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MACROSCOPIC MODELS FOR THE FUSION OF VERY HEAVY IONS

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Abstract

The surface friction and the extra-push models have been widely used to predict fusion barriers of very heavy ions. Despite their profound differences it has not been possible to establish which model gives a better description of the fusion process. In this work we show that consideration of thermal effects allows for a distinction between the two models. Comparison to experimental data seems to favor the extra-push model.

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It has been well established by several experiments [1–4] that the fusion barrier in collisions of very heavy nuclei is much higher than the Coulomb barrier predicted by standard nuclear potentials. A proper understanding of the dynamical origin of this "barrier shift" is very important, as it can teach us a lot about large-scale nuclear collective motions. Also, the higher fusion barriers play a decisive role in hindering the synthesis of superheavy elements [5–7]. Accurate predictions of the barrier shifts are crucial for selecting the most favorable projectile-target combinations leading to superheavy nuclei.

Two macroscopic models of nuclear dynamics have been widely used to calculate fusion barriers of very heavy ions: the surface friction model of Gross and collaborators [8,9], and the coalescence-reseparation model of Swiatecki (the "extra-push model") [10]. These models are based on very different pictures for the fusion process. The surface friction model is essentially an entrance-channel description of the nuclear collision. The collective degrees of freedom considered in the model are the radial distance between the projectile and target, and the quadrupole deformations of these nuclei. The dissipation mechanism is supposed to come from the piston-like motion of the nuclear field of one nucleus through the nucleons of its collision partner. The intensity of the friction coefficients is determined from fits to deep-inelastic and fusion data. In the surface-friction model fusion is supposed to be decided at the initial stages of the collision, before the nuclei reach close contact, and the further evolution of the nuclear system towards the compound nucleus is taken to be of no consequence [9]. On the other hand, the extra-push model follows the dynamical evolution of the colliding system through the dinuclear and mononuclear regimes of the reaction. The nuclear shapes are represented by three coordinates corresponding to the elongation, neck size, and mass asymmetry of the system. The potential energy has a simple form based on the liquid-drop model, and reproduces fairly well the location of the fission saddle points. The friction forces come from one-body dissipation mechanisms, and are calculated with the "wall-window" formula. In this model fusion is not yet decided when the projectile and target touch each other. This happens only at a much later stage of the collision, when the system overcomes the unconditional saddle point.

In fig. 1 we show fusion barrier shifts $\Delta B = B_{fus} - B_{Coul}$ calculated with the surface

friction and extra-push models (see refs. [9,11] for details). Only symmetric projectile-target combinations were considered in these calculations, and the results are given as function of the compound nucleus fissility parameter x. These predictions are compared with the experimental data available for almost symmetric systems [1–4]. Both calculations describe reasonably well the main trends of the experimental data. From such a comparison it is not easy to establish which of the two models is more appropriate to describe the fusion process.

The main purpose of this work is to show that such a distinction can be made, once the complete role of the friction mechanism is considered. Fusion probabilities for central collisions of very heavy ions have been measured as a function of energy [1,4]. They exhibit a smooth behavior, rising slowly from zero to one as the collision energy increases. This behavior has been related to the effects of thermal fluctuation in the evolution of the system towards fusion [1,11]. The two models we have just discussed assume that the friction forces arise from the interaction of the collective coordinates with a heat bath of nucleonic degrees of freedom. But calculations such as those presented in fig. 1 have not considered the random thermal component of this interaction, which is always present and may be very important in some cases. Thermal fluctuations accompanying friction are usually described by a Langevin force, assumed to be a markovian gaussian stochastic process. The intensity of this force is fixed by the friction coefficient and nuclear temperature, according to Einstein's relation.

The stochastic equations of motion resulting from the addition of the Langevin term to the friction force can be numerically solved with standard techniques [13]. The fusion probability is obtained following an ensemble of trajectories starting from the same initial condition and counting how many lead to fusion. Due to consideration of thermal fluctuations, the calculated fusion probability shows a smooth rise with the energy [11]. As in the experimental case, the theoretical fusion barrier is defined as the energy at which the calculated fusion probability for central collisions reaches 1/2. Following this procedure we have obtained the new barrier shifts predicted by the surface friction and extra-push models. Results for symmetrical projectile-target combinations are presented in fig. 2 and compared to the same experimental data of fig. 1. We notice that the extra-push model still follows the main trends of the data. On the other hand, the surface-friction barriers now lie system-

atically above the experimental results. This situation is made worse by the fact that the surface-friction model gives at best a lower limit to the fusion barrier, as this model ignores entirely the possibility of reseparation of the nuclear system after the Coulomb barrier has been overcome.

We conclude that the dynamical hindrance to fusion of very heavy ions seems to be better described by the extra-push model than by the surface-friction model. In particular this means that, for very heavy ions, fusion is not yet decided at the initial stages of the nuclear collision, when contact between projectile and target has just been established. Consideration of the further evolution of the system towards the compound nucleus is essential for understanding the fusion process.

