Evidence for Naturally Occurring Electron Capture of ^{123}Te

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Evidence for electron capture of ^{123}Te from the *K* shell has been obtained in an experiment performed underground with an array of four 340 g TeO_2 thermal detectors. This is the first real proof of the decay of this isotope. In our thermal approach, unlike in previous experiments, the TeO_2 bolometer acts at the same time as source and detector of the ^{123}Te decay and its resolution allows to discriminate between the lines produced by background x ray excitation and electron capture. In addition anticoincidence with the nearby detectors reduces the signal of x rays produced by excitation of Tellurium. The partial width for *K* electron capture of ^{123}Te is the smallest one ever measured for a single beta process and lower by six orders of magnitude with respect to the previously reported one for this decay. An analysis based on the expected fraction of electron captures accompanied by internal bremsstrahlung allows to set a stringent limit, independent on the decay channel, for the lifetime of ^{123}Te. [S0031-9007(96)01447-0]

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Nine isobaric doublets or triplets are known to exist in nature [1] and in all of them a single β process is expected to occur [1–4] (Table I). No evidence has been found for the second forbidden unique electron capture [17] of ^{123}Te which is expected to occur only to the ground state of ^{123}Sb with a transition energy of 51.3 ± 0.2 keV [1–4]. In fact published lower limits on the lifetime for the *K* channel of 2×10^{14} [18] and 1×10^{15} yr [19] are in contradiction with the positive value of $(1.24 \pm 0.10) \times 10^{13}$ yr indicated by Watt and Glover [20]. This disagreement can be explained by the fact that the above mentioned experiment, carried out with the best existing techniques at that time, was performed with a source of 2.26 g of natural TeO_2 powder deposited on the cathode of a proportional counter. The detecting gas is *outside* the source and electron capture was searched by observation the *K* x rays following deexcitation of the ^{123}Sb atom. This line is at about 26.1 keV very near to the corresponding tellurium *K* x-ray line (27.3 keV) which can be produced by excitation of the tellurium source by cosmic rays and radioactive background. The energy resolution and calibration in the experiment by Watt and Glover did obviously not allow one to determine the energy of the detected peak with sufficient precision. We believe therefore, also on the basis of the results of our experiment which will be discussed later, that the enhancement found by Watt and Glover can be attributed to x rays from excitation of the *K* shell of the tellurium atoms in the source and not to Sb x rays following tellurium electron capture. Careful "blank runs" were performed by the authors with Sb_2O_3 powder, but apparently the difference between the counting rates with TeO_2 and Sb_2O_3 was due to different internal activity or cosmic ray excitations in the two samples. The crucial difference of our experiment is that the source acts also as detector and that therefore the entire energy released by electron capture is recorded.

The last review on ^{123}Te [17] indicates no evidence for electron capture for this nucleus, but, despite the inconsistence with other experiments, the Watt and Glover lifetime is quoted in all tables of isotopes [2–4]. Activity of ^{123}Te is even assumed as a sizable contribution to environmental radioactivity [21].

Thermal detectors (bolometers) have been proposed [22], and recently adopted [23] in searches for rare events like $\beta\beta$ decay. In most of the present applications they consist of a diamagnetic and dielectric crystal in thermal contact with a suitable thermometer. If the temperature T is low, the heat capacity is proportional to T^3. As a consequence, even the tiny energy delivered by a particle to the crystal in the form of heat induces a measurable thermal pulse. The energy resolution of these detectors is still far from the theoretically expected one, but already definitely better than that of Si(Li) semiconductor detectors at x-ray energies, and comparable at high energies to that of Ge diodes. In addition these bolometers can be made with a vast variety of materials which allows the so called source = detector approach, namely, the use of the bolometer also as a source of the searched events. In this approach bolometers have already been used to search for beta decay of ^{113}Cd [9] and ^{187}Re [16].

We report here positive evidence for electron capture from the *K* shell of ^{123}Te obtained from one of the background spectra recorded in a series of searches on $\beta\beta$ decay carried out in the Laboratori Nazionali del Gran Sasso with bolometers of natural TeO_2 [24,25]. Double beta decay experiments require in fact long time measurements, and the background reduction plays a fundamental role if high sensitivities have to be reached.

TABLE I. Measured and expected single β processes.

