GDR Studies in $^{28}\text{Si} + ^{124}\text{Sn}$ at $E^*(^{152}\text{Gd}) \sim 71$ MeV

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Giant Dipole Resonance

A collective dipole oscillation between neutrons and protons

GDR built on excited states of nuclei is a useful probe to study the properties of hot and rotating nuclei.

GDR Centroid Energy ($E_{GDR}$) and Width ($\Gamma_{GDR}$)

\[ \downarrow \]

Evolution of nuclear properties as a function of temperature ($T$) and angular momentum ($J_{CN}$)
Motivation

Kusnezov et al. PRL, 81, (1998), 542

\[ \xi = J_{CN}/A^{5/6} \ ; \ \Gamma_{\text{red}} = \left[ \Gamma_{\text{GDR}}(T, J_{CN})/\Gamma(T, 0) \right]^{(T+3)/4} \]

\[ \Gamma(T, J_{CN} = 0, A) = \left( 6.45 - \frac{A}{100} \right) \ln \left( 1 + \frac{T}{T_0} \right) + \Gamma_0(A). \]

“Universal behavior of GDR width”

Differences observed in A \( \sim 150 \) region

- Variation of \( \Gamma_{\text{GDR}} \) in \( ^{152}\text{Gd} \) \((^{28}\text{Si}+^{124}\text{Sn})\) is studied at \( E^* \sim 87 \) and 116 MeV (NPA 770 (2006) 126; J. Phys. G 37 (2010) 055105)
  - Discrepancy observed in the \( \Gamma_0 \) at two energies.
  - \( \Gamma_{\text{GDR}} \) at higher \( T \) explained with collisional damping + LDM contribution.

- Present work: \( \Gamma_{\text{GDR}} \) variation at lower \( T \) and \( J_{CN} \) for the same system at \( E^* \sim 71 \) MeV; \( \langle J_{CN} \rangle \sim 24 \hbar \) and \( J_{\text{max}} \sim 48 \hbar \)
Experimental Details

- 2.0 mg/cm$^2$ enriched (99.90%) $^{124}\text{Sn}$ target was bombarded with 135 MeV $^{28}\text{Si}$ pulsed-beam from Pelletron Linac Facility at TIFR.
- Data was taken for 0.1 pmC of incident beam particles.

cosmic background reduction using plastic veto $\sim 94\%$
Electronics Block Diagram

Trigger: $E_{\text{Gamma}} > 4$ MeV
Data Analysis

- **Gain stability**: Periodic monitoring was done with $^{137}\text{Cs}$, $^{60}\text{Co}$ and Am-Be sources. Observed drift ± 2.0% at 4.4 MeV.
- **Pile up rejection**: Integrating the detector pulse in two window having gate widths 200 ns and 2 µs (~3%).
- **Time prompt**: Events were accepted if they were within the individual RF-BaF$_2$ and RF-BGO TOF $\gamma$-prompt window.
- **Chance correction**: Chance correction in RF-BaF$_2$ and RF-BGO TOF spectra is considered (~2%).
- **Doppler correction**: The $\gamma$-ray energy is corrected for velocity of the recoil nuclei ($\beta = 0.018$).
Experimental Spectra
• Simulated Monte Carlo Cascade (SMCC) is used for extraction of GDR parameters (D. R. Chakrabarty, NIMA 560 (2006) 546).
• Ignatyuk level density prescription is used with $a = A/8.5$ MeV$^{-1}$.
• We assume the GDR exhausts the 100% of the sum rule ($S_1 + S_2 = 1$).
• The $\gamma$-ray spectrum is fitted with function having two components Lorentzian of the form

$$F_L(E, E_t, \Gamma) = \frac{B^2\Gamma^2}{(B^2 - E_t^2)^2 + B^2\Gamma^2}$$

• The GDR centroid is calculated as

$$E_{GDR} = (S_1E_1 + S_2E_2)/(S_1 + S_2).$$

• The temperature of the final state is calculated as

$$U = aT_f^2,$$

where $U = E_f - E_{rot}(J_f) - \Delta_p.$
Statistical Model Calculation

- **Compound nucleus spin distribution**
  \[ \sigma_1(J_{CN}) = \frac{2J_{CN} + 1}{1 + \exp[\frac{J_{CN} - J_0}{\delta J}]} \]

- **Residue spin \((J_R)\) distribution of all the residues as a function of \(E_\gamma\) for each \(J_{CN} \Rightarrow \sigma_2(E_\gamma, J_R)\)**

