ELSEVIER

26 January 1995

PHYSICS LETTERS B

Physics Letters B 344 (1995) 72–78

The research of 2β decay of ^{116}Cd with enriched ^{116}CdWO$_4$ crystal scintillators

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Received 7 July 1994; revised manuscript received 16 November 1994
Editor: R.H. Siemssen

Abstract

The experiment was performed at the Solotvina Underground Laboratory with CdWO$_4$ crystal scintillators enriched in ^{116}Cd to 83%. The total data collection time was about 30000 hours. Limits of $T_{1/2}^{0\nu} \geq 2.9 \cdot 10^{22}$ y (90% CL) and $T_{1/2}^{2\nu} \geq 1.8 \cdot 10^{19}$ y (99% CL) were obtained for $0\nu2\beta$ and $2\nu2\beta$ decay of ^{116}Cd. After subtraction of the spectrum obtained with a natural CdWO$_4$ scintillator a remaining yield was seen consistent with $2\nu2\beta$ decay of ^{116}Cd with $T_{1/2}^{2\nu} = \{2.7^{+0.5}_{-0.4}(\text{stat.})^{+0.9}_{-0.6}(\text{syst.})\} \cdot 10^{19}$ y. However, the imitation of the effect by impurities of ^{90}Sr (at the level of $2 \cdot 10^{-3}$ Bq/kg) cannot be excluded.

1. Introduction

During the last decade remarkable advances have been made in the investigation of double beta decay and the theoretical interpretation. We name here:

- a half-life limit of greater then 10^{24} y for the $0\nu2\beta$ decay of ^{76}Ge [1–4];
- the large scale experiments on ^{76}Ge using enriched HP Ge detectors [3,4];
- half-life limits of greater than 10^{23} y for the $0\nu2\beta$ decay of ^{136}Xe [5] and 10^{22} y for ^{82}Se [6], ^{100}Mo [7] and ^{116}Cd [8];
- a low temperature high energy resolution bolometer with a TeO$_2$ crystal created for the study of the 2β decay of ^{130}Te [9];
- observation in direct counting experiments of the $2\nu2\beta$ decay of ^{76}Ge [2–4], ^{82}Se [6], ^{100}Mo [10–12], ^{116}Cd [13] and ^{150}Nd [11,14];
- progress in the theoretical interpretation of double beta decay [15–17].

The interest in double beta decay originates from the possibility to study the neutrino properties. It represents the only way to measure an effective Majorana mass of the electron neutrino and it yields presently the most stringent limits on this mass as well as on lepton charge nonconservation, right-handed admixtures in the weak interaction, the neutrino-Majoron coupling constant and other parameters of theories beyond the Standard Model. The progress made during the last decade would be impossible without advances in experimental techniques: the success of 2β decay experiments depends on many factors, the most important of which are the right choice of nuclides for the investigations, the development of adequate detectors with the required properties (a maximal content of nuclei to be examined, a low level of impurities, high effi-

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SSDI 0370-2693(94)01528-7

ciency and selectivity, stability in long-time measurements, etc.), and an extremely low background level.

The results of our 2β decay investigations of ^{116}Cd since 1987 are summarized in this paper. The problems of fabricating the detector and the development of the high-sensitive measuring techniques were solved during these investigations.

2. Detectors, installation and background measurements

The energy released in the transition ^{116}Cd–^{116}Sn is equal to 2802 keV [18], and the abundance of ^{116}Cd is 7.49(9)% [19]. Theoretical estimates [20] of $T_{1/2}(^{116}\text{Cd})$ with respect to $2\nu2\beta$ decay are in the range of 10^{18}–10^{20} y whereas the calculated value of $T^{0\nu}_{1/2} \cdot \langle m_\nu \rangle^2 = 4.87 \cdot 10^{23}$ y·eV^2 was found to be much more stable. This value of the product is one of the lowest of all $2\beta^-$ nuclides. It is nearly four times lower than the predicted values for ^{76}Ge and ^{136}Xe, thus for equal experimental limits obtained for $T^{0\nu}_{1/2}$ the experiment with ^{116}Cd should yield the most stringent limit on the neutrino mass.

