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THE DAMPING OF THE GDR AT FINITE TEMPERATURE: RECENT PROGRESS*

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The recent progress made in the study of the Giant Dipole Resonance in hot rotating nuclei in the medium mass region with mass number $A = 110$ and 170 is discussed. Particular emphasis is given to experimental studies of the spectral and angular distributions at temperatures between 1 and 2 MeV. The mechanisms that play a role in the width of the giant dipole resonance state are the nuclear shape and orientation and their fluctuations and the collisional damping, the latter found to be basically independent of temperature and rotational frequency.

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1. Introduction

Different properties of hot rotating nuclei can be investigated through the studies of the γ decay of the giant dipole resonance (GDR), depending on the value of the excitation energy.

The low excitation energy interval $E^* = 30 - -100$ MeV is of particular interest to study the transition between the region (close to the yrast line) dominated by quantal effects to the region where nuclei can be described by models based on classical and macroscopic concepts as in the case of the liquid drop model.

At higher excitation energies ranging from 150 MeV up to excitation energies not far from the fragmentation limit ($E^* = 500 - -1000$ MeV), the study of the GDR γ-decay is expected to provide new information on both the damping mechanism and on the time scales associated to collective excitations in very hot nuclear matter.

Another region of interest is that of the fission-instability for either very heavy nuclei or very fast rotating nuclei. The pre-fission GDR emission was shown to be a powerful tool to study nuclear viscosity and fission time scales (see reference [1] and the lecture by A. Maj at this school).

The present lecture addresses the problem of the relaxation of the giant dipole resonance in hot strongly rotating nuclei. The progress made in this field is based on new exclusive experiments on both the spectral function and the angular distribution of the high energy photons emitted by hot compound nuclei. Particular attention is given to hot nuclei with temperatures in the interval 1 to 2 MeV and with masses $A \approx 110$ and $A \approx 170$. Under these circumstances it is expected that the shell structure associated with both spherical (A=110) and deformed ($A = 160 - -170$) nuclei melts, leading to shape phase transitions and to a liquid drop behaviour of the system as a whole. These phenomena have revealed to constitute a severe test of the theoretical models which aim at describing the consequences statistical effects have on the GDR properties.

2. The GDR experiments

The experimental methods employed for the GDR studies in hot nuclei rely on the measurements of the spectral and angular distributions of the high energy photons emitted by compound nuclei formed in heavy ion fusion reactions. In the last few years a great deal of experimental effort has been made to obtain more exclusive data that allow to test in greater details the model predictions. A rather efficient system that was designed for GDR measurements is the HECTOR (High Energy deteCTOR) detector array. It consists of 8 large volume BaF_2 scintillators (placed at different angles with respect to the beam direction) for measuring high energy photons and a multiplicity filter of 38 smaller BaF_2 detectors measuring the coincidence fold of low energy gamma rays. More details about the HECTOR detector array are in the contribution of Mattiuzzi to this school and in Refs [2, 3].

3. Damping mechanisms of the GDR at finite temperature

A large body of data exists concerning the width of the GDR in nuclei of mass $A \approx 110$ associated to compound nuclei formed at a variety of excitation energies extending up to $E^* \approx 550$ MeV. At moderate excitation energies $E^* \leq 150$ MeV the width increases from the ground state value of 5 MeV up to approximately 11 MeV at $E^* = 130$ MeV [4, 5]. A width of 13 MeV has reproduced the experimental γ-ray spectra from CN with excitation energies up to $E^* = 250$ MeV [6, 7]. Above 300 MeV the experiments have shown a saturation of the γ-yield from the GDR decay [8–10]. This result has been recently confirmed by another experiment measuring high energy γ-spectra produced with the reaction ^{36}Ar at 27 MeV/u on ^{70}Zr [11]. The authors also concluded that the GDR width is 12 MeV.

However, one point that should be stressed in discussing the existing systematics as a function ofE^* is that the angular momentum and excitation energy effects are simultaneously present and both affect the distribution of shapes which describes the compound nucleus and to which the GDR couples. The Boltzman factor describing the probability for the Sn nucleus to have a deformation characterized by the quadrupole parameters β and γ, is shown in Fig. 1. The landscape of shape distributions becomes wider as temperature increases while the deformation associated to the maximum of the distribution becomes larger as the rotational frequency increases. In order to disentangle spin and temperature effects we have measured the strength function and the angular distribution of the γ -ray emitted by the GDR in ^{110}Sn at T$\approx$ 1.8 MeV at different values of the angular momentum. The reactions employed were ^{48}Ti+ $^{62,61}Ni$ at the incident energies of 223 and 203 MeV.

