Experimental search for double beta decay of Zr-96 to excited states of Mo-96

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Double beta decay

Different beta decay schemes

Energy conditions for double beta decay
• Probability can be expressed as the product of the kinematic and nuclear parts:

\[
\Gamma^{2\nu} = \frac{1}{T_{1}^{2\nu}} \cdot G^{2\nu} \cdot Q_{\beta\beta} \cdot Z \cdot |M^{2\nu}|^2
\]

• The probability of a neutrinoless mode, which is forbidden in the SM, can be expressed in a similar form:

\[
\Gamma^{0\nu} = \frac{1}{T_{1}^{0\nu}} \cdot G^{0\nu} \cdot Q_{\beta\beta} \cdot Z \cdot |M^{0\nu}|^2 \cdot \langle \eta \rangle^2
\]

there: \( G^{2\nu} \) and \( G^{0\nu} \)– phase spaces for standard and neutrinoless modes, proportional to the decay energy and charge number of the decaying isotope

\( M^{2\nu} \) and \( M^{0\nu} \) – matrix elements

\( \langle \eta \rangle \) – parameter characterizing the effective mass of neutrinos
Previously defined half-lives:

- \( ^{100}\text{Mo} [1] \):
  - \( T_{1/2} (\text{g.s.}) = 7.16 \pm 0.01 \cdot 10^{18} \text{ yr} \)
  - \( T_{1/2} (0^+_1) = 7.5 \pm 0.6 \cdot 10^{20} \text{ yr} \)

- \( ^{150}\text{Nd} [1] \):
  - \( T_{1/2} (\text{g.s.}) = 9.1 \pm 0.7 \cdot 10^{18} \text{ yr} \)
  - \( T_{1/2} (0^+_1) = 7.2 \pm 0.14 \cdot 10^{19} \text{ yr} \)

- \( ^{96}\text{Zr} [1,2] \):
  - \( T_{1/2} (\text{g.s.}) = 2.35 \pm 0.21 \cdot 10^{19} \text{ yr} \)
  - \( T_{1/2} (0^+_1) > 3.1 \cdot 10^{20} \text{ yr} \)

2. S. W. Finch and W. Tornow – Search for two-neutrino double-\( \beta \) decay of \(^{96}\text{Zr}\) to excited states of \(^{96}\text{Mo}\) – PHYSICAL REVIEW C 92, 045501 (2015)
Requirements for the experiment

- Zirconium sample that has enough mass (activity) for decay registration
- Absence of radioactive contamination of the test sample
- Low background experimental setup
- A detector with high efficiency and good energy resolution
Detectors and passive shielding

Active shielding

Sample container’s scheme
• A zirconium sample with a mass of 203.182 g and $^{96}$Zr isotope enrichment 88.18% (natural enrichment - 2.81%), supplied by JSC Electrochemical Plant

• High resolution HPGe detectors are used (FWHM=2.9 keV in ROI)

• Members of the collaboration:
  
  JINR DLNP
  
  INR BNO
  
  Kurchatov Institute ITEP
Monte Carlo simulations

Setup scheme in Geant4

Setup simulation histogram for $10^6$ events

$\varepsilon_{370} = 5.37 \pm 0.02\%$

$\varepsilon_{778} = 3.54 \pm 0.02\%$
Expected results

With the following input data:

- Pessimistic estimate of expected half-life of $10^{21}$ years
- Zirconium with a mass 203.182 g
- $^{96}$Zr enrichment 88.18 % (isotope mass 179.166 g)

Expectations:

- 2.14 decays per day
- Counts in 370 keV peak – 0.102 per day
- Counts in 778 keV peak – 0.068 per day
Current results

Half-life limit set after 10 days measurements in DLNP:

\[ T_{1/2}(0_1^+) > 1.19 \times 10^{18} \text{ yr} \]
Future plans

• Measurements of $^{238}$U distributed calibration source for comparison with Monte Carlo
• Setting limits on the thorium content in the sample
• Measurements of zirconium sample in underground laboratory of BNO
  
  Background level in DLNP: 4.94 counts per day in 370 keV peak
  2.21 counts per day in 778 keV peak

  Background level in BNO: ~1 count per 50 days
• Experiment is dedicated for the first detection of $^{96}$Zr double beta decay to excited states of $^{96}$Mo

• It will provide an opportunity to improve the determination of matrix elements of $2\beta$ decay

• The obtained results will contribute to expanding of our understanding of the nature of neutrinos
Thank you for attention!
Probabilities of different $^{96}\text{Zr}$ decay modes
Top view of setup geometry in Geant4