Beta decay of $^{115}$In to the first excited level of $^{115}$Sn: potential outcome for neutrino mass

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Abstract

Recent observation of $\beta$ decay of $^{115}$In to the first excited level of $^{115}$Sn with an extremely low $Q_\beta$ value ($Q_\beta \leq O(1)$ keV) could be used to set a limit on neutrino mass. To give restriction potentially competitive with those extracted from experiments with $^3$H ($\simeq 2$ eV) and $^{187}$Re ($\simeq 15$ eV), atomic mass difference between $^{115}$In and $^{115}$Sn and energy of the first $^{115}$Sn level should be remeasured with higher accuracy (possibly of the order of $\sim 1$ eV).

1 Introduction

Development of new real-time solar neutrino detectors is of great interest for current particle physics $^1$. $^{115}$In was proposed long ago $^2$ as a promising target for solar neutrino spectroscopy, having low threshold of 114 keV for the $\nu_e$ capture $^3$, which allows to measure flux of low energy solar $pp$ neutrinos, and high natural abundance of 95.71% $^4$. The process of $\nu_e$ capture can be effectively discriminated from the background processes using a specific tag: the emission of a prompt electron after the $\nu_e$ capture $^{115}$In $+ \nu_e \rightarrow ^{115}$Sn($E_{exc1}$=613 keV) $+ e^-$ with the subsequent emission, after typical time delay of $\tau$=4.7 $\mu$s, of two $\gamma$ quanta with energies of $E_{\gamma1}$=116 keV and $E_{\gamma2}$=497 keV from deexcitation of the second excited level of $^{115}$Sn. Notwithstanding these attractive features, the building of a $^{115}$In-based detector is a challenging task because $^{115}$In is unstable: it $\beta$ decays to ground state of $^{115}$Sn (albeit with big half life of $T_{1/2}$=4.41$\times$10$^{14}$ yr $^5$) creating intensive irremovable background. This makes necessary to divide the detector in small cells and search not only for time- but also for space-correlation between the emitted electron and the gamma quanta.

The possibility to create a solar neutrino detector with $^{115}$In as a target is under investigation in the LENS (Low Energy Neutrino Spectroscopy) project $^6$. In this framework, in particular, In radiopurity and bremsstrahlung from beta decay $^{115}$In $\rightarrow ^{115}$Sn were investigated, being important characteristics which could prevent the successful exploitation of time- and space-correlations. Measurements of In sample with HP Ge detectors were performed deep underground, in the Gran Sasso National Laboratories (Italy), on the depth of 3800 m w.e. As a by-product of these measurements, the $\beta$ decay of $^{115}$In to the first excited level of $^{115}$Sn ($E_{exc1}$=497.4 keV) was observed at the first time $^7$. It has an extremely low intensity ($1.2\times10^{-6}$ in comparison with the $\beta$ decay to $^{115}$Sn ground state) and long half life of $T_{1/2}$=3.7$\times$10$^{20}$ yr $^7$. These extreme values are related with the very

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low energy release, $Q_{\beta} = 1.6 \pm 4.0$ keV, that makes this process the $\beta$ decay with probably the lowest known $Q_{\beta}$ value.

After brief summary of the experiment and data analysis, we discuss in this paper a possible use of the $^{115}\text{In}\to^{115}\text{Sn}(E_{\text{exc}}=497$ keV) decay for setting a limit on the neutrino mass.

## 2 Detectors and measurements

A sample of natural high purity In with weight of $928.7 \pm 0.1$ g was measured with four HP-Ge detectors mounted in one cryostat with a well in the centre. The HP-Ge detectors were of 225.2, 225.0, 225.0 and 220.7 cm$^3$ volume, and had typical energy resolution of 2.0 keV (FWHM) at the 1332 keV line of $^{60}\text{Co}$. The experimental set-up was enclosed in a lead and copper passive shielding and had a nitrogen ventilation system against radon. Data were collected in the Gran Sasso National Laboratories (Italy), on the depth of 3800 m w.e. during 2762.3 h for the In sample and during 1601.0 h for the background, in both cases with the complete shielding around the detectors.