$Z - 1$		Nucleus		$Z + 1$	Lifetime (yr)
18	$\leftarrow$	^{40}K	$\rightarrow$	20	1.28×10^{9} [5]
23[a]	$\leftarrow$	^{50}V		$\cdots$	1.4×10^{17} [6]
$\cdots$		^{87}Rb	$\rightarrow$	38	4.8×10^{10} [7]
$\cdots$		^{113}Cd	$\rightarrow$	49	$(7-9) \times 10^{15}$ [8–10]
$\cdots$		^{115}I	$\rightarrow$	50	4.4×10^{14} [11]
51 (K)	$\leftarrow$	^{123}Te		$\cdots$	2.4×10^{19} (present exp.)
51 (total)	$\leftarrow$	^{123}Te		$\cdots$	$>6 \times 10^{14}$ (present exp.)
56	$\leftarrow$	^{138}La	$\rightarrow$	58	1.05×10^{11} [12]
72	$\leftarrow$	^{180}Ta(9^-)	$\rightarrow$	74	$>1.25 \times 10^{15}$ [13]
$\cdots$		^{187}Re	$\rightarrow$	76	$(4.1-4.5) \times 10^{10}$ [14–16]

[a] To an excited level.

The last of the above mentioned series of experiments is being carried out with an array of four 340 g crystals of TeO$_2$, the largest among the presently operating thermal detectors. This array is kept at a temperature around 10 mK in a dilution refrigerator heavily shielded against environmental radioactivity. The overburden of rock provides suppression of cosmic ray muons and neutrons by 6 and 4 orders of magnitude, respectively [26]. More details on the detectors, the read-out electronics, and the procedures adopted for the reduction of the background can be found elsewhere [24,25].

The present analysis was performed considering only the background spectrum (1548.4 h of effective running time) collected with one of the four 340 g bolometers of the array (detector number 4). In fact only this detector, due to its better energy resolution and lower energy threshold, allowed us to investigate unambiguously the low energy region where the peak due to the *K* electron capture of ^{123}Te is expected. The calibration of the spectrum is obtained using all identified x and γ lines due to internal and external contaminations of the detector (mainly in uranium and thorium) [27]. All these lines allow a careful control of the linearity of our detector and yield a FWHM resolution of about 2 keV in the low energy region. The uniformity in response over the whole detector volume is proved by the agreement between the energy resolution obtained with gamma calibrations and the energy resolution which could be predicted on the basis of noise measurements. In fact a nonuniform response should be necessarily associated to a position dependence of the pulse amplitude, with a consequent excess broadening of the monoenergetic peaks.

The spectrum of detector number 4 in the energy region of interest is shown in Fig. 1. There is clear evidence of the 46.5 keV γ line of ^{210}Pb, a common contaminant in these experiments, and an indication of the 39.9 keV line of ^{212}Bi. The peaks around 27 and 30.5 keV can be identified as due to Te *K* x rays and to *K* electron capture of ^{123}Te, respectively. We would like to note that in this source = detector approach the entire energy produced by atomic deexcitation following *K* electron capture is recorded. This leads to a pulse corresponding to the full binding energy of the involved electron and not to the x-ray energy only, as in the experiment by Watt and Glover [20].

The counts are 166 ± 44 and 123 ± 38 for the 27 and 30.5 keV peaks, respectively. The 27 keV peak is due to x rays produced by excitation from cosmic rays and environmental radioactivity of the tellurium in the other three detectors of the array. We would like to stress again the peculiar property of this source = detector approach. If the x ray produced by excitation of a particle in a nearby detector is absorbed by detector 4, a peak corresponding to the x-ray energy is detected. If on the contrary the excitation occurs in detector 4 itself the energy left by the particle producing the excitation adds to the x-ray energy yielding a continuum spectrum of pulses. This is clearly proved by the spectrum of the pulses from detector 4 *in anticoincidence* with the pulses of any one of the other three crystals (Fig. 2). This anticoincidence suppresses the x-ray peak (29 ± 32 counts) leaving practically unaffected the electron capture one.

