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Search for admixture of heavy neutrinos with masses between 5 and 55 keV

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Using a magnetic spectrometer at a momentum resolution of 0.3%, we have studied the beta spectrum from ^{35}S. We do not see evidence for the admixture of a heavy neutrino to the usual light ($m \simeq 0$) $\bar{\nu}_e$ accompanying beta decay, in the mass range between 5 and 50 keV, with a limit for the mixing strength of $|U|^2 < 3\times10^{-3}$ (90% confidence limit).

In a recent study of the beta spectrum from ^{3}H, Simpson[1] has reported evidence for a heavy neutrino with a mass of $m \simeq 17$ keV admixed with a strength of $|U|^2 \simeq 3\%$ to the ordinary light (mass $\simeq 0$) neutrino. This result, if correct, implies that beta spectra exhibit a deviation from the Fermi shape at 17 keV below the endpoint, E_0.

The present paper describes the results of a study of the beta spectrum from ^{35}S($E_0 = 166.8$ keV) aimed at exploring the presence of a heavy neutrino in the mass range of $5 < m < 55$ keV. It should be noted that wide ranges of other masses have been investigated.[2] In our experiment we have employed the Caltech iron-free double-focusing magnetic spectrometer.[3] The spectrometer has a mean radius of 35 cm and its momentum resolution was set at $\delta p/p = 0.3\%$ ($\delta E/E \simeq 0.6\%$).

The source consisted of a carrier free (45 mCi/μg)$Na_2{}^{35}SO_4$ solution deposited onto a 230 μg/cm^2 Mylar foil. The area of the deposit, prepared with a wetting agent was 2 mm wide and 20 mm high. The source strength was 2 mCi. The spectrometer and auxiliary coils for earth field compensation provide a magnetic field linear with the current to 1 part in 10^5. The accuracy with which the current is maintained over the period of several days (several complete runs) is also 1 part in 10^5.

To calibrate the momentum setting of the spectrometer use was made of the K and L internal conversion lines (at 126.91 and 159.61 keV) emitted by a ^{139}Ce source prepared in an identical fashion as the ^{35}S source.

The detector at the spectrometer focus was a liquid nitrogen cooled Si(Li) detector of 2 mm thickness. The pulse height spectrum of the Si(Li) detector for incident electrons of 126.9 keV shown in Fig. 1 exhibits a main peak [4 keV full width at half maximum (FWHM)] and a backscatter tail. To obtain the count rate for a given momentum setting the integral of this spectrum was used with the backscatter tail extrapolated to zero energy. The effect of the entrance contact layer of the detector (30 μg/cm^2 Au) varied between 0.5% at 110 keV and 0.2% at 166 keV and was estimated with the help of a Monte Carlo scattering calculation. The contribution from scattering within the spectrometer, a process which may affect the linearity of the response and thus the spectral shape, was studied with the ^{139}Ce lines, with particular emphasis on scattering into higher momentum bins, i.e., into bins with current settings above those of the Ce lines. These scattering effects are expected to be particularly important in distorting the high energy portion of the ^{35}S spectrum, where the spectrum decreases quadratically with energy. They were found to be negligible in our case.

Data were taken, alternatively in order of increasing and decreasing energy, from 110 to 166 keV in intervals of 2 keV, starting with two runs in which 10^5 counts were accumulated for each of the 29 energy bins, followed by two runs with 2.5×10^5 counts per bin and a final run with 3×10^5 counts. For the three highest bins, owing to the lower count rates, fewer counts were collected.

The fitted ratio minus one of measured counts to expected counts for $|U|^2 = 0$ is displayed in Fig. 2. The data agree

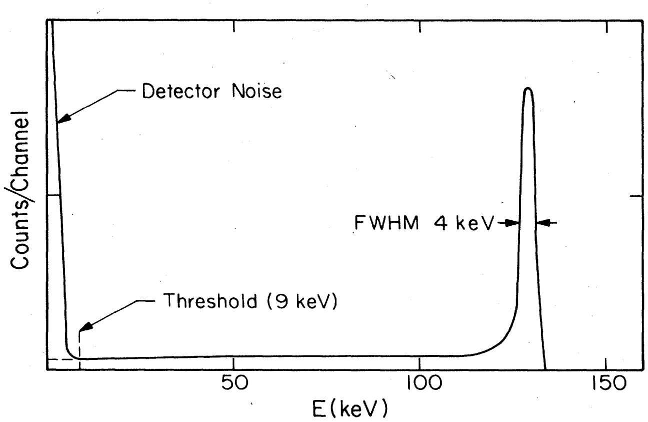

FIG. 1. Spectrum from ^{139}Ce K conversion line in cooled Si(Li) detector at spectrometer focal plane.