In the top part of Fig. 2 some spectral data are shown in a linearized form, namely the quantity $f(E_\gamma) * Y_\gamma^{exp}(E_\gamma)/Y_\gamma^{cal}(E_\gamma)$ is plotted to emphasize the details of the high energy γ- ray spectrum in the GDR region. The quantity $Y_\gamma^{exp}(E_\gamma)$ is the measured spectrum while $Y_\gamma^{cal}(E_\gamma)$ is the spectrum calculated with the statistical model and $f(E_\gamma)$ is the lorentzian function giving the best fit to the data. In the statistical model analysis the energy and the width of the GDR were free to vary until the χ^2 was minimized. The calculated and measured spectra were normalized in the region $E_\gamma = 9 - 19$ MeV assuming 100% of the EWSR strength. The GDR parameters were kept fixed in the different steps of the decay cascades of

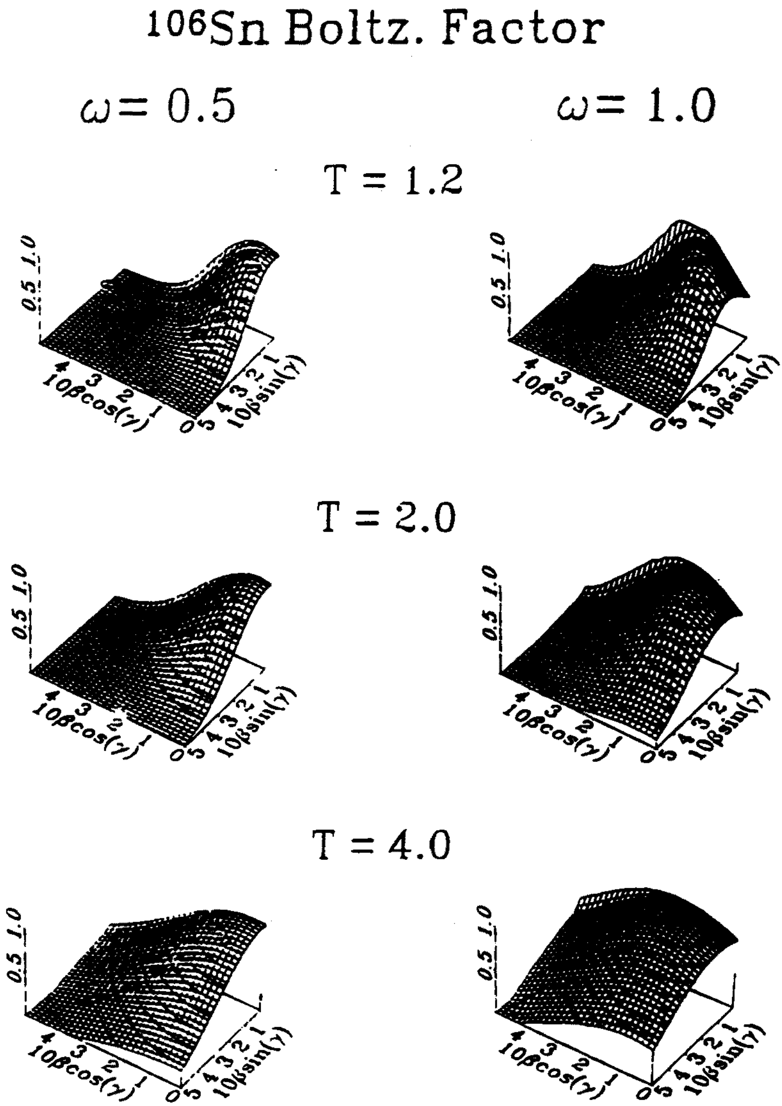

Fig. 1. Three dimensional representation of the shape probability given by the Boltzman factor $\exp(-F(T, \omega, \beta, \gamma)/T)$ (in the vertical axis), where F is the free energy. The calculation are shown as a function of the quadrupole deformation parameters β and γ at three different temperatures T and at two rotational frequencies ω.

the compound nucleus. The statistical model calculations were folded with the detector response function calculated using GEANT3 [12] libraries. In the statistical model calculations the spin distribution of the fusion cross section measured for the selected coincidence fold intervals was used. For the level density parameter the value $a = A/8$ was taken. The obtained values of the GDR width are shown as a function of angular momentum in the bottom part of Fig. 2.

