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# PROJECTILE FRAGMENTATION AT RELATIVISTIC ENERGIES: A POSSIBILITY TO DETERMINE THE VISCOSITY OF NUCLEAR MATTER*

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Up to now, the results on nuclear viscosity are rather contradictory. Values of the dissipation coefficient between $\beta \approx 0.5 \cdot 10^{21}\mathrm{s}^{-1}$ and $\beta \approx 20 \cdot 10^{21}\mathrm{s}^{-1}$ have been deduced from previous experiments. A new experimental access to the dynamics of fission is given by peripheral nuclear collisions at relativistic energies. This method has important advantages with respect to the traditional ones, since highly excited nuclei are produced with low angular momenta and small shape distortions. Preliminary results of applying this procedure at GSI Darmstadt are presented.

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## 1. Introduction

In the deexcitation process of a heavy excited compound nucleus, particle evaporation competes with disintegration by fission. The mean evaporation time is determined by the statistical model. Fission is the result of a diffusion process to large deformation, hence the system needs a time $\tau$ to build the quasistationary flow over the fission barrier. $\tau$ depends on the nuclear viscosity which is expressed by $\beta$, the dissipation coefficient [2].

Up to now, a large variety of experimental methods has been applied to the study of the viscosity: fusion [3] and fast fission [4], spallation [5],

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annihilation of anti protons [6], peripheral nuclear collisions in the Fermi-energy regime [7], etc. The main observables involved in these procedures are the fission cross sections the pre- and post-scission neutrons [1], and the pre-scission GDR radiation [8].

A new experimental approach to this subject is given by fragmentation reactions at relativistic energies. Projectile fragments have particularly well defined properties since they are produced with low angular momenta ($L < 20\hbar$ [9]) and small shape distortions. This is the mechanism we use to prepare highly excited fissile nuclei in our experiment at GSI. By measuring the fission cross sections of these nuclei and comparing them with the predictions obtained by the statistical model, we determine the viscosity for high excitation energies and small deformations.

## 2. Experiment

Figure 1 shows the experimental set up.

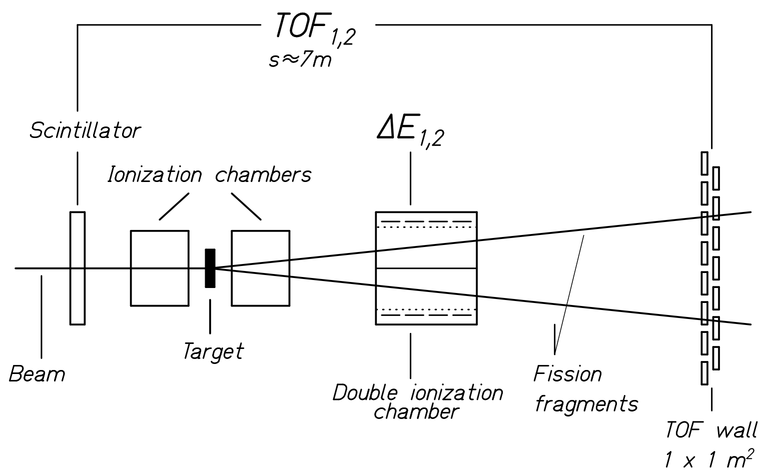


Fig. 1. Experimental setup. Fission events produced in the lead target are selected by comparing the values of the energy-loss measured in the ICs placed before and after the target. The nuclear charges of the two fission fragments are measured by the double IC. The scintillator and the TOF wall give the time of flight of the fragments.

A beam of $^{238}$U ions at 1 AGeV impinges on a lead target. Several detectors are installed to register the fission of projectile fragments.

