The shape of hot nuclei and the angular distribution of hard dipole photons

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The gamma decay of the giant dipole resonance (GDR) is a sensitive tool for investigating how the nuclear shape changes with spin and excitation energy. This information is however coded in a subtle way in the GDR response function, mainly because the shape and orientation of nuclei at finite temperature display large fluctuations.

Experimental studies have recently been made to understand the effects of the these fluctuations and of their dynamical coupling to the GDR vibrations making use of the spectrometer HECTOR. This spectrometer is described in the contribution of A.Maj [1] and J.J.Gaardhøje [2].

Particularly probing are the measurements of the angular anisotropy coefficient a_2 of the emitted γ-ray. The value of the a_2 does not depend of on the level density, and therefore can be directly compared with theoretical predictions, without any statistical model pre-analysis of the data. The a_2 coefficient is defined as:

$$a_2(E_\gamma) = \frac{1}{2}\frac{\sigma_0(E_\gamma) - 0.5(\sigma_1(E_\gamma) + \sigma_{-1}(E_\gamma))}{\sigma_0(E_\gamma) + \sigma_1(E_\gamma) + \sigma_{-1}(E_\gamma)} \tag{1}$$

In this expression $\sigma_0(E_\gamma)$ is the cross section for the emission of an unstreched γ ray ($\Delta I = 0$), $\sigma_1(E_\gamma)$ and $\sigma_{-1}(E_\gamma)$ are the cross section for the emission of a streched γ ($\Delta I = \pm 1$). An unstreched gamma ray is emitted when a nucleus oscillates along the rotational axis while the streched gamma are emitted when the oscillation of the nucleons is orthogonal to the spin axis. So it is clear that the value of the a_2 coefficient is strictly connected to the orientation and deformation of the decaying nucleus. In fact, in first approximation one can assume the gamma decay cross section $\sigma_{0,\pm 1}(E_\gamma)$ to be a lorentian function whose centroid and width depends on the length of the oscillating axis (i.e on the deformation of the nucleus) [3].

Figure 1a shows the gamma anisotropy coefficient $a_2(E_\gamma)$ produced by the gamma decay for four different nuclear orientations while figure 1b shows the associated dipole strength functions. Contrary to the strength functions for which it is barely possible to distinguish only the type of nuclear shape, the a_2 coefficient shows rather different patterns. In particular, the analysis of the minimum a_2^{min}, maximum a_2^{max} and of the crossing point a_2^{cross} of the anisotropy curve $a_2(E_\gamma)$ determines unequivoquely the "kind of deformation"; for example a minimum which is twice the value of the maximum characterizes a prolate collective deformation while if $|a_2^{min}| \sim |a_2^{max}|$ the nucleus feels an oblate non collective deformation.

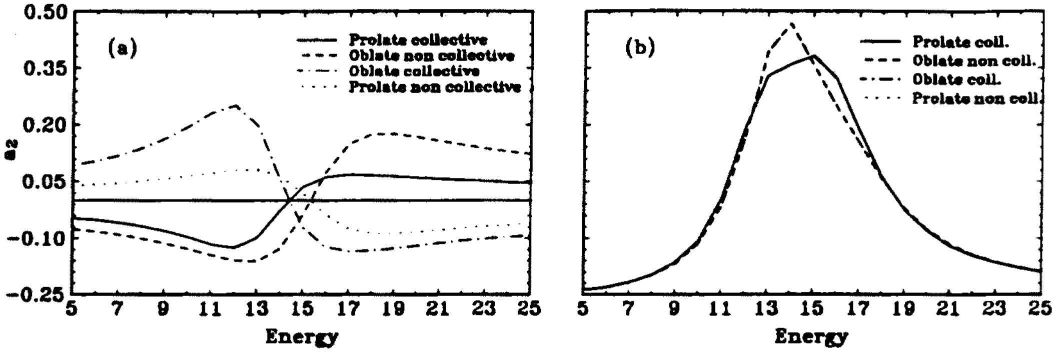

Fig. 1 *Angular anisotropies $a_2(E_\gamma)$ (a) and strength functions (b) of the high energy gamma rays from the GDR decay. The curves are relative to the same nucleus and deformation size and correspond to different orientation and types of deformation. In the horizontal axis the energy of the γ rays is in MeV*

The properties of the $a_2(E_\gamma)$ mentioned above could be easily seen in the experimental distributions from the γ decay of hot rotating nuclei only if nuclei at temperature T$\neq$0 and rotational frequency $\omega \neq 0$ had only one particular shape fixed in time. Instead, since hot rotating nuclei display fluctuations in shape and orientation, more realistic calculations including these effects are required for the interpretation of the experimental data (crf. also the contributions of A.Maj [1] and J.J.Gaardhøje [2]).

Here we present a recent work which is a part of a more extensive project that has been undertaken few year ago by the HECTOR collaboration. It concerns the measurements of angular distributions of high energy gamma rays for the two systems ^{110}Sn [4] and $^{165-167}$Er [5] formed in compound nucleus reactions at a variety of energies and of angular momenta (cfr tab. 1).

The Sn nuclei are spherical in their ground states and are expected to become oblate under the stress of rotations, with a deformation that increases with the size of the nuclear spin. The situation is different for the $^{165-167}$Er nuclei which have prolate ground states and which are expected to become first spherical and then oblate by increasing the rotational frequency and the temperature.

