Fragmentation of Spherical Radioactive Nuclei as a Novel Probe of Transient Effects in Fission

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The escape from a metastable state is a problem that appears in many various fields such as fluid mechanics, chemistry or nuclear physics. Systems that are initially out of equilibrium display a transient behaviour during which relaxation in all degrees of freedom takes place. The proper understanding of transient effects occurring before a quasi-equilibrium is reached is important due to their direct connection with the viscosity of the studied medium. Fission is an excellent probe to study such relaxation effects on the subatomic scale. Due to the transient effects, before the quasi-equilibrium is achieved fission is purely or partly inhibited. This delay of fission is commonly called the transient time τ_{trans}. In the present work (see [1]), very specific conditions for studying nuclear transient effects were achieved for the first time, using advanced technical installations at GSI, highly sensitive signatures, and elaborate model calculations.

The ideal initial conditions to study the transient effects are met with initially highly excited and fissile spherical nuclei [2]. Such an ideal scenario could be met for the first time at GSI. A two-step mechanism [3] based on fragmentation-induced fission was used to produce highly excited nearly spherical nuclei near N=126. Details on the experimental set-up and data analysis can be found in [1]. The experimental observable which is used to study the transient effects was the width σ_Z of the fission-fragment Z distribution. It has been shown [1,2,4] that, due to its strong correlation with the temperature at the saddle point, this observable is especially sensitive to the pre-saddle dynamics.

To isolate the influence of transient effects, the data are confronted with two types of calculations: A calculation based on Kramers' *time-independent* fission decay width [5] and a transient-type calculation using the realistic *time-dependent* formula for the *fission decay width* derived in [6]. Both options are implemented [7] in ABRABLA [8]. The difference between such two calculations is to be ascribed to the transient delay. For a sample of spherical projectiles, the measured σ_Z as a function of Z_1+Z_2 is compared in Figure 1 to Kramers- and transient-type predictions. In both calculations, the dissipation strength was fixed at $\beta = 4.5\times10^{21}$ s^{-1}. It can be seen that the slope of σ_Z with decreasing nuclear-charge sum depends strongly on the inclusion of transient effects in the calculation. This observation is valid independent of the value used for β (see ^{223}Ac case in Figure 1). Namely, it is *not* possible to reproduce the trend in σ_Z as a function of Z_1+Z_2 with the *time-independent* fission decay width and an artificial increase of β with decreasing Z_1+ Z_2 (for more details, see [1]). Thus, Figure 1 shows clear manifestation of transient effects in fission. For this set of nuclei an average τ_{trans} of (3.3±0.7)x10^{-21} s has been extracted. Our data indicate that this value is independent of excitation energy and fissility. These results are in favour of an overdamped motion of one-body nature at small deformation and high excitation energy. The extracted dissipation strength and transient time are, nonetheless, reduced compared to the predictions of the early one-body theory for compact shapes

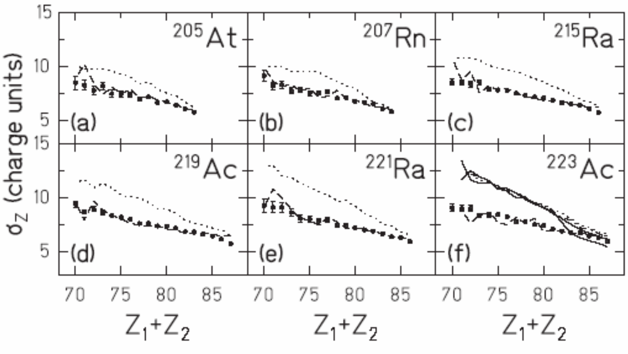

Figure 1. σ_Z plotted as a function of Z_1+Z_2 for a set of radioactive beams. The data (dots) are compared to Kramers- (dotted line) and transient- (dashed line) type calculations, assuming β = 4.5×10^{21} s^{-1}. For the ^{223}Ac, additional Kramers-type calculations are shown with β = 7× 10^{21} s^{-1} (dash-dotted line), 10×10^{21} s^{-1} (solid thin line), and 20×10^{21} s^{-1} (solid thick line).

To conclude, for the first time the deexcitation of highly excited and highly fissile spherical nuclei was used to establish unambiguously the build-up of quasi-equilibrium in nuclear matter. The present work demonstrates that peripheral heavy-ion collisions at relativistic energies are a powerful tool to study fission dynamics. To deepen our understanding of the temperature and fissility dependences of viscosity, exclusive measurements are required for an accurate characterization of the decaying system. Such studies will strongly profit from the R3B set-up to be used at the FAIR facility.

References

[1] C. Schmitt et al., Phys. Rev. C 81 (2010) 064602
[2] C. Schmitt et al., Phys. Rev. Lett. 99 (2007) 042701
[3] K.-H. Schmidt et al., Nucl. Phys. A 665 (2000) 221
[4] B. Jurado et al., Phys. Rev. Lett. 93 (2003) 072501
[5] H.A. Kramers, Physica 7 (1940) 284
[6] B. Jurado et al., Nucl. Phys. A 747 (2005) 14
[7] B. Jurado et al., Nucl. Phys. A 757 (2005) 329
[8] A. Kelić et al., arXiv:09096.4193v1 [nucl-th]