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Search for a heavy neutrino in the mass range under 750 keV using electron capture in ^{7}Be

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Neutrinos are massive and this property cannot be accommodated in the Standard Model. The simplest mechanism to provide neutrino with mass assumes the existence of new particles – right handed (or "sterile") neutrinos. Their number, masses and mixing angles with left handed ("active") neutrinos, apart from the existing observational restrictions, are free parameters of the theory. Sterile neutrino in the keV mass range is one of the best motivated dark matter particle candidates. Therefore, studies of the sterile neutrino mass may probe a new physics. Currently there have been many attempts to search for such heavy neutrino directly in the laboratory [1]. Nucleus β-decay and electron K-capture are prominent channels to search for a heavy neutrino component [2, 3]. We present reanalysis of the experimental data of electron capture in ^{7}Be embedded in Ta which have been published in [4]. We decided to use these data for estimation of the possible admixture of a heavy neutrino in contrast to emission of the standard electron neutrino.

^{7}Be is a two body decay with emitted neutrino and recoil ^{7}Li nucleus. ^{7}Be decays by electron capture from K- or L-orbit to ^{7}Li ground or first excited state with Q value of about 862 keV. Thus, it has four possible channels: with a 89.5 % probability the decay is to ^{7}Li ground state and a neutrino with the total energy of 862 keV is emitted and the residual recoil nucleus gets 57 eV kinetic energy; with a 10.5 % probability the decay from K-shell may go to ^{7}Li excited state and the neutrino total energy is 384 keV. This decay is quickly followed by a wide angle gamma emission with energy of 478 keV. The recoil nucleus energy spectrum becomes wide; if the capture is from K-shell an Auger electron is emitted from L-shell and its energy of about 55 eV adds to decay signal with a total energy of 112 eV. It allows one to separate K- and L-capture peaks. The capture from L-shell to the exited state is followed by gamma emission. As a result, the recoil nucleus spectrum has two similar parts: a prominent K line peak at 112 eV with a wide distribution from 55 to 112 eV centered at about 80 eV when the decay goes to the excited state, and L line peak at 57 eV and a relevant wide distribution centered at about 30 eV for decays to the excited state. These features were clearly seen in papers [4] and [5]. We assume that the detector response can be described by a finite resolution with Gaussian shape, the width of which does not depend on recoil energy. Formally, an additional heavy neutrino component should demonstrate a similar recoil energy spectrum but shifted to the lower range. Thus, first of all, we should search for other K- and L-line peaks to the left of the main ones. Our analysis has the following steps: we digitize the published recoil spectrum from the plot, and fill our own histogram with the same bin size. Estimation of energy resolution by fitting by Gauss function the main K-line gives $\sigma = 3.0$ eV. We set moving energy interval with edges E_L and E_R about ± 1–$1.5\,\sigma$ to search for a signal. The actual interval width was slightly varying to get the optimal ratio between the potential signal and the underlying background with changing shape. Calculation of statistical error done by taking square root from the total number of events for each interval, Sum. Each Sum is corrected for potential missing counts in Gauss tails beyond the interval: dividing by $K_{\rm erf}$, where $K_{\rm erf}$ is fraction of the Gauss function between E_L and E_R. Multiply the statistical error by 1.95 to get estimation at 95 % confidence level (CL). This value is used to set a 95 % upper CL. We have to correct for probability to decay to ground state dividing by its probability (0.895) and for probability to decay in K-channel (0.935). Final cumulative estimation of the maximum statistically excluded number of heavy neutrino contribution is:

$$N_{\rm excl} = 1.95 \cdot \sqrt{\rm Sum}/(K_{\rm erf} \times 0.895 \times 0.935). \qquad (1)$$

Dividing corrected value by total number of events in the spectrum minus gamma background, $\mathrm{CL} = N_{\rm excl}/N$,

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we get estimation of 95 % CL. A possible systematic error by assumption that the energy resolution or the shape of the peak are known with 10 % uncertainty translates to about 5 % of CL.

There is a simple relation between the measured energy E and the possible heavy neutrino mass, m: $m^2 = Q^2 - 2E(Q + M)$, M is recoil Li nucleus mass and $Q = 862$ keV.

Taking into account the statistical significance, we get upper 95 % CL limits, U^2, for probability to find a heavy neutrino versus its mass, Fig. 1, thick solid line. At the same figure we plot all existing published data. New limits are at least one order of magnitude lower.

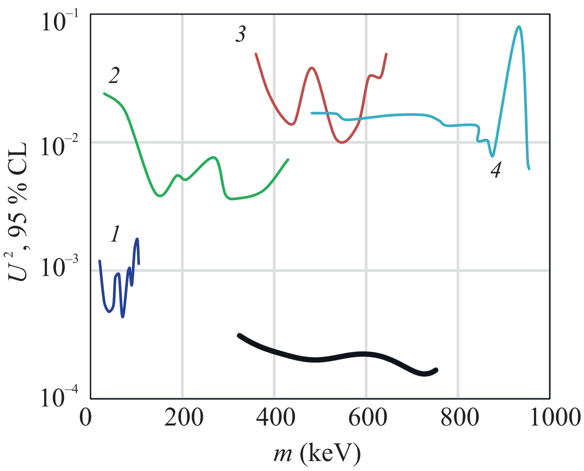

Fig. 1. (Color online) Upper 95 % CL limits, U^2, for probability to find a heavy neutrino versus its mass, thick solid line. Thin solid numbered lines are for published data: *1* – [2]; *2* – [3]; *3* – [6]; *4* – [7]

To conclude, we present our estimation of limits on search for a heavy right-handed (sterile) neutrino. We use the published high statistics data from [4] where they measured electron capture in ^{7}Be. Electron capture in ^{7}Be is a two body decay with emitted neutrino and recoil ^{7}Li nucleus. Neutrino mass defines the maximum energy released by ^{7}Li. After performing statistical analysis of the measured spectrum we get an upper 95 % CL in the mass range 300–750 keV. These limits are at least one order of magnitude lower than the existing published data.

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