Reevaluation of an experiment claiming a nonzero neutrino mass

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It is pointed out that, due to the neglect of the natural line width of internal-conversion lines used for determining the instrumental resolution, the experiment of Lubimov *et al.* does not determine a model-independent lower bound for the neutrino mass.

In 1980 Lubimov *et al.*[1] reported an experiment giving evidence of a nonzero mass for the electron antineutrino by measuring the shape of the β spectrum of tritium. This result was given added weight by the fact that they assigned a lower bound of 14 eV (at the 99% confidence level) to the mass which was independent of any atomic or molecular final-state effects. In other words, the lower bound was deduced from a model where there is only one atomic or molecular state produced in the decay of tritium to ^{3}He and any realistic case would produce a larger neutrino mass. Subsequently a paper giving a further description of their experiment appeared,[2] in which I observed[3,9] that in their analysis they had made an unjustified assumption, which is the subject of this note.

To extract a neutrino mass from a β spectrum it is important to have an accurate knowledge of the resolution function. This is because the shape of the β spectrum at its high-energy end, the region sensitive to the neutrino mass, is dominated by the resolution function of the experimental apparatus in all experiments carried out to date, including that of the ITEP group.[1,2] However, to measure this resolution function they used M conversion lines of ^{169}Yb but unfortunately they assumed that the natural line width of these conversion lines would have a negligible effect on their result. This is however not the case, for two reasons. Firstly, the M levels are expected to be broader than the L levels which have widths of about 5 eV in this atomic-mass region.[4] Theoretical predictions of the $M2$ level width give a value of ~ 11 eV at $Z=69$.[4] Subsequent to their neutrino-mass publications the ITEP group attempted to measure the width and obtained a value of 6.3 eV (Ref. 5). One other preliminary measurement of the $M2$ width gives a value ~ 9 eV (Ref. 6). Secondly, since the natural line width is represented by a Lorentzian function it can significantly change the observed resolution. For example, if the instrumental resolution function is itself a Lorentzian (not a bad approximation for some spectrometers) then the conversion line width adds directly to the instrumental width. If the instrumental resolution function is Gaussian, then the convolution is mathematically complicated[7] but as an adequate approximation the total width is $W^n = W_i^n + \Gamma^n$ where $n \simeq 1.2$, W (W_i) is the full width at half-maximum of the total (instrumental) line shape, and Γ is the Lorentzian width. Hence one expects that an instrumental resolution of 45 eV (appropriate to the ITEP experiment) would be broadened by 3.5 to 11 eV depending on the true value of the line width and the nature of the instrumental line shape. (In a proper analysis one would deconvolute the natural line width from the observed resolution function to obtain the intrinsic resolution function appropriate for the β spectrum.)

The primary effect of using a wider resolution function for analyzing the β spectrum of tritium than appropriate is to make the extracted neutrino mass larger than it really is. An example of this has been calculated[8] in which the spectrum for a true resolution function of 45 eV and neutrino mass of zero is analyzed using a resolution width of 56 eV. The best fit determines a neutrino mass of 29 eV. One can make a rough estimate of the effect of an overestimate ϵ in the resolution width R by assuming that the primary effect of the resolution function is to "bin" the data into bins of width R.[9] One can then derive that a neutrino mass M larger than the true mass m will be obtained such that

$$M^2 - m^2 = 2\epsilon R \ .$$

If the true mass is large, say 30 eV, and R is 45 eV then the broadening associated with the $M2$ widths estimated above leads to experimentally determined masses M of 35 to 44 eV (Ref. 10). If however the true mass is zero, then $M = \sqrt{2\epsilon R}$ and the $M2$ width would lead to experimentally determined masses ranging from 18 to 31 eV. It is clear therefore that the model-independent lower bound of 14 eV quoted by Lubimov *et al.* is incorrect and in fact that a neutrino mass of zero is consistent with the data for many final-state configurations.

A moral of this story is that in experiments of this sort one must carefully guard against systematic effects tending to make the experimentally determined resolution function broader than the one appropriate to the β particles since this will give rise to larger neutrino masses. Another example of this kind of systematic effect would be nonuniform tritium distribution in the source material.

In conclusion, due to the neglect of the natural line width of the ^{169}Yb conversion lines in the determination of the instrumental resolution function for β rays, the published experiment of Lubimov *et al.* does not give a model-independent lower bound on the mass of the electron neutrino. Consequently, any new measurement claiming a nonzero neutrino mass cannot be construed as corroboration of the result of Ref. 1.

[1] V. A. Lubimov *et al.*, Phys. Lett. **94B**, 266 (1980).
[2] V. A. Lubimov *et al.*, Zh. Eskp. Teor. Fiz. **81**, 1158 (1981) [Sov. Phys. JETP **54**, 616 (1981)].
[3] Letter to V. A. Lubimov from J. J. Simpson.
[4] O. Keski-Rahkonen and M. O. Krause, At. Data Nucl. Data Tables **14**, 139 (1974); M. H. Chen *et al.*, Phys. Rev. A **27**, 2989 (1983).
[5] V. A. Lubimov (private communication); S. Boris *et al.*, in *Proceedings of the International Europhysics Conference on High Energy Phy-*

sics, Brighton, 1983, edited by J. Guy and C. Costain (Rutherford Appelton Laboratory, Chilton, Didcot, United Kingdom, 1984), p. 386.

[6]C. L. Bennett *et al.* (private communication); and (unpublished).

[7]P. L. Lee, Nucl. Instrum. Methods **144**, 363 (1977).

[8]J. J. Simpson, in *Proceedings of the Third Workshop on Grand Unification, University of North Carolina, Chapel Hill, 1982,* edited by P. H. Frampton, S. L. Glashow, and H. van Dam (Birkhauser, Boston, 1982), p 258.

[9]J. J. Simpson, in *Proceedings of the International Colloquium on Matter Nonconservation, Frascati, 1983,* edited by E. Bellotti and S. Stipcich (Servizio Documentazione des Laboratori di Frascati, Frascati, 1982), p. 279.

[10]Dr. Lubimov, in his response (Ref. 5) to my letter pointing out the neglect of the natural line width, stated that the inclusion of a line width of 6.3 eV reduced to the average neutrino mass from 34 to 28 eV. This implies $\epsilon \simeq 4$ in the approximation used here.