$2\beta0\nu$ Decay with ^{150}Nd

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Introduction

Recently, much new data became available from the neutrino oscillation experiments (for overview see [1,2]). The combined results of solar neutrino and reactor experiments give $\delta m^2_{1,2} = 7.1^{+1.2}_{-0.6} \cdot 10^{-5}\ eV^2$ and $\theta_{1,2} = 32.5^{+2.4}_{-2.3}{}^{\circ}$ [3]. The atmospheric neutrino experiments lead to $|\delta m^2_{2,3}| = 2.0^{+1.0}_{-0.7} \cdot 10^{-3}\ eV^2$ and $\theta_{2,3} \approx 45\ ^{\circ}$ [4]. Till now only an upper limit was obtained for the third oscillation $\theta_{1,3} < 9\ ^{\circ}$ [5]. The planned Double Chooz experiment will be able to improve the situation [6].

Though the success of the neutrino physics is obvious there are still several fundamental questions to be answered. What is the absolute mass of neutrinos? Do neutrinos have inverse or normal hierarchy? Are neutrinos Dirac or Majorana particles? Do neutrinos violate the CP concervation?

If a neutrinoless double beta ($2\beta0\nu$) decay is observed, all these questions will be answered. The possibility of the $2\beta0\nu$ decay was discussed since 1937 [7] and till now only one positive result with the effective neutrino mass in the range of (0.2-0.6) eV was reported [8]. An independent confirmation of this result and an establishment of the new limits in the negative case is one of the most important issues for the modern neutrino physics.

Choice of the nuclide

There are a few nuclides considered for the search of the $2\beta0\nu$ decay (see Tab. 1). Normally, those candidates are chosen for the experiments, for which the detector technique is well developed. Up to now the best results were achieved with ^{76}Ge [8]. However, the comparison of the 2β emitters shows that ^{150}Nd has the most suitable properties for the detection of the $2\beta0\nu$ decay. It has one of the largest Q-values and a comparatively high ratio of $T^{2\nu}/T^{0\nu}$. Thus, both $2\beta2\nu$ and external backgrounds are expected to be rather low. Even more important is a short calculated half-time for the $2\beta0\nu$ decay. Compared to ^{76}Ge one needs about 10 times less material to get the same number of events.

Isotope	Q, keV	$T^{2\nu}$, 10^{19} a	$T^{0\nu}$ for $<m>=50$ meV, 10^{26} a	
^{76}Ge	2040 ± 1	13 ± 10	9.3	12.8
^{82}Se	2995 ± 6	9.2 ± 1.0	2.4	3.2
^{100}Mo	3034 ± 6	0.8 ± 0.06	5	1.2
^{116}Cd	2802 ± 4	3.2 ± 0.3	1.9	3.1
^{130}Te	2533 ± 4	270 ± 10	2	3.6
^{136}Xe	2479 ± 8	> 81	8.8	21.2
^{150}Nd	3367 ± 2	$0.7^{+1.2}_{-0.3}$	0.1	0.2
			[9]	[10]

Table 1: Typical 2β emitters, their half-times, Q-values and the calculated half-times for the $2\beta0\nu$ decay if the effective neutrino mass is 50 meV

Choice of the detector

The main challenge is to develop a detector for the registration of the ^{150}Nd decay. To obtain a high energy resolution and a low background it is practical to incorporate the source (^{150}Nd) in the detector. Three possibilities were considered: crystal scintillator, cryogenic detectors and a liquid scintillator with dissolved Nd.

It is known that almost all tungstates scintillate and some crystals were actively used ($PbWO_4$, $CdWO_4$, $CaWO_4$ [11]). In analogy to them $Nd_2(WO_4)_3$ was chosen for the investigation. 3 test crystals with a volume of about 1 cm^3 each were grown using the Czochralski method and delivered to Munich [V. Kochurikhin, General Physics Institute, Moscow, Russia]. The scintillating properties were studied applying standard sources of ^{60}Co, ^{137}Cs and ^{90}Sr with activities in the range of 0.1 - 1.5 MBq. The emitted light was registered with a PMT XP3461B (maximum of sensitivity at 420 nm). Additionally, the spectral characteristics in the range of 300 - 1000 nm were analyzed with a monochromator coupled with a CCD camera. In both cases no scintillation light was observed. Neither powders of other compounds (Nd_2WO_6 and $NdLi(WO_4)_2$) investigated at temperatures between 700 and 1100 °C showed scintillation [L. Nagorna, Scientific and Technological Center for Radiation Instruments, Institute for Single Crystals, Kharkov, Ukraine].

A technique similar to [11] was used to investigate a possibility of a cryogenic detector. A crystal of neodymium gallate ($NdGaO_3$) was mounted in a ^{3}He-^{4}He dilution cryostat and could be cooled down to 60 mK. A superconducting IrAu transition edge thermometer was glued on the absorber. No signals from the Nd gallate could be observed when it was exposed to a calibration standard.

The most promising detector concept at the moment is a liquid scintillator loaded with Nd. For this purpose, the counting test facility (CTF) can be used. It has an active volume of 5 m^3 and 20% of the solid angle is covered by 100 PMT. The background at the endpoint energy is $2.9 \cdot 10^{-5}\ \mathrm{kg^{-1}a^{-1}keV^{-1}}$. In the PXE used as a scintillator, it was possible to reach the stable concentrations of 10 g/l for Yb and of 1 g/l for Gd. Due to the similar properties of Gd and Nd it is expected that about 5 kg of Nd could be dissolved in CTF with the transmission length of the scintillation light of several meters. After increasing the number of PMT to 400 it will be possible to become sensitive to neutrino mass of 400 meV [8] with natural Nd within one year. And if enriched Nd (85%) is used the sensitivity of 50 meV can be reached within 5 years.

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