Quenching of giant dipole resonance width in ^{97}Tc due to thermal pairing and its fluctuations

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Introduction

The study of giant dipole resonance (GDR) is a powerful tool to investigate the basic nuclear structure properties and many-body interactions at high temperature (T) and angular momentum. The GDR width (Γ) which is an observable quantity, gives the information about the shape and damping mechanism in nuclei. Due to the progress in experimental facilities, now it is possible to reach different regimes of nuclear excitations. One among such a regime which holds several puzzles is the low-T region where both the pairing and shell effects are quite strong [1]. Recently, the low-T GDR measurements of ^{97}Tc were reported in Ref. [2] along with the results from the phonon damping model (PDM). PDM, which is a microscopic model, successfully explained the low-T GDR data with the proper inclusion of pairing. On the other hand, the thermal shape fluctuation model (TSFM) which is successful in explaining several GDR observations in hot and rotating nuclei, overestimates the Γ at low T, and was considered to be inadequate [3]. Here we show that with the proper inclusion of pairing correlations in TSFM, we are able to explain the low-T GDR measurements in ^{97}Tc.

Theoretical framework

We follow a macroscopic approach for GDR where the observables are related to the nuclear shapes, through a rotating anisotropic harmonic oscillator model with separable dipole-dipole interaction [4]. Within the conventional fluctuation model, the observables are averaged over the chosen degrees of freedom with the weights given by the Boltzmann factor $[\exp(-F_{\mathrm{TOT}}/T)]$. The total free energy (F_{TOT}) is calculated using the Nilsson-Strutinsky (NS) method as,

$$F_{\mathrm{TOT}} = E_{\mathrm{LDM}} + \sum_{p,n} \delta F \ . \qquad (1)$$

Here, E_{LDM} is the liquid-drop energy corresponding to a triaxially deformed nucleus and δF is the temperature dependent shell correction. The pairing is included in the formalism within the BCS approach (NS+BCS). We have considered the pairing fluctuations (PF) also (i.e. the averaging is over the pairing gaps also) along with NS method (NS+PF). While considering the pairing correlations the nucleus is described by grand canonical ensemble where the particle number fluctuation is allowed by fixing the chemical potential (λ). The corresponding free energy can be determined as [5],

$$F = \langle H_0 \rangle - \lambda N - TS \ , \qquad (2)$$

where H_0 is the nuclear Hamiltonian which is independent of temperature, N is the particle number, and S is the entropy. To understand the role of shell effects, we have done calculations where the free energies are given by simple liquid drop model (LDM).

Results

The potential energy surfaces (PES) of the nucleus ^{97}Tc calculated using NS and NS+BCS methods at $T = 0.2$ MeV are shown

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TABLE I: The proton and neutron pairing gaps (Δ_P and Δ_N, respectively), average deformation parameter ($\langle\beta\rangle$) and GDR width (Γ) at different temperatures for the nucleus ^{97}Tc. The pairing gaps are calculated using BCS and in addition with pairing fluctuations (PF). $\langle\beta\rangle$ and Γ are calculated with thermal shape fluctuation model utilizing free energies from liquid drop model (LDM), Nilsson-Strutinsky (NS) method without pairing, NS method with BCS pairing (NS+BCS) and NS method with PF (NS+PF). The experimental values for Γ are as given in Ref. [2].

T	Δ_P (MeV)		Δ_N (MeV)		$\langle\beta\rangle$				Γ (MeV)				
(MeV)	BCS	PF	BCS	PF	LDM	NS	NS+BCS	NS+PF	LDM	NS	NS+BCS	NS+PF	Expt.
0.1	0.86	1.65	1.21	1.94	0.07	0.24	0.11	0.10	5.86	7.10	5.71	5.19	-
0.4	0.54	1.63	0.99	1.83	0.15	0.21	0.15	0.19	6.49	7.18	5.91	5.16	-
1.0	0	1.43	0	1.66	0.23	0.23	0.24	0.23	7.52	7.54	7.65	5.77	$5.71\pm^{0.5}_{0.6}$
1.4	0	1.24	0	1.43	0.28	0.27	0.28	0.27	8.08	8.08	8.12	6.88	$6.90\pm^{0.5}_{0.6}$

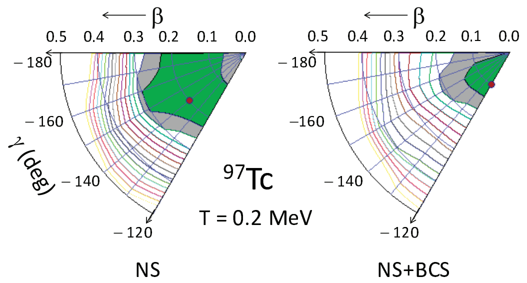

FIG. 1: The potential energy surfaces of the nucleus ^{97}Tc at T = 0.2 MeV calculated using Nilsson-Strutinsky (NS) and NS+BCS method. The contour line spacing is 0.5 MeV. The most probable shape is marked by a solid red circle and the first two minima are shaded.

in Fig. 1. The PES from NS method shows a clear gama softness which implies averaging over a larger deformation space and hence a larger Γ. The PES from NS+BCS method shows a smaller deformation and hence implies a smaller width with the inclusion of pairing. The dependance of T on pairing gaps, Γ and $\langle\beta\rangle$ are calculated using different methods are presented in Table I. The BCS pairing gap vanishes at critical T, but the pairing gaps from PF calculations are not vanishing at critical T, but decreases slowly with increase in T. The $\langle\beta\rangle$ from NS calculations show a higher value than the LDM results at low T. Hence we can understand that the shell correction increases the $\langle\beta\rangle$ at low T, whereas the NS+BCS, NS+PF calculations show a lower $\langle\beta\rangle$ value than the results of NS calculations.

The interplay between shell correction and the pairing effect determine the $\langle\beta\rangle$ as well as the Γ at low T. Even though the NS+BCS calculations give a lower Γ when compared to the NS calculations, but this is not sufficient to explain the experimental data since the pairing vanishes at critical T. But with the inclusion of PF, our calculations (NS+PF), can explain the quenching of Γ at low T.

Conclusion

The proper inclusion of thermal pairing in TSFM is very important at low temperatures. To understand the thermal pairing and its role on several thermodynamical properties of nuclei we need more and precise observations.

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