Experimental search for a heavy neutrino at a nuclear reactor

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The results of an experimental study of the reaction $\bar{\nu}_e + p \rightarrow n + e^+$ in the flux of $\bar{\nu}_e$'s from a nuclear reactor at the Rovno nuclear power plant yield a limitation on the mixing parameter of a heavy neutrino: $|U_{eH}|^2 < 0.02$ (at a 68% confidence level).

The results found in measurements of the energy spectra of β electrons have been a topic of discussion in the literature since 1985. In the papers reporting those studies, it was stated that the electron neutrino ν_e contains an admixture of a state with a mass of about 17 keV. This admixture of a heavy neutrino ν_H is manifested in anomalies which are observed, in the opinion of the authors,[1–6] in measurements of β spectra by semiconductor detectors with the isotopes H^3 (Refs. 1 and 2), S^{35} (Refs. 3 and 4), Ge^{71} (Ref. 5), and C^{14} (Ref. 6). The size of the ν_H-state component estimated in those papers corresponds to a value of the mixing parameter in the range

$$|U_{eH}|^2 \cong 0.01 - 0.03 . \tag{1}$$

In contrast, the results of experiments on the isotopes S^{35} (Refs. 7–9) and Ni^{63} (Ref. 10), carried out with magnetic spectrometers, do not confirm distortions in the electron spectra due to a mixing of neutrinos, at a limitation level $|U_{eH}|^2 < 0.005$ for a mass $m_\nu \simeq 17$ keV.

This discrepancy in the experiments means that it is not yet possible to draw final conclusions regarding a neutrino with a mass of 17 keV. It is thus worthwhile to study other possible experimental manifestations of heavy neutrinos. We have accordingly carried out a reactor experiment at the Rovno nuclear power plant.[12] Specifically, the experiment was carried out to measure the cross section for the reaction

$$\bar{\nu}_e + p \Rightarrow n + e^+. \tag{2}$$

The $\bar{\nu}_e$ flux from the reactor is generated through the β decay of fission fragments of the nuclear fuel. If the electron antineutrino is represented as a superposition of mass states with a small admixture of a heavy neutrino, then there could be oscillations in the $\bar{\nu}_e$ flux. For the typical energies of the reactor antineutrinos, $E_\nu < 10$ MeV, and for the typical difference between the squared masses of the neutrino states, $\Delta m^2 \simeq (17\ \text{keV})^2$, the length of the oscillations would be

$$L_{\text{osc}} = 2.5 \times 10^{-4} (\text{cm}) \frac{E_\nu (\text{MeV})}{\Delta m^2 (\text{keV})^2} < 10^{-5}\ \text{cm}.$$

We thus see that the value of L_{osc} is considerably smaller than the dimensions of the reactor in which the $\bar{\nu}_e$'s are produced, and the oscillations are averaged over the dimensions of the source.

Bilenky *et al.*[11] have shown that under some fairly general assumptions the probability that an electron antineutrino which has been emitted will still be in the same state at the point at which it is detected is

$$P(\bar{\nu}_e \to \bar{\nu}_e) = 1 - 2|U_{eH}|^2. \tag{3}$$

They also showed that the $\bar{\nu}$ flux which is observed will be smaller than that expected in the absence of an admixture of a heavy neutrino. A neutrino experiment at a reactor would thus have a certain sensitivity to the mixing parameter. The latter can be determined from the relation

$$|U_{eH}|^2 = \frac{1}{2}|1 - X|, \tag{4}$$

where X is the ratio of the intensity of experimentally observed interaction (2) to that which would be expected in the absence of oscillations.

The following ratio was found from the measurements carried out at the nuclear reactor of the Rovno power plant:[12]

$$X = 0,993 \pm 0.035. \tag{5}$$

Most of the error in the ratio X stems from the error in the thermal data from the measurements of the reactor power (2%), the error in the measurement of the detector characteristics (1.2%), the statistical error (1%), and the error in the calculation of the cross section σ^{theo} for reaction (2).

The value of σ^{theo} was calculated in the standard *V–A* model of the weak interaction, through a summation of the probability for the capture of monoenergetic $\bar{\nu}_e$'s by a proton over the spectra of reactor antineutrinos. These calculations made use of a theoretical analysis[13] of reaction (2) and the $\bar{\nu}_e$ spectrum from Refs. 14–16. The $\approx 2\%$ error in σ^{theo} stems from the error in the energy spectrum of the $\bar{\nu}_e$'s from the reactor. There is a further uncertainty in the calculations because of the uncertainty in the value of the combination of weak constants $G_V^2 + 3G_A^2$. This combination can be determined within an error of 0.2–0.4%, either from measurements of the lifetime of a free neutron[17] or by an independent method based on data on superallowed $0^+ \to 0^+$ β transitions[18] and angular correlations in the neutron decay.[19] Despite the high accuracy, the results found by these two methods differ by more than 1%. This discrepancy has recently become the topic of a separate discussion (Ref. 20, for example). In the present letter we use an unweighted average value with an error of 0.8%, which includes both results.

From the value found for the ratio, (5), we find a limitation on the mixing parameter for a heavy neutrino:

$$|U_{eH}|^2 < 0.02 \text{ (68\% CL)}. \tag{6}$$

This result narrows the range of $|U_{eH}|^2$ reported in Refs. 1–6 [see (1)] and shows that the sensitivity of the reactor experiment reached a level suitable for a search for an admixture of a heavy neutrino.

Improving the sensitivity will require refining the method for monitoring the reactor and a more careful study of the spectral composition of the neutrinos emitted from the fission reactor. Progress in this direction could also be made by carrying out experiments at other reactors, of the same type as the VVÉR reactor of the Rovno nuclear power plane (a pressurized light water reactor), by the high-precision measurement procedure described in Ref. 12. Comparison of the results of the additional experiments and improvements in the reliability of the calculation of the cross section expected for reaction (2) will make it possible to improve the sensitivity to the heavy-neutrino mixing parameter by a factor of 1.5 or 2.

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