Experiment on Fission Transients in Highly Fissile Spherical Nuclei produced by Fragmentation of Radioactive Beams

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While transferring energy between the collective and intrinsic degrees of freedom of the system, viscosity intricately influences nuclear dynamics. Fission of highly excited spherical nuclei provides optimal conditions for probing this dissipation phenomenon. In nuclei, when the system is initially well-localized around its spherical ground-state minimum, any shape evolution is exclusively initiated by dissipative forces. A finite time, referred as the transient time τ_{trans}, is then required for populating the states at the fission barrier [1]. Information on the strength β of nuclear viscosity *at small deformation* can be directly inferred from τ_{trans}. Most direct probes of fission times are pre-scission multiplicities of light particles and γ-rays as they can be associated with a clock (see [2] and therein). Yet, they give access to the *total* reaction time encompassing, in addition to τ_{trans}, the compound nucleus formation time, the statistical decay time and the saddle-to-scission time. Hence, experiment is not able to isolate the various stages of the process, and the analysis relies on the interplay of complex influences caused by the poorly known dependences of dissipation on deformation, temperature, angular momentum and fissility. This difficulty explains the still vivid debate on both the origin and magnitude of nuclear viscosity. We presently report on the *first* realization of experimental conditions which are ideal for isolating the early τ_{trans} contribution. Highly fissile nuclei characterized by well-defined initial conditions - in excitation energy, angular momentum and deformation - have been produced by fragmentation of radioactive beams. In addition, the width of the fission-fragment charge distribution σ_Z, which is sensitive to the limited region inside the fission saddle [3], has been accurately measured, yielding a chronometer at the saddle.

The above ideal scenario was successfully realized by an intense experimental effort invested at GSI [4]. Fragmentation of a primary stable ^{238}U beam at 1 *A* GeV in a beryllium target produces a large variety of nuclei among which 45 radioactive highly fissile spherical astatine up to thorium isotopes. The latter, separated and identified with the Fragment Separator, acted as secondary relativistic beams. Fragmentation of these projectiles in a secondary lead target yields pre-fragments with high excitation energies [5], small angular momenta [6] and still nearly spherical shapes [7]. The pre-fragment finally de-excites by a competition between fission and evaporation. Both fission fragments were detected simultaneously and accurately identified in atomic number thanks to the use of a double-ionisation chamber ($\Delta Z_{1,2}$ = 0.4 for FWHM).

The measurement of the sum Z_1+Z_2 of the charges of the two fragments allows judiciously classifying the data, since Z_1+Z_2 is correlated to the initial excitation energy E_{prf} of the pre-fragment [3] – the lower the Z_1+Z_2, the higher the E_{prf}. In Fig. 1. the experimental σ_Z is seen to increase with decreasing Z_1+Z_2, i.e. increasing temperature. To investigate the slope of this rise, we use the reaction code ABRABLA which reliability has been widely assessed for the present purpose [8]. As seen in Fig. 1. a good agreement is achieved with β=(4.5±0.5)·10^{21}s^{-1} independent on Z_1+Z_2 i.e. independent on E_{prf} [9]. That corresponds to a transient time of <τ_{trans}> = (3.3±0.7)·10^{-21}s. Also displayed, are the predictions of Bohr-and-Wheeler transition state model [10] and Kramers diffusion picture [11]: Both overestimate the experimental σ_Z due to the absence of the transient delay.

The control of the initial conditions achieved in our experiment constitutes a step further as compared to previous works, and the result points out the *undeniable* manifestation of transient effects at high excitation energy. The magnitude extracted for the dissipation strength at small deformation is an information of importance for our microscopic understanding of nuclear viscosity.

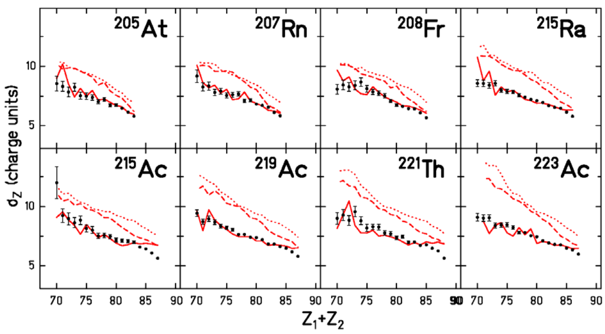

Figure 1: Width σ_Z as a function of Z_1+Z_2 for a sample of spherical beams as indicated. The data (dots) are compared with Bohr-and-Wheeler- (dotted lines), Kramers- (dashed lines) and ABRABLA $\Gamma_f(t)$- (full lines) predictions. In the two latter cases, β is set to 4.5·10^{21}s^{-1}.

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