Statistics in the In and background measurements was accumulated in few independent runs that resulted in some minor shifts in position of peaks present in the spectra. Internal peaks of known origin and with good statistics were used to recalibrate spectra from individual runs to obtain summary spectra with the help of the SAND0 routine [8]. In result, the peaks positions in the sum spectra deviate from their table values of less than 0.1 keV in the range of 300–2615 keV both for the In and background measurements.

Efficiency of the detectors for gamma quanta emitted from the In sample was calculated with a GEANT4-based code [9]. The results were checked in measurements with a $^{60}\text{Co}$ source, performed with the same set-up. The measured absolute efficiencies agree with the computed ones within 12% and are consistent within their statistical uncertainties. In the following, we estimate the systematic uncertainty of the Monte Carlo efficiencies to be 10%.

The measured spectra for the In sample and for the background are presented in Fig. 1. The bremsstrahlung emission from the $^{115}\text{In} \beta$ decay with end point of 499 keV is clearly visible as the continuous component in the In spectrum. In both spectra, 42 gamma lines with energy above 200 keV were found. All lines (except of line with energy of 497.4 keV in the In sample) were identified; they come from the natural radionuclides and radioactive series ($^{40}\text{K}$, $^{238}\text{U}$, $^{235}\text{U}$, $^{232}\text{Th}$) and from cosmogenic or anthropogenic nuclides ($^{60}\text{Co}$, $^{137}\text{Cs}$, $^{207}\text{Bi}$, $^{26}\text{Al}$) that are usually present as contaminations in copper and lead [7]. The counting rates of the $\gamma$ lines for the In sample and the background were equal within their statistical uncertainties.

The only $\gamma$ line of the In spectrum which is not present in the background measurement and cannot be ascribed to the usual radioactive contaminants is located at the energy of 497.48±0.21 keV (see insert in Fig. 1). From the fit of the In spectrum in the energy region 487–508 keV with a Gaussian peak and linear background assumption, the net area is $90 \pm 22$ counts, inconsistent with zero at more than 4$\sigma$. Variations of the energy interval for the fit result in changes of the area inside the quoted uncertainty. With the same procedure applied to the background spectrum, no Gaussian peak could be found, and the resulting area is $0 \pm 14$ counts; the corresponding upper limit derived with the
Figure 1: Experimental spectrum of the In sample (accumulated during 2762.3 h) and background spectrum (1601.0 h) measured with 4 HP-Ge detectors at LNGS in the energy interval 70–600 keV. The region of 600–2800 keV, where the spectra are practically undistinguishable, is not shown. Background is normalized to the same counting time. In the insert, the region of the 497.4 keV peak is shown in more detail; here the In spectrum is shifted upward on 150 counts.

Feldman-Cousins method [10] is 23 counts at 90% C.L. It can hence be concluded that the peak of 497.4 keV is statistically significant and related with the In sample, being absent in the background measurement.

3 Data analysis and interpretation

The energy of the first excited level of $^{115}$Sn, daughter nucleus after the $^{115}$In $\beta$ decay, is equal to 497.35±0.08 keV. If populated, this level deexcites with the emission of a $\gamma$ quantum with energy $E_\gamma$=497.358±0.024 keV [3, 11] which is in nice agreement with that of the observed peak 497.48±0.21 keV. However, the $Q_\beta$ value (i.e. atomic mass difference $\Delta M_a$ between $^{115}$In and $^{115}$Sn) given in the atomic mass tables of Audi & Wapstra, known at the moment of our measurements, was equal to 495 keV [12] and 496 keV [13]. Thus
the transition to the first excited level of $^{115}$Sn was energetically forbidden$^2$, and the $\beta$ decay of $^{115}$In was considered as going exclusively to the ground state of $^{115}$Sn [3, 11] (see Fig. 2a).

However, revised value of $Q_\beta=499\pm 4$ keV in the last tables [14] allowed to avoid this contradiction: with this value, the decay to the first excited level $^{115}$In $\rightarrow$ $^{115}$Sn($E_{\text{exc}}=497.4$ keV) is kinematically allowed, though with an extremely small $Q_\beta$ value, $Q_\beta=1.6\pm 4.0$ keV.

