Prompt Gamma Rays in $^{77}$Ge after Neutron Capture on $^{76}$Ge

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Outline

- Motivation
  - Neutrinoless double beta decay
  - GERDA
- Cross section of $^{76}\text{Ge}(n,\gamma)$ reaction
- Prompt gamma ray spectrum
- Status of GERDA
- Summary
Double Beta Decay

Double beta decay ($2\nu\beta\beta$) occurs if single beta decay is energetically forbidden, but the transition of two neutrons into two protons (or $pp \rightarrow nn$) is allowed. The nucleus emits two electrons (positrons) and two anti-neutrinos (neutrinos).

$2\nu\beta\beta$ was observed in 11 isotopes: $^{48}\text{Ca}$, $^{76}\text{Ge}$, $^{82}\text{Se}$, $^{96}\text{Zr}$, $^{100}\text{Mo}$, $^{116}\text{Cd}$, $^{128}\text{Te}$, $^{130}\text{Te}$, $^{150}\text{Nd}$, $^{238}\text{U}$, $^{130}\text{Ba}$ ($\beta^+\beta^+$)
2νββ Decay

$\Delta L = 0$   no lepton number violation

$2e$, right-handed

$\nu_e$, right-handed

$n \rightarrow p + e^- + W^- + W^-$

29.08.2008    Georg Meierhofer, Kepler Center for Astro and Particle Physics, University Tübingen    CGS13 Cologne
0νββ Decay

Conditions for 0ν2β:

\[ \bar{\nu} = \nu \quad \text{Majorana particle} \]
\[ \Delta L = 2 \quad \text{Lepton number violation} \]
\[ P(\bar{\nu}_e, \text{left-handed}) \sim (m/E)^2 \text{ for } m_\nu > 0 \]

\[ n \rightarrow \bar{\nu}_e, \text{left-handed} \rightarrow W^- \rightarrow e^- \]
\[ n \rightarrow \nu_e, \text{right-handed} \rightarrow W^+ \rightarrow e^+ \]

\[ t_{1/2} : 10^{19} - 10^{25} \text{ y} \]
\[ t_{1/2} : > 10^{25} \text{ y} \]
What can we learn from $0\nu\beta\beta$?

If $0\nu\beta\beta$ is observed:

- Neutrino is a Majorana particle
- Neutrino mass
- Mass hierarchy (degenerate, inverted or normal)

\[
[T_{1/2}^{0\nu}]^{-1} = G^{0\nu}(E_0, Z) \mid M^{0\nu} \mid^2 m_{ee}^2
\]

\[
m_{ee} = \left| \sum U_{ei}^2 m_i \right|
\]
Experiments

Past
- Heidelberg-Moscow ($^{76}$Ge): limit $t_{1/2} > 1.19 \times 10^{25}$ y, claim for observation by a small group of the collaboration
- IGEX ($^{76}$Ge): limit $t_{1/2} > 1.6 \times 10^{25}$ y

Present
- Courecino
- Nemo3

Future
- Coure
- Majorana
- SuperNemo
- Majorana
- GERDA
**GERDA**: The GERmanium Detector Array

Location: LNGS, Gran Sasso, Italy

Isotope: $^{76}\text{Ge}$

$Q_{\beta\beta} = 2039\text{ keV}$

$t_{1/2} > 1.6 \times 10^{25}\text{ y}$

Source ↔ Detector enriched material (~87% $^{76}\text{Ge}$)
GERDA: The GERmanium Detector Array

Shielding: LAr, no high Z-materials, water Cherenkov veto, 3400 m.w.e. of rock
Sensitivity

Background

Phase I: $10^{-2}$ cts/(keV kg y)
Phase II: $10^{-3}$ cts/(keV kg y)
Background

Radiopurity of:
- Germanium detector (Cosmogenic $^{68}\text{Ge}$)
- Germanium detector (Cosmogenic $^{60}\text{Co}$)
- Germanium detector (bulk)
- Germanium detector (surface)
- Cabling
- Copper holder
- Electronics
- Cryogenic liquid
- Infrastructure

