	[11]	[15]	[17]	[18]
$^{26}Mg + ^{248}Cm$	63	0.89 ± 0.13	0.18	0.23	0.19	0.25	0.36

number of compound nuclei. With this method the value obtained is 0.36.

Comparative study on W_{sur}^{xn} between the experiments and theories are numerous, but that on $\frac{\Gamma_n}{\Gamma_{tot}}$ is extremely rare. Now we compare an experimental figure of $\frac{\Gamma_n}{\Gamma_{tot}}$ for ^{274}Hs with various theoretical estimates described above till the experiment was conducted [5] (Table I). They are statistical method using Fermi gas model [14] and the same method but with various corrections [11,15,17,18]. We see here that experimental value is 5.0 to 2.5 times higher than various theoretical counterparts lying in the range 0.18 to 0.36. Since theories underestimate the experimentally observed value, we have made an attempt to explore whether a suitable approach has been evolved in the post era of the experiment [5].

B. Models in the post era of the experiment

An analytical expression for Γ_n/Γ_f using the Fermi-gas model [7] is obtained as follows:

$$\Gamma_n/\Gamma_f = \frac{4A^{2/3}(E^* - B_n)}{k(2[a(E^* - B_f)]^{1/2} - 1)} \times [2a^{1/2}((E^* - B_n)^{1/2} - (E^* - B_f)^{1/2}], \tag{17}$$

where $k = 9.8$ MeV^{-1} and B_n is neutron binding energy. B_f is the energy dependent fission barrier. In the above formula, Pahlavani and Alavi [19] have considered level density parameter differently at ground state (a_n) and saddle point (a_f). Then decay width ratio of neutron to fission is modified as

$$\frac{\Gamma_n}{\Gamma_f} = \frac{4A^{2/3}a_f(E^* - B_n)}{ka_n(2[a_f(E^* - B_f)]^{1/2} - 1)} \times \exp\left[2\left(a_n^{1/2}((E^* - B_n)^{1/2} - a_f^{1/2}(E^* - B_f)^{1/2})\right)\right]. \tag{18}$$

The ratio a_f/a_n here is related to rate of change of nuclear structure from ground state (g.s.) to saddle point (s.d.). The influence of level density parameter on fusion probability, decay width of neutron to fission width and compound nucleus formation probability have been calculated using the Woods-Saxon potential. The results have also shown the influence of the level density parameter in decay width. The decay width corresponding to $a = A/12$ shows higher value than that at $a = A/10$.

Rahmatinejad *et al.* [20] have written the level density parameters using the Fermi-gas model in the frame work of macroscopic-microscopic approach [21] as follows:

$$\rho_{FG} = \frac{\sqrt{\pi}}{12[a(U)]^{1/4}U^{5/4}} \exp(2\sqrt{a(U)U}), \tag{19}$$

where the connection between the nuclear temperature (T) and thermal excitation energy (U) is established by the level-density parameter $a(U)$ as $U = a(U)T^2$. The energy dependent level density parameter is given by

$$a(U) = \tilde{a}\left[1 + \frac{1 - \exp(-U/E_D')}{U}\delta E\right], \tag{20}$$

where E_D' is the inverse damping parameter which is adjusted along with ã to reproduce the microscopic calculations. By incorporating the pairing effects in Eq. (20), we get

$$a(U) = \tilde{a}[1 + \frac{1 - \exp(-U/E_D')}{U}\delta E - \frac{1 - \exp(-U/E_D')}{U}\delta P], \tag{21}$$

where δP is the pairing energy. This work shows the linear dependency of level-density parameter on the mass number, i.e., $\tilde{a} = A/(12.4 - 12.6)\, MeV^{-1}$ and $\tilde{a} = A/(10.3 - 11)$ MeV^{-1} for Dy and Mo isotopes, respectively. The consistent average value of $\tilde{a}$ is approximately equal to $A/(8 - 13.5)$ MeV^{-1}.