In order to increase the sensitivity, ^{116}CdWO$_4$ crystal scintillators enriched in ^{116}Cd to 83% were grown [21,22]. For this aim the sample of metallic ^{116}Cd (618.8 g, the ^{116}Cd concentration being 91.2%) was purified twice by vacuum distillation and put in the form of the oxide ^{116}CdO. A cadmium tungstate crystal with a mass of 510 g (112 mm long, 35 mm diameter) was grown by the Czochralski method from a mixture of the oxides WO$_3$ and ^{116}CdO. The crystal was cleaved into five samples, three of which (19.0, 14.0 and 12.5 cm^3) were used separately in the different runs of the present experiment. The number of ^{116}Cd nuclei in these samples is $2.09 \cdot 10^{23}$, $1.54 \cdot 10^{23}$ and $1.37 \cdot 10^{23}$, respectively. The energy resolution of the crystals with the XP2412 (Philips) photomultiplier is about 12–13% for the energy of 662 keV. Natural CdWO$_4$ scintillators of volumes 8.0, 9.1 and 56.8 cm^3 were also used in the investigations.

Aside from the first experiment in Kiev [21] all measurements were carried out in the Solotvina Underground Laboratory of INR built in a salt mine at a depth more than 1000 mwe [23] where the cosmic muon flux is suppressed by a factor of greater than 10^4. Due to a low radioactive contamination of the salt (NaCl) the natural γ background is nearly 30–70 times lower than in the chambers built of common materials [23]. The data acquisition system consists of a microcomputer, a magnetic tape recorder and a CAMAC crate with electronic units. Since the decay time of the CdWO$_4$ scintillators is 25–30 μs, a special electronic unit was used which integrates the PMT output signal during ~40 μs and forms the short output pulses required by the ADC. The same unit performs a rejection of scintillator signals from PMT noise pulses using their different time characteristics. The CdWO$_4$ energy threshold was lowered to 30–40 keV due to this. A stabilization system [24] was used during the experiments. A remaining shift in the gain could be corrected also by the software. As a result, the resolution of the detector for the background γ peak of ^{208}Tl (2615 keV) measured during 12000 h (7.4%) does not differ from the resolution in the calibration measurements during 3 h (7.0%). This fact shows the high quality of the hardware and software tools for the energy scale stabilization.

The detector background in the energy interval 2.7–2.9 MeV was reduced successively by more than two orders of magnitude with different installations [8,21,22,25]. The measurements led to clarifying the origins of the different components of the detector background and to constructing the installation with the best characteristics. Both active and passive shieldings were applied. The passive shielding of OFHC copper (5 cm) and lead (23 cm) surrounds the plastic scintillator which was used as active shielding. The cadmium tungstate crystal is viewed by a PMT (FEU-110) through a light-guide 51 cm long. The light-guide is glued of two parts: quartz 25 cm and plastic 26 cm long. The energy resolution of the detectors is equal to 14.1, 8.2 and 7.1% at the energies 662, 1770 and 2615 keV, respectively, for the ^{116}CdWO$_4$ crystal and to 12.2, 7.9 and 6.7% for natural CdWO$_4$. The active shielding polystyrene scintillator is viewed by two low-background PMT (FEU-125). In case of a coincidence between CdWO$_4$ and plastic, a short (2.5 μs) signal is generated vetoing the CdWO$_4$ events. If the energy released in the plastic is above 2–3 MeV (which may by associated with cosmic ray muons), the veto signal is generated during 1.5 ms. It is enough to thermalize and capture most of the neutrons produced by the muons. The dead time of the acquisition system was periodically monitored by

