Anomaly in the giant dipole resonance spectrum of $^{28}$Si

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The Jacobi shape transition, an abrupt change of shape from non-collective oblate to collective triaxial or prolate shape above a critical spin ($J_C$), has been predicted to appear in atomic nucleus due to its liquid drop nature at high excitation energy [1]. The onset of Jacobi shape transition has been observed in a few light nuclei through the Giant Dipole Resonance (GDR) decay spectrum, characterized by a narrow low energy component $\sim 10$ MeV arising due to the Coriolis splitting [2]. Recently, it has been reported that a self-conjugate $\alpha$-cluster $^{32}$S nucleus populated with the angular momentum $J > J_C$, does not undergo the Jacobi shape transition and was explained in terms of formation of $^{16}$O + $^{16}$O molecular structure in a superdeformed state of $^{32}$S [3]. In another case, the observation of a narrow resonance in the reaction $^{24}$Mg + $^{24}$Mg populating $^{48}$Cr at $J = 36 \hbar$ ($> J_C$) was interpreted in terms of the highly deformed Jacobi like shape corresponding to a molecular state, but no clear signature of the Jacobi shape transition was observed [4]. It is therefore interesting to study high energy $\gamma$-ray spectra in self-conjugate $\alpha$-cluster nuclei at high $J$ to understand the interplay of nuclear orbiting, cluster structure and Jacobi shape transition etc. With this motivation, measurement of the GDR spectrum from a self-conjugate $\alpha$-cluster nucleus $^{28}$Si, populated in the reaction $^{16}$O + $^{12}$C at $\langle J \rangle \sim 21 \hbar$, which is higher than $J_C = 17 \hbar$, is carried out [5].

The experiment was performed using pulsed beam of 125 MeV $^{16}$O from the Pelletron Linac Facility (PLF) at Mumbai bombarding a self-supporting $^{12}$C target (400 µg/cm$^2$). The high energy $\gamma$-rays in the region of 5–30 MeV were measured in an array of seven close-packed hexagonal BaF$_2$ detectors, surrounded by an annular plastic shield for cosmic muon veto. A 14-element BGO multiplicity filter was employed for measuring the multiplicity of low energy discrete $\gamma$-rays to extract angular momentum information. The details of the experimental set-up and data analysis are discussed in Ref. [5].

The high energy $\gamma$-ray spectra for different folds ($F$) are generated in offline analysis after taking care of corrections due to chance coincidence and Doppler effect. In order to extract the GDR parameters, fold gated high energy $\gamma$-ray spectra are compared with the SMCC calculation [6] after incorporating a bremsstrahlung component [7] folded with the detector response function. A calculated $\gamma$-ray spectrum with an arbitrary constant $E_1$ strength of 0.2 W.u., folded with the detector response function, was used for generating the divided plots for better visualization. The high energy $\gamma$-ray spectrum for $F \geq 4$ and the corresponding divided plot along with the best fit statistical model calculations are shown in

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Available online at www.sympnp.org/proceedings
FIG. 1: Fold \((F)\) gated high energy \(\gamma\)-ray spectrum (a) and the corresponding divided plot (b). The divided plot for \(F \geq 6\) is shown in (c).

Fig. 1. It is observed that a two component strength function corresponding to a prolate shape describes the experimental data reasonably well. The best fit GDR parameters from the SMCC analysis are given in Table I. The mean centroid energy \(E_{\text{GDR}} = 20.5\) MeV, is consistent with the ground state systematics.

TABLE I: Best fit GDR parameters for \(^{28}\text{Si}\) from the SMCC analysis \((\langle J \rangle = 21(6) \hbar, \langle T \rangle = 2.1(3)\) MeV\)

<table>
<thead>
<tr>
<th>(E_{\text{GDR}}) (MeV)</th>
<th>(I_{\text{GDR}}) (MeV)</th>
<th>(S_{\text{GDR}})</th>
</tr>
</thead>
<tbody>
<tr>
<td>14.6(3)</td>
<td>6.0(3)</td>
<td>0.44(4)</td>
</tr>
<tr>
<td>24.6(8)</td>
<td>10.0(7)</td>
<td>0.62(3)</td>
</tr>
</tbody>
</table>

As mentioned earlier, since \(\langle J \rangle = 21\) \(\hbar\) is higher than \(J_C = 17\) \(\hbar\) [1], the \(^{28}\text{Si}\) nucleus is expected to undergo a Jacobi shape transition. The TSFM calculations also predict an equilibrium shape to be highly deformed tri-axial \((\beta_2 \sim 0.4, \gamma \sim 140^\circ)\) shape for the measured temperature \((T)\) and \(J\) [5]. In such a scenario, the high energy \(\gamma\)-ray spectrum should have shown a distinct peak around \(\sim 10\) MeV. The experimental spectrum does not display a signature of the Jacobi shape transition and hence, appears to be anomalous. It should be noted that the data for \(F \geq 6\), corresponding to \(\langle J \rangle = 24(6) \hbar\), has lower statistics but has similar shape - namely, no low energy component is visible [Fig. 1(c)]. However, the deformation deduced from the conventional statistical model analysis is large \((\beta_2 > 0.6)\) and points towards the elongated structure.

It should be pointed out that reactions involving \(\alpha\)-cluster nuclei are known to exhibit nuclear orbiting phenomenon [8]. Such a molecular configuration akin to a two body rotor with mass concentrated on the periphery, will have a large moment of inertia and consequently the angular frequency would be smaller. It should be pointed out that the net excitation energy as well as effective \(T\) and \(J\) for such a state can not be estimated in a simple manner. Further, in case of quasi-molecular resonances there would be an interplay of rotational motion of the dinuclear complex and vibrational motion of constituent nuclei, which would result in the fragmented strength [9] and detailed theoretical calculations are required to extract the strength function. Based on the present result for \(^{28}\text{Si}\) and similar observation in \(^{32}\text{S}\) [3], it is proposed that the nuclear orbiting phenomenon exhibited by \(\alpha\)-cluster nuclei, hinders the Jacobi shape transition.

Acknowledgements

We would like to thank Mr. K.S. Divekar, Mr. M.E. Sawant, A. Singh, S.P. Singh and R. Kujur for assistance during the setup, Mr. R.D. Turbhekar for the target preparation and the PLF staff for smooth operation of the accelerator.

References