Comparison between statistical model results using potential and free energy as driving forces

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I. INTRODUCTION

The experimental data from fission of compound nuclei formed in heavy-ion induced fusion reactions at energies above the Coulomb barrier have been analyzed quite extensively using the statistical model. In most cases, it is observed that a dissipation in fission dynamics is necessary to fit the experimental data [1]. The Kramers' fission width which takes into account nuclear dissipation, is usually used in the statistical model calculations. The strength of the nuclear dissipation is obtained by fitting various kinds of experimental data, e.g. multiplicity of pre-scission neutrons (n_{pre}) and evaporation residue cross sections.

The original form of Kramers' fission width [2] was obtained by considering a collective potential to provide the driving force in the system. It was later realized [3, 4] that use of the Helmotz free energy to cause the driving force will be more appropriate for a thermodynamic system like an excited nucleus. We shall consider both the potential and free energy in the present work in order to study the resulting dissipation strength to fit n_{pre} data.

II. FISSION WIDTH FROM KRAMERS' FORMULA

The Kramers' formula for the stationary fission width of a compound nucleus at temperature T and with fission barrier B_V in potential landscape is given as

$$\Gamma_K = \frac{\hbar\omega_{vg}}{2\pi}\exp(-\frac{B_V}{T}) \times \left\{\sqrt{1+\left(\frac{\beta}{2\omega_{vs}}\right)^2}-\frac{\beta}{2\omega_{vs}}\right\}, \quad (1)$$

where β is the reduced dissipation strength and ω_{vg} and ω_{vs} are the frequencies of the harmonic oscillators representing the nuclear potential at the ground state and at the saddle configurations.

Approximating a hot nucleus by a Fermi gas, the free energy is obtained as

$$F = V - aT^2 \quad (2)$$

where a is the level density parameter which depends upon nuclear shape as given by [5]. The shape dependence of the level density parameter gives rise to a free energy profile which is T dependent and is different from the potential profile. Consequently, the fission barrier (B_F) in free energy profile is smaller than B_V as shown in Fig. 1.

The Kramers' fission width using free energy profile will consequently read as

$$\Gamma_K = \frac{\hbar\omega_{fg}}{2\pi}\exp(-\frac{B_F}{T}) \times \left\{\sqrt{1+\left(\frac{\beta}{2\omega_{fs}}\right)^2}-\frac{\beta}{2\omega_{fs}}\right\}, \quad (3)$$

where B_F, ω_{fg} and ω_{fs} are the appropriately defined quantities in free energy landscape.

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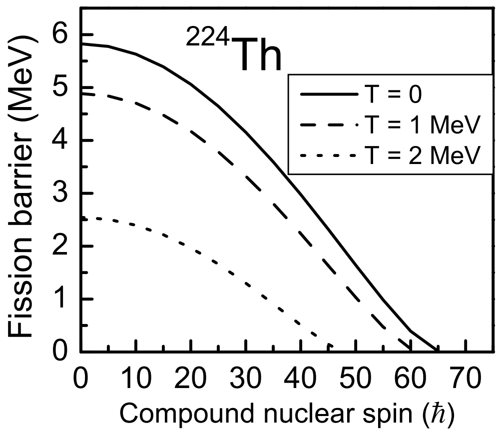

FIG. 1: Fission barrier in potential ($T = 0$) and free energy profile.

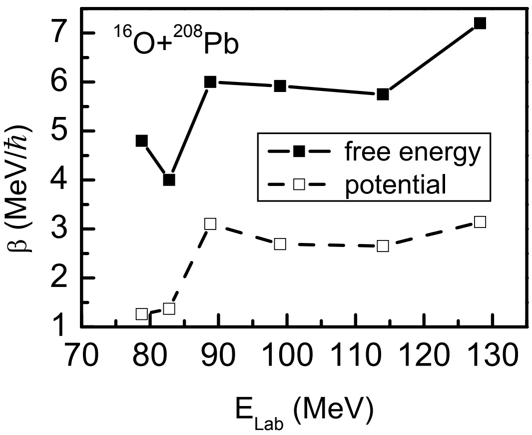

FIG. 2: Best fit β values.

III. CALCULATION AND RESULTS

Using the Kramers' fission width with potential we first perform statistical model calculation for the decay of ^{224}Th and obtain the n_{pre} values. The best fit β value at each excitation energy is then extracted. We next perform similar calculations using the free energy profile. Fig. 2 shows the best fit β values obtained with potential and free energy profile. It is observed that larger β values are required to fit the data with free energy profile compared to those from the potential profile. This is due to the lowering of the barrier in the free energy profile as shown in Fig. 1.

The present work therefore indicates that the dissipation strength can indeed be larger than those obtained in earlier studies using statistical model analysis with potential profile.

References

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