Taking the energy back shift effect by $\Delta = 24/\sqrt{A}$, $12/\sqrt{A}$, and 0 MeV for even-even, odd-even, and odd-odd isotopes, respectively [22], we get the Fermi gas expression for the level density as

$$\rho_{FG}(U) = \frac{\sqrt{\pi}}{12a^{1/4}(U - \Delta)^{5/4}} \exp(2\sqrt{a(U - \Delta)}), \tag{22}$$

the effect of back shift energy Δ alters the phenomenological level density parameter as

$$a(U) = \tilde{a}(A)\left[1 + \frac{1 - \exp(-(U - \Delta)/E_D')}{(U - \Delta)}\delta E\right], \tag{23}$$

where the inverse damping parameter $E_D' = A^{1/3}/\gamma_0$ and ã$= \alpha A + \beta A^2$ is asymptotic value. Here, α, β, and γ_0 are the best fitting parameters for energy level density parameters for a given nucleus. With the above back-shifted Fermi gas model, $\frac{\Gamma_n}{\Gamma_f}$ takes the form [22]

$$\frac{\Gamma_n}{\Gamma_f} = \frac{4A^{2/3}a_f(U - B_n - \Delta_n)}{k_0 a_n\left[\left(2a_f^{1/2}(U - B_f - \Delta_f)^{1/2} - 1\right)\right]} \times \exp\left[2a_n^{1/2}\left(U - B_n - \Delta_n\right)^{1/2} - 2a_f^{1/2}\left(U - B_f - \Delta_f\right)^{1/2}\right], \tag{24}$$

where Δ_n and Δ_f are the back shifts in the Fermi-gas level densities at the ground state and saddle point, respectively.

C. Present model

We develop a model where the level density term $\rho(E^*, J)$ in Eqs. (6) and (7) at the ground and saddle points can be evaluated with the following set of equations. First, the transmission probability in Eq. (7) is written according to Xia *et al.*

[17] as

$$T_f(\epsilon_f) = \left(1 + \exp\left[-\frac{2\pi\epsilon_f}{\hbar\omega_{s.d}}\right]\right)^{-1}, \tag{25}$$

where $\hbar\omega_{s.d}$ is the barrier width at saddle point and we have taken it as 2.2 MeV [17]. The term fission barrier height of the rotating nucleus (B_f) [15] is a function of shell corrections [23] with excitation energy (E^*) and angular momentum (J) as follows:

$$B_f(E^*, J) = B_0(E^*, J) - (\hbar^2/2\Im_{g.s} - \hbar^2/2\Im_{s.d})J(J+1). \tag{26}$$

Here, $\Im_{g.s,s.d} = k\frac{2}{5}MR^2(1 + \beta_2^{g.s,s.d}/3)$ are the moment of inertia at the ground state and at the saddle point [16] of the fissioning nuclei. The value of $k \approx 0.4$ and $B_0 = B_{LD} - \delta E$. The term B_{LD} is the liquid drop model fission barrier [24] and δE is the shell correction [25] in the ground state.

The level density $\rho(E^*, J)$ is evaluated according to back-shifted Fermi-gas model [26] as follows:

$$\rho(E^*, J) = \frac{2J+1}{12}\left(\frac{\hbar^2}{2I_{\text{eff}}}\right)^{3/2}\sqrt{a}\frac{\exp(2\sqrt{aU})}{U^2}, \tag{27}$$

where a, E^*, and U are related as

$$U = E^* - E_{\text{rot}} - \delta P \tag{28}$$

with the rotational energy E_{rot},

$$E_{\text{rot}} = \frac{\hbar^2}{2I_{\text{eff}}}J(J+1). \tag{29}$$

The average angular momentum takes a vital role in such calculation and its average value $\langle J\rangle$ can be deduced from Capurro *et al.* [27] as

$$\langle J\rangle = \begin{cases} \frac{2}{3}\sqrt{2\mu R_b^2(E_{\text{c.m.}} - V_b)/\hbar^2} & \text{for } E_{\text{c.m.}} \geqslant V_b \\ \frac{4}{3}\sqrt{2\mu R_b^2\,\epsilon/\hbar^2} & \text{for } E_{\text{c.m.}} < V_b \end{cases}, \tag{30}$$

where μ is the reduced mass of the projectile and target nuclei and R_b the barrier radius. $E_{\text{c.m.}}$ is the center of mass energy and fusion barrier height, respectively. The pairing energy term δP is evaluated using the set of equations given in [28].

