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Search for the decay of ^{96}Zr

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We used the Oak Ridge National Laboratory low-background γ-ray spectrometer in an attempt to measure the decay of ^{96}Zr. Less than 0.13 disintegration min^{-1} was observed from a sample enriched in ^{96}Zr; this corresponds to a $t_{1/2} \geq 3.56 \times 10^{17}$ yr and a $\log ft$ value of ≥ 21.6.

[RADIOACTIVITY ^{96}Zr (from nature); measured I_γ from ^{96}Nb; set limit on specific activity and $t_{1/2}$.]

There are 19 nuclei that are found in nature even though they are thermodynamically capable of radioactive decay. Eight of these are α emitters including ^{232}Th, ^{235}U, and ^{238}U. The remaining 11 are β unstable but possess half-lives long compared to the age of the universe, since their only decay mode is a highly forbidden one. Details of many of these "fossil nuclei" have been summarized by Raman and Gove.[1]

The half-lives of only two of the four nuclei which can decay by a fourth-forbidden mode have been measured. This note describes an attempt to observe the decay of ^{96}Zr by means of the Oak Ridge National Laboratory (ORNL) low-background γ-ray spectrometer designed for lunar sample studies.[2]

Since the Q value for β decay of ^{96}Zr is 183 ± 6 keV,[3] the only levels of ^{96}Nb which can be populated are the ground state (6^+) and the excited states[4] at 45 keV (5^+) and 152 keV (4^+). The expected β transition is the fourth-forbidden nonunique transition to the 4^+ 152-keV excited state. The energy of this transition is calculated to be only 31 keV.

We attempted to detect the β decay of ^{96}Zr by the presence of its daughter nuclide 23.4-h ^{96}Nb, which has a large decay energy (~3.1 MeV) and decays via a series of triple γ-ray cascades.[5] In the ORNL low-background γ spectrometer,[2] this pattern of coincident γ-ray transitions can lead to both a high detection sensitivity and an identification of the radionuclide.

The sample consisted of 9.64 g of zirconium enriched to 57.4% ^{96}Zr. The zirconium as the chemical compound ZrO_2 was compressed into a cylinder and loaded into a plastic holder. The sample was measured in a low-background γ-ray spectrometer for 9573 min, and the background for 6637 min. A preliminary analysis of the data showed that the ZrO_2 sample as received from the ORNL Isotopes Division contained small but detectable amounts of thorium and uranium. Spectrum libraries for calibration of the instrument were prepared from ZrO_2 samples of natural isotopic composition, each containing a known amount of either ^{96}Nb, Th, or U.

The data analysis followed the general approach used for lunar sample studies.[2] The experimental singles and coincidence spectra were fitted by use of a least-squares computer program developed by Schonfeld.[6] The computer analysis showed that our ability to detect ^{96}Nb decays in the enriched zirconium sample was seriously impaired by the presence of γ rays from 3.8 ppm Th and 0.8 ppm U. No ^{96}Nb was detected in this experiment. An upper limit of ≤ 0.13 dis min^{-1} of ^{96}Nb was established by least-squares analysis, from which we compute a half-life of $\geq 3.56 \times 10^{17}$ yr, possibly the longest half-life known for a β unstable nucleus.

The energy of 31 keV for the $0^+ \to 4^+$ β transition and the lower limit for the half-life lead to a value of $\log ft \geq 21.6$. This result is consistent with values[1] of $\log ft$ for the two measured fourth-forbidden nonunique β transitions: 22.6 for the transition $^{115}In(\frac{9}{2}^+) \to {}^{115}Sn(\frac{1}{2}^+)$, and 23.2 for the transition $^{113}Cd(\frac{1}{2}^+) \to {}^{113}In(\frac{9}{2}^+)$.

In a search for the double-β decay of ^{96}Zr, Awschalom[7] utilized two NaI(Tl) scintillation crystals with an over-all efficiency of about 60% for electrons in the 2.5- to 4.5-MeV region—well above the β-ray end point energy for single β decay of either ^{96}Zr or ^{96}Nb. He reported the partial half-life of ^{96}Zr for double-β decay to be $>3.6 \times 10^{17}$ yr. Awschalom might have detected the single-β decay of ^{96}Zr via the summing of radiations following ^{96}Nb decay. For example, the 749-keV β group with an average energy of ~380 keV might sum with the 812-850-778 keV γ-ray cascade to exceed the 2500-keV discriminator setting. However, such a process would imply a miniscule detection efficiency and thus Awschalom's result has no bearing on the single-β decay $t_{1/2}$ of ^{96}Zr.

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