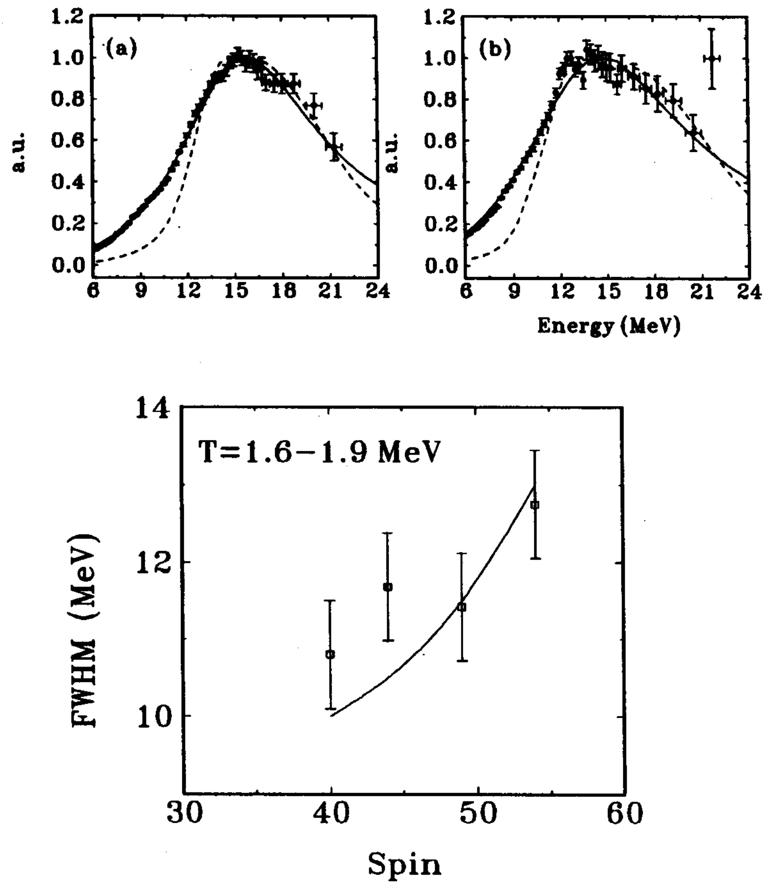

Fig. 2. Top part: Measured spectra multiplied by $f(E_\gamma, E_{\rm GDR}, \Gamma_{\rm GDR})/Y_\gamma^{\rm cal}(E_\gamma)$ where $Y_\gamma^{\rm cal}(E_\gamma)$ is the spectrum calculated with the statistical model, and $f(E_\gamma)$ is the Lorentzian function associated to the values of $E_{\rm GDR}$ and $\Gamma_{\rm GDR}$ giving the best fit to the data. This Lorentzian is shown with the full drawn line. Data and calculations are for the decay of the ^{110}Sn compound nucleus at $E^* = 92$ MeV for different spin windows, the left one is associated to the average value of 42 $\hbar$ and the right one to 50 $\hbar$.
Bottom part: Experimental widths of the GDR in ^{109,110}Sn as a function of the compound nucleus spin at the average temperature T$\approx$ 1.8 MeV. The full drawn line gives the width predicted by the adiabatic model of thermal fluctuations.