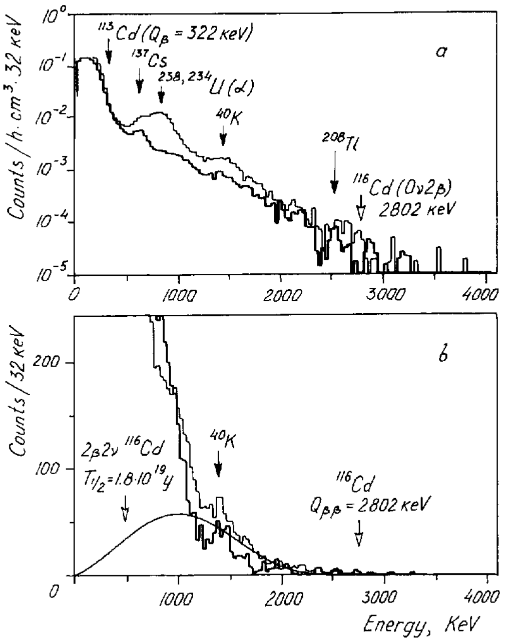

Fig. 1. (a) The background of the $^{116}CdWO_4$ crystal with an initial volume of 19.0 cm^3 (2633 h) and of this crystal ground to a volume 15.2 cm^3 (2982 h). The reduction of the α peak and the continuous distribution is connected with the removal of U impurities concentrated in the surface layer of the crystal. (b) The background of enriched $^{116}CdWO_4$ (15.2 cm^3, 2982 h – thick line) and natural $CdWO_4$ (9.1 cm^3, 1596 h – bold line; normalized to the volume and measuring time of the $^{116}CdWO_4$) crystals. The smooth curve is the theoretical distribution for $2\nu2\beta$ decay of ^{116}Cd with $T^{2\nu}_{1/2} = 1.8 \cdot 10^{19}$ y (99% CL limit).

means of pulses from the light emitting diodes. Its value was within 3–6%. The energy calibration was carried out with ^{207}Bi weekly and with ^{232}Th once in three weeks.

The background spectrum of $^{116}CdWO_4$ (19 cm^3) measured in this installation for 2633 h is shown in Fig. 1a (thin line) where the following peculiarities exist: the sharp increase below 320 keV, the comparatively broad peak with intensity ~3.3 counts/h near 830 keV and the very weak peaks at the energy 1461 keV (^{40}K) and 2615 keV (^{208}Tl). The distribution in the low energy region is the spectrum of the fourth-forbidden β decay of ^{113}Cd ($T_{1/2} = 9.3 \cdot 10^{15}$ y [26], $Q_\beta = 316$ keV [18]) which is present in the enriched crystal (2.15%). The broad peak near 830 keV could be caused by α-particles from intrinsic contamination of the enriched crystal by nuclides of the U family. This was confirmed in measurements with α/β pulse shape discrimination. The ^{238}U content amounted to $(0.9–2.9) \cdot 10^{-3}$ Bq/kg for crystal of 12.5, 14 and 19 cm^3. It was assumed that the U impurities were located in a thin layer on the surface of the scintillators, and the $^{116}CdWO_4$ crystal (19 cm^3) was ground on 0.8–1.5 mm (its volume decreased to 15.2 cm^3). The spectrum of this crystal for 2982 h is also shown in Fig. 1a (bold line). It clearly demonstrates the disappearance of the overwhelming part of the α peak. Besides, one can see a reduction of the continuous component of the background up to the energy of 2.2 MeV in good agreement with a removal of the β contribution from the ^{234m}Pa-member of the ^{238}U family. Analysis of the background in the energy region 0.8–1.2 MeV gives the limit $< 6 \cdot 10^{-5}$ Bq/kg for the ^{238}U activity (50 times less than before). The weak peak with the energy 664(10) keV can be explained by the presence of ^{137}Cs with an activity of $1.5(4) \cdot 10^{-3}$ Bq/kg. For ^{40}K, ^{90}Sr, ^{226}Ra and ^{232}Th the following upper limits of the activities are determined: $< 3.8 \cdot 10^{-3}$, $< 2.8 \cdot 10^{-3}$, $< 5.0 \cdot 10^{-5}$ and $< 4.0 \cdot 10^{-5}$ Bq/kg, respectively. The sensitivity to weak ^{235}U, ^{238}U and ^{232}Th impurities was improved by the analysis of the time distribution of the background events. For example, the sequence of two α decays belonging to the ^{232}Th family was searched for: ^{220}Rn ($E_\alpha = 6.29$ MeV, $T_{1/2} = 55.6$ s) $\rightarrow$ ^{216}Po ($E_\alpha = 6.78$ MeV, $T_{1/2} = 0.145$ s) $\rightarrow$ ^{212}Pb. The ^{232}Th content was found to be equal to $1.7(4) \cdot 10^{-5}$ Bq/kg as a result. Applying the same technique to the ^{235}U, ^{238}U families the limits $< 7 \cdot 10^{-6}$ and $< 2 \cdot 10^{-5}$ Bq/kg for ^{235}U and ^{226}Ra were defined, which is lower than the restrictions determined by the direct analysis of the spectrum.

