Decay of $^{61}\text{Cu}$ in oxide and metallic environment

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Motivations and previous results

- For the most radionuclides that decay by electron capture or internal conversion, the probability for these processes is usually insensitive to the nuclear environment.
- The decay rate depends only very weakly on the electron wave functions.
- Be-7 decays only by electron capture.

Decay of $^7$Be in metallic environment

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Kettner et al. predicted a possibility to observe:
- shorter half-life for $\alpha$ and $\beta^+$-decay
- longer half-life for $\beta^-$-decay and electron capture

High-Z electron screening: the cases $^{50}\text{V}(p,n)^{50}\text{Cr}$ and $^{176}\text{Lu}(p,n)^{176}\text{Hf}$

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Environmental effects on nuclear decay rates

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If the half-life of radioactive nuclei depends on the electron density at the nucleus due to the physical or the chemical state of the atoms

Different half-life in stellar plasma than in the laboratory

Different probability for nucleosynthesis in stars
Experiment

produced in the reaction: $^{60}\text{Ni}(p,\gamma)^{61}\text{Cu}$

- Oxide and metallic nickel targets were activated for 12 hours by proton beam
- Beam energy: 2.48 MeV
- $p$ accelerated by the 2 MV Tandetron accelerator at Jožef Stefan Institute
- Decays were recorded in low-background laboratory every half hour for three days
• Half-life is determined from decay law:

\[
\begin{align*}
A(t) &= A(0) \left(1 - e^{-\lambda t}\right), \\
\lambda &= \frac{\ln(2)}{t_{1/2}}
\end{align*}
\]

• \(A(t)\) is the number of decays occurred at time \(t\)

• Table value \(A\downarrow 1/2\) of \(^{61}\text{Cu}\): 3.333 (5) h

• Half-life in nickel-oxide: 3.3280 (2) h

• Half-life in nickel: 3.3238 (2) h
Electronic configuration of nickel in the ground state is: \([\text{Ar}] \, 3d^8 \, 4s^2\)

- The weakest bound electrons are from shell 4s and over them nickel can build chemical bond with an oxygen atom.
- In NiO this electrons cannot contribute to the electron capture, but in Ni they can.

If we take into account the electron capture from N shell, for the fractional capture probabilities holds:

\[
\begin{align*}
A\downarrow A + A\downarrow A + A\downarrow A + A\downarrow A &= 1 \\
A\downarrow A &= \{1 + A\downarrow A / A\downarrow A [1 + A\downarrow A / A\downarrow A (1 + A\downarrow A / A\downarrow A)]\}^{-1} \\
A\downarrow A &= A\downarrow A (A\downarrow A / A\downarrow A ) , \quad A\downarrow A = A\downarrow A (A\downarrow A / A\downarrow A ) \\
A\downarrow A / A\downarrow A &= A\downarrow A / A\downarrow A (A\downarrow A / A\downarrow A - A\downarrow A A\downarrow A / A\downarrow A ) - A\downarrow A A\downarrow A / A\downarrow A ) \uparrow 2
\end{align*}
\]
\[ A \downarrow A \uparrow 1 \uparrow 2 / A \downarrow A \uparrow 2 \cdot A(A \downarrow 1)/A(A) \cdot [1+(A \downarrow A \downarrow 2 / A \downarrow A \downarrow 1]/1+(A \downarrow A \downarrow 2 / A \downarrow A \downarrow 1] \]

\[ A \downarrow A \uparrow = A \downarrow A \downarrow 1 \uparrow 2 / A \downarrow A \downarrow 1 \uparrow 2 \cdot A(A \downarrow 1)/A(A) \cdot [1+(A \downarrow A \downarrow 2 / A \downarrow A \downarrow 1]/1+(A \downarrow A \downarrow 2 / A \downarrow A \downarrow 1] \]

\[ A \downarrow A \uparrow 1 \uparrow 2 / A \downarrow A \uparrow 2 \cdot A(A \downarrow 1)/A(A) \cdot [1+(A \downarrow A \downarrow 2 / A \downarrow A \downarrow 1]/1+(A \downarrow A \downarrow 2 / A \downarrow A \downarrow 1] \]

- The ratios of the radial wave functions
- The ratios of the correction factors for overlap and exchange
- The subshell ratios
Conclusions

- For difference in half-live time in metallic compared to oxide targets from the experiment we got 0.12(1) %
- For the variations in electron densities from the theoretical model we got 0.035(3) %
- We are not sure what is the electronic configuration of copper in the nickel lattice
- In atomic beryllium decay rate is much more sensitive to chemical state of the atoms than in copper
Thank you for your attention!