Giant Dipole Resonance with at very low temperatures and the critical behavior

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Giant Resonance: Collective modes of vibration of nucleus

Giant Dipole Resonance

\[
F(E_\gamma) = \frac{E_\gamma^2 \Gamma_{GDR}^2}{(E_\gamma^2 - E_{GDR}^2)^2 + E_\gamma^2 \Gamma_{GDR}^2}
\]

Centroid Energy: Inversely proportional to the linear dimension of the nucleus.

Strength Function: Gives an idea about the nuclear shape degrees of freedom.

Resonance Width: Related to the damping mechanism of the collective motion.
Evolution of GDR width as a function of temperature

Experimental observation

Mostly investigated Nucleus $\rightarrow$ $^{120}$Sn

Experimental systematic shows $\rightarrow$ GDR width increases monotonically with temperatures (typically 6-10 MeV for change in ‘T’ of 1.5-2.5 MeV)

Why GDR width increases with increase in temperature ???

Thermal Shape Fluctuation Model : $(\Delta\beta \ vs \ T)$
Critical Temperature Fluctuation Model: Including an important physics point

GDR vibration itself produce a quadrupole moment causing the nuclear shape to fluctuate even at T = 0 MeV (GDR vibration induced intrinsic fluctuation): $\beta_{GDR}$

Critical behavior:
- At low T: $\beta_{GDR} > \Delta \beta$
- $\beta_{GDR} \rightarrow$ Independent of T
- $\Delta \beta \rightarrow$ Increases with temperature
- Competition between $\beta_{GDR}$ and $\Delta \beta$

The effect of thermal fluctuation on GDR width will appear only when it becomes greater than the intrinsic fluctuation.
Study of GDR width at very low temperatures ($T < 1.5$ MeV).

Verify the critical behavior: The number of GDR width measurements at low $T < 1$ MeV are inadequate to conclude that GDR width remains same at below the critical point.

Mass dependence of the critical behavior.

We probed $A=100$ mass region at very low temperature ($T \sim 0.8$ to 1.5 MeV) to understand exact nature of the damping mechanism inside the nucleus.
Experimental Details

High energy gamma photons are the main tools to study GDR characteristics → Need a detector system with high detection efficiency and very good time resolution.

**Projectile**: \(^4\text{He}\)

**Target**: \(^{93}\text{Nb}\)

\(E_{\text{lab}}\): 28, 35, 42, 50 MeV

\(^4\text{He} + ^{93}\text{Nb} \rightarrow ^{97}\text{Tc}^*\)

\(E^*\): 29.3, 36.0, 43.0, 50.4 MeV

\(J = 10 – 20\ h\)
**Experimental Setup**

- LAMBADA set-up (close view)
- Neutron detector set-up (close view)

**Electronics Setup**

- Schematic view of complete Experimental set-up
- LAMBADA array
- Multiplicity filter
- BC501A detector
- A single BaF$_2$ detector for neutron measurement
Extraction of GDR parameters

Experimental data compared with a theoretical model (CASCADE) to extract the GDR parameter

!! The following steps are essential !!

- Detector Response Function
- Measuring angular momentum distribution
- Measuring Nuclear Level Density parameter
Detector simulation studies using GEANT4

Detector response function must be folded with CASCADE calculation. Only after that it can be compared with experimental spectrum.
(2) Mapping of experimental Fold to Angular Momentum space with a very realistic technique

Very essential
- To determine average angular momentum
- To determine average rotational energy
- To construct initial population matrix for CASCADE calculation

Incident distribution:
\[
P(M_\gamma) = \frac{2M_\gamma + 1}{1 + \exp \left[ \frac{(M_\gamma - M_{\text{max}})}{\delta m} \right]}
\]

\[J = 2M_\gamma + C\]
Nuclear level density parameter from neutron evaporation spectrum

Crucial input for CASCADE Calculations & important for the proper estimation of nuclear temperature

Neutron detector (BC501A) is generally used to measure the neutron energy spectrum by TOF technique.
High energy gamma spectra along with CASCADE calculation
Final GDR spectra along with CASCADE calculation
Results and Discussion

First experimental data at below and above the critical temperature

$T_c = 1.08$ MeV

GDR induced intrinsic fluctuation could play a decisive role in describing the increase of GDR width as a function of $T$.

Intrinsic fluctuation due to GDR vibration should be incorporated in TSFM (macroscopically) to explain the behavior of GDR width at low $T$.

Exp data follows the CTM and PDM predictions (continuous line)!!!

TSFM (dotted line) over predicts the data ???

PDM: PRC 86 (2012) 044333

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Summary and conclusion

- A systematic study of the Giant Dipole Resonance width at very low temperature ($T = 0.8 \text{–} 1.5 \text{ MeV}$) in $A \sim 100$ mass region.

- GDR widths have been compared with different theoretical calculations (TSFM, CTFM and PDM).

- TSFM fails to explain the experimental data whereas CTFM and PDM calculation nicely matches with the experimental data.

- GDR induced intrinsic fluctuation plays an important role in describing the evolution GDR width as a function of temperature.

- First experimental data at below and above the critical temperature.

- Microscopic PDM (with pairing fluctuation) also explain the data very well.

- It would also be interesting if the pairing fluctuation can be included in the TSFM calculation.
THANKS

GDR group at VECC, kolkata, India
Detector properties

- **The time resolution of**
  - 35cm BaF2 detector = 960 ps
  - 5cm BaF2 detector = 460 ps

- **The energy resolution of**
  - 35cm BaF2 detector = $16/\sqrt{E}$ MeV
    - thus 20% at 0.662 MeV
  - 5cm BaF2 detector = 12% MeV

- **The intrinsic efficiency of**
  - 35cm BaF2 detector = 95% at 0.662 MeV, 93% at 10 MeV.
  - 5cm BaF2 detector = 80% MeV, 73% at 1 MeV.

- **The photopeak efficiency of**
  - Cluster summing technique (3x3)
    - 35cm BaF2 detector = ~ 50% from energy range 10 MeV
  - Cluster summing technique (7x7)
    - 35cm BaF2 detector = ~ 70% from energy range 10 MeV

- **What is the advantage of BaF2 detector over NaI detector?**
  - BaF2 are non-hygroscopic whereas NaI is highly hygroscopic.
  - NaI detectors cannot be used in modular (array) form since they have to be kept inside an air tight container.
  - Energy resolution is comparable.
  - BaF2 (600 ps) have better timing resolution than NaI (250 ns).
  - Density of BaF2 (4.88 g/cc) is greater than NaI (3.67 g/cc) hence for efficient high energy detection.
  - BaF2 has high Z (56) than NaI (53) which is required for high energy gamma detection. Also BaF2 has low capture cross section for thermal neutrons due to

\[
T_c = 0.7 + 37.5/\langle 8 \rangle
\]