The target is surrounded by two ionisation chambers (ICs). When fission is induced in the target, the energy-loss in the second chamber is reduced by about a factor of two. Because of the relativistic energy of the fissioning nucleus, the two fission fragments are ejected in forward direction and detected simultaneously in the double ionisation chamber with an efficiency close to 100%. Measuring the energy-loss signals of both fission fragments in the double ionisation chamber we determine their nuclear charges. However, in order to improve the charge resolution, the energy-loss signal must be corrected for its dependence on the velocity. The velocity is obtained by measuring the time of flight of the fission fragments with the scintillator and the TOF wall.

Once the nuclear charges $Z1$ and $Z2$ of the fission fragments are obtained, the partial fission cross sections can be deduced. These are defined by the fission yield measured for a specific value of $Z1 + Z2$ divided by the number of ions in the incident beam and the number of target atoms per unit area.

## 3. Preliminary results

In figure 2, the preliminary partial fission cross sections are given in comparison with theoretical predictions obtained by the Monte-Carlo code ABRABLA [2, 10, 11] for different values of $\beta$.

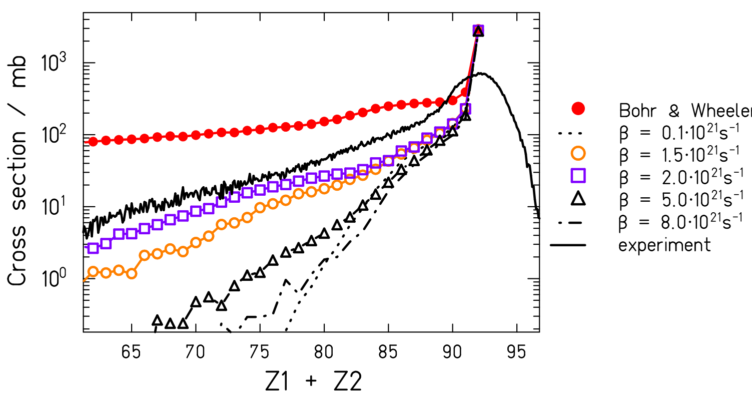


Fig. 2. Partial fission cross sections as a function of the sum of the nuclear charges of the fission fragments. The preliminary experimental values (full line) which are not yet corrected for the charge resolution are compared with theoretical predictions for different values of $\beta$.

Obviously, the data are very sensitive to the magnitude of nuclear viscosity. The Bohr–Wheeler assumption which is based on the statistical model overestimates the fission cross sections. The inclusion of viscosity effects gives a better description, especially for $\beta$ close to $2 \cdot 10^{21} \mathrm{s}^{-1}$.

We finally want to remark that this quantitative conclusion is preliminary, since the data must still be corrected for parasitic reactions. Furthermore, the influence of other model parameters on the theoretical calculation has to be studied, and the description of the time dependence of the fission probability, which is now roughly represented in the code by a step function, that means by a sudden increase from zero to the stationary value at time $\tau$, should be replaced by a more realistic one.

## REFERENCES


[1] D. Hilscher *et al.*, *Ann. Phys. Fr.* 471 (1992).

[2] A.-V. Ignatyuk *et al.*, *Nucl. Phys.* **A593**, 519 (1995).

[3] V.A. Rubchenya *et al.*, *Phys. Rev.* **C58**, 1587 (1998).

[4] J. Velkovska *et al.*, *Phys. Rev.* **C59**, 1506 (1999).

[5] X. Ledoux *et al.*, *Phys. Rev.* **C57**, 2375 (1998).

[6] W. Schmid *et al.*, *Phys. Rev.* **C55**, 2965 (1997).

[7] E.-M. Eckert *et al.*, *Phys. Rev. Lett.* **C64**, 2483 (1990).

[8] P. Paul *et al.*, *Annu. Rev. Nucl. Part. Sci.* **44**, 65 (1994).

[9] M. de Jong *et al.*, *Nucl. Phys.* **A613**, 435 (1997).

[10] A.R. Junghans *et al.*, *Nucl. Phys.* **A629**, 635 (1998).

[11] J.-J. Gaimard *et al.*, *Nucl. Phys.* **A531**, 709 (1991).