Using the area of the 497 keV peak observed in the indium spectrum, corresponding partial half life for the transition to the first excited level of $^{115}$Sn can be calculated as

$$T_{1/2}(^{115}\text{In} \rightarrow ^{115}\text{Sn}^*) = \frac{\ln 2 \cdot N \cdot \varepsilon \cdot t}{S \cdot (1 + \alpha)},$$

where $N$ is the number of $^{115}$In nuclei in the sample, $\varepsilon$ is the efficiency to detect the full energy $\gamma$ with the 4 HP Ge detectors, $t$ is the measurement time, $S$ is the area of the peak and $\alpha$ is the coefficient of conversion of $\gamma$ quanta to electrons for the given nuclear transition.

The full peak efficiency at 497 keV was calculated with the Monte Carlo simulation as $\varepsilon=3.32\pm 0.33\%$. Taking into account the total mass of the indium sample (928.7 g), the atomic weight of indium (114.818 g·mol$^{-1}$ [15]) and the isotopic abundance of $^{115}$In (95.71% [4]), the number of $^{115}$In nuclei in our sample is $N=4.66\times 10^{24}$. With the area of the peak 90\pm 22 counts, the electron conversion coefficient for the transition $\alpha=8.1\times 10^{-3}$ [11], and $t=2762.3$ h, the $T_{1/2}$ value is equal

$$T_{1/2}(^{115}\text{In} \rightarrow ^{115}\text{Sn}^*) = (3.73 \pm 0.98) \times 10^{20} \text{ yr}.$$ 

Half life for the ground state to ground state $\beta$ decay of $^{115}$In, because of the large change in the nuclear angular momentum ($9/2^+ \rightarrow 1/2^+$, that classifies this decay as 4-fold forbidden transition) and of the relatively small $Q_\beta$ value, is equal to $T_{1/2}=4.41\times 10^{14}$ yr [5, 3, 11, 16]. Thus the probability of decay to the first excited level is near one million times lower than for the transition to the ground state of $^{115}$Sn; the experimental branching ratio is $b=(1.18\pm 0.31)\times 10^{-6}$.

The uncertainty on the half life and on the branching ratio mainly comes from the statistical error on the net area of the 497 keV peak. An updated scheme of the $^{115}$In $\rightarrow ^{115}$Sn $\beta$ decay is presented in Fig. 2b.

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$^2$If to forget about 4 keV uncertainty in the $Q_\beta$ value [12, 13].
4 Possible imitation of the effect

In some nuclear processes γ rays with energies close to 497 keV are emitted. This could give an alternative explanation of the peak observed in the experimental spectrum. Luckily, additional γ rays are also emitted in such decays, allowing to tag those mimicking effects.

The $^{115}$In nucleus has an isomeric state $^{115m}$In with the energy $E_{iso}=336.2$ keV and a half life of 4.5 h [3]. With the probability of 0.047% the $^{115m}$In nucleus β decays to the first excited level of $^{115}$Sn, with the subsequent emission of a 497 keV γ ray [3][11]. However, in this case a γ ray with the energy $E_{iso}=336.2$ keV is emitted with much higher probability (45.84% [3]) because of the electromagnetic transition from the isomeric $^{115m}$In to the ground $^{115}$In state. This huge peak at 336.2 keV, whose area should be $\sim 10^3$ times bigger than that of the observed 497.4 keV peak, is absent in the experimental spectrum; only a peak at 338.3 keV is observed, with the net area of 138±50 counts, which corresponds to the decay of $^{228}$Ac from the $^{232}$Th natural chain. Therefore the decay of the isomeric state $^{115m}$In is absolutely negligible and the 497 keV peak cannot be ascribed to it, not even in part.

Capture of thermal neutrons by $^{115}$In results in $^{116}$In in excited state and subsequent cascade of γ quanta. In particular, γ quantum with energy of 497.7 keV and relative yield of 1.32% will be emitted [17]. However, accompanying intensive peak of 273.0 keV and, for example, peak of 492.5 keV (8.68%) are absent in the spectrum (see Fig. 1). Capture of thermal n on $^{113}$In (natural abundance 4.29% [3]) also results in emission of γ quantum with close energy: 496.7 keV (0.75%) [17]. However, more intensive peaks (311.6 keV – 100%, 502.6 keV – 5.00%) also are absent in the spectrum. Thus, due to the underground location of the experimental setup and the low flux of neutrons [18], we conclude that $(n, \gamma)$ reactions cannot contribute to the peak under analysis.

