Search for a double beta decay of ^{136}Xe

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A high-pressure ionization gas chamber has been used to establish the limits on the decay half-lives of ^{136}Xe nuclei relative to the double β decay along different channels: $T_{1/2}$ $(0\nu; 0^+ - 0^+) > 1.2\times 10^{21}$ yr, $T_{1/2}$ $(0\nu; 0^+ - 2^+) > 4.9\times 10^{20}$ yr, $T_{1/2}$ $(2\nu; 0^+ - 0^+) > 2.1\times 10^{19}$ yr.

Barbanov *et al.*[1] obtained a limit on the half-life ($T_{1/2}$) for the decay of ^{136}Xe (0ν; $0^+ - 0^+$): $T_{1/2} > 2.36\times 10^{21}$ yr.[1] The search for the $2\beta = (2\nu)$ decay, however, is now of considerable interest because of the discrepancy between the theoretical calculations and experimental data.[2–4] In the present letter we determine the limits on the 2β decay of ^{136}Xe for the $0\nu(0^+ - 0^+)$ mode ($E_{2\beta} = 2481$ keV), for the $0\nu(0^+ - 2^+)$ mode ($E_{2\beta} = 1662$ keV), and for the $2\nu(0^+ - 0^+)$ mode. We have estimated the value of the Gamow-Teller matrix element $|M_{\rm GT}|$ on the basis of the constraint imposed on the half-life $T_{1/2}(2\nu;\ 0^+ - 0^+)$.

The search for 2β decay of ^{136}Xe was carried out with use of a high-pressure ionization chamber filled alternately with natural xenon (8.87% ^{136}Xe) and enriched xenon (93% ^{136}Xe). The chamber has a 3.14-liter effective volume. The working mixture $Xe + 0.8\%\ H_2$ is used at a pressure of 25 kgf/cm^2. The gas mass in the effective volume of the chamber in this case is 550 g. The energy resolution is 3.8% (FWHM) at 2.5 MeV. A passive shield consisting of 15 cm of lead and 10 cm of oxygen-free copper is used to reduce the γ-ray background. The α-particle background from ^{222}Rn and from its decay products is suppressed by identifying the shape of the ionization signals. The entire apparatus is installed in an underground laboratory at the Baksan Neutrino Observatory of the Institute of Nuclear Studies, at a depth of 850 meters water equivalent. The apparatus is described in more detail in Ref. 5.

Figure 1 shows spectra measured with the enriched and natural xenon. The measurement times are 243 and 120 hours, respectively. At energies to 0.7 MeV, an appreciably higher background of natural Xe than of ^{136}Xe is attributable to the presence of ^{85}Kr ($E_\beta = 0.672$ MeV) in the natural xenon. At higher energies the spectra are essentially the same, and there are no structural features of any sort in the energy region of 2.481 and 1.662 MeV. Only the upper limits of the various modes of the 2β decay of ^{136}Xe can therefore be determined.

$\beta\beta(0\nu)$ decay, $0^+ - 0^+$ *transition.* In the region 2.481 ± 0.094 MeV the counting rate is 0.4 event/h. The limit on the decay half-life was calculated from the equation

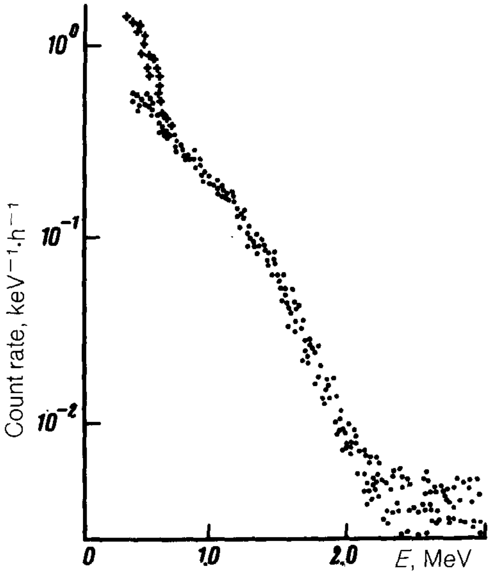

FIG. 1. Background spectra of $^{nat}Xe(\times)$ and ^{136}Xe (●) obtained in the ionization chamber's low-background shield. Since the spectra are essentially the same at energies above 0.7 MeV, only a partial spectrum of ^{nat}Xe is shown.

$$\lim T_{1/2} = \frac{\ln 2\epsilon N_0 t}{\sqrt{N_b}}, \tag{1}$$

where ϵ is the detection efficiency, N_0 is the number of ^{136}Xe atoms, N_b are the counts in the energy interval of interest, and t is the measurement time. Substituting $\epsilon = 0.27$, $N_0 = 2.2\times 10^{24}$, and $T = 243$ h, we find the decay half-life of ^{136}Xe to be

$$T_{1/2}(0\nu; 0^+ - 0^+) > 1.2\times 10^{21} \text{ yr},$$

with a confidence level of 68%.

$\beta\beta(0\nu)$ decay, $0^+ - 2^+$ transition. The count rate in the energy interval 1.662 ± 0.063 MeV is 4.8 events/h. The limit on the decay half-life was calculated from Eq. (1). In this case we have $\epsilon = 0.4$, $N_0 = 2.2\times 10^{24}$, and $t = 243$ h. The decay half-life of ^{136}Xe is thus found to be

$$T_{1/2}(0\nu; 0^+ - 2^+) > 4.9\times 10^{20} \text{ yr},$$

with a confidence level of 68%.

$\beta\beta(2\nu)$ decay, $0^+ - 0^+$ transition. The count rates in the energy interval 0.7–2.0 MeV for ^{136}Xe and ^{nat}Xe is $^{136}R = 159.12 \pm 0.79$ events/h and $^{nat}R = 159.84 \pm 1.15$ events/h. The limit on the decay half-life is calculated from the equation

$$\lim T_{1/2} = \frac{\ln 2\epsilon N_0 t}{\Delta N}, \tag{2}$$

where $\Delta N = (\sqrt{^{136}\Delta R^2 + {}^{nat}\Delta R^2} + {}^{syst}\Delta R)t$, and $^{syst}\Delta R = 1.62$ events/h is a reasonable systematic error which stems from an inaccurate determination of the amount of gas in the chamber and of the α-particle background in the energy interval 0.7–2.0 MeV. In this case we have $\epsilon = 0.42$, $N_0 = 1.9\times 10^{24}$, and $t = 243$ h.

As a result, we find the decay half-life of ^{136}Xe to be

$$T_{1/2}(2\nu; 0^+ - 0^+) > 2.1\times 10^{19}\ \text{yr},$$

with a confidence level of 68%, consistent with the theoretical calculations of Vogel *et al.*[2,3] Using this limiting value and the theoretical results of Ref. 6, we find the limit on the value of the matrix element $|M_{GT}|$ to be < 1.3.

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