The effect of GDR - GQR couplings on the GDR width at low temperature

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Recently, the couplings between collective vibrations such as the isovector giant dipole and isoscalar giant quadrupole resonance have been studied in the framework of time-dependent Hatree-Fock theory [1]. It is shown that the residual interaction couples the isovector giant dipole resonance (GDR) and the isoscalar giant quadrupole resonance (GQR) which induces a nonlinear evolution of the quadrupole moment after a dipole boost. In general, a dipole motion produces quadrupole oscillations in all atomic nuclei [1]. On the other hand, the thermal shape fluctuation model (TSFM) proposes that at finite excitation energy, the nucleus does not possess a single determined shape, but rather gives an average of a broad ensemble of shapes due to thermal fluctuations. In the adiabatic assumption, the GDR cross-section is made up as a weighted average over all shapes and orientations. This gives rise to temperature-driven broadening of the GDR width [2, 3]. Although this widely accepted model gives reasonable description of the GDR width variation with temperature ($T > 1.5$ MeV), it fails miserably to explain the experimental data below $T < 1.5$ MeV in different mass regions [3, 4, 5]. We show that the discrepancy observed at low temperature is due to the competition between GDR induced quadrupole moment and the thermal shape fluctuations, which leads to a critical point in the increase of the GDR width with temperature.

The effect of angular momentum (J) on the GDR width is explained remarkably well within the TSFM [3]. It is shown in Ref[6] that with increasing angular momentum, the nucleus undergoes oblate flattening due to centrifugal effects. The equilibrium deformation (β_{eq}) increases rapidly with J, and as a consequence, the total strength function undergoes splitting which increases the overall width of the resonance. However, it needs to be mentioned that even though β_{eq} increases with angular momentum, an increase of GDR width does not occur until β_{eq} becomes greater than the variance of the deformation $\Delta\beta = \left(\langle\beta^2\rangle - \langle\beta\rangle^2\right)^{1/2}$. This is illustrated in Fig.1 [6]. Thus, the competition between β_{eq} and $\Delta\beta$ gives rise to a critical angular momentum (J_c) value which is observed experimentally in all mass region given by the relation $J_c = 0.6A^{5/6}$ [3]. Similarly, the effect of thermal fluctuations on the GDR width should not be evident when $\Delta\beta$ due to thermal fluctuations is smaller than the intrinsic deformation (β_{GDR}) induced by the GDR quadrupole moment. The competition between β_{GDR} and $\Delta\beta$ should lead to a critical temperature (T_c) in the behavior of the GDR width with T. As a result, the GDR widths should remain roughly constant at the ground state values upto T_c and increase subsequently above it when thermal fluctuations become larger than the intrinsic GDR fluctuation. Indications of such behavior were seen recently in our experimental study on ^{119}Sb [4] and ^{201}Tl [5], where the GDR widths were found at ground state values at T~1 MeV and increased subsequently thereafter in complete contrast to TSFM which predicts gradual increase of GDR widths from T=0 MeV.

Quadrupole moment (Q_Q) induced by the GDR motion has been calculated under the framework of time dependent Hartree-Fock theory in Ref[1]. Using the reported values of Q_Q for ^{208}Pb, ^{120}Sn, ^{90}Zr and ^{40}Ca as 99.0, 56.0, 46.5 and 21.4 fm^2, respectively, the β_{GDR} values were estimated considering β proportional to $Q_Q/\langle r^2\rangle$ for ellipsoidal shapes in general, using the relation $\langle r^L\rangle = 3R^L/(L+3)$. We found that β_{GDR} decreases with increase in mass and shows a linear behavior with 1/A given as $\beta_{GDR} = 0.04 + 4.13/A$ [5]. Since the critical temperature should depend on the competition between β_{GDR} and $\Delta\beta$, we calculated the variance of the deformation for

