Gamma decay of the isovector giant dipole resonance in $^{90}$Zr: damping mechanism and fine structure

Atsushi Tamii
Shoken Nakamura

Research Center for Nuclear Physics (RCNP)
Osaka University, Japan

for the RCNP-E498 collaboration

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Electric Dipole Response Probed by Proton Scattering

In an oscillating electric field $E(\omega)$, the photon energy $\omega$ (MeV) is probed by proton scattering.

D. Savran, T. Aumann and A. Zilges, PPNP\textbf{70}, 210 (2013)

Electric Dipole Response Probed by Proton Scattering

Proton scattering at forward angles for probing electric dipole response by Coulomb excitation

P. von Neumann-Cosel and AT, EPJA55, 110 (2019)
Width of the IVGDR

PDR
Low-energy dipole strength

IVGDR
Coulomb excitation by proton scattering

Width \( \propto \text{life time}^{-1} \)

How is the width created?
Fine structure of IVGDR

- PDR
- IVGDR

Low-energy dipole strength

The fine structure would have its characteristic width dep. on $E_x$

What is the origin of the fine structure?
Does it have characteristic width dep. on $E_x$?
Damping Mechanism of Collective Excitations (IVGDR)

Macroscopically

IVGDR: relative dipole oscillation between $p$ and $n$

Damping: due to viscosity between the $p$ and $n$ fluids

see e.g. J. Wambach, Rep. Prog. Phys. ’88
Damping Mechanism of Collective Excitations (IVGDR)

**Macroscopically**

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**Microscopically**

Origins of the damping

\[ \Gamma = \Delta \Gamma + \Gamma^\downarrow + \Gamma^\uparrow \]

$\Gamma$ total width

- $\Delta \Gamma$ **Landau damping**: distribution of the unperturbed 1p-1h components
- $\Gamma^\uparrow$ **escape width**: particle and gamma decays from the doorway state to another state with losing energy
- $\Gamma^\downarrow$ **spreading width**: spreading from the doorway state into more complex configurations damping due to the loss of coherence without losing energy

wikipedia
Damping of IVGDR: Spreading Width

Damping of IVGDR

**Spreading width:**
W.F. of an excited state

\[ |\psi_i\rangle = |DW_i\rangle + \sum |2p2h_i\rangle + \ldots + \sum |CN_i\rangle \]

- doorway collective state
- damping due to the loss of coherence

How can we study it?
Another Way to Study $\Gamma$: the Decay

Damping of IVGDR

IVGDR eventually transits to another state with losing its energy.

Each decay channel is categorized by the emitted particle (gamma) and the energy

$$\Gamma = \sum \Gamma_n + \sum \Gamma_p + \sum \Gamma_\gamma + \ldots$$

Experimentally, branching ratio can be measured for each decay

branching ratio: $b_i = \frac{\Gamma_i}{\Gamma}$

We focus on the gamma decay to the ground state.

$$\Gamma_{\gamma_0} \quad b_{\gamma_0} \sim 1\%$$

Why?
The g.s. gamma-decay is the inverse process of the Coulomb excitation.

\[ \frac{d^2\sigma}{d\Omega dE_x} \] by Coulomb excitation

\[ \rightarrow B(E1)^\uparrow \]
\[ \rightarrow B(E1)^\downarrow \text{ (detailed balance)} \]
\[ \rightarrow \Gamma_{\gamma_0} \]

Gamma coincidence measurement

\[ \rightarrow \text{branching ratio } b_{\gamma_0} = \frac{\Gamma_{\gamma_0}}{\Gamma_{\text{bin}}} \]

\[ \rightarrow \Gamma_{\text{bin}}(E_x) \text{ can be determined.} \]

What will be observed? How is \( \Gamma \) distributed in \( E_x \)?
E498: Experimental Methods
GR 0-deg mode + large volume LaBr$_3$