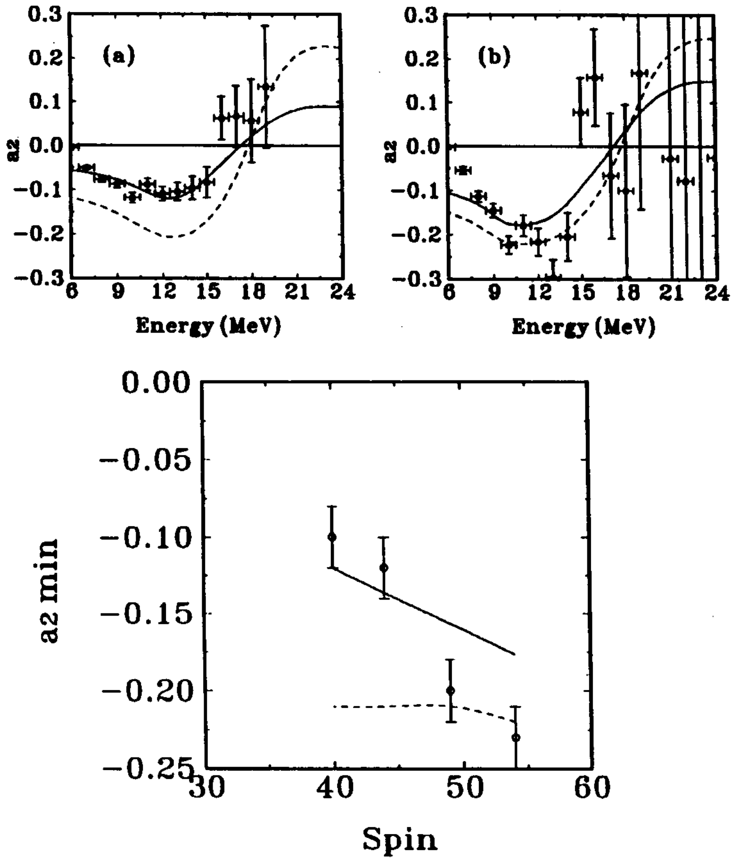

Fig. 3. The upper part of the figure shows the experimental angular distribution coefficient $a_2(E_\gamma)$ for two different spin windows measured for ^{110}Sn (the left panel corresponds to $42\hbar$ and the right to $54\ \hbar$). The lower part shows the minimum a_2 from experiment and theory. The dashed curve was obtained from calculations including only shape fluctuations whereas the full drawn line displays the calculations including also orientation fluctuations.

The increase of the measured width could indicate either an increase in deformation with spin or an increase of the collisional damping width (intrinsic width). In the first case the magnitude of the $a_2(E_\gamma)$ should also increase while in the second it should decrease (see discussion in reference [13]). In the present case the the associated $a_2(E_\gamma)$ distributions, displayed in Fig. 3, show a marked increase when the angular momentum is increased, pointing to large deformation effects driven by angular momentum and suggesting that the collisional damping width does not depend on temperature, as predicted in reference [14]. However, to understand the different sensitivity of the two observables to spin effects and thermal fluctuations it is

