AN ATTEMPT TO DETECT DOUBLE BETA DECAY IN Ca^{48}

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The lower limit of the Ca^{48} lifetime with respect to double beta decay is estimated by means of the scintillation technique, using a sample containing 3.8 g of pure Ca^{48}. The lifetime exceeds 5×10^{19} years for neutrinoless decay and exceeds 3×10^{18} years for two-neutrino decay.

In all earlier attempts to detect double beta decay very small amounts of the investigated isotopes were used, usually tens of milligrams and more rarely hundreds of milligrams. In the present work four grams of Ca^{48} were used. In double beta decay a nucleus (A, Z) is transformed into a lighter nucleus (A, Z ± 2) by the simultaneous emission of two β particles. Two types of double beta decay are possible in principle. In the first of these,

$$(A, Z) \rightarrow (A, Z \pm 2) + 2e^{\mp} + 2\nu^{\pm},$$

the decay energy is distributed among four leptons (disregarding the negligible recoil energy of the daughter nucleus), but in the second type

$$(A, Z) \rightarrow (A, Z \pm 2) + 2e^{\mp}$$

it is distributed between only two leptons. The energy spectra of the decay electrons are thus extremely dependent on the type of process, and this, in turn, depends on the nature and properties of the neutrinos.

"Neutrinoless" double beta decay can be understood as follows, according to Furry.[1] An initial nucleus (A, Z) emits a single β particle and is transformed into a virtual intermediate nucleus (A, Z ± 1) plus a virtual neutrino. The latter interacts with the intermediate nucleus and "induces" its decay through the emission of a second β particle, while the neutrino itself is absorbed. This process is possible if lepton conservation is violated and at least one of the following possibilities is realized: a) The neutrino is not polarized longitudinally exactly 100% in the intermediate state, or its mass differs from zero; b) S-T interactions occur as well as V-A interactions.

The first possibility has been examined very thoroughly by Greuling and Whitten,[2] and the second by Goeppert-Mayer and Telegdi in their theory of twin neutrinos.[3]

Recent measurements of the longitudinal polarization of electrons and of the angular asymmetry of the beta decay of polarized nuclei are consistent with a lifetime exceeding 10^{18} years for neutrinoless double beta decay, whereas the two-neutrino process should have a lifetime of about $10^{20\pm2}$ years.[4]

The occurrence of double beta decay has hitherto not been confirmed by even a single experiment. Numerous attempts have only established a lower limit of about 7×10^{18} years for the lifetime of the neutrinoless process in Ca^{48}.[5] Individual experiments which appeared to yield positive results were either contradicted by subsequent experimental work, or did not eliminate other processes that could have misled the investigators.

Neutrinoless double beta decay, which has been considered much more likely to occur than two-neutrino decay, is also distinguished from the latter by the fact that the total energy of the emitted electrons is constant. Therefore almost all experimental attempts to observe double beta decay were performed with the assumption that the neutrinoless process occurs; this has now become questionable. Because of the continuous spectrum of total electron energy and the predicted long lifetime, two-neutrino decay could only be observed in very large samples during long periods of measurement.

The present experimental search for double beta decay in Ca^{48} supersedes an experiment performed about seven years ago.[5] The experimental arrangement remained essentially unchanged; photoelectric detectors were used to observe the number and intensity of light flashes in a scintillator surrounding the sample. A working sample enriched in Ca^{48} alternated with a control sample. The almost 10-fold increase in the weight and size of the sample necessitated special steps to ensure maximum uniformity in the collection of

photoelectrons despite the different locations of the light flashes in the scintillator. This problem will be examined separately in another communication by one of the present authors.

We shall now consider the principal parts of the apparatus and the principal results. The sample was positioned between two scintillation counters 150 mm in diameter. Each counter consisted of a FÉU-49 photomultiplier and a compensator of nonuniform electron collection from the photocathode, and a plastic scintillator 20 mm thick separated from the photomultiplier by a 20-mm layer of diffusion oil. This oil served two purposes; it provided optical contact between the photocathode and the scintillator, and it absorbed radioactive emission from K^{40} contained among other impurities in the glass of the photo-multiplier. Both scintillation counters along with the sample were placed inside a space filled with a liquid scintillator that surrounded the assembly in all directions with not less than 150-mm thickness. The volume of the liquid scintillation counter was scanned from all directions by six FÉU-24 multipliers connected for anticoincidence with the main scintillation counters. In addition, the background was reduced by placing the apparatus underground (at 65 m water equivalent) with a 100-mm lead shield.

Pulses from the two scintillation counters that coincided to within 0.2 μsec in the absence of a signal from the liquid scintillator were fed to a special double oscilloscope and were registered on photographic film. The samples were prepared out of calcium fluoride, which contains a minimum number of inactive atoms. The working sample contained calcium enriched to 66% Ca^{48}; this was a thin disk 140 mm in diameter and about 80 mg/cm^2 thick, pressed from calcium fluoride powder combined with polystyrene, and containing 3.7 g Ca^{48}. The control sample was identical in both its geometric dimensions and in the number of calcium fluoride molecules. The only difference lay in its nonidentical isotopic composition; the control sample was enriched to 89.6% Ca^{44}.[1)] The materials used to prepare the samples were subjected to thorough chemical and isotopic analyses and were tested for the absence of ordinary radioactivity.

