Experiment: Investigation of two-phonon gamma-vibrational states in ^{164}Er

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The manifestation of two-phonon γ-vibrations in deformed nuclei has been a stimulating theme and extensively-discussed phenomenon in nuclear structure physics research over the past few decades [1 – 7]. The importance of such collective vibrations lies in the fact that these essentially provide insight into whether the nucleus vibrates with respect to an axially symmetric or a γ-deformed equilibrium shape. Moreover, the observation of such states provides stringent constraints on nuclear models. The existence of two-phonon γ-vibrations in a deformed nucleus is visible through the presence of $K^{\pi} = 0^{+}$ and $K^{\pi} = 4^{+}$ states/bands at more than twice the energy of the single-phonon, $K^{\pi} = 2^{+}$ bandhead. Such excitations were proposed earlier in a number of transitional and deformed nuclei. However, it was later pointed out that many of those suggested states [6] may not be predominantly two-phonon in their characters, rather, these could be well described in terms of hexadecapole phonon vibrations, or *g*-boson structures [7].

The difficulty in the experimental observation of the two-phonon γ-vibrational (γγ) states has been attributed to their possible existence at excitation energies close to the pairing gap. This results in an enhanced level density near the γγ states, and thereby, possibly, a fragmented vibrational strength through mixing with other close-lying, non-collective two-quasiparticle states. In many deformed nuclei, the one-phonon γ-vibrational (γ) band, which is generally the lowest collective vibration, lies close to, or even above 1 MeV. As a consequence, the expected γγ band, if it exists, lies considerably above 2 MeV, thereby placing it well beyond the pairing gap where the density of states is high.

Among the Erbium isotopes, ^{168}Er and ^{166}Er were predicted to be the most favourable ones for the experimental observation of γγ states by the quasiparticle-phonon nuclear model (QPNM) [7]. The Erbium isotopes, indeed, offer a unique opportunity to experimentally observe such exotic collective excitations, and test alternative theoretical model approaches. The bandheads of the γ band appear at 821.2 keV and 785.9 keV excitation energies for ^{168}Er and ^{166}Er nuclei, respectively. In ^{168}Er, the two-phonon character of the $K^{\pi} = 4^{+}$ state (E_x=2.055 MeV), along with the 5^{+} member (E_x=2.169 MeV) of the $K^{\pi} = 4^{+}$ band, were affirmed by Börner *et al* [1]. Multiple $K^{\pi} = 4^{+}$ two-phonon states (E_x=1.978 MeV, E_x=2.028 MeV) were reported in ^{166}Er [4 – 5]. Additionally, the $K^{\pi} = 0^{+}$ two-γ-phonon state (E_x=1.943

MeV) was also reported in this nucleus [5]. In other Erbium isotopes, particularly toward the neutron-deficient side, this mode of exotic excitation was never investigated.

Nevertheless, predictions from Triaxial Projected Shell Model (TPSM) calculations suggest ^{164}Er as another favourable candidate nucleus for experimental observation of this rare mode of nuclear excitation. The bandhead energy of the lowest collective two-γ-phonon $K^{\pi} = 4^{+}$ state for this nucleus has now been calculated, and subsequently found to be located at E_x=1.940 MeV. The systematic experimental observation tells that these energies are below the pairing gap where the density of states is not high, thereby rendering a fair probability of finding these highly non-yrast states in experiments employing low-mass projectile and a high-efficiency gamma-detector array like INGA.

We plan to investigate this exotic mode of nuclear excitation in ^{164}Er to extend the investigation toward neutron-deficient side in the Er chain of isotopes. The ^{162}Dy(^{6}Li, d2*n*) ^{164}Er reaction at ^{6}Li beam energy of 42-44 MeV (highest available) will be used. This will produce the ^{164}Er residual nucleus at ~100 mb cross-section (~100% reaction channel following α-transfer from ^{6}Li to the target). In the same experiment, we'll also be able to further explore the low-spin structures in the odd-odd ^{162}Ho nucleus where Gallagher-Moszkowski (GM) doublet bands were reported [8]. This ^{162}Ho nucleus will be populated with ~300 mb (~100% reaction channel following *d*-transfer from ^{6}Li to the target) cross-section following ^{162}Dy(^{6}Li, α2n) reaction. The INGA array at TIFR, along with the CPDA will be employed to detect the de-exciting γ-rays from nuclei of interest with proper channel selection. The possibility of employing a few $LaBr_3$(Ce) detectors, which will be useful to determine the associated collectivity of the levels/level-structures of interest, can be explored.

At least six days (18 shifts) of beam time will be required to acquire reasonable statistics for the nuclei of interest and the associated physics case. It may be noted that the population of the two-gamma-phonon states are expected to be substantially weak (as always), and thereby, possible experimental observation of the deexciting γ-rays from these states, in particular, the intraband ones, are highly challenging. The compelling as well as challenging physics case, as outlined in this proposal, strongly justifies this measurement using INGA + CPDA at PLF, TIFR.

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