Search for massive neutrinos at the Rovno nuclear power station reactor

V. I. Kopeĭkin, L. A. Mikazlyan, and S. A. Fayans
I. V. Kurchatov Institute of Atomic Energy, Academy of Sciences of the USSR, Moscow

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A scintillation neutrino spectrometer with a working volume of 1050 liters placed 18 m from the Rovno nuclear power station reactor is used to search for a heavy neutrino in the decay $\nu_H \to \nu_L + e^+ + e^-$. New limits are obtained on the neutral lepton mixing parameter.

If neutrinos of different generations $(\nu_e, \nu_\mu, \nu_\tau)$, create in weak processes with a definite lepton number, are represented as a superposition of states with different masses, e.g.,

$$\nu_e = \nu_L \cos\theta + \nu_H \sin\theta, \quad \nu_\chi = -\nu_L \sin\theta + \nu_H \cos\theta \tag{1}$$

(where ν_L are light neutrinos, ν_H are heavy neutrinos, and $\chi = \mu, \tau$), then, in addition to oscillations $\nu_e \rightleftarrows \nu_\chi$, decays $\nu_H \to \nu_L$ become possible.

In the standard model, which unifies the weak and electromagnetic interactions, decay and oscillation are not possible, since in this model the neutrino mass is zero and their lepton number is strictly conserved. The observation of neutrino decay would imply the existence of a fundamentally new phenomenon lying outside the framework of the standard model.

The search for neutrino oscillations and for decay in the nuclear reactor complement one another in their search methods and in their areas of information in the mass and mixing angle.

In order to find $\tilde{\nu}_e \rightleftarrows \tilde{\nu}_\chi$ oscillations, one tries to observe the "disappearance" of $\tilde{\nu}_e$, created in the β decay of fission fragments. Recent experiments of Gösgen[1] and at the Rovno nuclear power station,[2] and in other reactors in the USSR[3] and in France and the United States[4] have permitted important advances into the region of extremely small values of the mass parameter $\delta m^2 = m_H^2 - m_L^2 \approx m_H^2$ (we assume that $m_H^2 \gg m_L^2$) for a relatively low sensitivity to the mixing angle.

The search for the decay is an experiment involving the appearance of the decay products of a heavy neutrino. This experiment is much more sensitive to the mixing angle, but only in the range of mass $m_H > 2m_e$, where the channel $\nu_H \to \nu_L + e^+ + e^-$ is open. According to a frequently discussed model,[5] the masses ν_H increase very rapidly from generation to generation, and at a few MeV/c^2 states related to the mixing of ν_e and ν_τ may exist.

The decay via the channel $\nu_H \to \nu_L + e^+ + e^-$ is described by the diagram of Fig. 1, for which the calculation gives the probability of decay of a neutrino at rest[6]

$$\lambda_H = 3.5 \cdot 10^{-5} (m_H/1\,\mathrm{MeV})^5 \sin^2\theta\, h(m_e^2/m_H^2)\,\mathrm{s}^{-1}, \tag{2}$$

where h is the dimensionless phase volume factor, which vanishes at the threshold $m_H = 2m_e$ and goes rapidly to unity with increasing m_H. For $m_H = 3$ MeV, for example, the lifetime of the ν_H turns out to be only about two minutes (for $\sin^5\theta = 1$).

One can show that the relative fraction of heavy neutrinos in the $\tilde{\nu}_e$ spectrum of the reactor is $(v/c)\sin^2\theta$, where v is the velocity of the ν_H, so that the effect expected in the detector is proportional to the fourth power of sin θq.

In the experiment we used the Rovno neutrino spectrometer, containing as a target a liquid organic scintillator of volume 1050 liters. In the operating reactor the flux of light $\tilde{\nu}_e$ of all energies at the detector was 6×10^{12} cm^{-2} s^{-1}, so that in the working volume there were about 10^8 $\tilde{\nu}_e$ of energy above 1 MeV. We measured the spectra of events detected in the range from 1 to 8 MeV with the reactor operating and with it shut down and constructed the difference spectrum of the effect $S^{\exp}(E)$, where E is the energy absorbed in the spectrometer. No statistically significant effect which

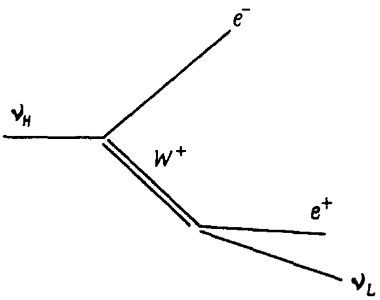

FIG. 1. Diagram of the decay $\nu_H \to \nu_L + e^+ + e^-$.

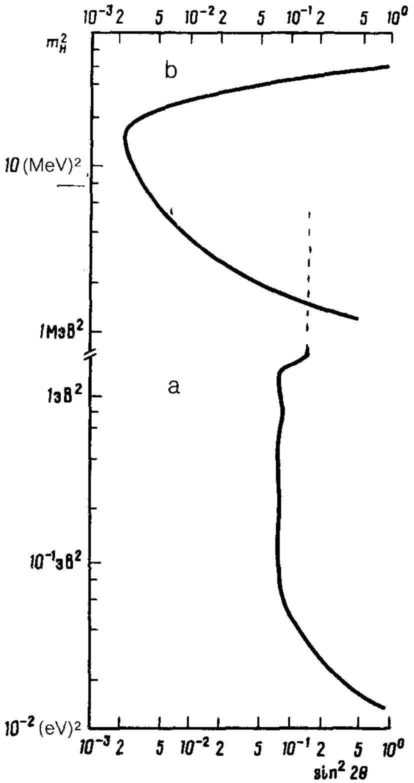

FIG. 2. Limits on the mass m_H of the heavy neutrino and the mixing angle θ (90% confidence level). The forbidden range of parameter values is to the right of the curves. a) From the results of the searchers for $\tilde{\nu}_e \rightleftarrows \tilde{\nu}_\chi$B oscillations in the experiments of Refs. 1–4. b) From the experiments looking for the decay $\nu_H \to \nu_L + e^+ + e^-$ (present work).

might be attributed to the decay of a neutrino was observed. To obtain limits on the mass and mixing angle, we calculate the "expected" effect $S^{\rm calc}(E, m_H \sin\theta)$, which was compared with the spectrum obtained in the experiment. In these calculations, in accordance with the kinematics of the decay, we found the distribution of energy imparted to an e^+, e^- pair and assumed that the annihilation photons remain in the spectrometer at an energy of 0.7 MeV. We used the $\tilde{\nu}_e$ energy spectrum of the reactor, measured previously at the Rovno nuclear power station by inverse beta decay:[7] $\rho_R = 6.78\exp[-E_\nu/1.342) - (E_\nu/6.868)^2 - (E_\nu/8)^{10}]$ MeV^{-1} per fission.

The limits found are shown in Fig. 2b. For convenience of comparison with the results of experiments designed to find $\tilde{\nu}_e \rightleftarrows \tilde{\nu}_x$ oscillations (Fig. 2a), we used the coordinates m_H^2, and $\sin^2 2\theta$. Experiments previously carried out in Gösgen to detect the decay $\nu_H \rightleftarrows \nu_L + e^+ + e^-$ were not as sensitive as ours, mainly because of the smaller volume of the scintillator, the lower $\tilde{\nu}_e$ flux, and the less effective shielding of the detector from external background. A comparison of the data shown in Figs. 2a and 2b suggests that the limits on the mixing angle in our experiment are much more stringent than in experiments involving the disappearance of $\tilde{\nu}_e \rightleftarrows \tilde{\nu}_\chi$.[1–4]

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