Title
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Journal
Physical Review Letters, 68(9)

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Publication Date
1991-10-01

LBL-31366
Preprint

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Submitted to Physical Review Letters

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October 1991

NUCLEAR SCIENCE DIVISION

Prepared for the U.S. Department of Energy under Contract Number DE-AC03-76SF00098

Reply to a Comment by N.K. Sherman

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To be submitted to Physical Review Letters

This work was supported by the Director, Office of Energy Research, Office of High Energy and Nuclear Physics, Nuclear Physics Division of the U.S. Department of Energy under Contract No. DE-AC03-76SF00098.

Sur *et al.* Reply: In the preceding Comment[1], Sherman raises the interesting question of whether the channeling of electrons and x-rays in Ge could account for the distortion we observed[2] in the β spectrum of ^{14}C. We have addressed this question in two ways. First, we remeasured the response function of our detetctor to look for evidence of channeling. Secondly, we reanalyzed our ^{14}C data to see if the observed distortion is compatible with that expected from channeling.

We irradiated our ^{14}C-doped Ge detector with 166-keV γ-rays using an external ^{139}Ce source. At this energy, the fraction of γ-interactions in Ge which occur via the photoelectric effect is 84%, and approximately 87% of these occur on a K-shell electron.[3] Thus, 73% of all interactions of this γ-ray in our detector produce photoelectrons with an energy of 166 - 11 = 155 keV. These electrons are emitted from Ge lattice sites throughout the crystal and have a fairly broad angular distribution relative to the initial γ-ray's direction. Because of the large mass of the recoiling Ge^+ ion, the energy spread of these electrons is very small. Thus, if 156-keV β's from ^{14}C decays undergo the channeling proposed by Sherman, then this should also happen to these photoelectrons. The effect of this would be that in a few percent of all events $\sim$ 22 keV would escape from the crystal and thus not show up in the ionization signal. This would produce an energy spectrum which contains both a full-energy peak and a small satellite peak $\sim$ 22 keV below it.

Figure 1 shows the relevant portion of the spectrum observed with the ^{139}Ce source placed on the front face of our ^{14}C-doped Ge detector. These data are events in which a signal was observed in the center region of the crystal and nothing was observed above threshold in the guard ring (i.e. type 2 events).[2] The full-energy peak contains 2.93×10^5 counts. A small Ge x-ray escape peak ($\sim$ 125 net counts) is observed at 166-10 = 156 keV. At the point 22 keV below the full-energy peak, no peak-like structure is observed. The limit we can place on the net number of counts in such a hypothetical peak is approximately 100 for any proposed energy loss from

10-50 keV. The same limits were obtained in a second measurement performed with the source mounted on the side of the detector which sent the γ rays through the edge of the crystal. Nearly identical limits were also obtained for center-region singles (i.e. type 1)[2] events. Thus, our measurements show that if channeling does occur , it produces an energy loss of this size less than 0.05% of the time for a 155-keV electron in Ge. This is a much smaller fraction than that estimated by Sherman.

The second approach we took was to assume that Sherman's proposed effect actually occurs and that a small number of β's lose a fraction of their energy to a process that does not produce ionization. We modified our analysis programs[2] to perform six different fits to a 420 point type-2 data set containing 224 days of counting with the ^{14}C-doped crystal and 111 days of counting with the background crystal. This represents all the data we previously reported[2] plus an additional 102 days of ^{14}C counting and an additional 59 days of background counting. If one assumes that $m_\nu = 0$ and that no channeling occurs, the lowest χ^2 obtained is 479. The absolute minimum value of $\chi^2 = 461$ is found for $m_\nu = 17$ keV and an emission probability of 1.2%. If instead, one assumes that $m_\nu = 0$ but that 1.2% of all β's lose 17 keV through channeling, the best fit χ^2 is 500. If the amount of energy lost to channeling and the fraction of events affected are allowed to vary, the lowest χ^2 obtained is again 479 for an energy loss of 50 keV and a fraction = 0.01%. This shows that even if Sherman's channeling mechanism did occur at the level he estimated, it would not produce a spectrum that quantitatively fits our data.

We also performed fits which assumed that $m_\nu = 0$ but that our data contained two beta spectra whose endpoint energies differ. Assuming that 1.2% of all events are associated with a spectrum whose endpoint is 156 - 17 = 139 keV, the lowest χ^2 obtained is 496. Allowing the second component's endpoint energy and fractional area to vary yields a minimum value of $\chi^2 = 475$ for an endpoint shift of 4 keV and a fractional area of 3%.

