Search for double beta decay of ^{106}Cd in TGV-2 experiment

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Abstract. Search for double beta decay ($\beta^+\beta^+$, β^+/EC, EC/EC) of ^{106}Cd was performed at the Modane underground laboratory (4800 m w.e.) using a spectrometer TGV-2 with 32 HPGe detectors. New limits on the half-lives of 0νEC/EC resonant decay - $T_{1/2} \geq 1.6 \times 10^{20}$ y, and on 2νEC/EC decay of ^{106}Cd - $T_{1/2} \geq 4.1 \times 10^{20}$ y (at 90% CL) were obtained from preliminary calculations of experimental data accumulated for 12900 h of measurement of ~13.6 g of ^{106}Cd with enrichment of 75%. The limits on 2νEC/EC decay of ^{106}Cd to the 2^+,512 keV and 0^+_1,1334 keV excited states of ^{106}Pd and on $2\nu\beta^+\beta^+$ and $2\nu\beta^+$/EC decay of ^{106}Cd were improved

1. Introduction

Investigation of double beta decay processes ($\beta^-\beta^-$, $\beta^+\beta^+$, β^+/EC , EC/EC) are of great importance for particle and nuclear physics as a sensitive tool for testing of lepton number conservation and studying neutrino properties and nuclear structure. Up to now, more attention has been given to $\beta^-\beta^-$ channels (two-neutrino and neutrinoless modes). There are also other channels of double beta decay, in particular the double capture of two bound atomic electrons (EC/EC), capture of the bound electron with emission of a positron (β^+/EC) and decay with emission of two positrons ($\beta^+\beta^+$). In comparison with $\beta^-\beta^-$ - decay these channels are disfavored by smaller available kinetic energy, by Coulomb repulsion on the positron or due to a small overlap of the bound electron wave function with nucleus. But the study of neutrinoless $0\nu\beta^+\beta^+$, $0\nu\beta^+$/EC, 0νEC/EC decays can yield the same information as the $0\nu\beta^-\beta^-$ - process. In contrast to the $\beta^-\beta^-$ - decay, where the two-neutrino mode of the process was experimentally investigated in the decay of several isotopes, other double beta processes has not been yet observed in direct experiments. The main purpose of our studies is to search for 2νEC/EC decay of ^{106}Cd ($Q_{EC/EC}$ = 2770±7.2 keV) with the transition to the ground state of ^{106}Pd and 0νEC/EC resonant decay of ^{106}Cd with the transition to the 2741 keV excited state of ^{106}Pd. The first decay is characterized by the emission of only two quanta of characteristic KX radiation of palladium (Pd) with the energy of ~21 keV. The second one will have minimum (almost zero) energy of decay and this decay will be accompanied by emission of additional particle(s) - γ2741 keV or γ2229 keV+γ512 keV.

2. Experiment TGV-2

The experiment was performed at the Modane Underground Laboratory (depth of 4800 m w.e.) using the spectrometer TGV-2 (Telescope Germanium Vertical) [1]. The detector part of TGV-2 (Figure 1) consists of 32 HPGe planar type detectors mounted one over another in a low-background cryostat.

The sensitive area of each detector is about 2040 mm^2 and its thickness is 6 mm. The total sensitive volume and the total mass of TGV-2 detectors are about 400 cm^3 and 3 kg respectively. Double beta emitters were the foils of ^{106}Cd (enrichment 75%) with a diameter of 52 mm and thickness of ~50 μm. The foils were inserted between the entrance windows of the neighboring detectors in the TGV-2 cryostat. The distance between detectors and emitters were about 1.5 mm. The energy resolution of the detectors ranged from 3.0 to 4.0 keV at 1332 keV (^{60}Co). The total efficiency of the TGV-2 spectrometer is 50-70% depending on the energy threshold. The detector part of the TGV-2 (Figure 2) was surrounded by copper shielding (>20 cm), a steel airtight box against radon, a led shielding (>10 cm), and an antineutron shielding made of borated polyethylene (16 cm). To suppress both the electronic and microphone noise in the low energy region, a method of comparison of two signals generated by processing with two different shaping times (2 and 8 μs) is used in TGV-2 [1].

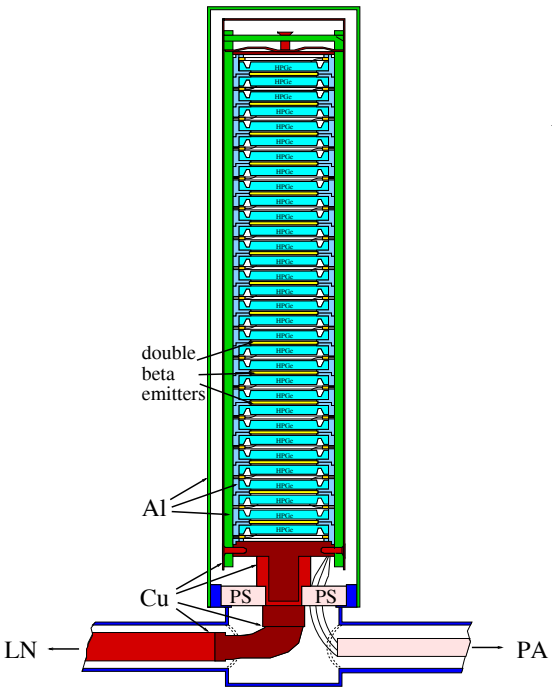

Figure 1. The detector part of TGV-2 spectrometer.