In Eq. (29), the effective moment of inertia of the deformed nuclei $I_{\text{eff}} = I_0(1 + \delta_1 J^2 + \delta_2 J^4)$; I_0, δ_1, and δ_2 are the rigid body moment of inertia and deformity coefficients, respectively. If we neglect the deformity coefficients due to the fact that the values of δ_1 and δ_2 are very small and I_0 is taken as $\frac{2}{5}MR^2$, then I_{eff} is written as $\frac{2}{5}MR^2(1 + \beta_2/3)$. Further the nuclear level density parameter used in Eq. (27) is defined as

$$a = \tilde{a}\left[1 - \frac{\delta E}{U}(1 - \exp(-\eta U))\right], \tag{31}$$

where $\tilde{a} = 0.114A + 0.162A^{2/3}$ is the asymptotic parameter, $\eta = 0.079\ \text{MeV}^{-1}$ is the shell damping parameter, δE is the ground state shell correction [29].

To estimate the ratio of the neutron to the total decay width correctly, Yanez *et al.* [5] speculated the role of the dissipative and high fission barrier effects during de-excitation in addition to the static effect due to the shell-related phenomena.

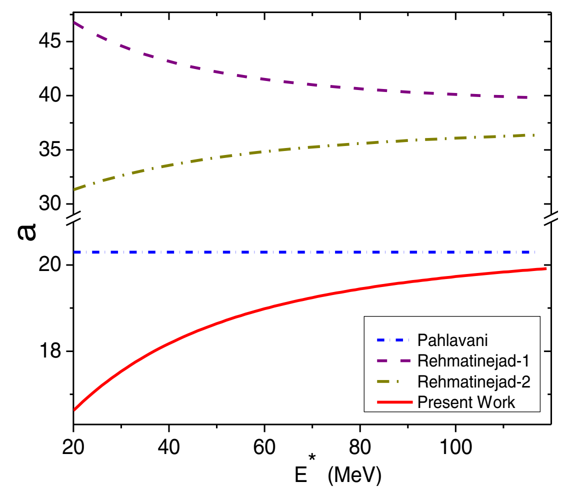

FIG. 1. Variation of level density parameter (a) with excitation energy (E^*) in the case of superheavy compound nucleus ^{274}Hs using different models such as Pahlavani [19], Rahmatinejad-1 [20], Rahmatinejad-2 [22], and the present one.

Kramers [30] suggested that the fission width $\Gamma_f(E^*, J)$ given in Eq. (7) can be reduced by the dissipative effect and the reduced width $\Gamma_f^{\text{Kramers}}$ is written as

$$\Gamma_f^{\text{Kramers}} = \Gamma_f(\sqrt{1+\gamma^2} - \gamma), \tag{32}$$

where γ is a dimensionless dissipation coefficient.

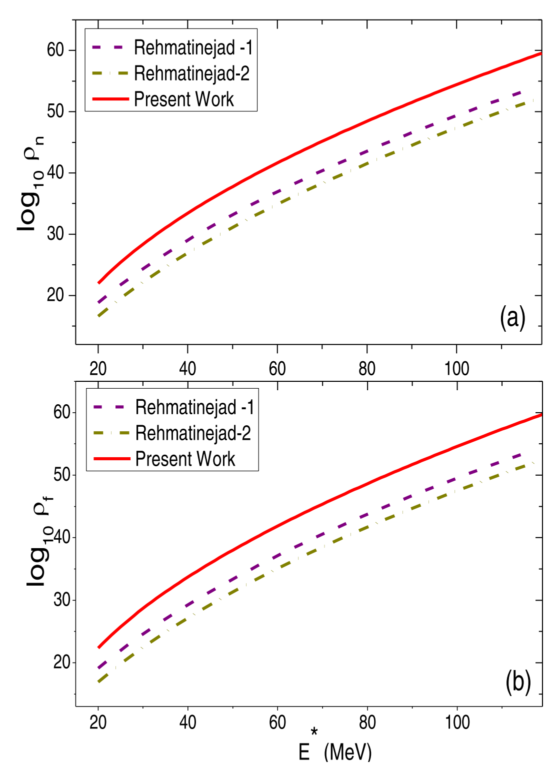

FIG. 2. Level density of (a) neutron (ρ_n) and (b) fission (ρ_f) for the superheavy compound nucleus ^{274}Hs as a function of the excitation energy (E^*) as seen in the models of Pahlavani [19], Rahmatinejad-1 [20], Rahmatinejad-2 [22], and the present one.