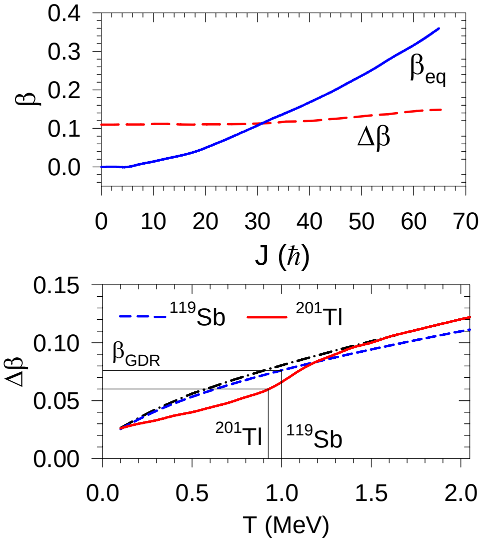

Fig.1. (Top) The equilibrium deformation (β_{eq}) is compared with $\Delta\beta$ as a function of J for ^{106}Sn. (Bottom) The variance of the deformation as a function of T for ^{201}Tl and ^{119}Sb. The dot-dashed line represents the calculation for ^{201}Tl without shell effects. The corresponding β_{GDR} is compared with $\Delta\beta$ (thin continuous lines).

^{119}Sb and ^{201}Tl applying the formalism described in Ref[7]. The β_{GDR} values for ^{119}Sb and ^{201}Tl were estimated from the systematics $\beta_{GDR} = 0.04 + 4.13/A$ and compared with the corresponding $\Delta\beta$ values (Fig. 1). It is interesting to note that the temperatures at which β_{GDR} is equal to $\Delta\beta$ correspond to the experimentally measured critical temperatures for both ^{119}Sb and ^{201}Tl (Fig. 2) [4, 5]. The $\Delta\beta$ values for ^{201}Tl were calculated for two cases i.e. with and without shell effects. It can be seen that without the inclusion of shell effect, $\Delta\beta$ and β_{GDR} are equal at T ~ 0.55 MeV whereas the experimental result shows T_c ~ 0.9 MeV. The inclusion of shell effect in $\Delta\beta$ for thermal fluctuations leads to a higher T_c in agreement with the experimentally extracted value. Thus, we find that shell effects indeed play an important role in A ~ 200 as predicted earlier in the variation of GDR width with T.

We propose a new model by modifying the phenomenological parametrization based on TSFM (pTSFM) [3] by including the GDR induced quadrupole moment and term it as critical temperature included fluctuation model (CTFM). The GDR widths predicted within CTFM [5], microscopic phonon damping model (PDM) [8] and pTSFM [3] as function of T are shown in Fig. 2. It can be clearly seen that the microscopic PDM and phenomenological CTFM give similar results and represent the experimental data quite well. However, the pTSFM fails to represent the experimental GDR width sytematics since it does not take into account the GDR fluctuations induced by the quadrupole moment. Thus, the appearance of a critical temperature in the variation of the GDR width could perhaps be the experimental signature of GDR-GQR couplings at finite T. The J & T dependence of the phenomenological CTFM and the behavior of T_c as a function mass will be discussed during the conference.

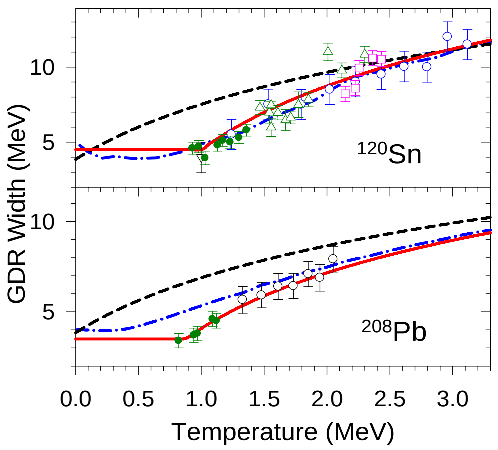

Fig.2. The GDR widths as function of T. The continuous, dot-dashed and dashed lines correspond to CTFM, PDM and pTSFM, respectively. The filled circles are our experimental data for ^{119}Sb and ^{201}Tl compared with ^{120}Sn and ^{208}Pb data, respectively.

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