ON THE TEMPERATURE DEPENDENCE OF THE GDR IN ^{120}Sn

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The study of the properties of the Giant Dipole Resonances (GDR) in hot nuclei is of major interest in nuclear structure. The damping mechanism of the GDR as a function of spins and temperature has been highly debated and remains a central question in the field [1]. Two of the theoretical models aiming to explain the temperature dependence of the GDR are the thermal fluctuation model in the adiabatic coupling scheme [2] and the two-body collisional damping model [3]. Whether the temperature dependence of the GDR arises from thermal fluctuations of the nuclear potential landscape or collisional damping of nucleons is still unclear [4].

Experimentally, it has been shown that the GDR depends on the angular momentum of the states the vibration is built on [1] and the nuclear temperature [5]. In most previous analysis, the comparisons between experiment and theoretical models relied on the capability of extracting GDR parameters which assumed that the spectra could be well-reproduced by statistical calculations including a lorentzian strength function. These parameters, the resonance energy E_{GDR} and the FWHM $,_{GDR}$, were then compared with the centroid and FWHM of theoretical GDR strength functions at the (average) nuclear temperature deduced from the experiment. The extraction of the nuclear temperature, crucial to obtain a meaningful comparison between the measured and calculated GDR parameters includes an inherent uncertainty due to the level density parameterization and the contribution of daughter nuclei populated by the hot compound nucleus to the γ-ray spectra. It is often unclear if the calculations were compared with an experimental nuclear temperature derived from the compound nucleus in the first decay step or by a mean temperature averaged over all daughter nuclei populated, the latter being significantly lower at high excitation energies. We report in this progress report on a new approach in which the theoretical models are directly incorporated into full statistical decay calculations and thus can be directly compared with the data. This analysis does not rely on the extraction of the GDR parameters and the nuclear temperature of one data point from the experiment.

The calculations were performed with the computer code CASCADE for which the (temperature independent) phenomenological lorentzian strength function was substituted for the theoretical strength functions from the thermal fluctuation and collisional damping model (shown in fig. 1). In the first model, the spreading of the GDR strength function arises from the increasing shape fluctuations in the nuclear potential landscape with temperature. A complete adiabatic coupling is assumed, i.e. the time scale associated with thermal fluctuations is long compared to the shift in dipole frequency caused by the fluctuations. All possible shapes and orientations can be explored by the nucleus and the final result consists of a weighted average over both shape and orientation degrees of freedom. In the two-body collisional damping approach, the spreading of the GDR width arises from a decrease of the relaxation time due to two-body collisions at higher temperature and the magnitude of the spreading width depends strongly on the nucleon-nucleon scattering cross-section. It should be noted that the effect of nucleon-nucleon collisions on the GDR spreading width is still controversial [6].

In fig. 1, the results of the calculations for the thermal fluctuation (left panel, figure right) and collisional damping (right panel, figure right) model are shown. These theoretical spectra are compared with the results of CASCADE calculations (thin lines with shaded area) with parameters that fit the experimental data from ref. [4] where the shaded area is the experimental uncertainty of the width. The