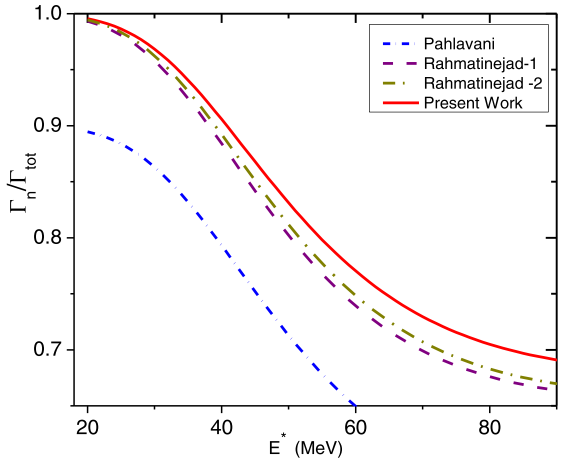

FIG. 3. Excitation energy (E^*) dependence of neutron decay width to total width (Γ_n/Γ_{tot}) of superheavy compound nuclei ^{274}Hs during the fusion reaction of ^{26}Mg + ^{248}Cm using different models available in literature such as Pahlavani [19], Rahmatinejad-1 [20], Rahmatinejad-2 [22], and the present model.

III. RESULTS AND DISCUSSIONS

We can notice the level density parameter (a) takes different form in different models. Let us now compare them as a function of excitation energy in Fig. 1 as obtained from various models developed in recent past along with the present one. We see that the values of a have increasing tendency for the present model and Rahmatinejad *et al.* [22], whereas a of Rahmatinejad *et al.* [20] has a decreasing tendency and that of Pahlavani and Alavi [19] remains almost unchanged. In contrast, the level density in every model increases with the excitation energy as shown in Fig. 2 . However, the value of Γ_n/Γ_{tot} keeps on decreasing with the excitation energy as shown in Fig. 3 . Out of the four models compared in the figure, the present model predicts the maximum value

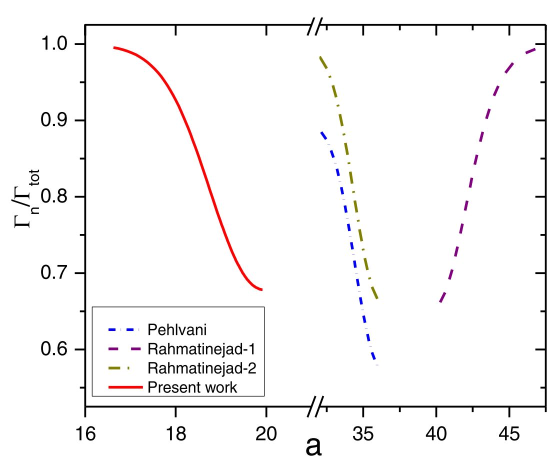

FIG. 4. A plot of decay width of neutron to total width ratio (Γ_n/Γ_{tot}) for superheavy nuclei ^{274}Hs as a function of level density parameter (a) taken from the present model, Pahlavani [19], Rahmatinejad-1 [20], and Rahmatinejad-2 [22].

TABLE II. Comparison of experimental Γ_n/Γ_{tot} with theoretical predictions for the reaction ^{26}Mg + ^{248}Cm. The value of the level density parameter in every model is also given.

Model [Ref.]	a	Theo	Exp [5]
Stat. model with coll. enhanc. [19]	24.48	0.640	0.89 ± 0.13
Semiemp. caln. using W.S. Pot. [20]	41.35	0.725	
Microscopic-Macroscopic model [22]	34.97	0.733	
Pres. model using a mod. BSFGM	20.29	0.756	

of Γ_n/Γ_{tot} throughout the excitation energies. All the models except the Pahlavani and Alavi [19] predict Γ_n/Γ_{tot} close to one at the excitation energy around 20 MeV. These models can thus predict the measured value of Γ_n/Γ_{tot} at much lower excitation energy ≈40 than that observed at 63 MeV. The model predictions at the experimental excitation energy are compared in Table II . One can notice that the present model prediction is close to the lower limit of the measured value and the value of Rahmatinejad *et al.* [20,22] are also quite close to this.

