Comments

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Comment on "Feasibility of detecting neutrinoless double-beta decay between pairs of single-beta emitters"

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We reexamine the feasibility of an experiment proposed by Skalsey to observe neutrinoless double-beta processes between pairs of single-beta emitters.

In a recent article,[1] Skalsey has rediscussed the feasibility of double-beta process experiments of the generic type first considered by Pacheco,[2] and presented a new variant which, according to Skalsey, looks more promising than the experiment originally conceived by Pacheco. Since the kind of experiment newly proposed by Skalsey, if it is indeed feasible, can certainly be extremely important, and since the main conclusion of Ref. 1 is stated in referring to the content of Ref. 3, authored by Yazaki and two of us, we wish to describe here our view on the proposed experiment. We hope that our comment, taken together with the argument of Ref. 1, will be useful to those people who are planning an experiment based on Ref. 1.

Let us start with a brief summary of the issue.[4] Pacheco[2] proposed an experiment to detect neutrinoless double-beta *decay* between separated pairs of single-beta emitters. In this process one nucleus in a sample of element X beta decays, emitting one virtual antineutrino, which propagates to another nucleus in the sample, where, if the neutrino is a Majorana particle, the antineutrino can cause neutrino-induced beta decay. That is,

$$ {}^{A}_{Z}X \rightarrow {}^{A}_{Z+1}Y + e^- + \bar{\nu}_e \ , \tag{1a}$$

$$ \nu_e + {}^{A}_{Z}X' \rightarrow {}^{A}_{Z+1}Y' + e^- \ . \tag{1b}$$

This new type of double-beta decay may be called the "internuclear" double-beta decay in contradistinction to the "usual" double-beta decay,[4] which, taking place within a single nucleus, may be called the "intranuclear" double-beta decay. Pacheco emphasized that the internuclear double-beta decay experiment, if it is at all feasible, should have the following advantages: (1) It is free from the intervention of the two-neutrino mode; (2) in extracting information on the Majorana nature of the neutrino from the observed decay, one need not depend on nuclear models. This last feature comes about because the relevant nuclear transition matrix element can be unambiguously determined from the ft value of the single-beta decay.

According to the analysis in Ref. 3 (hereafter to be referred to as KKY), the internuclear double-beta decay experiment is expected to be much harder than envisaged in Ref. 2. In order to summarize the main points of KKY, we first mention that reaction (1) occurs only when the virtual Majorana neutrino has mixed helicities, which is possible (a) if $m_\nu \neq 0$, or (b) if the leptonic weak current contains an admixture of the "wrong-handed" component. Since it is not warranted at the present stage to complicate the argument by considering the above two possibilities simultaneously, we may concentrate on one of them. So, let us limit ourselves to case (a). Then, the significance of a given double-beta decay experiment is measured by its sensitivity to m_ν. The "traditional" intranuclear double-beta decay experiments have so far set an upper limit m_ν less than several eV.[5] Because of the ambiguity in the nuclear transition matrix elements involved in the analyses,[6] it might be better to cite the conservative upper limit, $m_\nu \lesssim 10$ eV. This implies that an internuclear double-beta decay experiment can be of current relevance insofar as it can provide information on m_ν in the range $m_\nu \lesssim 10$ eV. In reexamining the feasibility of the experiment proposed by Pacheco,[2] KKY used this criterion and the observation that the detection of the internuclear double-beta decay would be unrealistic unless the event rate per parent nucleus, denoted by Λ/N, is comparable to or larger than the already established upper limit to the decay rate of the intranuclear double-beta decay. The main conclusions of KKY may be summarized as follows. The large decay rate (hence small ft value) of a parent single-beta emitter and the large size of a sample of the single-beta emitters, two requirements which must be satisfied simultaneously in order to have a large enough event rate, seem to be practically incompatible with each other. If we impose an additional (quite reasonable) requirement that at least one internuclear double-beta decay takes place before the entire sample disintegrates, the constraint on the sample size becomes even more severe. Based on these observations, KKY concluded that the internuclear double-beta decay experiment proposed by Pacheco seems to be harder than considered in Ref. 2.

Skalsey's proposal may be summarized as follows.

Consider the detection of a new kind of internuclear double-beta process:

$$e^- + {}^A_Z X \rightarrow {}^A_{Z-1} Y + \nu_e , \quad (2a)$$

$$\bar{\nu}_e + {}^A_Z X' \rightarrow {}^A_{Z-1} Y' + e^+ . \quad (2b)$$

If the Q value for the reaction shown in Eq. (2a) satisfies $m_e < Q_{EC} < 2m_e$, then the positron coming from the reaction shown in Eq. (2b) will, ideally speaking, constitute a signal for the neutrinoless double-beta process. A close examination of the competition of the signal with the background events indicates that the following three nuclides are possible candidates for this type of experiment: ^{37}Ar, ^{49}V, and ^{119}Sb. Of these one may use ^{49}V for the illustrative purpose. The consideration of the attenuation of pair-annihilation photons in the source material sets the limit to the source size; the largest conceivable size for the source (assumed to be spherical for simplicity) is about 1 cm, giving a mass of 25 g. If one uses an intense source ($\sim$200 kCi if pure ^{49}V) surrounded by an extensive 4π detector array, then 1–2 yr running will be sensitive to an initial double-beta process event rate of one per day. These figures give a value of 10^{-21} yr^{-1} for the parameter Λ/N used in KKY, which is just inside the range KKY consider of current interest. Thus the positron-emitting K capture, Eqs. (2a) and (2b), may be a promising alternative to the double-beta decay shown in Eqs. (1a) and (1b). This summarizes the main points of Skalsey's argument in Ref. 1.