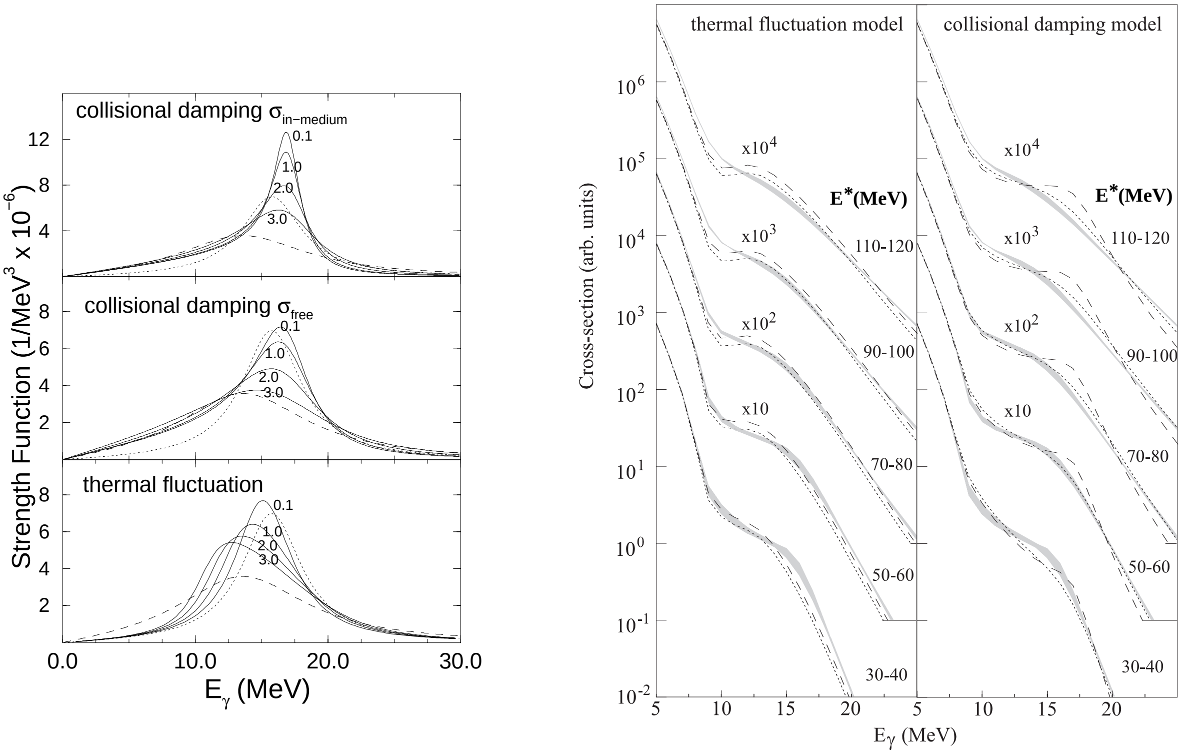

Figure 1: LEFT: Theoretical GDR strength functions (solid lines) of the ^{120}Sn isotope for the two-body collisional model (upper and mid panel) and the thermal fluctuation model (lower panel). They are shown for nuclear temperatures 0.1, 1, 2 and 3 MeV. Also plotted on each panel, a single-lorentzian strength function of GDR parameters E$_{GDR}$ $= 16.0$ MeV and , $_{GDR}$ $= 5.5$ MeV (dotted line) and of GDR parameters E$_{GDR}$ $= 14.8$ MeV and , $_{GDR}$ $= 12.0$ MeV (dashed line), used previously [4] to reproduce the experimental spectra at excitation energies $30 - 40$ MeV and $110 - 120$ MeV, respectively. RIGHT: High-energy γ-ray spectra for ^{120}Sn at several excitation energies. The thin lines (shaded area) correspond to CASCADE calculations (uncertainties of the width) that reproduced the experimental data of ref. [4]. The right panel shows the theoretical spectra of the collisional damping model for a free (dotted line) and an in-medium (dashed lines) nucleon-nucleon scattering cross-section. For both cross-sections, S_{GDR} was chosen to be one. The left panel shows the theoretical spectra of the thermal fluctuation model for a sum rule strength parameter S_{GDR}=1 (dashed lines) and S_{GDR}=0.8 (dotted lines).

spectra of ref. [4] include contributions from bremsstrahlung and were folded with the detector response whereas fig. 1 only shows the raw CASCADE calculations. On the right panel, the overall agreement of the collisional damping model using a free-space cross-section (dotted lines) and a fixed value of $S_{GDR} = 1$ with the experiment is good. A slight excess in the GDR region at higher excitation energies ($90 - 100$ and $110 - 120$ MeV) and a lack of strength at lower excitation energies is observed indicating that the temperature dependence of the GDR spreading width is larger than predicted by the model. The use of the in-medium nucleon-nucleon scattering cross-section (dashed lines) with parameters $\alpha^{NN}_{medium} = 2\alpha^{NN}_{free} = 4.6$ MeV ($S_{GDR} = 1$) exhibits a large excess in the GDR region relative to the experimental curves. This excess is caused by the narrower FWHM of the strength function with an in-medium scattering cross-section, as it is seen in figure 1.

Although a better agreement with the experiment is found for the collisional damping model in the present analysis, it must be tested and verified in other systems and conditions. For example, the model predicts a spin-independent strength function inconsistent with the spin effects on the GDR observed by Bracco *et al.* [1]. If the effects of temperature discussed in this work can be explained within this theoretical framework, it would certainly be an incomplete theoretical picture of the evolution of the spreading width for both spins and temperature. The evolution of the strength function in this model is also highly dependent on the nucleon-nucleon scattering cross-section introduced as a free parameter. By contrast to the analysis of ref. [3] where a comparison of calculated and extracted GDR widths led to a better agreement of the model using an in-medium scattering cross-section, it is found in this work that the use of the strength function calculated with the free-space nucleon-nucleon scattering cross-section provides a theoretical spectra in better agreement with the experiment. However, other nuclei such as ^{208}Pb for which experimental data are available should be investigated.

The thermal fluctuation approach with its spin-dependent strength function is potentially a more complete theoretical framework to explain both the temperature and spin dependence observed in the ^{120}Sn isotope. However, this model presents an inherent problem in the low-energy region of its strength function. To achieve a good agreement with the data at high-excitation energy, the model require a reduced value of 0.8 for the energy weighted sum rule, while a better agreement with $S_{GDR} = 1$ is found at low-excitation energy. The loss in strength at high excitation energies could be due to processes like pre-equilibrium emission which do not result in high target excitations, but nevertheless contribute to the γ-ray spectra up to 8 MeV [4]. Finally, we emphasize on the fact that the good agreement between the model and GDR data found by previous analyses was achieved by comparing the calculated FWHM with the experimental GDR widths compared at the nuclear temperature derived from the compound nucleus in the first step [2, 4], thus neglecting the contribution to the spectra of daughter nuclei populated at lower temperature. The present analysis shows that only a comparison of the FWHM and resonance peak of the calculated quantities is not accurate but the complete shape of the GDR strength function should be considered and included into full statistical decay calculations to achieve a meaningful comparison between theory and experiment.

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