As a result of all improvements, the background of the $^{116}CdWO_4$ detector in the region of ^{116}Cd $0\nu2\beta$ decay (2.7–2.9 MeV) was reduced to 0.53 counts/y·kg·keV. This value is similar to that of the best ultra low-background set-ups with HP Ge detectors employed in ^{76}Ge 2β decay investigations [3,4].

3. Two-neutrino 2β decay of ^{116}Cd

The investigation of the $2\nu2\beta$ decay is complicated by the fact that the electron spectra of this process have a continuous distribution like a background in contrast to the peak in the $0\nu2\beta$ decay. In this case the signal-to-background ratio is of decisive importance for the observation of the $2\nu2\beta$ process and – above all – for a convincing proof of its existence. Its value ranged between 1/10 and 1/7 in the previous experiments in which $2\nu2\beta$ decay was observed [6,10], and only in last three studies it was possible to increase this ratio to 1.3:1 for ^{76}Ge [3], (2–3):1 for ^{100}Mo [11,12] and (3–4):1 for ^{150}Nd [11,14].

To estimate the probability of ^{116}Cd $2\nu2\beta$ decay, the results of the last measurements with natural and enriched detectors were used: ^{116}CdWO$_4$ (15.2 cm^3) – 2982 h, CdWO$_4$ (9.1 cm^3) – 1596 h (Fig. 1b). The simplest (and very conservative) method to estimate the limit on $2\nu2\beta$ in enriched crystal is to set the $2\nu2\beta$ distribution equal to the experimental spectrum in some energy region and to take the full distribution area as a limit. To calculate the efficiency of the detector its response function was simulated by a Monte Carlo code [27]. The energy and angular distributions of the electrons in various mechanisms of ^{116}Cd 2β decay, the processes of interaction of the electrons with the crystal as well as the detector's resolution were taken into account. The response function calculated in this way for $2\nu2\beta$ decay events is shown in Fig. 1b. and corresponds to a limit $T^{2\nu}_{1/2} > 1.8 \cdot 10^{19}$ y (99% CL).

The measurements with the natural CdWO$_4$ crystal (9.1 cm^3) and experimental data on the intrinsic radioactive impurities of the crystals were then used. In this case the model distributions were subtracted from the measured spectra. These distributions correspond to a background induced by impurities of ^{40}K (2.3·10^{-3} Bq/kg), ^{137}Cs (1.5·10^{-3} Bq/kg), ^{226}Ra (1.5·10^{-5} Bq/kg), ^{232}Th (1.7·10^{-5} Bq/kg), ^{238}U (1.8·10^{-5} Bq/kg) in the enriched crystal and ^{40}K (3.6·10^{-3} Bq/kg), ^{232}Th (1.2·10^{-5} Bq/kg) in natural one. It should be noted that the subtracted part was equal to 13% of the measured spectrum in the energy region of 1.2–2.4 MeV and to 7.9% – in the region of 1.4–2.4 MeV for the enriched detector and 24% and 14% respectively – for the natural crystal.

The maximal possible contribution of thermal neutron capture by ^{113}Cd to the spectrum in the region of the ^{116}Cd $2\nu2\beta$ decay was also estimated. If the rejection of capture events by the active shielding is taking into account, this contribution does not exceed 7 counts and is negligible (less than 1%).

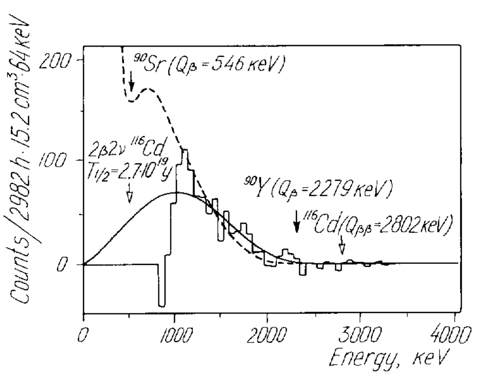

Fig. 2. The difference of the backgrounds of the ^{116}CdWO$_4$ and CdWO$_4$ crystals. The spectra are normalized to the same volumes and measurement time and the contribution of radioactive impurities is subtracted (see text). The smooth line corresponds to the $2\nu2\beta$ decay of ^{116}Cd with $T^{2\nu}_{1/2} = 2.7 \cdot 10^{19}$ y. The dashed line is β spectrum of ^{90}Y with an activity 2 mBq/kg.