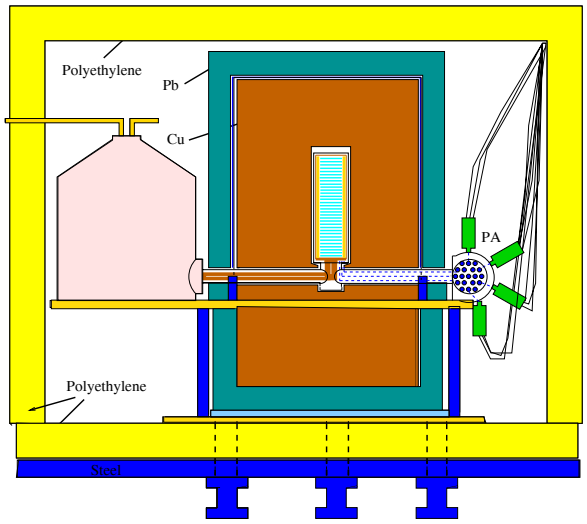

Figure 2. The detector part in passive shielding.

Two experimental runs were performed on the TGV-2 spectrometer to measure the foils of ^{106}Cd with enrichment of 75%. In the first one (February 2005 – February 2006) 12 samples of ^{106}Cd with a total mass of ~10 g and 4 foils of natural Cd with a total mass of ~3.2 g were studied during 8687 h [2]. In the second run (December 2007 – July 2009) 16 samples of ^{106}Cd with a total mass of ~13.6 g were studied during 12900 h. The main differences of the second run in comparison with the first one are: a) the level of TGV-2 background (it was decreased in several times [3]); b) .enlarged energy region in one of spectroscopy channels of each detector from ~800 keV to ~ 3 MeV.

3. Results

The preliminary calculations of experimental data accumulated for 12900h of measurements of the second run were performed. The coincidences between two characteristic KX- rays of Pd detected in neighboring detectors were analyzed to search for 2νEC/EC decay of ^{106}Cd to the ground 0^+ state of ^{106}Pd (Figure 3)(Figure 4). The search for 0νEC/EC resonance decay of ^{106}Cd to the 2741 keV excited state of ^{106}Pd was based on the analysis of KX(Pd) - γ2741 keV and KX(Pd) – γ2229 keV- γ512 keV coincidences. Investigation of other branches of ^{106}Cd decay - 2νEC/EC decay to the 2^+,511.9 keV and

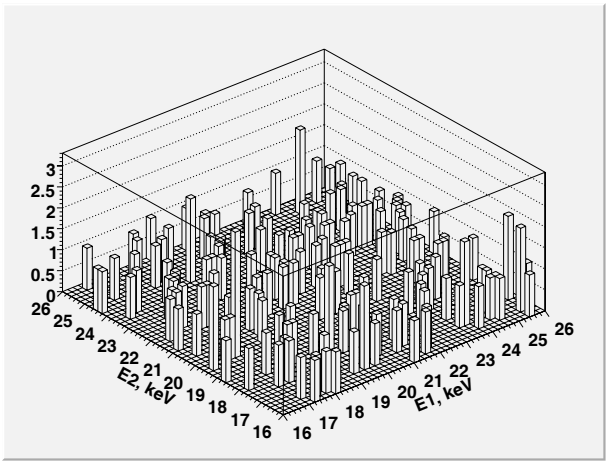

Figure 3. Double coincidence events (DC).

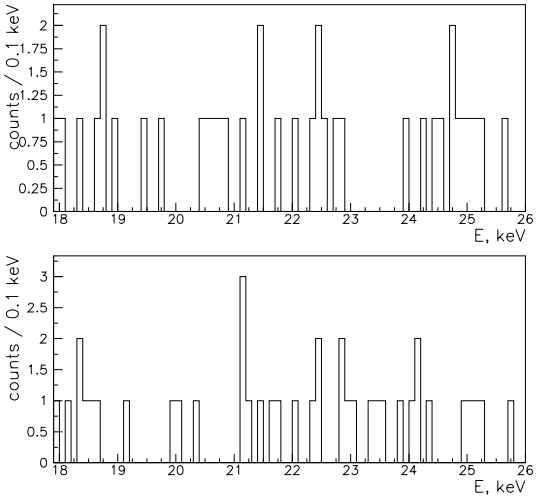

Figure 4. DC spectra with KX(Pd) in one of detectors

0^+_1, 1334 keV excited states of ^{106}Pd, $2\nu\beta^+$/EC and $2\nu\beta^+\beta^+$ decays to the ground and excited states of ^{106}Pd were based on the analysis of KX-511 keV, KX-622 keV, 511 keV-511 keV and 511 keV – 622 keV coincidences. Our limits on half-lives of double beta decay of ^{106}Cd are presented in a Table.1.

Table 1. The limits on half-lives of double beta decay of ^{106}Cd

Decay mode	Transition to	$T_{1/2}$, 10^{20} y (C.L. 90%)	
		run 1 [2]	run 2 [this work]
2νEC/EC	0^+, ground state	3.0	4.1
	2^+,511.9 keV	0.42	0.63
	0^+_1, 1334 keV	0.31	0.52
0νEC/EC	$1,2^+$, 2741 keV	-	1.6
$2\nu\beta^+$/EC	0^+, ground state	0.59	1.1
	2^+,511.9 keV	0.59	1.1
	0^+_1, 1334 keV	-	1.6
$2\nu\beta^+\beta^+$	0^+, ground state	0.6	1.4
	2^+,511.9 keV	0.57	1.7

Our results for 2νEC/EC decay of ^{106}Cd to the ground 0^+ state of ^{106}Pd are more than 2 orders of magnitude higher than those obtained in resent experiment [4] and reaches theoretical predictions ranging [5] from 1.0×10^{20} to 5.5×10^{21} y.

4. Acnowledgements

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