Limits on Majoron emitting neutrinoless double-beta decay of ^{100}Mo

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Double beta decays are of current interest from both astroparticle physics and nuclear physics view points Neutrinoless double beta decays ($0\nu\beta\beta$), which violate the lepton number conservation law by ΔL=2, provide one with quite stringent tests for properties of neutrinos and weak interactions beyond the standard electroweak model(SM) of $\mathrm{SU_L}(2)\times$ U(1). Actually, $0\nu\beta\beta$ is very sensitive to the Majorana neutrino mass, the right-handed weak currents, the SUSY particle masses associated with the R-parity violating interactions and so on[4, 5].

The Majoron is a Goldstone boson associated with spontaneous breaking of global $B-L$ symmetry. Gelmini and Roncadelli proposed the neutral Majoron as a neutral component of the triplet Higgs boson[6]. The coupling constant between the Majoron and neutrino is given by $h_{ee} \simeq m_\nu/v_H$. Where m_ν and v_H are the neutrino mass and the vacuum expectation value (v.e.v.) of the Higgs triplet. Since the v.e.v. must be small, the coupling h_{ee} is not so small. Then the Majoron emitting double beta decays ($(A,Z) \rightarrow (A,Z+2)+e^-+e^-+\chi$) provide sensitive tests for the coupling constant. The decay probability of single Majoron emitting double beta decay is written as,

$$[T_{1/2}^{\beta\beta B}]^{-1} = |<g_B>|^2|M_{GT}^{0\nu}|^2(1-\chi_F)^2G_B, \tag{1}$$

where $|<g_B>|$ is the coupling constant, G_B is the phase space integral, $M_{GT}^{0\nu}$ is the Gamow-Teller (GT) nuclear matrix element and χ_F is the ratio of the Fermi-type and the GT-type nuclear matrix elements.

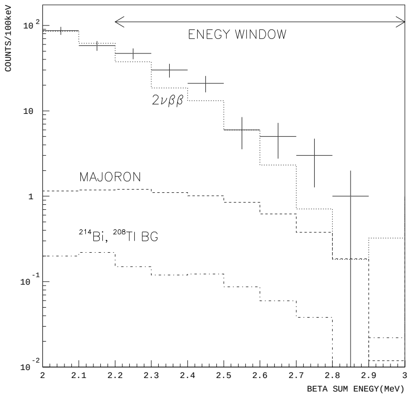
The present work reports the new data at Oto Cosmo Observatory. The measurement was carried out by means of ELEGANT V at Oto Cosmo Observatory (1400m.w.e.). The detector system ELEGANT V consists of three drift chambers (A,B and C), pairs of plastic scintillator arrays and NaI(Tl) arrays. Two ^{100}Mo source films, each with 20mg/cm^2 in thickness and 0.7m×0.7m in size and the total mass 171g, were set in DC-C, as shown in Fig.1. They were enriched to 94.5% in ^{100}Mo and were purified to the level below 0.5ppb for ^{238}U and ^{232}Th contaminants. The number of ^{100}Mo was 1.03×10^{24}.

Background contributions from the natural radioactive contamination were estimated. The ^{214}Bi and the ^{208}Tl are two major isotopes, which may cause background events. These isotopes are descendants of ^{238}U- and ^{232}Th-chain isotopes contained in the source film and detector elements. The ^{214}Bi is produced also from ^{222}Rn contained in the air around the source. The total amounts were evaluated from the single beta event rates in coincidence with gamma rays characteristics of the decays.

The sum energy spectrum was obtained by selecting the events with several conditions with the live time of 7583 hours.

The energy window for the present analysis was set between 2.2MeV and 3.0MeV. Since there are no excess Majoron emitting events beyond the statistical fluctuation, we set the upper limit on the yield caused by the $0\nu\beta\beta B$ decay. This leads to the lower limit on the half-life as $T_{1/2}^{0\nu\beta\beta B} > 2.12(1.58) \times 10^{21}$yr at 68(90)% confidence level.

The upper limit on the Majoron coupling constant $|<g_B>|$ is calculated by using the equation (1). The nuclear matrix element was calculated on the basis of several models.



Fugure 1: The sum energy spectrum of two electron events. The contributions of $2\nu\beta\beta$, background from and Majoron-emitting double beta decay are shown.

With the phase space integral G_B and the nuclear matrix element $|M_{\mathrm{GT}}^{0\nu}|(1-\chi_F)$ calculated in the QRPA model [7] we obtain $|<g_B>| < 3.2 \times 10^{-5}$. Using the G_B and the matrix element calculated in the QRPA model with proton-neutron pairing [8] we obtain $|<g_B>| < 6.0 \times 10^{-3}$. Thus we conclude that the upper limit on $|<g_B>|$ lies in the range of $10^{-3} \sim 10^{-5}$. The experimental results by the other nuclei and methods are listed in Table 1.

Table 1: Experimental limits on the half-life and on the Majoron coupling constant.

Nucleus	$T_{1/2}^{0\nu\beta\beta B}$yr	$\lvert<g_B>\rvert$	References
^{100}Mo	2.1×10^{21}	3.2×10^{-5}	This work
^{116}Cd	5.9×10^{21}	9.5×10^{-5}	[9]
^{136}Xe	7.2×10^{21}	1.4×10^{-4}	[10]
^{150}Nd	2.8×10^{20}	9.96×10^{-5}	[11]

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