The spectrum of the CdWO$_4$ crystal (normalized to the volume and time of the measurements) was subtracted from the spectrum of ^{116}CdWO$_4$. This difference is shown in Fig. 2 together with the theoretical $2\nu2\beta$ distribution for ^{116}Cd with $T^{2\nu}_{1/2} = 2.7 \cdot 10^{19}$ y. The signal-to-background ratio is equal to 1.1:1 in the energy interval 1.4–2.4 MeV. Taking into account the possible errors in the determination of the amounts of radioactive impurities and the uncertainty of the normalization to the volume, we derive the following value of the half-life of ^{116}Cd with respect to $2\nu2\beta$ decay:

$$T^{2\nu}_{1/2} = \{2.7^{+0.5}_{-0.4}(\text{stat.})^{+0.9}_{-0.6}(\text{syst.})\} \cdot 10^{19}\ \text{y}.$$

Recently another experiment to study ^{116}Cd was made at the Kamioka Underground Laboratory by the Osaka University group in collaboration with the INR (Kiev) group by means of the ELEGANTS V setup [13]. This apparatus consists of two drift chambers (to detect the electron tracks) and two plastic scintillators in order to measure the electron energies. The half-life of the ^{116}Cd $2\nu2\beta$ decay was measured:

$$T^{2\nu}_{1/2} = \{2.6^{+0.9}_{-0.6}\} \cdot 10^{19}\ \text{y}.$$

Although our result is similar to that of the experiment of Ref. [13] we cannot exclude, however, that the observed effect could be explained also by the im-

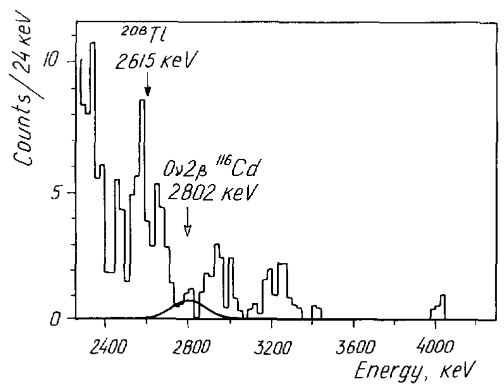

Fig. 3. The total background spectrum of ^{116}CdWO$_4$ detectors for 5822 h in the region of the ^{116}Cd $0\nu2\beta$ decay. The theoretical distribution (smooth line) corresponds to $T^{0\nu}_{1/2} = 1.0 \cdot 10^{22}$ y.

purity of ^{90}Sr/^{90}Y in the enriched crystal with an activity of $2 \cdot 10^{-3}$ Bq/kg (or by the difference for this value in enriched and natural crystals). Our experimental restrictions on ^{90}Sr impurities do not exclude this possibility: ^{116}CdWO$_4$ – $< 2.8 \cdot 10^{-3}$ Bq/kg; CdWO$_4$ – $< 1.4 \cdot 10^{-3}$ Bq/kg. Therefore a firm conclusion that the effect observed in our experiment is really due to the $2\nu2\beta$ decay of ^{116}Cd can be made only after more precise measurements of the ^{90}Sr impurities in the crystals. Notwithstanding the difficulties of this task we are going to do it, in collaboration with the group from the National Laboratory for High Energy Physics (Japan) which is working on the ^{136}Xe project [28] and which has appropriate equipment for analysis.

4. Neutrinoless 2β decay of ^{116}Cd

In order to obtain a limit on the $0\nu2\beta$ decay the total spectrum was used that was obtained by all measurements with the ^{116}CdWO$_4$ crystals in different installations in which the background rate in interval 2.7–2.9 MeV was below 1.0 counts/y·kg·keV. The total time of these measurements is 5822 h, the product of the number of ^{116}Cd nuclei with time is $1.08 \cdot 10^{23}$ nuclei·y, the mean background rate is 0.55 counts/y·kg·keV (2.7–2.9 MeV). A part of the total spectrum in the energy range 2.2–4.0 MeV is shown in Fig. 3. Since the peak of the $0\nu2\beta$ decay is evidently absent, the data were used to obtain a lower limit of the half-life of this process with the expression:

