Giant resonance built on excited states of nuclei

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The theoretical understanding of nuclear many-body problem is built upon the models with adequate phenomenological inputs. Such models representing the nature of ever-intriguing nuclear force can be robust if they render applicability over various domains, including the extremes of temperature (T), spin (I), isospin and density. Hence, extending the nuclear models to study nuclei at these extremes also gains significance. Important task in this regard is to identify the relevant phenomena for which the observables can be calculated reliably in all the considered domains. Giant resonances (GR) in nuclei is one such fundamental mode of excitation which can be built on any nuclear state. In a simplistic view, the GR are due to collective oscillations of protons and neutrons under the influence of the electromagnetic field induced by the emitted/absorbed photons, which results in a large peak in the emission/absorption spectrum of γ-rays. Among the various possible modes of the GR, the most dominant mode is the isovector giant dipole resonance which is commonly termed as GDR. Constructing a theoretical framework to study the GDR built on various nuclear states so as to unravel the underlying nuclear structure, is the broad aim of this thesis work.

Various theoretical approaches have been introduced to investigate the GDR. In a macroscopic approach, GDR couples directly to the shape of the nucleus, hence providing corresponding structure information. This link is not so straight-forward especially in hot nuclei where thermal fluctuations are expected to be large since the nucleus is a tiny finite system. The thermal shape fluctuation model (TSFM) is based on the macroscopic approach for GDR and takes into account the thermal fluctuations over the possible degrees of freedom, in a simple case, the shape parameters. This is achieved through a weighted average of the observable over the considered degrees of freedom. The weights are given by the Boltzmann factor $[\exp(-F/T)]$ where the free energy (F) is calculated within the Nilsson-Strutinsky (microscopic-macroscopic) approach. The theoretical framework developed in this thesis work is built upon such a TSFM.

Several earlier works on GDR focussed on the high-I regime whereas the recent studies at extreme isospins have potential astrophysical implications. Apart from the higher limits of T, I and isospin, the properties of atomic nuclei are intriguing and less explored at the limits of lowest but finite temperatures. Such studies have gained acceleration in recent times. At very low temperatures there is a strong interplay between the shell (quantal fluctuations), statistical (thermal fluctuations), and residual pairing effects. At high-I, the pairing collapses but still the other two effects are strong and so is their interplay. In these cases, conclusive experimental results are scarce. This thesis work is an attempt to understand such warm nuclei both in the rotating and nonrotating cases, by studying the GDR observables. As the physics cases we have chosen the following:

1. Warm nuclei
   (a) Role of pairing and its fluctuations
   (b) Role of the choice of mean-field
2. Warm and rotating nuclei: Shape transitions at higher spins.

Several properties of nuclei at low T are still not clear, for example, the existence of pairing phase transition, the order of it if it exists, the role of fluctuations, etc. The success of pairing approach at low T and that

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of the TSFM elsewhere have motivated us to consider a combination of pairing correlations within the TSFM. Thermal shape fluctuations and fluctuations in the pairing field are the dominating fluctuations and they have been so far studied separately within different models. Both of these fluctuations are expected to be present at low temperatures. However, the interplay between them has not been investigated so far and forms a motivation for our above case 1(a) [1, 2]. Our results for ^{97}Tc, ^{120}Sn, ^{179}Au and ^{208}Pb clearly demonstrate that the TSFM can be quite successful if the shell effects (with explicit temperature dependence) and the pairing ones are properly incorporated in the free energy. The observed quenching of GDR width at low-T in ^{97}Tc, ^{120}Sn, ^{179}Au and ^{208}Pb can be understood in terms of simple shape effects caused by the pairing correlations. More measurements with better precision could yield rich information about several phase transitions that can happen in warm nuclei.

The availability of GDR data for nuclei away from stability like the case of ^{179}Au demands a careful introspection of the choice of the mean-field because a simple potential like that of Nilsson could not be a reliable choice for such cases. Previous work to calculate the triaxially deformed Woods-Saxon potential has been extended to perform full microscopic-macroscopic calculations where all the above-mentioned developments are carried forward [3].

The case 2 above is motivated by the fact that most of the earlier GDR studies of rotating nuclei were at sufficiently larger T. With dominant thermal fluctuations, and melting of shell effects, the features of such nuclei can be explained even by a liquid drop model. More interesting shape transitions driven by the shell effects can be studied only at lower T and hence considered in this work [4, 5]. The gamma softness suggested by our calculations in ^{144}Sm nucleus in the given temperature range explains the enhanced thermal fluctuations and hence the measured GDR width. However, some phase transitions are strongly smoothed by the wide window of angular momentum and temperature that can be disentangled with the present experimental information. In the case of ^{152}Gd, certain anomalies reported can attributed to the uncertainties in experimental data. Our results for GDR cross sections are in good agreement with the experimental values except for a component peaking around 17 MeV, where the data has large uncertainties [6].

For the first time, we have developed a theoretical framework to study the GDR in hot nuclei with proper treatment of pairing, pairing fluctuations and shape fluctuations with the temperature dependent shell effects calculated in a numerically exact method. Within the limited time frame of this thesis work, we have applied our formalism to a few nuclei and brought out several interesting observations.

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