Protons produced by fast neutron or cosmic ray muons can populate the second excited level of $^{115}$Sn ($E_{exc2}=612.8$ keV) via the $(p, n)$ reaction on $^{115}$In ($E_{thr}=0.9$ MeV); the $^{115}$Sn nucleus quickly returns to the ground state with the emission of two γ rays of energy 115.4 and 497.4 keV. The contribution originated by fast neutrons is practically zero (see f.i. [19]) because of the deep underground location and the lack of hydrogenerous materials in the setup. On the other hand, since the muon flux in the laboratory is extremely low (1 $\mu$/m$^2$·h) [20], also the contribution of $(p, n)$ reactions induced by cosmic rays (see also [21]) to the 497 keV peak is negligible (<10$^{-3}$ counts).

Some decays from the natural $^{238}$U and $^{232}$Th chains can also give γ rays in the energy region of interest, though with very low intensity. They are in particular $^{214}$Bi ($E = 496.7$ keV, $I = 0.0069\%$), $^{228}$Ac ($E = 497.5$ keV, $I = 0.0059\%$) and $^{234m}$Pa ($E = 498.0$ keV, $I = 0.062\%$). However, the sum contribution of these decays to the 497 keV peak is less than 1 count and can be estimated using their stronger associated γ lines. For instance, the area of the 338.3 keV line of $^{228}$Ac, whose relative intensity is 11.27%, is only 138±50 counts. Therefore, if the contamination were located in the In sample, the estimated contribution to the 497 keV peak, taking also into account the different full peak efficiency, would be (7.3±2.6)$\times 10^{-2}$ counts.

$^{3}$Intensity of γ line with energy of 273.0 keV is accepted as 100%.
5 \( \beta, \gamma-\beta \) and \( \beta-\gamma \) decays of \( ^{115}\text{In} \)

In addition, possible imitation of the effect could come from the so-called \( \gamma-\beta \) decay of \( ^{115}\text{In} \). In this process, also called induced “photobeta” decay [22], an external \( \gamma \) quantum is absorbed by the nucleus, thereby providing additional energy. This allows the \( \beta \) transition to excited levels of daughter nucleus, otherwise energetically forbidden, or even stimulates the \( \beta \) decay of stable nuclei. In cases when the decay to ground state is strongly suppressed by a large change in the spin (as for \( ^{115}\text{In} \to ^{115}\text{Sn} \)), transitions to excited levels would be preferable.

The process could be actual in the case of strong electromagnetic fields in stars [22] or in a field of synchrotron radiation [23], but also in the searches for extremely rare processes, like ours. If the \( ^{115}\text{In} \) nucleus absorbs a \( \gamma \) quantum with energy \( E_{\gamma}>114 \text{ keV} \) from an external source, or even a bremsstrahlung \( \gamma \) from \( ^{115}\text{In} \) \( \beta \) decay itself, the second excited level of \( ^{115}\text{Sn} \), with energy 612.8 keV, could be populated (spin changes from 9/2\(^+\) to 7/2\(^+\), and this is an allowed \( \beta \) transition). In the subsequent deexcitation process, two \( \gamma \)'s with energies of 115.4 keV and 497.4 keV will be emitted, thus leading to the peak of 497.4 keV (see Fig. 3).

![Diagram of \( \gamma-\beta \) decay of \( ^{115}\text{In} \to ^{115}\text{Sn} \).](image)

Figure 3: \( \gamma-\beta \) decay of \( ^{115}\text{In} \to ^{115}\text{Sn} \). The absorption of the external \( \gamma \) quantum increases the nucleus energy and makes possible the \( \beta \) decay to the excited levels of \( ^{115}\text{Sn} \), otherwise energetically forbidden.