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References

[1] C.-C. Sahm, H.-G. Clerc, K.-H. Schmidt, W. Reisdorf, P. Armbruster, F.P. Hessberger, J.G. Keller, G. Münzenberg and D. Vermeulen, Nucl. Phys. **A441**(1985)316

[2] W. Reisdorf, F.P. Hessberger, K.D. Hildenbrand, S. Hofmann, G. Münzenberg, K.-H. Schmidt, W.F.W. Schneider, K. Sümmerer, G. Wirth, J.V. Kratz, K. Schlitt and C.-C. Sahm, Nucl. Phys. **A444**(1985)154

[3] J.G. Keller, K.-H. Schmidt, F.P. Hessberger, G. Münzenberg, W. Reisdorf, H.-G. Clerc and C.-C. Sahm. Nucl. Phys. **A452**(1986)173

[4] A.B. Quint, Ph. D. Thesis (TH Darmstadt, 1988), GSI Reports GSI-89-22 and GSI-89-23

[5] P. Armbruster, Ann. Rev. Nucl. Part. Sci. **35**(1985)135

[6] G. Münzenberg, Rep. Prog. Phys. **51**(1988)57

[7] K.-H. Schmidt and W. Morawek, Rep. Prog. Phys. **54**(1991)949

[8] D.H.E. Gross and H. Kalinowski, Phys. Rep. **45**(1978)175

[9] P. Fröbrich. Phys. Rep. **116**(1984)337; Phys. Lett. **B215**(1988)36

[10] W.J. Swiatecki. Prog. Part. Nucl. Phys. 4(1980)383; Phys. Scripta **24**(1981)113; Nucl. Phys. **A376**(1982)275

[11] C.E. Aguiar. V.C. Barbosa and R. Donangelo, Nucl. Phys. **A517**(1990)205

[12] R. Bass, Proc. Symp. on Deep-inelastic and fusion reactions with heavy-ions (Berlin, 1979), ed. W. von Oertzen (Springer, Berlin, 1980), p. 281

[13] C.E. Aguiar. V.C. Barbosa, R. Donangelo and S.R. Souza, Nucl. Phys. **A491**(1989)301

Figure Captions

Figure 1. Fusion barrier shifts $\Delta B = B_{fus} - B_{Coul}$ for nearly symmetrical projectile-target combinations, shown as a function of the compound nucleus fissility parameter x. The Coulomb barriers B_{Coul} were calculated with the Bass potential [12]. Predictions of the extra-push and surface-friction models are represented by the solid and dashed lines, respectively.

Figure 2. Same as fig. 1, but considering the effects of thermal fluctuations in the calculation of the barrier shifts.

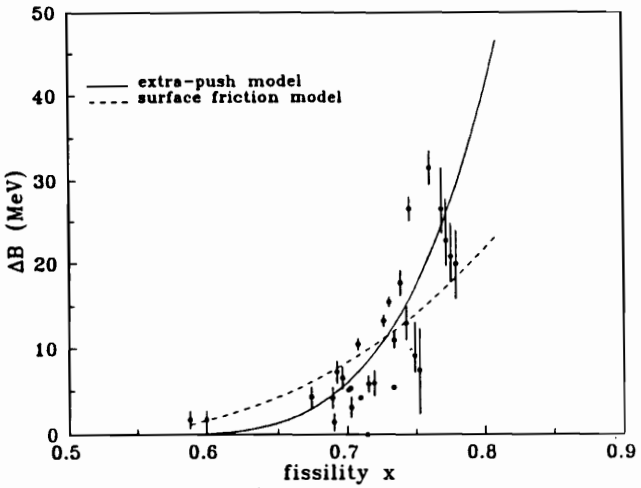

Figure 1

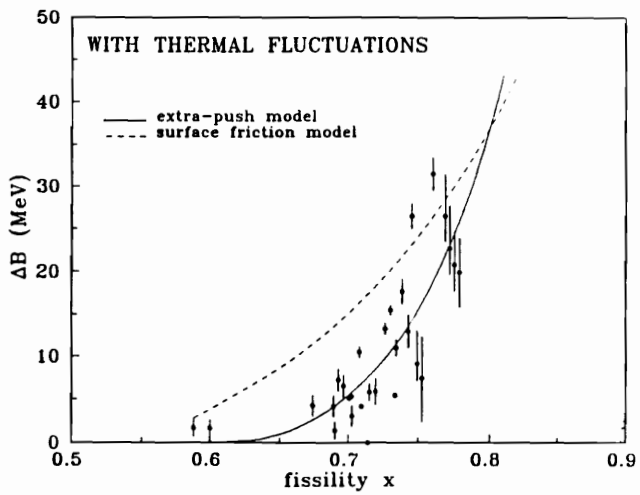

Figure 2