The scenario described above for the tin nuclei is reproduced by the present measurements displayed in fig 2. In fact the measured angular anisotropy increases with the increasing average angular momentum of the nucleus.

A completely different behavior of the a_2 coefficient is seen in figure 3 which shows the measured angular distributions for ^{165}Er, ^{166}Er and ^{167}Er. Even though the spin and the excitation energies are different, the amplitude and the shape of the $a_2(E_\gamma)$ do not show a particular structure or dependence on spin and excitation energy. These experimental results indicate that the averaging process due to shape and orientation fluctuations is so strong that washes out any characteristic structure of the $a_2(E_\gamma)$.

Reaction	E^*	I_{max}
$^{48}Ti(222MeV) + ^{62}Ni = ^{110}Sn^*$	79 MeV	60 $\hbar$
$^{17}O(70MeV) + ^{148}Nd = ^{165}Er^*$	45 Mev	21 $\hbar$
$^{18}O(79MeV) + ^{148}Nd = ^{166}Er^*$	51 MeV	34 $\hbar$
$^{17}O(85MeV) + ^{150}Nd = ^{167}Er^*$	61 MeV	39 $\hbar$

Tab. 1 *A summary of the most significative quantities for the present work. In the first column the reaction that were used are listed. The incident laboratory energy of the projectile is shown inside the parenthesis near its symbol. The excitation energy E^* and the maximum spin of the compound I_{max} are listed in the second and third columns, respectively.*

The erbium and tin data are compared with the results of adiabatical calculations [5] (displayed with the solid lines in figures 2 and 3) and with the anisotropy calculation relative to the equilibrium deformation (displayed with the dot dashed line of figure 2 and 3).

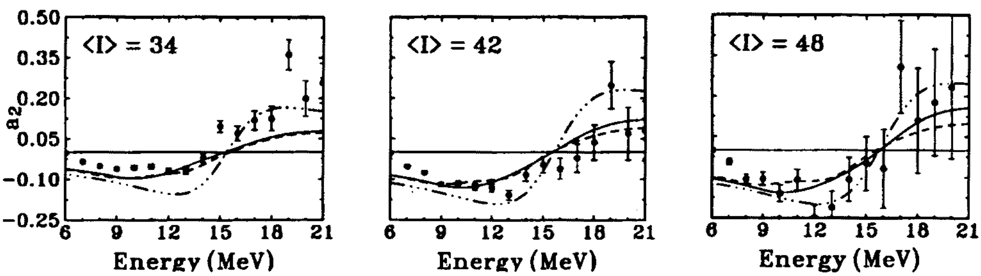

Fig. 2 *The $a_2(E_\gamma)$ coefficient as obtained from the angular distribution of the high energy gamma rays emitted in the decay of the compound nucleus of ^{110}Sn at different value of angular momenta. The average spins are listed at the top of each figure. The calculated curves correspond to: equilibrium deformation (dot dashed line), adiabatical model with schematic GDR shape (solid line) and adiabatical model with more realistic GDR lineshape (dashed line).*

Even though the calculations of the $a_2(E_\gamma)$ within the adiabatic model [5] give a fair account of the experimental data, some disagreement is evident in both systems. In the case of $^{165-167}$Er some discrepancy between the adiabatical calculations and the data is evident at the lowest spin (figure 3, sector 1) while for the ^{110}Sn case the discrepancies get larger at the highest spin (figure 2). The most interesting conclusions following this comparison of the data with these simple predictions are that the orientation fluctuation are very important at low spin and that for $I > 30\hbar$ the hopping time for the change of the nuclear shape and orientation seems to vary with angular momentum. These two points are motivating more calculations and more exclusive experiments with which we hope to have a deeper understanding of the role of thermal fluctuations in the GDR decay.

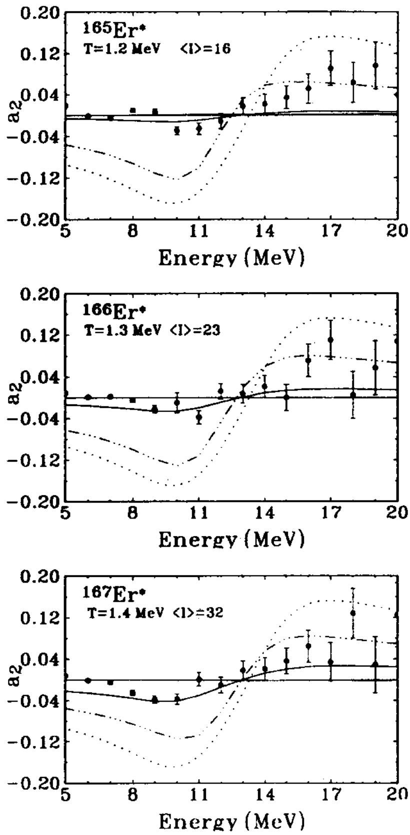

Fig. 3 *The $a_2(E_\gamma)$ coefficient as obtained from the angular distribution of the high energy gamma rays emitted in the decay of the compound nuclei ^{165}Er, ^{166}Er and ^{167}Er. T is the nuclear temperature and $< I >$ is the average spin of the distribution associated to the chosen interval of coincidence fold of the multiplicity filter. The calculated curves correspond to: equilibrium deformation (dot dashed line) and adiabatical model with schematic GDR shape (solid line) The dashed curve correspond is a calculation assuming only shape fluctuations.*

References

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[5] E. Ormand et al. Phys. Rev. Lett. 64,2254 (1990)