The calculated cross-sections of the \( \gamma-\beta \) process are quite low: of the order of \( 10^{-49} - 10^{-45} \text{ cm}^2 \), depending on the \( Z \) of the parent nucleus, on \( E_{\gamma} \) and on the energy threshold [23]. Nevertheless, it was calculated that in a field of intensive synchrotron radiation from the SPring-8 source (Japan), the \( \beta \) decay of \( ^{115}\text{In} \) could go faster by 2 orders of magnitude [23]. However, scaling the SPring-8 intensity of \( \sim 10^{17} \gamma/(\text{s-mm}^2\cdot\text{mrad}^2\cdot\text{keV}) \) to the \( \gamma \) radiation intensity in our measurements, \( <0.1 \gamma/(\text{s-keV}) \) (see Fig. 1), it is evident that the contribution of \( \gamma-\beta \) decay to the 497.4 keV peak is negligible.

It is interesting to note here another interesting process, the so-called \( \beta-\gamma \) decay [24]: when the direct \( \beta \) transition to the ground state of daughter nucleus is highly forbidden,
a process could take place in which a $\gamma$ quantum is emitted simultaneously with the electron and antineutrino. Such a process is second-order in perturbation theory and is similar to the double $\beta$ decay of a nucleus. The branching ratio of such decay for $^{115}$In was calculated in [25] as: $6.7 \times 10^{-7}$. Because in this case three particles ($\gamma$, $\beta$ and $\bar{\nu}_e$) are emitted with sum energy equal to $Q_\beta$, and the $\gamma$’s energy distribution is continuous, the 497.4 keV peak could not be imitated. However, it should be noted that it could be an additional source of $\gamma$ quanta in the In-based solar neutrino detector (with the branching ratio of $\approx 10^{-6}$, as in $\beta$ decay $^{115}$In $\rightarrow ^{115}$Sn*) which also should be taken into account [25].

6 Possible outcome for the neutrino mass

With the value of $Q_\beta=1.6\pm4.0$ keV, decay $^{115}$In $\rightarrow ^{115}$Sn* possibly is the $\beta$ decay with the lowest known $Q_\beta$ value (to be compared with that of $^{163}$Ho: 2.555 keV and $^{187}$Re: 2.469 keV [14]). Below we will try to determine the $Q_\beta$ value more exactly on the basis of the systematics of log $ft$ values for such kind of decay and the measured value of $T_{1/2}$.

Nuclear spin and parity are changed in the observed transition from the initial $9/2^+$ of the $^{115}$In ground state to $3/2^+$ of $^{115}$Sn*; this is therefore a 2-fold forbidden unique $\beta$ decay. The recent compilation of log $ft$ values [26] gives for such a decay the average value log $ft=15.6\pm1.2$; for the 12 known experimental cases, the range is from 13.9 to 18.0. With the measured value of the half life of $(3.73\pm0.98)\times10^{20}$ yr, the “experimental” log $f$ value is log $f=-12.47\pm1.21$. On the other hand, the log $f$ can be estimated with the help of the LOGFT tool at the National Nuclear Data Center, USA [27] which is based on the procedure described in [28]. For $Q_\beta=1.6$ keV, the value calculated with the LOGFT code is log $f=-10.8$; this means that with such a $Q_\beta$ the $\beta$ decay should go near 50 times faster.

One can solve the inverse problem and use the LOGFT code to adjust the $Q_\beta$ value corresponding to the “experimental” log $f=-12.47\pm1.21$. Such a procedure gives a value of $Q_\beta=460^{+700}_{-280}$ eV. The lowest value of log $ft=13.9$ in the range of the known 2-fold forbidden unique $\beta$ decays [26] corresponds to $Q_\beta=120$ eV, while the highest value (log $ft=18.0$) gives $Q_\beta=2.85$ keV.

While possibly the LOGFT tool was not intended to be applied for such low energies, in any case it is clear that the $Q_\beta$ value in the $\beta$ decay $^{115}$In $\rightarrow ^{115}$Sn* is very close to zero. Such a unique situation could be used to establish a limit on the antineutrino mass, in addition to the experiments with $^3$H and $^{187}$Re, where up-to-date limits are in the range of $\approx 2$ eV [29] and $\approx 15$ eV [30], respectively. Two approaches could be proposed.