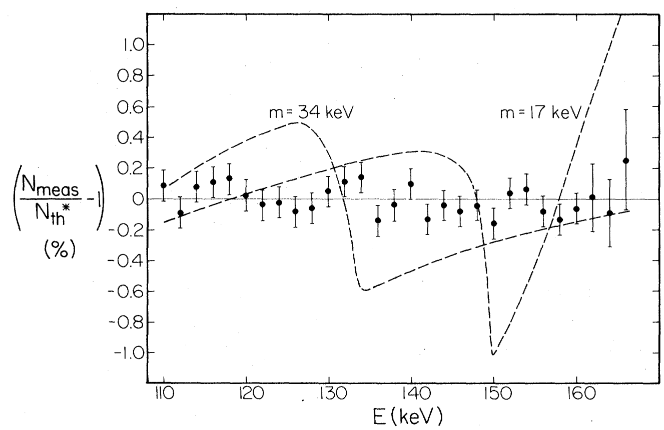

FIG. 2. Experimental results for ^{35}S. The horizontal line corresponding to $|U|^2 = 0$ fits the data best. The dashed curves illustrate the expected results for the case of an admixture of $|U|^2 = 0.03$, for neutrino masses of 17 and 34 keV.

well with the horizontal line

$$[N_{\mathrm{meas}}/N^*_{\mathrm{th}}(|U|^2=0)]-1=0 \ .$$

The dashed curves,

$$[N^*_{\mathrm{th}}(m=17,\ |U|^2=0.03)/N^*_{\mathrm{th}}(|U|^2=0)]-1$$

and

$$[N^*_{\mathrm{th}}(m=34,\ |U|^2=0.03)/N^*_{\mathrm{th}}(|U|^2=0)]-1 \ ,$$

indicate where the data are expected to lie for the case of a 3% admixed neutrino with $m=17$ and 34 keV, respectively.

The expected spectrum is determined using the theoretical spectrum, $N_{\mathrm{th}}(p)$, with a neutrino admixture,

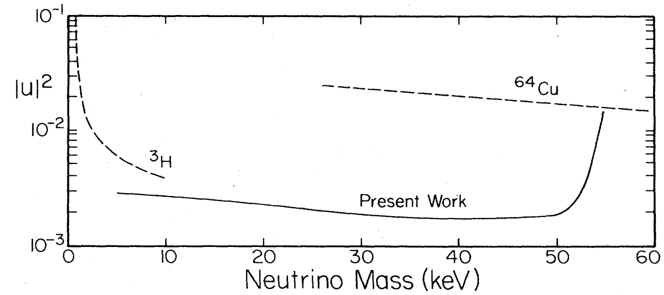

FIG. 3. Upper limits (90% confidence limit) for heavy neutrino admixture from the present experiment and from previous work (see Ref. 2).

$$N_{\mathrm{th}}(p)=Ap^2(E_0-E)^2dp\{1-|U|^2+|U|^2[1-(m^2)/(E_0-E)^2]^{1/2}\}FGS \ ,$$

convoluted with the spectrometer response function measured with the ^{139}Ce source to give $N^*_{\mathrm{th}}(p)$. Here $p^2(E_0-E)^2dp \sim p^3(E_0-E)^2$ is the usual phase space factor for zero neutrino mass as observed in a magnetic spectrometer, F is the Fermi function obtained from a relativistic Hartree-Fock calculation,[4] including nuclear finite size and electron screening, G is the radiative correction,[5] and S is a shape factor assumed to be unity. The quantity A is a normalization constant.

Fits were made of N^*_{th} to N_{meas} treating $|U|^2$ and E_0 as free parameters for various values of m. The results are given in Fig. 3 as a 90% confidence limit contour line. For the case of $m=17$ keV we find the best fit for $|U|^2=0$ with $\chi^2=1.07$ per degree of freedom, and $E_0=166.93\pm0.2$ keV, in agreement with the literature value[6] of $E_0=166.8\pm0.2$ keV. A mixing coefficient of $|U|^2=3\%$ (Ref. 1) gives rise to a value of $\chi^2=11.7$. At the 90% confidence limit our data allow setting a limit for the mixing coefficient of $U^2<0.25\%$.

In conclusion, we find no evidence for heavy neutrino admixture in the range $5<m<55$ keV. In particular, the heavy neutrino proposed in Ref. 1 cannot be confirmed. As this work was in progress we learned of similar experiments at Princeton[7] and at Tokyo[8] with similar results. It should be noted that the beta spectrum from the Princeton spectrometer showed an extraneous shape factor necessitating a linear and quadratic correction term in the amount of 1.3% over the energy region studied. No such correction ($<0.1\%$) was necessary in the present work.

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