Search for unusual events in a flux of reactor antineutrinos

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Several search experiments have been carried out in the flux of reactor antineutrinos at the Rovno nuclear power plant. Limitations are found on the specific $\tilde{\nu}_e$ energy loss in matter, on the production of axions in the reactor, on the probability for the decay $\nu_2 \rightarrow \nu_1 + \gamma$, and the effect of $\tilde{\nu}_e$ flux on the probabilities for β^+ and β^- decays.

Several search experiments have been carried out in the neutrino laboratory at the Rovno nuclear power plant.[1] The measurements were carried out in $\tilde{\nu}_e$ fluxes $\sim 3 \times 10^{12}$–3×10^{13} cm$^{-2} \cdot$s^{-1}.

1. ANOMALOUS NEUTRINO STOPPING MECHANISM

In the neutrino experiments which have been carried out by the scintillation method at reactors, the detection energy threshold has been set above 0.2–0.5 MeV. As a result, events with a small momentum transfer in $\nu - e$ interactions have been discarded. If an interaction which was very weak at a large momentum transfer q and which strengthened rapidly in the limit $q \rightarrow 0$ did occur between the $\tilde{\nu}_e$ and the electron, this circumstance might have remained unnoticed. As it passes through matter, an antineutrino $\tilde{\nu}_e$ might lose energy in small portions in the fashion of fast charged particles. On the other hand, the total energy lost per unit path length might be significantly larger than the value of 10^{-20}–10^{-21} (MeV/g)$\cdot$cm^2 which we would expect on the basis of the theory of the electroweak interaction or by virtue of the magnetic moment $\mu_\nu \sim 10^{-10} \mu_B$ (μ_B is the electron Bohr magneton).

The question of the possible existence of an energy-loss mechanism of this sort has been discussed previously in connection with the problem of solar neutrinos.[2,3]

In the present experiments we use an integrating method. The detector is a cesium iodide scintillating crystal with a mass of 9.3 kg.

The energy evolution in the crystal is determined from the output current of a photomultiplier as the $\tilde{\nu}_e$ flux is changed by an amount 6×10^{12} $cm^{-2}\cdot s^{-1}$. The photomultiplier current is calibrated with help of γ sources.

For the specific energy loss, the following limitation has been found:

$$j < 2\cdot 10^{-16}\,(MeV/g)\cdot cm^2.$$

This value is 10^{16} times lower than the ionization loss of a fast charged particle. The scale length over which the $\tilde{\nu}_e$ particles lose a significant fraction of their energy is therefore 5×10^{15} g/cm^2. This distance is 10^3 times greater than that corresponding to the path from the center of the sun to its periphery.

We might also note that if the characteristic energy loss in a single event were comparable to or lower than the ionization potentials of the cesium iodide, our method would lose sensitivity. In this case the energy loss might depend strongly on the electronic structure of the material.[2] It is therefore worthwhile to search for energy losses of $\tilde{\nu}_e$ in semiconductors and metals.

2. SEARCHES FOR UNSTABLE PENETRATING PARTICLES

Some 10^{21} nuclear conversions of various types occur each second in the reactor at the Rovno nuclear power plant. If hypothetical unstable particles which decay with the emission of γ rays are produced, then they might be detected under certain conditions by detectors in the experiment hall of the laboratory. For such a detection, the particles would have to have a lifetime which is not too short ($\tau_{lab}\geqslant 3\times 10^{-8}$ s), and they would to have a sufficient penetrating power (the shielding thickness is 1.5×10^4 g/cm^2). The mass of such particles apparently could not be much greater than ~ 1 MeV.

The question of the existence of a neutral pseudoscalar particle, the axion ($a\rightarrow 2\gamma$), has been discussed repeatedly in recent years. This particle was introduced in Refs. 4 and 5 in connection with the problem of CP violation. Another candidate for the role of this particle is the neutrino itself; the question of the decay of the neutrino ($\nu_2\rightarrow\nu_1+\gamma$) was raised in connection with the deficiency of solar neutrinos[6] and was recently discussed in Ref. 7. Our search for such particles was carried out at a distance of 18 m from the reactor with the help of an $\tilde{\nu}_e$ scintillation spectrometer[8] containing 238 liters of an organic scintillator and cesium iodide scintillating crystals. In the experiments, we measured the energy spectra over the range 1–4 MeV with the reactor in operation and shut down. We observed no effects of any sort associated with the operation of the reactor.

