An alternative search for the electron capture of $^{123}$Te

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A search for the second forbidden electron capture of $^{123}$Te has been performed. A new technique for searches of rare nuclear decays using CdZnTe detectors has been established. After a measuring time of 195 h no signal could be found resulting in a lower half-life limit of $T_{1/2} > 3.2 \times 10^{16}$ yrs (95 % CL) for this process. This clearly discriminates between existing experimental results which differ by five orders of magnitude and our data are in strong favour of the result with longer half-lives.

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I. INTRODUCTION

In the past decades the investigation of $\beta$-decay has played a major role in understanding weak interactions and their structure. Even though being a little bit out of fashion, there are still interesting problems to be investigated. Among them is the second forbidden unique electron capture (EC) of $^{123}$Te occurring to the ground state of $^{123}$Sb with a transition energy of $53.3 \pm 0.2$ keV [1]. Two positive evidences obtained for this decay mode show a discrepancy by six orders of magnitude, namely $(1.24 \pm 0.10) \cdot 10^{13}$ yrs [2] and $(2.4 \pm 0.9) \cdot 10^{19}$ yrs [3]. Even with the lower value already in slight disagreement with other bounds on the lifetime of K shell capture in $^{123}$Te [4] it is quoted quite often in literature [5]. However, still only a lower bound of about $10^{13}$ yrs is used [6]. One of the main problems of the past measurements was associated with the fact that observations relied on the outside detection of K X-rays following the deexcitation of $^{123}$Sb. This line is at 26.1 keV, very close to the Te K X-ray line at 27.3 keV which might be excited by other processes like cosmic rays and radioactive background. In the measurement reported here, a new technique for searches of rare nuclear decays using CdZnTe semiconductor detectors has been used for the first time. These offers several advantages. The natural abundance of $^{123}$Te is 0.9 %, hence it is intrinsic to any detector containing Te. Due to this fact, the total cascade after K-capture is contained within the detector resulting in a peak at 30.5 keV. Cd(Zn)Te detectors are well known devices in X-ray and $\gamma$-ray astronomy and offer good energy resolution. The study was performed within a pilot project for the COBRA-experiment [7], which plans to use a large amount of CdZnTe detectors to explore double beta decay.

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II. EXPERIMENTAL SETUP

The measurements were performed with a $10 \times 10 \times 5$ mm$^3$ CdZnTe detector provided by eV-Products$^1$. The detector is encapsulated within an aluminium-tube. It is working with the coplanar grid technology, focussing on the readout of electrons [8]. This avoids asymmetric peaks normally seen because of the insufficient collection of holes due to trapping within CdZnTe.

The energy resolution was measured with various sources, among them $^{241}$Am and $^{57}$Co, resulting in lines at 59.5, 122.1 and 136.5 keV respectively. An FWHM-energy resolution of $\Delta E = 4.7$ keV is determined for 30.5 keV by extrapolation.

To be sensitive for rare decays, a special shielding had to be constructed to reduce background events due to environmental radioactivity and cosmic rays. A schematic plot of the setup is shown in Fig.1. In this way, a $50 \times 50 \times 50$ cm box made of copper and lead was designed. The inner $20 \times 20 \times 20$ cm consisted of electrolytic copper, the outer part was made of spectroscopy lead. In a first step, the copper was cleaned in an ultrasonic bath. All lead bricks were etched shortly before installation with HCl and HNO$_3$ to clean the surfaces, the copper was electropolished. The complete shielding was surrounded

$^1$ eV-PRODUCTS, Saxonburg, PA, USA, www.evproducts.com
by an air-tight box of aluminium, which was flushed with nitrogen. This prevents air and with it $^{222}\text{Rn}$ from penetrating into the apparatus. To suppress signals due to cosmic ray muons, an active veto consisting of 19 plastic scintillators was used. They covered all four sides of the box in a single layer with about 95 % detection efficiency as well as the top side in two layers resulting in about 99.5 % efficiency. All scintillators were fed into discriminators and a common OR was used to form the veto signal. In that way after the firing of any of the scintillators the data acquisition was blocked for $20 \mu$s resulting in a dead-time of about 1.6 %. Only accepted signals were fed into a multichannel analyzer card in a PC, serving as DAQ-system. The shielding depth was about 5 meter water equivalent (mwe).

III. RESULTS

Single runs were taken with 30 minutes life-time each. 392 runs were obtained of which 2 had to be removed resulting in 195 hours of good data. The obtained spectrum of interest is shown in Fig.2. No signal is visible at 30.5 keV. Fitting the region from 17 to 45.5 keV with a $1/E + \text{const}$ function results in a $\chi^2$/dof of 11.7/11 within the $2\Delta E$-region around the peak position, a fit including a Gaussian peak at the right position and with the correct energy resolution gives a $\chi^2$/dof of 11.8/11 while the gaussian content is consistent with zero. Excluding the $2\Delta E$-region around 30.5 keV (i.e. 25 to 36 keV) from the fitpoints, the resulting $\chi^2$/dof of the pure background fit is still 12.0/11. Therefore, the background-only hypothesis is well within allowed parameters.

Using the fit without the peak region and adding a Gaussian more than 31.2 events can be ruled out (95 % CL). Knowing the mass of 2.89 g the upper bound can be converted into a lower limit on the half-life for the electron capture of $^{123}\text{Te}$:

$$T_{1/2} > 3.2 \cdot 10^{16} \text{ yrs} \quad 95\% \text{CL} \quad (1)$$

This clearly rules out possible observations with half-lives of the order of $10^{15}$ yrs and is in strong favor of the results of Alessandrello et al. [3]. Longer half-lives are also supported from theoretical considerations [1][10].

IV. SUMMARY

A novel technique for studying rare nuclear decays using CdZnTe semiconductor detectors was used to investigate the second forbidden unique electron capture of $^{123}\text{Te}$ . It takes advantage of the fact that source and detector are identical. The main motivation for this search was to discriminate between two published results which differ by six orders of magnitude. No evidence for this process was found and a half-life limit larger than $3.2 \cdot 10^{16}$ yrs (95 % CL) is obtained. This clearly rules out the solutions obtaining $10^{13}$ yrs. The measurement was performed during tests for the planned COBRA-experiment to search for double beta decay. A proof for the quoted half-life of $2.4 \pm 0.9 \cdot 10^{19}$ yrs can only be done with a setup using a larger amount of CdZnTe detectors.

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