(1) To measure the shape of the $\beta$ spectrum $^{115}$In $\rightarrow ^{115}$Sn*, registering $\beta$ particle in coincidence with $\gamma$ 497 keV, which allows to reduce the background due to the $\beta$ decay of $^{115}$In to the ground state of $^{115}$Sn. New In-based semiconductor detectors or fast

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4 We can derive on this basis the atomic mass difference $^{115}$In$-^{115}$Sn: it is equal to 497.9$^{+2.3}_{-0.3}$ keV (with the error bars corresponding to the whole range of 13.9–18.0 of log $ft$ values), which is more precise than the recent value of 499$\pm$4 keV [14].

5 Even the history of the $Q_\beta$ evaluation for $^{115}$In gives some indication for this: the $Q_\beta$ value was slightly lower than 497.4 keV energy of the first excited $^{115}$Sn state in accordance with older tables of atomic masses, $Q_\beta=495\pm4$ keV [12] and 496$\pm$4 keV [13], while it is slightly higher in the last evaluation, 499$\pm$4 keV [14].
bolometers could be used for the purpose. Mass of antineutrino could be derived from distortion of the spectrum shape (as in $^3$H experiments). It should be noted, however, that such measurements would be quite difficult because of: (i) extremely low $Q_\beta$ value; (ii) the shape of 2-fold forbidden $\beta$ decay has to be theoretically calculated very precisely, that may be not so easy also due to low $Q_\beta$ value.

(2) Just to use evident relation $m_\nu<Q_\beta$. Thus, low $Q_\beta$ value means also low limit on neutrino mass. Because predictive power of any theoretical calculation for such low energies is uncertain, the best way to derive potentially good limit on $m_\nu$ is to measure experimentally with accuracy better than current: (i) the atom mass difference $\Delta M_a(^{115}\text{In}^{115}\text{Sn})$; (ii) the energy of the first excited level of $^{115}\text{Sn}$. Energy of $\gamma$ quantum emitted from the first excited $^{115}\text{Sn}$ level is known currently as $497.358\pm 0.024$ keV [3, 11], i.e. with precision of 24 eV. However, this uncertainty could be reduced further in measurements of electron capture $^{115}\text{Sb} \rightarrow ^{115}\text{Sn}$. It should be noted that many calibration lines of radioactive sources were already measured with accuracy of 0.1–0.3 eV, also in the $\sim 500$ keV region of our interest [3].

Current uncertainty $\delta(\Delta M_a)$ on atomic mass difference between $^{115}\text{In}$ and $^{115}\text{Sn}$ is equal to 4 keV [14]. It should be noted that current technics (Penning traps) allows to reach accuracy of $\lesssim 10^{-10}$ in atomic mass measurements [31, 32, 33], that corresponds to $\sim 10$ eV for nuclei with $A\approx 100$. For example, in work [33] absolute masses of $^{32}\text{S}$ and $^{33}\text{S}$ were determined with accuracy of 1.5 eV, and masses of $^{129}\text{Xe}$ and $^{132}\text{Xe}$ with accuracy of 9 eV. Even lower uncertainties could be expected for measurement of difference of atomic masses. As the first step, it could be useful to measure $\Delta M_a(^{115}\text{In}^{115}\text{Sn})$ with not-challenging accuracy of $\sim 100$ eV: if, for example, $\Delta M_a$ will be equal $460\pm 100$ eV, it will be enough not to expect good limit on $m_\nu$. However, if it will be measured as $\sim 0\pm 100$ eV, uncertainty on $\Delta M_a$ should be further reduced. In case if we are lucky and $\Delta M_a(^{115}\text{In}^{115}\text{Sn}) \approx E_{\text{exc}}(^{115}\text{Sn})$, we could obtain $\lim m_\nu$ possibly concurrent with that from experiments with $^3\text{H}$ ($\sim 2$ eV) or $^{187}\text{Re}$ ($\sim 15$ eV). Both measurements of $E_{\text{exc}}$ and $\Delta M_a(^{115}\text{In}^{115}\text{Sn})$ require strong experimental efforts but the physical result could be very interesting and important.

7 Conclusions

Evidence for the previously unknown $\beta$ decay of $^{115}\text{In}$ to the first excited state of $^{115}\text{Sn}$ at 497.4 keV was found from the measurement of the $\gamma$ spectrum of a sample of metallic indium performed with HP Ge detectors in the Gran Sasso Laboratory. The $Q_\beta$ value for this channel is $Q_\beta=1.6\pm 4.0$ keV which could be the lowest of all the known $\beta$ decays. The branching ratio is found to be $b=(1.2\pm 0.3)\times 10^{-6}$.