Proton beam at 392 MeV
Beam: 2 nA
Target: $^{90}$Zr 20 mg/cm$^2$

Achromatic mode: $\Delta E_x = \sim 100$ keV
Gamma ray detector array

**Scylla**

- **Total Number of detectors**: 8
- **Detectors at 90’**: 4
- **Detectors at 135’**: 4
- **Distance from target**: 135 mm
- **Solid angle**: 20% of 4π
- **Efficiency @ 15MeV**

**Absorbers**
- Plastic (2mm\(t\)) for charged particle veto
- Pb(2mm\(t\)) and Cu(4mm\(t\)) absorber for low energy gammas

by S. Nakamura
Coincidence matrix of Grand Raiden and LaBr3

means the ground state gamma decay

$^{90}\text{Zr}(p,p')_p = 392 \text{ MeV}$

LaBr$_3$ energy [MeV]

Excitation energy by Grand Raiden [MeV]

by S. Nakamura
$^{90}\text{Zr}(p,p')$ at 0 deg

$E_p = 392$ MeV

$|\theta| < 0.5$ deg

$|\phi|$: full acceptance

b.g. subtracted

Excitation Energy (MeV)

Counts/10 keV

90$^{\text{Zr}}(p,p'\gamma)$ g.s $\gamma$-decay

8 LaBr$_3$ detectors

$|E_x - E_{\text{LaBr3}}| < 1$ MeV

random coin. subtracted

Excitation Energy (MeV)

Counts/500 keV

g.s. $\gamma$-decay was clearly measured covering fully the IVGDR
The g.s. gamma-decay is the inverse process of the Coulomb excitation.

\[ \frac{d^2\sigma}{d\Omega dE_x} \text{ by Coulomb excitation} \]

\[ \rightarrow \quad B(E1)\uparrow \]
\[ \rightarrow \quad B(E1)\downarrow \quad \text{(detailed balance)} \]
\[ \rightarrow \quad \Gamma_{\gamma_0} \]

Gamma coincidence measurement

\[ \rightarrow \quad \text{branching ratio} \quad b_{\gamma_0} = \frac{\Gamma_{\gamma_0}}{\Gamma_{\text{bin}}} \]

\[ \rightarrow \quad \Gamma_{\text{bin}}(E_x) \text{ can be determined.} \]

What will be observed? How does it distribute in \( E_x \)?
Experimental Results

We are sorry that the unpublished data were removed from the slides on the web.
Future Plans

• Systematic measurements of other representative nuclei
  $^{208}\text{Pb}$, $^{120}\text{Sn}$, $^{48}\text{Ca}$, …

• Deformed nuclei

• Extension to other excitation modes (ISGQR, GT, etc)

• New ideas are welcome!

An experimental campaign of GR+SC$\gamma$LLA experiments is under preparation.

Also there are experimental plans at Krakow, iThemba LABS, ELI-NP.

A lot of systematic data are coming in near future.
PANDORA Project

Photo-Absorption of Nuclei and Decay Observation for Reaction in Astrophysics

Systematic Measurement on E1 Strength Distribution and n, p, α, γ decays up to A~56

as a joint project of the three facilities

Combination of experiments with complementary devices.
Systematic Measurement on E1 Strength Distribution and n, p, α, γ decays up to A~56

- E1 excitation strength distribution
- n, p, α, γ decay branching ratios
- from light to A~56 for stable nuclei

- Lack of data especially for charged particle decays
- Inconsistency among experiments
- Unsatisfactory prediction by models
Summary

• Gamma-decay to the g.s. has been successfully measured from IVGDR in $^{90}$Zr.

• The observed b.r. was $\sim$1%…

• The extracted $\Gamma_{\text{bin}}$ …

• Comments, suggestions are welcome.

I thank the RCNP-E498 collaborators.

Thank you for your attention
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RCNP, Osaka Univ. | IKP TU-Darmstadt | Univ. Milano and INFN
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Thank you for your attention!