$$\lim T_{1/2} = \ln 2 \cdot \varepsilon \cdot t \cdot N_n / \lim S_e,$$

where N_n is the number of nuclei of isotope under study, ε is the detection efficiency, t is the measuring time and $\lim S_e$ is the limiting number of events associated with the neutrinoless 2β decay which can be excluded with a given confidence level. The response function of the ^{116}CdWO$_4$ detectors for potential events of the ^{116}Cd $0\nu2\beta$ decay is a Gaussian with its center at 2802 keV and FWHM = 189 keV (such a distribution is shown in Fig. 3 with $T_{1/2} = 1 \cdot 10^{22}$ y). By simulation [27] it was found, that edge effects (escape of one or both electrons and bremsstrahlung γ quanta from the crystals) remove from the peak 16–17% of the events for different crystals (12.5, 15.2 and 16.2 cm^3). The total detection efficiency is $\varepsilon = 83.5\%$. The value of $\lim S_e$ was evaluated by the method of maximum likelihood and by standard least-squares techniques [29]. It was assumed that the experimental spectrum can be described in the region of 2420–3420 keV by a sum of three functions, one of which corresponds to the 2β decay, while the other two correspond to the background. For the latter two functions a first-degree polynomial and a Gaussian centered at 2614.5 keV with FWHM = 183 keV (γ line of ^{208}Tl) were selected. A maximization of the likelihood function in the region 2420–3420 keV gives for the limiting area of the $0\nu2\beta$ peak a value between 0.7 to 2.0 counts with a confidence level 90%. It corresponds to the limit $T^{0\nu}_{1/2} \geq 3.1 \cdot 10^{22}$ y (90% CL). It is known, however, that estimates of parameter values by the maximum likelihood method can be biased [30]. In this connection a least-square fit of the experimental spectrum by the set of above-mentioned functions was fulfilled. It gave also for the peak area a value of less than 2.2 counts (90% CL) which corresponds to a limit $T^{0\nu}_{1/2} \geq 2.9 \cdot 10^{22}$ y. Thus different evaluation methods give values in close agreement which confirm the reliability of the results and allow to set the following limit for ^{116}Cd $0\nu2\beta$ decay:

$$T^{0\nu}_{1/2} \geq 2.9(5.4) \cdot 10^{22}\ \mathrm{y}, \quad 90\%\ (68\%)\ \mathrm{CL}.$$

Comparing this limit with theoretical calculations [20] we have computed the restrictions on the neutrino mass and right-handed admixtures in the weak interaction: $\langle m_\nu \rangle \leq 4.6$ eV, $\langle \eta \rangle \leq 5.9 \cdot 10^{-8}$,

Table 1
Limits on neutrino mass from the most advanced experiments

Isotope	Experiment lim $T_{1/2}^{0\nu}$, y	Theory [20] $T_{1/2}^{0\nu}\cdot\langle m_\nu\rangle^2$, y·eV^2	Limit $\langle m_\nu\rangle$, eV	
			68% CL	90% CL
^{76}Ge	$1.9\cdot10^{24}$ (90% CL) [3]	$2.33\cdot10^{24}$	-	1.1
		$2.6\cdot10^{24}$ (68% CL) [3]	0.94	-
^{82}Se	$2.7\cdot10^{22}$ (68% CL) [6]	$6.03\cdot10^{23}$	4.7	-
^{100}Mo	$4.4\cdot10^{22}$ (68% CL) [7]	$1.27\cdot10^{24}$	5.4	-
^{116}Cd	$2.9\cdot10^{22}$ (90% CL)	$4.87\cdot10^{23}$	-	4.1
		$5.4\cdot10^{22}$ (68% CL)	3.0	-
^{130}Te	$8.2\cdot10^{21}$ (90% CL) [9]	$4.89\cdot10^{23}$	-	7.7
^{136}Xe	$3.7\cdot10^{23}$ (90% CL) [5]	$2.21\cdot10^{24}$	-	2.4
		$6.9\cdot10^{23}$ (68% CL) [5]	1.8	-
^{150}Nd	$2.1\cdot10^{21}$ (90% CL) [31]	$3.37\cdot10^{22}$	-	4.0

$\langle\lambda\rangle \leq 5.3\cdot10^{-6}$. Neglecting the right-handed contributions ($\langle\eta\rangle = 0$, $\langle\lambda\rangle = 0$) and using the value [20] $T_{1/2}^{0\nu}\cdot\langle m_\nu\rangle^2 = 4.87\cdot10^{23}$ y·eV^2, the restriction $\langle m_\nu\rangle \leq 4.1$ eV (90% CL) can be obtained.