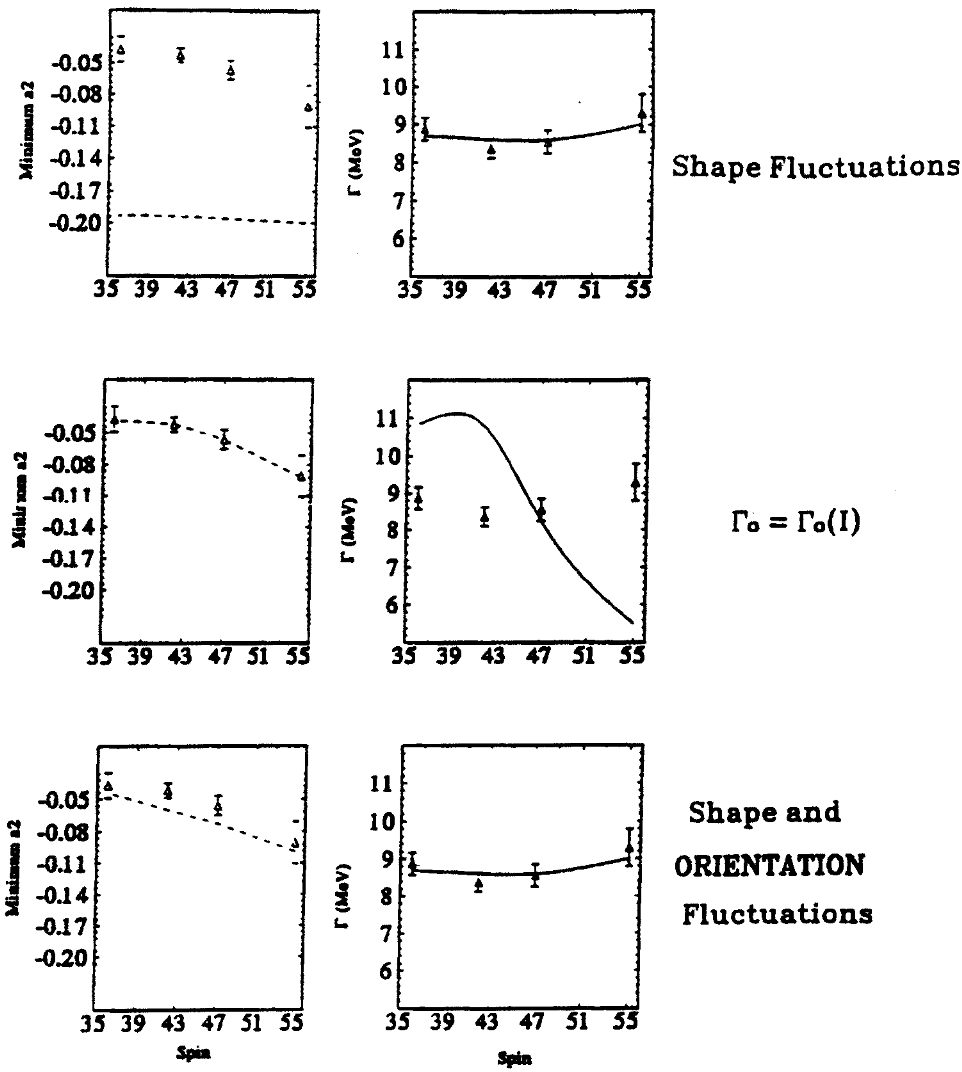

Fig. 4. The measured value of the minimum of the a_2 (left column) and of the GDR width Γ_{GDR} (right column) as a function of spin of the compound nucleus ^{176}W are compared with three different calculations. In the first row, adiabatical model calculations including only shape fluctuations and assuming the intrinsic width fixed and equal to the zero temperature value are shown. In the second row, in addition to shape fluctuations, the values of the intrinsic width Γ_0 were varied to reproduce the measured a_2. In the third row shape and orientation fluctuations are both included in the adiabatic limit and the intrinsic width was assumed to be fixed and equal to the zero temperature value.

important to remember that while the strength function depends only on shape fluctuations, the $a_2(E_\gamma)$ depends also on orientation fluctuations. The measured $a_2(E_\gamma)$ and GDR width for ^{109,110}Sn at 4 different angular momentum values are compared with calculations which include thermal shape and orientation fluctuations in the adiabatic limit [15–19] and which assume that the collisional damping width has the value equal to that at temperature $T = 0$ and at rotational frequency $\omega = 0$ for all the angular momenta considered here. These predictions give a good account of the data, with exception of the $a_2(E_\gamma)$ for the high spin cases. However, an increase of the collisional damping width with angular momentum would worsen the agreement between data and calculations. The $a_2(E_\gamma)$ data at high angular momenta are instead well described by calculations including only shape fluctuations and freezing the orientation fluctuations (see dashed curves in Fig. 3).

Nuclei in the mass region $A \approx 170$ have a different behaviour in the same angular momentum interval (35–55 $\hbar$) and at comparable temperatures. We have studied ^{176}W making use of the compound nucleus reaction ^{28}Si(147 MeV)+^{148}Nd. This study is discussed in detail in the contribution by M. Mattiuzzi *et al.* to this school. Here we summarize in Fig. 4 the results for the minimum of the $a_2(E_\gamma)$ (in the γ-transition energy region 10–12 MeV) and of the GDR widths, to make a more complete discussion on the damping mechanisms. In this figure the data are compared with different calculations which include thermal fluctuations in the adiabatic limit. In the top part of the figure the data are compared with calculations considering only shape fluctuations. In this case only the measured width is well reproduced and not the minimum of the a_2. For these calculations the intrinsic width was taken equal to the zero temperature value. If one tries to reproduce the minimum of the a_2 by changing the intrinsic width (see calculation in the first panel of the second row) one finds that it is not possible to reproduce at the same time the measured width. Instead, by adding to the shape fluctuations also the orientation fluctuations and using a constant collisional damping width equal to the value at $T = 0$, a consistent description of both observables is obtained at all angular momenta (see third row of Fig. 4). In fact, orientation fluctuations do not change the strength function and are able to account for the measured anisotropy.

4. Conclusion

The study of the high energy γ rays emitted by the GDR decay has demonstrated the unique opportunity of investigating the properties of hot rotating nuclei and the damping mechanisms of collective states at finite temperature. We have focussed on the problem of the damping of this collective state at finite temperature.

The present most exclusive measurements of the strength function and of the angular distribution at the temperature interval $T = 1.5 - -2$ MeV and at different spins (in the region 35 to 55 $\hbar$) indicate that the collisional damping width is independent of temperature and angular momentum. The increase of the measured width has been understood as being due to the coupling of the GDR to large deformations induced by angular momentum and by thermal fluctuations.

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