Impurities were found to comprise at most 0.02%. The energy calibration of the apparatus was performed as described in [5]. The resolution of the scintillation spectrometers was 28% for 0.625-MeV electrons. The film registered pulses induced by electrons having energies above 0.6 MeV, with the total electron energy exceeding 1.6 MeV.

With lower discrimination thresholds there was a sharp increase in the number of registered events due to the background. This greatly complicated the treatment of the data, and yielded no perceptible gain in sensitivity.

The two samples were placed alternately, at intervals of 23 hours, between the scintillation counters. At each interchange the stability of the instrumental parameters was checked. For the same purpose, during the entire period of measurement a statistical control was maintained; measurements were compared with those that had immediately preceded them. Our measurements, performed in 1962, ran 759 hours divided into 392.5 hours with the Ca^{48} sample and 366.5 hours with the Ca^{44} sample.

Figure 1 shows the differential spectrum of the combined energy of coinciding electrons; the number of pulses was reduced to a 100-hour count. The entire investigated energy range contains no interval exhibiting a significant difference between the Ca^{48} and Ca^{44} counting rates.

The lower limit of the Ca^{48} lifetime with respect to double beta decay was estimated for each of the possible decay processes separately. For this purpose we calculated the expected spectral shapes taking into account the discrimination thresholds, the geometric factor, the size and weight of the samples, and other instrumental parameters. The initial theoretical data were

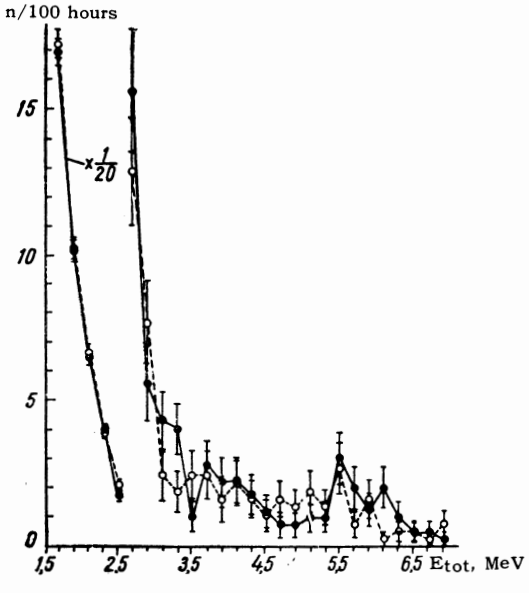

FIG. 1. Differential spectrum of the combined energy of coinciding electrons. ● – Ca^{48}; ○ – Ca^{44}.

[1)] We are indebted to V. S. Zolotarev for providing the separated calcium isotopes.

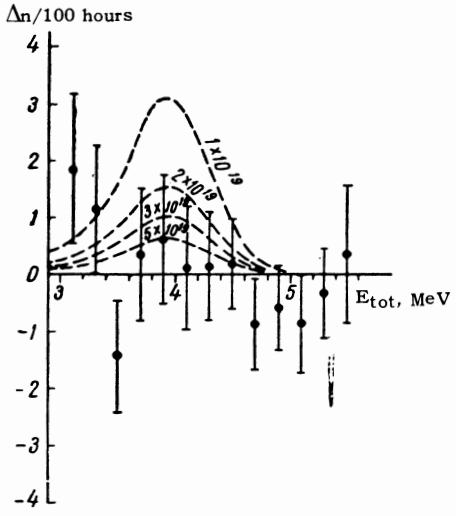

FIG. 2. Difference between the energy spectra of Ca^{48} and Ca^{44} for the decay process $Ca^{48} \rightarrow Ti^{48} + 2e^-$.

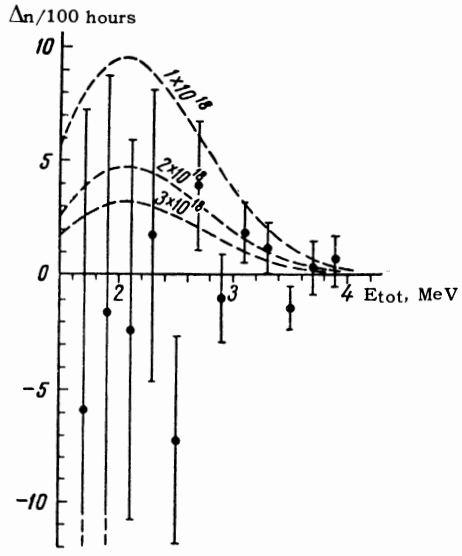

FIG. 3. Difference between the energy spectra of Ca^{48} and Ca^{44} for the decay process $Ca^{48} \rightarrow Ti^{48} + 2e^- + 2\nu$.

spectra calculated for Ca^{48} in [2]. Figures 2 and 3 show the difference between the energy spectra of Ca^{48} and Ca^{44} for the decays $Ca^{48} \rightarrow Ti^{48} + 2e^-$ and $Ca^{48} \rightarrow Ti^{48} + 2e^- + 2\nu$. The dashed curves represent the expected spectral shape for each of the two decay processes assuming a number of different lifetimes.

The minimum lifetime of Ca^{48} with respect to neutrinoless double beta decay exceeds 5×10^{19} years; with respect to two-neutrino decay the lifetime exceeds 3×10^{18} years.

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