The reason for these results is that the shape of a β spectrum near the endpoint is very different for massless and massive neutrinos. If $m_\nu=0$, the β energy spectrum goes to zero with a slope of zero, while a massive neutrino produces a β spectrum that goes to zero with an infinite slope. The above analyses demonstrate that our ^{14}C experiment is sensitive not only to the position of the spectral distortion, but also to its detailed shape. So far, the only model which quantitatively explains this result is that a neutrino with a mass of 17 ± 1 keV is emitted $1.2\pm0.3\%$ of the time in the β decay of ^{14}C.

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Received __August 1991

PACS numbers: 23.40.Bw, 14.60.Gh, 27.20.+n

References

1. N. K. Sherman, preceding Comment.
2. B. Sur *et al.*, Phys. Rev. Lett. **66**, 2444 (1991).
3. E. Storm and H. I. Israel, Nucl. Data Tables **A7**, 590 and 681 (1970).

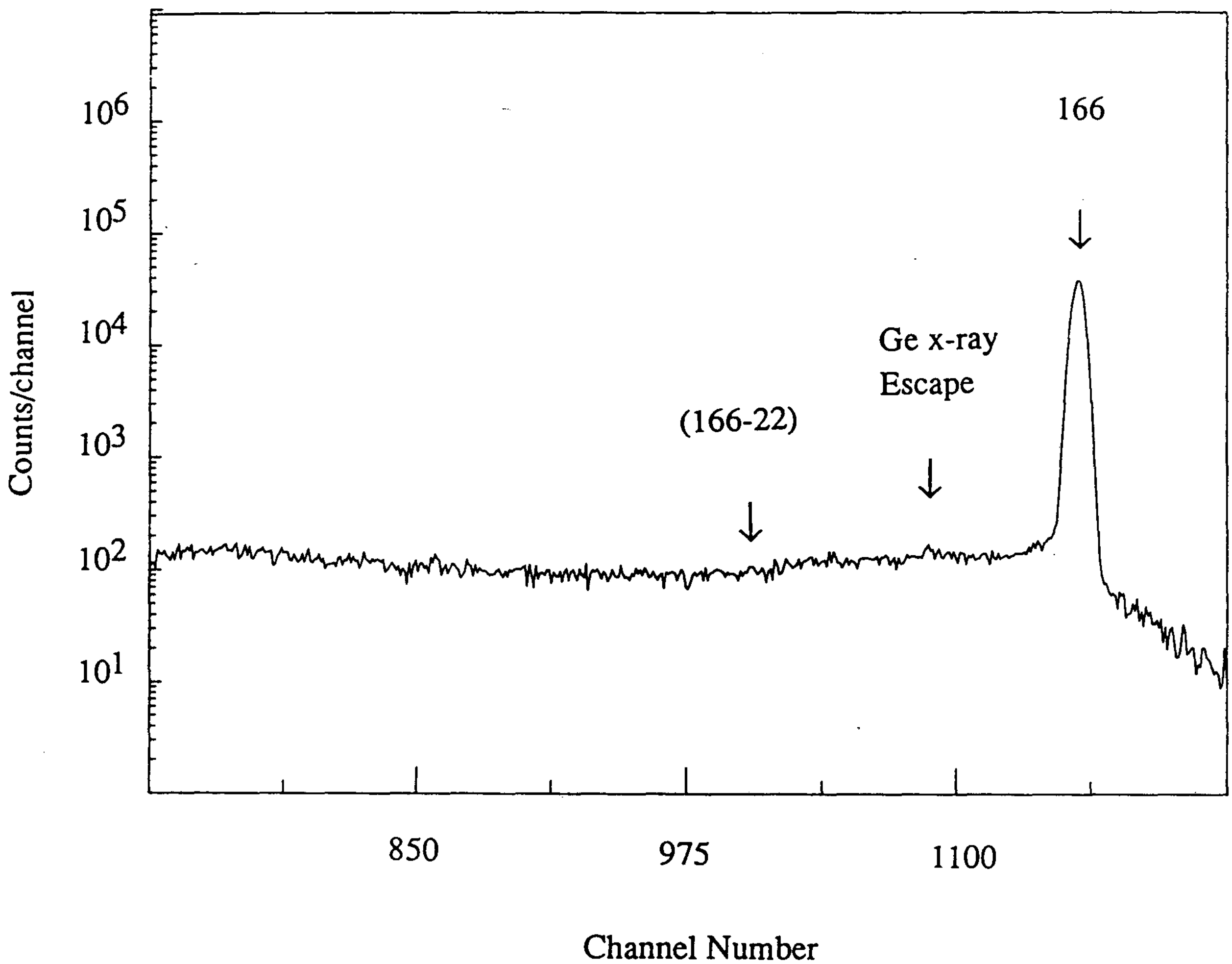

Figure 1. Type-(2) spectrum observed in our ^{14}C-doped germanium detector when a ^{139}Ce souce was placed on the front face of the detector. All enegies are given in keV. Note that the weak ^{14}C beta spectrum was measured separately and was subtracted from the raw data to produce this plot.

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