Both the neutron and fission widths vary quite strongly with the level density parameter. Hence, different model predicted Γ_n/Γ_{tot} values have been plotted as a function of the

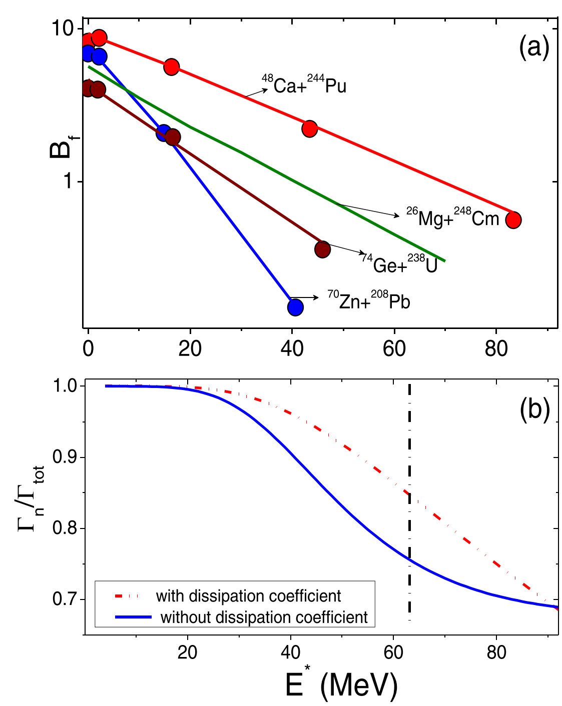

FIG. 5. (a) Comparison of fission barriers (B_f) of different compound nuclei formed with the three fusion reactions such as ^{48}Ca + ^{244}Pu, ^{74}Ge + ^{238}U, and ^{70}Zn + ^{208}Pb using Eq. (26) as taken from [15] (continuous line) with that of available accurate calculation (solid spheres) [31]. The B_f of the CN with the reaction ^{26}Mg + ^{248}Cm is also shown. (b) A plot of Γ_n/Γ_{tot} without (continuous line) and with dissipative effects (friction coefficient ($\gamma = 18$) (dotted line) as a function of excitation energy (E^*, given in MeV). The ratio Γ_n/Γ_{tot} is evaluated using the present model where the fission barriers (B_f) is estimated using the approach given in (a).

level density parameter in Fig. 4. Here, we see that the Γ_n/Γ_{tot} value reduces with a in every model except that in Rahmatinejad *et al.* [20]. This fact is complimentary to the trend seen in Fig. 1. Further, the highest value of Γ_n/Γ_{tot} is seen to occur with the present model and it is obtained at the lowest value of a (see Table II). This value of a is equal $A/13.5$, which is a good a value according to Pahlavani and Alavi [19].

Till now we have not considered yet the dissipative effect in the calculation, if we take it into account in the Kramers way [30] using Eq. (32) and treating the dissipation coefficient γ as a free parameter, the observed value of $\Gamma_n/\Gamma_{tot} = 0.89$ for the compound nuclei ^{274}Hs at $E^* = 63$ MeV can be reproduced if $\gamma = 22$. This relatively large value of γ is quite consistent with Hofman *et al.* [32], Yanez *et al.* [5], who have obtained it as 18 and 15, respectively. If we use $\gamma = 15$ and 18 then the said ratio increases to 0.82 and 0.843 from 0.756, respectively and the ratio is well within the measured value 0.89 ± 0.13. Using the dimensionless dissipation coefficient equals to 18 as obtained by Yanez *et al.* [5], the change in Γ_n/Γ_{tot} with E^* can be viewed as shown in Fig. 5 .

Let us now examine the role of the high fission barrier. According to Fig. 4 of Ref. [5], as high as the measured ratio can be obtained if the barrier height B_f approaches to ≈12 MeV. Let us examine whether such a high barrier is at all viable. We have estimated B_f as a function of excitation function (E^*) using a simple macroscopic model of Zagrebaev *et al.* [15] and compared with the isentropic fission barriers by means of the self-consistent nuclear density functional theory [31] for three superheavy compound nuclei as shown in Fig. 5(a). The comparison shows good agreement except the low excitation regime. Hence, the Zagrebaev *et al.* [15] formula has been used for ^{26}Mg + ^{248}Cm reaction in the present model. The B_f decreases slowly with E^*. The highest value at low E^* is only 6.93 MeV. Hence, B_f as high as 12 MeV is highly nonphysical and it is not essential too.

IV. CONCLUSIONS

The present model prediction is in well agreement with the measured value for the ratio Γ_n/Γ_{tot} of a hot fusion reaction ^{25,26}Mg + ^{248}Cm. It reveals that a modified back-shifted Fermi-gas model with shell and pairing energy correction provides a good representation of the neutron decay for the hot fusion reactions. However, the same model needs a dissipative effect also to estimate the fission decay width correctly. Though the exact nature of dissipative effect is not known yet, the large value of the dissipation coefficient $15 \leqslant \gamma \leqslant 22$ represents the observed ratio very satisfactorily.

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