In the most model-independent form, the limitations which were found can be expressed as a ratio of two quantities: η, which is the particle production probability per fission event, and τ_{lab}, the lifetime in the laboratory frame:

$$\eta/\tau_{lab} < 5\times 10^{-8}\ \text{fission}^{-1}\cdot s^{-1}. \quad (1)$$

For neutrinos ($E_\nu\geqslant 2$ MeV, $\eta\simeq 1$), under the assumption $m_{\nu_2}\gg m_{\nu_1}$ we find the estimate $\tau_{lab}\geqslant 2\times 10^7$ s for the lifetime, so that the product $c\tau_{lab}$ is 4×10^3 times greater than the distance from the sun to the earth. A more accurate analysis allowing for the $\tilde{\nu}_e$ spectrum and the kinematics of the decay yields the intrinsic lifetimes

$$\tau_0 / m_\nu > 30 \text{ s/eV (Dirac neutrinos)},$$

$$\tau_0 / m_\nu > 20 \text{ s/eV (Majorana neutrinos)}.$$

In the case of the axion, we can add details to estimate (1), making use of the relationship between its mass and its lifetime: $\tau^a_{\rm lab} \simeq 15 \times (100 \text{ keV}/m_a)^6$ (Ref. 9) for an axion with an energy ≈ 2 MeV.

We then find a limitation on the axion production probability:

$$\eta_a < 0.8\left(\frac{100 \text{ keV}}{m_a}\right)^6 \times 10^{-16}, \text{ fission}^{-1}$$

so that, with $m_a \simeq 0.5$ MeV, for example, fewer than 10^{-10} a/fission would be produced. The most detailed estimates can be found in the model if the so-called standard axion,[9] which furnishes a quantitative relationship between the mass and the production probability of the axion in nuclear magnetic transitions. In that case, we have $m_a \geqslant 150$ keV. If we assume that the axions are produced in a reactor only during the capture of slow neutrons by hydrogen ($E_a = 2.2$ MeV), then at the minimum possible mass we would not see an effect with a 40-fold "margin."

3. EFFECT OF THE EXTERNAL $\tilde{\nu}_e$ FLUX ON THE PROBABILITY FOR β DECAY

There is no known factor which would case the probability for the β decay of a nucleus to change if this nucleus happened to be in a flux of reactor neutrinos[1], ν_e. Consequently, the experimental observation of such a change would require a radical reexamination of existing ideas. To the best of our knowledge, the effect has not previously been studied experimentally.

For the positron source ^{22}Na and the electron source ^{60}Co, a search was made for a relative change in the decay constant $\delta\lambda/\lambda$ as the external flux was increased and reduced by an amount $f_\nu \simeq 3 \times 10^{12}$ cm$^{-2}\cdot$s^{-1}. In the case of the comparatively short-lived isotope ^{24}Na ($T_{1/2} = 15.02$ h), the decay half-lives of two identical samples were measured. One sample had been exposed to a flux of 3.2×10^{13} cm$^{-2}\cdot$s^{-1}. In none of these cases did we observe an effect. These limitations can be characterized by the quantity $\alpha = (1/f_\nu)(\delta\lambda/\lambda)$, which has the dimensionality of (square centimeters) $\times$seconds. We would then have $|\alpha| < 1.6 \times 10^{-15}$ for ^{60}Co and ^{22}Na and $|\alpha| < 3 \times 10^{-16}$ for ^{24}Na.

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[1] We are ignoring effects associated with the reaction $\tilde{\nu}_e(Z,Z+1)\beta^+$, which increases the rate of β^+ conversions, and effects associated with the Pauli principle, which would reduce the rate of β^- decay; these effects are totally negligible under the conditions of this experiment.

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