Sources:
- Natural activity of rock
- Muons and neutrons
Background

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Germanium detector (Cosmogenic $^{68}\text{Ge}$)
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Sources:
Natural activity of rock
Muons and neutrons
Neutron Capture by $^{76}\text{Ge}$

$^{76}\text{Ge}(n,\gamma)\,^{77}\text{Ge}$

$\begin{array}{c}
\text{n} \\
\sim 0.1\text{eV} \\
^{77}\text{Ge}^m \\
^{77}\text{Ge} \\
^{77}\text{Ge}^+ \\
6072\text{ keV}
\end{array}$

$Q_\beta = 2703 \quad 690\text{ keV}$

Burson. Et.al. 1957
Neutron Capture in GERDA

⇒ 1 n-capture/(kg y) (MC simulation)

⇒ Possible background in the region of interest (2039 keV)

  Segemented detectors allow to distinguish single site events ⇔ multi site events
  ⇒ If prompt spectrum is known, chance to trigger a veto on the prompt gammas after neutron capture to reduce the background from beta decay of $^{77}$Ge$^m$

But: Only 15% of the energy weighted intensity known
PGAA @ FRM II

TALK on Monday by P. Kudejova
Prompt Gamma Activation Analysis

Samples of enriched Germanium were irradiated with cold neutrons at the FRM II (Munich)
\[ \langle \lambda \rangle = 6.7 \text{ Å} \]
\[ \Phi = 2 \times 10^9 \text{ n/(cm}^2 \text{s)} \]

Using the PGAA technology the

- cross section of \(^{76}\text{Ge}(n,\gamma)^{77}\text{Ge}^m\) and \(^{76}\text{Ge}(n,\gamma)^{77}\text{Ge}^m\)

- prompt gamma spectrum (single/coincidence)

were measured
Cross Section

$^{76}$Ge target was activated and after irradiation the $\gamma$-radiation of the $\beta$-decay was measured by HPGe detectors.

![Decay spectrum of $^{77}$Ge](image)

The total cross section was calculated using the emission probabilities given in NUDAT.
Cross Section

Preliminary results:

<table>
<thead>
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<th>Our measurement</th>
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<td>cross section</td>
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Graph showing cross section vs energy [keV].
## Cross Section

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![Graph showing cross section vs. energy](image)

*Ge$^{78}(n,\gamma)$Ge$^{77m}*

I.T. 54 sec $\rightarrow$ $\beta^-$

Ge$^{76}(n,\gamma)$Ge$^{77}$$\rightarrow$$\beta^-$$\rightarrow$As$^{77}$$\rightarrow$Se$^{77}$

I.T. 54 sec $\rightarrow$ $\beta^-$

11.3 hr $\rightarrow$ $\beta^-$ 39 hr
Cross Section

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Ng: relative data, normalised to NUDAT (A. Ng, Phys. Rev. 176, (1968), 1329)
Prompt Gamma Ray Spectrum

Single spectra
m ~ 300 mg
Irradiation time > 50 000 s

Coincidence spectra
m ~ 300 mg
Irradiation time 10 d
Status GERDA

- Phase I detectors ready
- Cryostat, water tank built
- „Superstructure“ under construction
- Moun veto to be installed in autumn
- Tests, commissioning spring 2009
- Start of measurement 2009
Summary

- GERDA is a new type of $0\nu\beta\beta$ Decay experiment with $^{76}\text{Ge}$ (bare Ge diodes in cryogenic liquid)

- Background reduction and rejection major task in GERDA

- With good knowledge of the prompt gamma ray spectrum a veto on the delayed beta decay of $^{77}\text{Ge}$ can be triggered

- Therefore the cross section and the prompt gamma spectrum of the $^{76}\text{Ge}$(n,gamma)$^{77}\text{Ge}^{g,m}$ was measured