We now present our comment on Skalsey's argument. Our main point is concerned with the *actual* calculation of the transition rate for the internuclear double-beta process represented by Eqs. (2a) and (2b). If we denote by Λ' the transition rate for this process, an elementary second-order perturbation calculation gives

$$\Lambda' = 2.32\times 10^{-35} Z_i^3 \mathcal{F} \frac{R\,(\mathrm{cm})\rho(\mathrm{g/cm^3})}{A} N \times [m_\nu(\mathrm{eV})]^2 [E\,(\mathrm{MeV})]^2 \left[\frac{10^4}{ft\,(\mathrm{sec})}\right]^2 \mathrm{yr}^{-1} . \quad (3)$$

This formula applies to a source sample 100% consisting of ^{49}V, whose shape is, for simplicity, assumed to be spherical; R is the radius of the sample. A, ρ, and N are, respectively, the mass number, the mass density, and the total number of the single-beta emitters; Z_i is the initial nuclear charge, E the total energy of the emitted positron, and $\mathcal{F}$ the Gamow factor representing Coulomb distortion; ft stands for the ft value for the electron capture Eq. (2a). In order to normalize the transition rate Λ' of the internuclear process with respect to that of the intranuclear process, it is convenient to use, as in KKY, Λ'/N rather than Λ' itself. From the observed ft value one can easily evaluate Λ'/N as a function of m_ν and R. The results are given as

$$\Lambda'/N(\mathrm{V}) = 3.82\times 10^{-37} R\,(\mathrm{cm})[m_\nu(\mathrm{eV})]^2\ \mathrm{yr}^{-1} , \quad (4a)$$

$$\Lambda'/N(\mathrm{Ar}) = 3.45\times 10^{-35} R\,(\mathrm{cm})[m_\nu(\mathrm{eV})]^2\ \mathrm{yr}^{-1} , \quad (4b)$$

$$\Lambda'/N(\mathrm{Sb}) = 1.05\times 10^{-34} R\,(\mathrm{cm})[m_\nu(\mathrm{eV})]^2\ \mathrm{yr}^{-1} , \quad (4c)$$

where we have included the results of similar calculations for the other two candidate isotopes as well. [A solid argon source is assumed in Eq. (4b).] According to Ref. 1, $R\sim 1$ cm is more or less the maximum source size compatible with the survival of photon signals from the process Eqs. (2a) and (2b). One can therefore conclude from Eq. (4) that for $m_\nu \lesssim 10$ eV, which is a range of current interest, Λ'/N for any of the three candidate isotopes is much smaller than 10^{-23} yr^{-1}, a typical event rate that can be investigated in usual intranuclear double-beta decay experiments.[5] Thus the actual calculation of the transition rate presented here indicates that a careful reexamination of the argument and conclusion of Ref. 1 is required. We notice that, in Ref. 1, the significance of the proposed experiment is discussed in terms of the assumed event rate rather than its sensitivity to the Majorana neutrino mass m_ν. Namely, Ref. 1 assumes implicitly that any double-beta process experiment that deals with an event rate per parent nucleus around $10^{-21\pm 2}$ yr^{-1} should have relevance with the current issue on m_ν. Our explicit estimation above demonstrates that this assumption is not always tenable. In the case of internuclear positron-emitting K capture, Eqs. (2a) and (2b), the transition rate of $\Lambda'/N \sim 10^{-21}$ yr^{-1}, which, as mentioned in Ref. 1, corresponds to one transition per nucleus per day, would correspond to $m_\nu \gtrsim 1$ MeV. Therefore, even if 1–2 yr of running of the experiment described in Ref. 1 can be sensitive to the event rate of one transition per nucleus per day, information on m_ν we would obtain from this experiment will be of rather little use compared with the information we already have from "traditional" intranuclear double-beta decay experiments. Of course, a similar warning should be given also for the case where the mixing amplitude of the "wrong-handed" current is used as a measure of possible neutrinoless double-beta processes [case (b), mentioned earlier in the paper]. The author of Ref. 1 cautiously analyzed various technical difficulties one must surmount before experiments on the process shown in Eqs. (2a) and (2b) become realistic. It is our hope that the above-mentioned warning will be taken into account along with those technical difficulties.

[1]M. Skalsey, Phys. Rev. C **36**, 820 (1987).
[2]A. F. Pacheco, Phys. Rev. Lett. **53**, 979 (1984).
[3]Y. Kohyama, K. Kubodera, and K. Yazaki, Phys. Lett. **168B**, 21 (1986).
[4]For a review on double-beta decay in general, see, e.g., W. Haxton and G. J. Stephenson, Prog. Part. Nucl. Phys. **12**, 409 (1984).
[5]For a recent review, see, e.g., J. Vergados, Phys. Rep. **133**, 1 (1986).
[6]See Ref. 4.