Double-beta decay of $^{96}$Zr: nuclear physics meets geology

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Motivation and summary

- Double-beta decay measurements give insight into properties of the neutrino, one of the least well understood particles.
- Objective: Determine the half-life of the $\beta\beta$-decay of $^{96}$Zr $\rightarrow$ $^{96}$Mo.
- Approach: Use two different measurements to determine different parameters related to the half-life.
  - At U of Calgary: geochemical measurement of $\beta\beta$-decay half-life.
  - At U Jyväskylä: measure the Q-value of the decay.
- Motivation: Understand a discrepancy between a direct measurement of the decay at NEMO in 2010 and the last geological measurement from 2001.
$^{96}$Zr decay scheme

- Geochemical measurement
  - $0.94(32) \times 10^{19}$ a
  - Wieser and DeLaeter 2001
- $\beta\beta$ counting measurement
  - $2.4(3) \times 10^{19}$ a
  - NEMO Collaboration 2010
- > 2σ difference!
- Competing single beta-decay half-life?
  - Theoretical half-life: $\sim 2.6 \times 10^{20}$ a
  - Dependent on Q-value of the decay
Double-beta decay half-life by stable isotope geochemistry

- Verify measurements by Wieser and DeLaeter in 2001
- Excess $^{96}\text{Mo}$ compared to $^{96}\text{Zr}$ tells us the half-life of the decay

Isotopic Composition of Mo

<table>
<thead>
<tr>
<th>Atomic Number</th>
<th>Isotopic Abundance</th>
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<tbody>
<tr>
<td>92</td>
<td>10%</td>
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<tr>
<td>93</td>
<td>5%</td>
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<td>94</td>
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<td></td>
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<tr>
<td>99</td>
<td></td>
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</tbody>
</table>

$^{96}\text{Zr} \rightarrow {96}\text{Mo}$

Zircon
1.8 Ga
ZrSiO$_4$
2.8% $^{96}\text{Zr}$
$^{96}\text{Zr} \rightarrow {96}\text{Mo} + 2e^- + 2\bar{\nu}$
Sample preparation: Acid digestion

- Sample digested in high temperature concentrated HF in an acid digestion bomb

250 mg zircon

10 mL HF

200 °C
Sample preparation: Mo separation

- In order to measure $^{96}\text{Mo}$, we must first separate the Mo from the Zr.
Sample analysis: MC-ICP-MS
How will we improve over the previous measurement?

- Original measurements performed with Thermal Ionization MS

<table>
<thead>
<tr>
<th></th>
<th>Previous (TIMS)</th>
<th>New (MC-ICP-MS)</th>
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</thead>
<tbody>
<tr>
<td>Sensitivity</td>
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<td>10 ng Mo</td>
</tr>
<tr>
<td>Chemistry blank</td>
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<td>1 ng Mo</td>
</tr>
<tr>
<td>Precision</td>
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<td>0.1 ‰</td>
</tr>
</tbody>
</table>

- All related measurements, i.e. Zr concentration and U-Pb dating will be performed in house
Q-value measurements at JYFLTRAP

- Geological measurements so far provide evidence for 2nd decay route
- Single β-decay half-life dependent Q-value
JYFLTRAP

- Penning trap mass spectrometer at University of Jyväskylä, Finland
Penning trap mass measurements

- Ion motion dependent on $q/m$ and trap parameters
  - (1) magnetron
  - (2) axial
  - (3) reduced cyclotron
- Apply RF quadrupole field
  - Excite reduced cyclotron motion
- Measure time-of-flight to determine energy gain
- Measure relative to reference isotope (i.e. $^85\text{Rb}$) to eliminate uncertainty due to B-field

$v_c = \frac{qB}{m2\pi}$
Questions we will answer

- Can we confirm the discrepancy between the NEMO direct and Wieser/DeLaeter geological measurements?
- Is a highly forbidden single-beta decay also contributing to the decay?
- If the discrepancy is confirmed, and cannot be accounted for, is this evidence for time-dependent double-beta parameters?