Double Beta Decay Study of Tin Isotopes

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Introduction

Underground experiments specially relevant for neutrino oscillation, neutrinoless double beta decay and dark matter have acquired status of mega projects globally for their potential to explore fundamental problems in physics, astrophysics and cosmology. The mass and nature of neutrinos play an important role in the theories beyond the Standard model. Double beta decay (0υββ) can provide the information on absolute effective mass of neutrinos. ^{124}Sn is one of the promising nuclei for double beta decay experiment.

Double beta decay processes in Tin isotopes

Double beta transitions of tin isotopes that emit γ rays are discussed here. There are three double beta isotopes of tin, namely ^{112}Sn, ^{122}Sn and ^{124}Sn the formar decays via β^+/EC and EC/EC mode where as the later two decay through $\beta^-\beta^-$ mode. The Q values of the transition for ^{122}Sn, ^{124}Sn and ^{122}Sn isotopes are 366, 2287 and 1922 keV, and the natural abundances are 4.63%, 5.79%, and 0.97%, respectively. As there is no excited state of interest for ^{122}Sn decay, following decays are considered:

$$^{124}\text{Sn} \rightarrow {}^{124}\text{Te} + 2e^- + 2\bar{\nu}_e + \gamma \quad \ldots (1)$$

$$2e^- + {}^{112}\text{Sn} \rightarrow {}^{112}\text{Cd} + (2\nu_e) + \gamma \quad \ldots (2)$$

$$e^- + {}^{112}\text{Sn} \rightarrow {}^{112}\text{Cd} + e^+ + (2\nu_e) + \gamma \quad \ldots (3)$$

Detailed double beta decay schemes of ^{124}Sn and ^{112}Sn have been reported in [2, 3]. The general expression used to calculate half-life for ββ decay is given by

$$T_{1/2} \sim \ln 2(Nt\varepsilon)/S \quad \ldots (4)$$

where N is number of ββ nuclei in the sample, ε is the detector efficiency, t is the duration of experiment and S is the maximum number of ββ events which can be excluded with a given confidence level.

Experimental details

Experiment was done at Gran Sasso National Laboratory of the INFN. Low background HPGe (GeBer) detector of volume 244 cm^3 was used. Natural tin sample of 13.3 gram was placed inside Polystyrene support and Copper holding.

Analysis

The total measuring time of the obtained data is over 101 days. Background was measured for 262 days in LNGS HPGe detector and normalized to 101 days. The natural tin sample was found to have a small quantity of natural radio activities.The natural radioactivities had only limits which are given: < 2.3 mBq/kg of ^{228}Ac, < 6.1 mBq/kg of ^{214}Bi, < 7.2 mBq/kg of ^{214}Pb, < 5.3 mBq/kg of ^{212}Pb, < 10.7mBq/kg of ^{40}K, < 5.2 mBq/kg of ^{208}Tl, < 3.5mBq/kg of ^{137}Cs, < 1.2 mBq/kg of ^{60}Co. The branching ratios of radioactive nuclei have been taken from Table of Isotopes 8th edition [4].

Search for β^+EC and ECEC processes in ^{112}Sn and $\beta^-\beta^-$ decay of ^{124}Sn to the excited states of ^{124}Te

The ECEC (0ν + 2ν) transition to the excited states of ^{112}Cd is accompanied with gamma radiation with different energies. These gamma quanta are used to search ECEC processes in ^{112}Sn. The β^+EC (0ν + 2ν) transition to the ground state is accompanied by two annihilation gamma quanta with energy of 511 keV. The efficiency simulated is the photopeak efficiency. The efficiencies are computed using Geant4.9.0 [5] and event generator Decay0 [6]. Bayesian approach is used to determine the number of possible events for each predicted gamma emission. A binned maximum likelihood fit is performed to determine the most likely values for the magnitude of background component and the Gaussian peak at each possible gamma energy.

The halhlifes are calculated for the numbers written in bold.

Table 1: **The experimental limits for the β^+EC and ECEC processes in ^{112}Sn:**

TRANSI-TION	Energy of gammarays KeV (efficiency)	$T_{1/2}$ in yr (90% C.L)
β^+EC(0ν+2 ν); g. s.	**511.0(3.76%)**	0.15×10^17^
β^+EC(0ν+2 ν); 2_1^+	**617.5(2.85%)**	1.6×10^17^
ECEC(0ν) K^1L^2; g. s.	**1889.1(0.32%)**	0.81×10^17^
ECEC(0ν) K^1K^2; g. s.	**1866.1(0.98%)** 511.1(3.76%)	1.25×10^17^
ECEC(0ν); 2_1^+	**617.5(2.31%)**	1.29×10^17^
ECEC(0ν); 0_1^+	**607.9(1.99%)** 617.5(1.98%)	0.39×10^17^
ECEC(0ν); 2_2^+	617.5(1.39%) 694.7(1.26%) **1312.3(0.35%)**	0.18×10^17^
ECEC(0ν); 2_3^+	**617.5(2.33%)**	0.29×10^17^
ECEC(2ν); 0_1^+	617.5(1.55%) 694.7(1.46%) **1312.3(0.41%)**	0.44×10^17^
ECEC(2ν); 2_2^+	617.5(1.87%) **815.8(0.69%)**	0.21×10^17^
ECEC(2ν); 0_2^+	617.5(1.51%) 851.1(1.11%) **1468.8(0.45%)**	0.16×10^17^

Conclusion:

Limits on β^+EC and ECEC processes for decay of ^{112}Sn to the excited states of ^{112}Cd and $\beta^-\beta^-$ decay of ^{124}Sn to the excited states of ^{124}Te have been obtained 10^{17} and 10^{18} years resepectively. If we use low background HPGe detector of volume 468 cm^3 and 7.25 kilogram Natural tin sample for same period, the sensitivity for the double beta decay of ^{124}Sn to the excited states of ^{124}Te can be reached the order of 10^{23} years.

Table 2: **The experimental results for (0ν+ 2ν + 0νχ^0) $\beta^-\beta^-$ decay of ^{124}Sn to the excited states of ^{124}Te :**

Excited state (K eV)	Energy of gamma raysK eV (efficiency)	$T_{1/2}$ in yr (90%C.L.)
2_1^+ (602.7)	**602.7(2.78%)**	0.39×10^18^
2_2^+ (1325.5)	602.7(2.62%) **722.8(2.23%)**	0.32×10^18^
0_2^+ (1657.3)	602.7(3.07%) **1054.6(1.94%)**	1.31×10^18^
0_3^+(1882.9)	**557.5(2.99%)** 602.7(2.40%) 722.8(2.06%)	0.6×10^18^
2_3^+(2039.3)	602.7(2.08%) 722.8(1.78%) **1436.6(1.01%)**	0.93×10^18^
2_4^+(2091.6)	602.7(3.11%) **1488.7(1.48%)**	1.1×10^18^
0_5^+ (2153.3)	602.7(3.09%) 722.8(1.66%) **1550.6(0.31%)**	0.22×10^18^
2_5^+ (2182)	602.7(2.71%) **1580(1.16%)**	0.61×10^18^

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