- **Multiplicity \((M)\) for all residues \(\sigma_3(J_R, M)\) is calculated incorporating**
  - relative transition probability of \(\Delta J_R = 1 \& \Delta J_R = 2\) from spin \(J_R\) to ground state
  - multiplicity of statistical \(\gamma\)-rays
  - isomers

- **The response of BGO multiplicity array - GEANT3 simulations incorporating efficiency and crosstalk probabilities \(\Rightarrow \sigma_4(M, F)\)**
  \[ \sigma(E_\gamma, F) = \sum_{J_{CN}} \sigma_1(J_{CN}) \sigma_2(E_\gamma, J_R). \sigma_3(J_R, M). \sigma_4(M, F) \]
Good agreement for fold ≥ 8
Peak at lower fold could be due to impurities in the target (like C, O)
Fold Gated Gamma Ray Spectra

Divided plots with constant E1 strength (0.2 W.U.)
data and statistical model fits
### Results

#### Extracted GDR parameters

<table>
<thead>
<tr>
<th>Fold</th>
<th>$&lt;J_{CN}&gt;$</th>
<th>$&lt;T&gt;$ (MeV)</th>
<th>$E_1$ (MeV)</th>
<th>$\Gamma_1$ (MeV)</th>
<th>$E_2$ (MeV)</th>
<th>$\Gamma_2$ (MeV)</th>
<th>$S_2$</th>
<th>$E_{GDR}$ (MeV)</th>
<th>$\Gamma_{GDR}$ (MeV)</th>
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</thead>
<tbody>
<tr>
<td>8-9</td>
<td>26(9)</td>
<td>1.37 (29)</td>
<td>12.8 (1)</td>
<td>4.8 (2)</td>
<td>16.5 (2)</td>
<td>5.8 (2)</td>
<td>0.67 (2)</td>
<td>15.3 (2)</td>
<td>8.6 (3)</td>
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<tr>
<td>10-12</td>
<td>33(8)</td>
<td>1.33 (28)</td>
<td>12.7 (1)</td>
<td>4.6 (2)</td>
<td>16.1 (2)</td>
<td>6.2 (2)</td>
<td>0.70 (2)</td>
<td>15.1 (2)</td>
<td>7.8 (3)</td>
</tr>
<tr>
<td>13-15</td>
<td>38(7)</td>
<td>1.29 (27)</td>
<td>12.5 (1)</td>
<td>5.6 (2)</td>
<td>16.0 (2)</td>
<td>6.2 (3)</td>
<td>0.70 (2)</td>
<td>15.0 (2)</td>
<td>8.0 (4)</td>
</tr>
<tr>
<td>16-36</td>
<td>42(6)</td>
<td>1.25 (26)</td>
<td>12.3 (1)</td>
<td>5.9 (2)</td>
<td>15.8 (2)</td>
<td>6.0 (3)</td>
<td>0.70 (2)</td>
<td>14.8 (2)</td>
<td>8.3 (4)</td>
</tr>
</tbody>
</table>

$E_{GDR} \sim$ constant, average shape $\sim$ Prolate
Data consistent with Kusnezov Parameterization $\Gamma_0 = 3.2$ MeV → behaviour is consistent with liquid drop model
GDR width variation as a function of $J_{\text{CN}}$

$$\Gamma_0 = 3.2 \text{ MeV explains both present and } E^* = 87 \text{ MeV data} \ (\text{NPA 770 (2006) 126})$$
GDR width variation as a function of $J_{CN}$

\[ \Gamma_{GDR} \sim \text{constant} \text{ \ until} \ J_{CN} \sim 45 \hbar \]

Comparison of all measurements in $^{152}\text{Gd}$

$\Gamma_{GDR}$ \sim \text{constant \ until} \ J_{CN} \sim 45 \hbar$

GDR width variation as a function of $T$

- $\Gamma_{\text{GDR}} \sim \text{constant} \; T \sim 1.2 - 1.5 \text{ MeV}$ and increases rapidly at higher $T$

Summary

• Exclusive measurement of GDR is performed in $^{152}\text{Gd}$ at $E^* \approx 71$ MeV
• Statistical model calculations (using Simulated Monte Carlo Cascade) have been done for extraction of GDR parameters.
• The GDR centroid energy is constant for $T, J_{CN}$ range studied
• Observed behavior of GDR width as a function of angular momentum is consistent with liquid drop model.
• Present data together with earlier measurements indicates that
  – $\Gamma_{\text{GDR}} \sim$ constant for $T \approx 1.2 - 1.5$ MeV & increases rapidly at higher $T$
  – $\Gamma_{\text{GDR}}$ shows nearly constant upto $J_{CN} \sim 45 \hbar$ (weak $J$ dependence)
• It will be interesting to compare the data with TSFM calculations
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