With measured value of $T_{1/2}=(3.7\pm 1.0)\times 10^{20}$ yr and calculation of $\log f$ value with the LOGFT code, the derived atomic mass difference between $^{115}\text{In}$ and $^{115}\text{Sn}$ is equal $497.9^{+2.3}_{-0.4}$ keV, which is more exact than the recent value $499\pm 4$ keV [14].

The low value of $Q_\beta$ could be used to set limit on the neutrino mass. In the case when $\Delta M_a(^{115}\text{In}^{115}\text{Sn}) \approx E_{\text{exc}}(^{115}\text{Sn})$, there is a chance to obtain result similar to that from experiment with $^3\text{H}$ ($\sim 2$ eV), if we will be able to accurately measure $\Delta M_a(^{115}\text{In}^{115}\text{Sn})$ and $E_{\text{exc}}(^{115}\text{Sn})$, possibly with $\sim 1$ eV uncertainty.
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References

[1] A.B. McDonald, New J. Phys. 6 (2004) 121.
[2] R.S. Raghavan, Phys. Rev. Lett. 37 (1976) 259; R.S. Raghavan, hep-ex/0106054.
[3] R.B. Firestone et al., Table of isotopes, John Wiley & Sons, New York, 1996 and CD update, 1998.
[4] K.J.R. Rosman, P.D.P. Taylor, Pure and Applied Chem. 70 (1998) 217.
[5] L. Pfeiffer et al., Phys. Rev. C 19 (1979) 1035.
[6] D. Motta et al., Nucl. Instrum. Meth. A 547 (2005) 368; I. Barabanov et al., Nucl. Phys. B (Proc. Suppl.) 143 (2005) 559.
[7] C.M. Cattadori et al., Nucl. Phys. A 748 (2005) 333.
[8] V.I. Tretyak, Preprint KINR-90-35, Kiev, 1990.
[9] O. Cremonesi, JAZZY code, unpublished.
[10] G.J. Feldman, R.D. Cousins, Phys. Rev. D 57 (1998) 3873.
[11] J. Blachot, Nucl. Data Sheets 86 (1999) 151.
[12] G. Audi, A.H. Wapstra, Nucl. Phys. A 565 (1993) 66.
[13] G. Audi, A.H. Wapstra, Nucl. Phys. A 595 (1995) 409.
[14] G. Audi et al., Nucl. Phys. A 729 (2003) 337.
[15] J.R. De Laeter et al., Pure and Appl. Chem. 75 (2003) 683.
[16] G. Audi et al., Nucl. Phys. A 729 (2003) 3.
[17] http://www.nndc.bnl.gov/capgam.
[18] P. Belli et al., Nuovo Cimento A 101 (1989) 959.
[19] M. Cribier et al., Astrop. Phys. 4 (1995) 23.
[20] MACRO Collaboration, M. Ambrosio et al., Phys. Rev. D 52 (1995) 3793.
[21] M. Cribier et al., Astrop. Phys. 6 (1997) 129.
[22] P.B. Shaw et al., Phys. Rev. B 140 (1965) 1433.
[23] I.V. Kopytin, K.N. Karelin, Phys. At. Nucl. 68 (2005) 1138.
[24] C.L. Longmire, Phys. Rev. 75 (1949) 15.
[25] A.F. Pacheco, D. Strottman, Mod. Phys. Lett. A 2 (1987) 625.
[26] B. Singh et al., Nucl. Data Sheets 84 (1998) 487.
[27] http://www.nndc.bnl.gov/nndc/physco
[28] N.B. Gove, M.J. Martin, Nucl. Data Tables 10 (1971) 205.
[29] V.M. Lobashev, Nucl. Phys. A 719 (2003) 153.
[30] M. Sisti et al., Nucl. Instrum. Meth. A 520 (2004) 125.
[31] F. DiFilippo et al., Phys. Rev. Lett. 73 (1994) 1481.
[32] M.P. Bradley et al., Phys. Rev. Lett. 83 (1999) 4510.
[33] W. Shi et al., Phys. Rev. A 72 (2005) 022510.