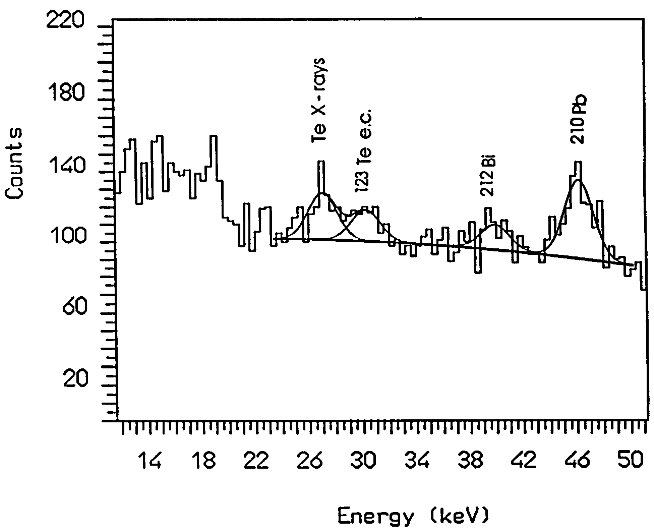

FIG. 1. The spectrum of detector 4 in the low energy region. Both the lines indicative of the *K* electron capture of ^{123}Te (30.5 keV) and of *K* x-rays due to excitation of tellurium (27 keV) in the other detectors can be seen.

Taking into account the mass of the detector and the isotopic abundance (0.905%) of ^{123}Te we obtain positive evidence for electron capture from the K shell of this isotope with a lifetime of $(2.4 \pm 0.9) \times 10^{19}$ yr. To our knowledge this corresponds to the narrower width ever detected for a single beta process. It corresponds to a rate for K electron capture of ^{123}Te 6 orders of magnitude smaller than that previously claimed and reported in nuclear tables. We would like to note that our sensitivity largely exceeds that of all previous experiments and particularly that of Watt and Glover [20], due to larger mass of the source and lower background per unit mass (both by 2 orders of magnitude) and better detection efficiency (100% versus 3.6%).

The low background in our experiment allows us to set a limit for the overall decay rate of ^{123}Te on the basis of the predicted probability of internal bremsstrahlung. About 0.14% [4] of the electron capture events are expected to be accompanied by an internal bremsstrahlung x ray with an energy between 20 and 40 keV, which would be fully detected in our bolometer. We record in this energy region 4027 ± 63 events which could be conservatively attributed entirely to internal bremsstrahlung. Taking into account the above mentioned percentage for this process we can therefore set a *lower* limit of 6×10^{14} yr for electron capture of ^{123}Te in any channel. Assuming this capture to be dominated by the L channel one obtains a L/K ratio of the corresponding rates of $<4 \times 10^4$ not in disagreement with the value predicted [28] by the atomic theory ($\sim 10^3$).

We present the first evidence for the decay of ^{123}Te by K electron capture with a lifetime of $(2.4 \pm 0.9) \times 10^{19}$ yr. This value is 6 orders of magnitude larger than the previously claimed one. According to the calculations of the nuclear theory group of our department [28] the lifetime for capture of a K electron in ^{123}Te from our experiment can be evaluated to be larger than 10^{16} yr. Using the counting rate in the region between 20 and 40 keV and the predicted percentage of internal bremsstrahlung in this energy range we set a lower limit on the lifetime of overall electron capture of ^{123}Te of 6×10^{14} yr. These results clearly indicate strong suppression of nuclear matrix elements due to particle-particle and particle-hole correlations [28].

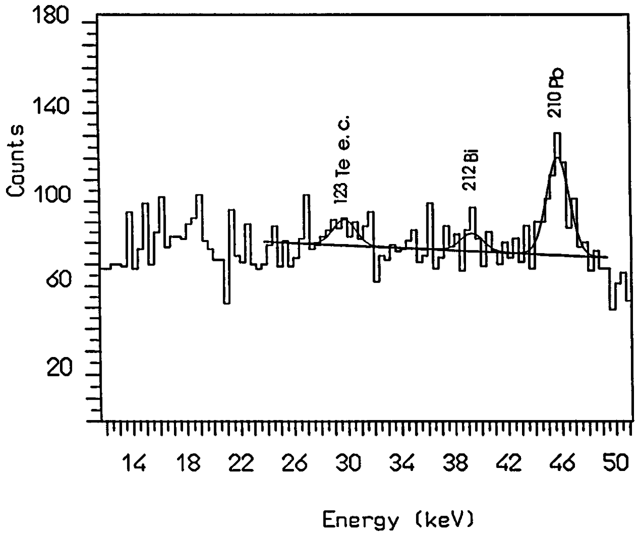

FIG. 2. The spectrum of detector 4 in anticoincidence with pulses from any o the other three detectors. The line due to K x rays from excitation of tellurium is suppressed.

Our result also shows how promising thermal detectors could be in searches for naturally occurring isotopes with very long lifetimes.

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