Study of fission hindrance using γ-decay from the hot giant dipole resonance

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Introduction

In a seminal work, Bohr and Wheeler proposed the statistical theory of nuclear fission based on the transition state method where the fission rate is fully governed by the ratio of level densities at the saddle point and the initial state [1]. Nevertheless, it has been observed that the conventional calculations based on the standard statistical model significantly underestimate the yield of pre-scission particles [2, 3] and γ rays [4, 5]. One plausible approach to understand this excess yield of pre-scission particles and γ rays is to assume that the fission process is delayed. This delay can be comprehended by considering the fission as a large-scale mass diffusion process across the barrier in a dissipative medium [6-8]. The dissipative force reduces the fission width in the following manner. Within the saddle, it takes a finite time for the fission flux to accumulate. At the saddle point, the fission width decreases compared to that predicted by Bohr and Wheeler due to dissipative forces. Indeed, it is observed that inside the saddle, the fission width increases exponentially with time, converging asymptotically towards the width predicted by Kramers

$$\Gamma_K \propto \Gamma_{BW}[(1+\gamma^2)^{1/2}-\gamma] \quad (1)$$

where $\gamma = \beta/(2\omega_s)$, β is the reduced dissipation coefficient and ω_s represents the frequency of the inverted harmonic potential at the saddle point. In addition, the dissipative force retards the progression of the compound nucleus from the saddle to the scission point. Consequently, the dynamical evolution of the compound nucleus is delayed by dissipation, resulting in a reduced fission decay rate. In contrast, the particles and γ rays are emitted continuously throughout this dynamical evolution from the equilibrium to the scission point, resulting in an enhanced yield of pre-scission particles and γ rays.

The pre-scission high-energy γ rays originate in competition with particle evaporation from the decay of the giant dipole resonance (GDR) built on the excited states of the compound nucleus. Additionally, the γ rays can be emitted from the fission fragments, which are populated at several MeV excitations after scission. Typically, the complete γ-ray spectrum (E_γ ~ 4 - 25 MeV), encompassing both the pre-scission and post-scission contributions, is measured. Through statistical model analysis, the dissipative coefficient γ , which is treated as a free parameter, is derived from the excess yield of the pre-scission γ-rays. There is a strong debate on the nature of variation of γ with temperature. In certain cases, strong temperature dependence is observed implying a two-body dissipation [5]. Conversely, other studies have shown that γ may not be temperature-dependent [9, 10], signifying a one-body dissipation. This conclusion is reached when properly accounting for the shape and spin dependence of the Kramers width, the temperature fluctuations of the fission barriers, the shape dependence of nuclear level density, etc. In this context, we are planning to do a series of experiments at VECC. The preliminary result of our recently concluded experiment is presented here.

Experimental details

The experiment was performed by bombarding a pulsed ^{4}He-ion beam from the K-130 room-temperature cyclotron on a self-supporting ^{232}Th target. The compound nucleus ^{236}U was populated at the initial excitation energy and average angular momentum of ~ 27 MeV and ~ 10$\hbar$, respectively. The schematic diagram of the experimental setup is shown in Fig. 1. A segment of the LAMBDA spectrometer [11] was employed to detect the high-energy γ-rays. The array was placed at a distance of ~ 50 cm from the target, at an angle of approximately 90˚ with respect to the beam direction. Two Parallel Plate Avalanche Counter (PPAC) were used to detect the fission fragments. They were placed at a distance ~ 7.5 cm from the target position at an angle of ~ 90˚ with respect to the beam direction. For the time stamp of each event registered in each element of the LAMBDA array and the PPAC detectors, the start signal was taken from a 25-element multiplicity filter [12].

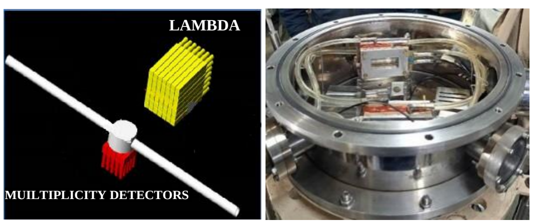

Fig 1: Different detector systems used in the experiment

Data analysis

The energy of the γ rays was reconstructed using the cluster summing technique [11]. The neutron events were rejected taking the prompt cut in the time of flight (TOF) spectrum for each element of the LAMBDA array. The fission-related events were selected by taking proper cuts in the TOF spectrum of the PPAC detectors. The pile up events in the LAMBDA array were rejected using a pulse shape discrimination technique.

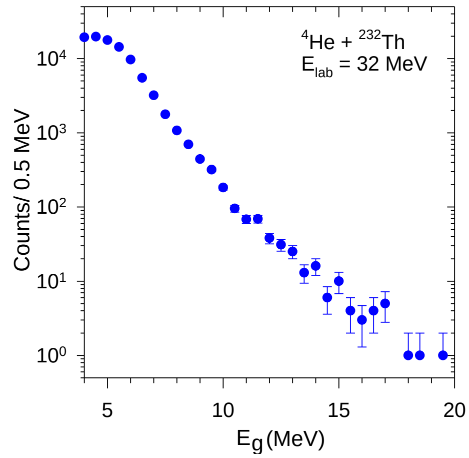

Fig. 2: Fission-gated high-energy γ-ray spectrum for the reaction mentioned.

Fig. 2 displays the complete γ-ray spectrum, comprising γ rays from the CN and the fragments. However, as $E_{GDR} \propto A^{-1/3}$, the γ rays originating from the CN and the fragments can be distinguished. The γ rays above ~ 12 MeV primarily originate from the initial-stage decay of the fragments while those below E_{γ} ~ 8 MeV are emitted below the particle thresholds of the fragments. In the spectrum, a distinct change in slope occurs around E_{γ} ~ 7 MeV, and an excess yield is observed in the range of E_{γ} ~ 7-11 MeV. These γ rays originate from the decay of the hot GDR in the CN, and are superimposed on the exponential spectrum of the fragments. The detailed statistical model analysis is in progress and will be presented during the symposium.

References

[1] N. Bohr *et. al.* Phys. Rev. **56,** 426 (1939).
[2] A. Gavron *et. al.*, PRL **47**, 1255 (1981).
[3] D.J. Hinde *et. al.*, PRL **52**, 986 (1984).
[4] M. Thoennessen *et. al.* PRL **59**, 2860 (1987).
[5] I. Diószegi *et. al.* PRC **61**, 024613 (1987).
[6] H.A. Kramers, Physica **7**, 284 (1940).
[7] P. Grangé *et. al.* PRC **27**, 2063 (1983).
[8] K.H. Bhatt *et. al.* PRC **33**, 954 (1986).
[9] S.G. McCalla *et. al.*, PRL **101**, 032702 (2008).
[10] J. Sadhukhan *et. al.*, PRC **81**, 031602(R) (2010).
[11] S. Mukhopadhyay *et al.*, NIM A **582**, 603 (2007).
[12] D. Pandit *et al.*, NIM A **624**, 148 (2010).