PHYSICAL REVIEW C VOLUME 33, NUMBER 6 JUNE 1986

Brief Reports

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Half-life limit for ^{48}Ca(2β^-)^{48}Ti(0_2^+,2997)

D. E. Alburger and J. B. Cumming
Brookhaven National Laboratory, Upton, New York 11973

(Received 31 January 1986)

Gamma-gamma coincidence data from a previous search for the decay sequence ^{48}Ca(β^-)^{48}Sc(β^-)^{48}Ti, in which a sample containing 3.71 g of ^{48}Ca was counted for 206 days in a HPGe(well-type)-NaI(Tl) detector combination, were reanalyzed to place a half-life limit on ^{48}Ca(2β^-)^{48}Ti(0_2^+, 2997). The signature for this decay would be the detection of 2014-983-keV $\gamma\gamma$ coincidences. An ^{88}Y source was used to establish the $\gamma\gamma$ coincidence efficiency. A lower limit (95% confidence) of $T_{1/2} > 8\times 10^{18}$ yr was obtained for the partial half-life for the 2β^- decay of ^{48}Ca to the 2997-keV 0_2^+ level of ^{48}Ti.

Thus far, all of the searches for the 2β^- decay of ^{48}Ca have been aimed at detecting the branch to the ^{48}Ti ground state by various measurements on β rays. Since $Q_{2\beta^-}=4271$ keV, double β^- decay can also lead to excited states of ^{48}Ti. In the context of gauge theories Vergados[1] estimated that the 2β^- branch to the 0_2^+ 2997-keV level of ^{48}Ti would have a partial half-life of about 10^{23} yr. Zamick and de Guerra[2] also found that the matrix element for decay to the 0_2^+ excited state should be greater than that to the ground state, and pointed out that the greater experimental sensitivity expected for detecting the 0_2^+ branch would partially compensate for the relative reduction due to the smaller decay energy (1274 keV to the 0_2^+ level compared with 4271 keV to the ground state).

In a recent experiment[3] we searched for the ^{48}Ca(β^-)^{48}Sc(β^-)^{48}Ti decay sequence and obtained a lower limit of $T_{1/2} > 6\times 10^{18}$ yr for the ^{48}Ca(β^-) unique fourth forbidden decay to the $J^\pi = 5^+$ first-excited state of ^{48}Sc. Pellets of ^{48}CaCO$_3$ containing 3.71 g of ^{48}Ca were located in a well-type HPGe detector which was enclosed in a large NaI(Tl) detector. Gamma rays from the β^- decay of 44-h ^{48}Sc, which would follow ^{48}Ca β^- decay (see Fig. 1 in Ref. 3), were searched for in the HPGe detector by requiring coincidences with a 1900-2550-keV window on the NaI(Tl) detector output. The window included all three $\gamma\gamma$ double-sum photopeaks due to the γ rays of 983.5, 1037.5, and 1312.1 keV in the triple cascade following the β^- decay of ^{48}Sc. The total counting time of the experiment was 206 days and no coincidence peaks of the expected energies were observed in the HPGe spectrum.

It was very kindly pointed out to us by Sherr that the coincidence condition of our experiment would also allow us to place a limit on the 2β^- decay of ^{48}Ca to the 2997-keV 0_2^+ excited state of ^{48}Ti. This level is known[4] to decay 100% via a 2014-keV γ ray to the 983-keV 2^+ first-excited state. In the ^{48}Ca(β^-)^{48}Sc(β^-)^{48}Ti search[3] the lowest energy of the three $\gamma\gamma$ double sums is $983.5+1037.5=2021$ keV and thus the window would also have completely encompassed the photopeak from the 2014-keV γ ray. The upper limit on the 983-keV coincident γ rays in the HPGe spectrum would therefore also give an upper limit on the intensity on the 2β^- decay branch, provided that the 2014-983 $\gamma\gamma$ coincidence efficiency were known.

By utilizing an ^{88}Y source we have established the $\gamma\gamma$ coincidence efficiencies, in the same experimental arrangement, as a function of the position of the source in the well of the HPGe detector. ^{88}Y decays nearly 100% by electron capture and emits[5] cascade, coincident γ rays of the 898 and 1836 keV, with intensities of 91.9% and 99.3% per decay, respectively. Their energies are fairly close to the 983- and 2014-keV γ rays expected from the deexcitation of the ^{48}Ti 0_2^+ level. The ^{88}Y source was produced in the Brookhaven National Laboratory 60-inch cyclotron via the ^{88}Sr(p,n)^{88}Y reaction at $E_p = 18$ MeV using a target of SrO$_2$. About a month's delay was necessary for decay of the principal contaminant 80.3 hr ^{87}Y. The absolute ^{88}Y strength was determined in a separate well-calibrated Ge(Li) detector system. By following the procedures described earlier,[3] the intensities of the 898-keV γ ray in singles and in coincidence with a NaI(Tl) window on the 1836-keV γ-ray photopeak were measured at six positions of the source in, or just above, the well (see Fig. 2 in Ref. 3). The intensity was taken as the sum of the 898-keV photopeak and weak satellite lines ~14 and ~2 keV higher due to summing with the (K-L) and (L-M) x rays following K and L electron capture. An effective average $\gamma\gamma$ absolute coincidence efficiency over the length of the ^{48}CaCO$_3$ sample, weighted according to the lengths and enrichments of the separate samples as before,[3] was obtained after making small efficiency versus energy corrections for both the HPGe and NaI(Tl) detectors so as to correspond to the 2014-983-keV cascade expected for the ^{48}Ca $2\beta^-$ decay. The coincidence efficiency thus derived is 1.4%.

By combining the previous upper limit on the 983-keV intensity with the $\gamma\gamma$ efficiency quoted above, and other factors discussed previously,[3] the lower limit for the half-life of $^{48}\mathrm{Ca}(2\beta^-)^{48}\mathrm{Ti}(0_2^+,2997)$ is found to be $T_{1/2} > 8\times10^{18}$ yr (95% confidence limit).

The present limit is about four orders of magnitude shorter than the theoretical estimate.[1] As discussed in our recent paper[3] a considerable reduction in the background from cosmic rays could be realized by moving to a deep underground location and by following some of the other procedures developed elsewhere (see, for example, Refs. 6 and 7 where background reductions by two orders of magnitude have been achieved). Also, a narrower window on the NaI(Tl) output, limited to the 2014-keV γ-ray photopeak, would reduce the background, as compared with the $^{48}\mathrm{Ca}(\beta^-)$ search. However, it seems very unlikely that with present technology the $2\beta^-$ decay of ^{48}Ca to the 0_2^+ excited state of ^{48}Ti will be observed.

We are indebted to R. Sherr for pointing out the additional information on $2\beta^-$ decay contained in our earlier experiment, and to D. Schlyer for preparation of the ^{88}Y source in the BNL 60-inch cyclotron. This work was supported by the U.S. Department of Energy, Division of Basic Energy Sciences, under Contract No. DE-AC02-76CH00016.

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