In Table 1 we compare the obtained limit on the neutrino mass with the results of other – the most sensitive at present – experiments with ^{76}Ge, ^{82}Se, ^{100}Mo, ^{130}Te, ^{136}Xe and ^{150}Nd [31]. It is clear from the table that the experiments with ^{76}Ge and ^{136}Xe presently give the most stringent restrictions on the neutrino mass of 1–2 eV, then ~4 eV with ^{116}Cd and ^{150}Nd, while in the other three experiments the obtained limits lie in the interval 6–8 eV.

5. Conclusions

(1) A limit for neutrinoless 2β decay of ^{116}Cd $T_{1/2}^{0\nu} \geq 2.9(5.4)\cdot10^{22}$ y with 90% (68%) CL has been achieved. It corresponds to restrictions on the value of the neutrino mass $\langle m_\nu\rangle \leq 4.1$ eV and right-handed mixing amplitudes in weak interactions $\langle\eta\rangle \leq 5.9\cdot10^{-8}$, $\langle\lambda\rangle \leq 5.3\cdot10^{-6}$.

(2) The limit $T_{1/2}^{2\nu} \geq 1.8\cdot10^{19}$ y is obtained with a 99% confidence level for the two-neutrino mode of ^{116}Cd 2β decay. Subtracting the spectrum obtained with the natural CdWO$_4$ crystal from the spectrum of the enriched ^{116}CdWO$_4$ detector gives a positive yield which could be explained by the $2\nu2\beta$ decay of ^{116}Cd with $T_{1/2}^{2\nu} = \{2.7^{+0.5}_{-0.4}(\text{stat.})\ ^{+0.9}_{-0.6}(\text{syst.})\}\cdot10^{19}$ y. However, the imitation of the effect by the impurities of ^{90}Sr ($\sim2\cdot10^{-3}$ Bq/kg) cannot be excluded.

(3) The background rate in the region of the ^{116}Cd $0\nu2\beta$ decay (2.7–2.9 MeV) was reduced to the level of 0.53 counts/y·kg·keV.

(4) The high intrinsic purity of the natural and enriched CdWO$_4$ crystals was demonstrated: $\delta(^{238}\text{U}) < 1.4\cdot10^{-11}$ g/g, $\delta(^{232}\text{Th}) < 5\cdot10^{-12}$ g/g, $\delta(^{235}\text{U}) < 3.4\cdot10^{-13}$ g/g, $\delta(^{226}\text{Ra}) < 1\cdot10^{-18}$ g/g.

At present a large scale experiment for the investigation of the ^{116}Cd 2β decay is prepared by a collaboration between the INR (Kiev) and the Max-Planck-Institut für Kernphysik (Heidelberg). It is planned to use a multicrystal assembly of ^{116}CdWO$_4$ detectors, each of which has a weight of about 2 kg. Such large crystals are available now due to the recent progress made in their development. At the first stage these detectors would be used as scintillators but in the future they could be applied as low-temperature bolometers with a high energy resolution. Such a possibility was demonstrated in measurements performed in the Gran Sasso Underground Laboratory in collaboration with the group from the Milan University. For a small volume CdWO$_4$ crystal ($\oslash25 \times 15$ mm) a resolution of 5 keV was achieved for the γ line of ^{208}Tl (2615 keV) [32]. The realization of this project will allow to obtain for the ^{116}Cd $0\nu2\beta$ decay a limit $T_{1/2}^{0\nu} \geq 10^{25}$ y which would push the Majorana neutrino mass to the level of $\sim$0.1 eV, independently of the results of the ^{76}Ge and ^{136}Xe experiments. Such a sensitive experiment with ^{116}Cd is very important in the case of a possible observation of the $0\nu2\beta$ peak of ^{76}Ge or ^{136}Xe.

Acknowledgements

The research described in this publication was made possible in part by Grant No U54000 from the International Scientific Foundation. Authors would like to thank O.A.Ponkratenko for a more accurate definition of the influence of bremsstrahlung on the response function of the $CdWO_4$ detector.

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