объединенный
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исследований
дубна

E2-84-153

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REACTOR EXPERIMENTS AND SOLAR NEUTRINO PROBLEM

Sumbitted to "Letters Nuovo Cimento"

1984

Finite neutrino masses and neutrino oscillations have been hypothesized for a long time, and various types of related experiments have been proposed /1/ . These are performed now at accelerator /2-5/ and reactor /6-8/ facilities and also with the help of cosmic atmospheric /9/ and solar neutrinos /10/. Yet, the situation is by no means clear.

The ITEF recent result /11/ that the antineutrino mass is larger than 20 eV is extremely important. It must be confirmed, of course, as any experiment of such a significance should be, and, as a matter of fact, experiments on the ^3H decay are being performed by various groups /12/.

Oscillation experiments can be successful if the oscillation lengths are adequate, that is, if they are smaller of or comparable with the distance between the neutrino source and neutrino detector. This condition being fulfilled, there is a big difference between reactor (and accelerator) experiments, where even a small oscillation amplitude may be revealed, and solar neutrino experiments, where a relatively large amplitude of oscillations is detectable.

Below we will discuss a type of situation in support of which there are some hints:

i) The mass of electron antineutrinos is about 30 eV /11/; as is well known, a value of the neutrino mass of such an order is very desirable from a cosmological and astrophysical point of view /13/.

ii) The detectable flux of solar electron neutrino (I_{ν_e} = = 1.8 ± 0.3 SNU) is significantly smaller than that expected under the hypothesis that no oscillations take place /10/ ($I^0_{\nu_e}$ = 7.6 ± 3.3 SNU); this implies /14/ that $|m_i^2 - m_k^2| \gtrsim 10^{-12} eV^2$ (m_i and m_k are the masses of the corresponding neutrino mass eigenstates);

iii) There might exist /8/ oscillations of reactor antineutrino intensity with one period, corresponding to $\Delta m^2 \simeq 1$ eV^2 and with a small amplitude ($\simeq 0.1$). By the way in ref. /6/ among the possible solutions with oscillations there is one solution given in terms of $\Delta m^2 = 0.6$ eV and $\sin^2 2\theta = 0.1$, where $\sin^2 2\theta$ is the amplitude.

Now the above points are in principle well reconcilable from a phenomenological point of view. Of course, we do not imply that our arguments below support points i), ii), iii). We simply consider a situation which may arise in future experiments.

From point i) at the present stage of the experiments it is not possible to make any conclusion on oscillations and their amplitudes. Point ii) would indicate large oscillation amplitudes.

At distances typical of reactor neutrino oscillation experiments point iii) has the only effect of changing slightly the intensity of electron antineutrinos.

We may imagine a scenario in which there is a group of n-1 neutrino masses $m_1 < m_2 < \ldots < m_{n-1}$ very close to each other and around, let us say, 30 eV and one mass m_n such that $|m_n^2 - m_1^2| \simeq 1 eV^2$ We assume that the masses $m_1, m_2, \ldots m_{n-1}$ are so close that no oscillation lengths connected with their mass differences will appear, which are adequate in reactor (or accelerator) experiments. Under such conditions the intensity of reactor antineutrinos $I_{\bar\nu_e}(E,R)$ with energy E at a distance R from the reactor is given by the following expression, well approrriated for the point iii):

$$I_{\bar\nu_e}(E,R) = [1 - 2|U_{en}|^2(1 - |U_{en}|^2)(1 - \cos\frac{(m_n^2 - m_1^2)R}{2E})] I^0_{\bar\nu_e}(E,R) . \qquad (1)$$

Here $I^0_{\bar\nu_e}(E,R)$ is the intensity of $\bar\nu_e$ expected in the absence of oscillations, the neutrino mixing being given by the standard expression

$$\nu_{\ell L} = \sum_{i=1}^{n} U_{\ell i}\, \nu_{iL} , \qquad (2)$$

where ν_i is the neutrino (either Dirac or Majorana) field of mass m_i, U is an unitary mixing matrix.

Let us note that the relation (2) refers to the case when sterile neutrino states are absent as well as to the case when such states are present. Of course in the first case the number of massive neutrinos n is equal to the number of charged leptons, whereas in the second case it may be twice as large /15/.

We consider now solar neutrinos and put the question: how the usual picture of solar neutrino oscillations /1,14/ would be modified by the circumstance that one period of oscillations with a small amplitude has been observed in reactor (or other artifical neutrino) experiments. In the discussion of the solar neutrino experiments, one is usually considering the maximum decrease of the detectable neutrino intensity with respect to intensity expected in the absence of oscillations.

It is then assumed that all the oscillation lengths are more than adequate (all cosinusoidal terms disappearing on averaging) and the mixing is maximum. The maximum mixing corresponds to equal values of the moduli of the matrix elements of the matrix U. We have

$$I_{\nu_e} = \delta I^{\circ}_{\nu_e}, \tag{3}$$

where I_{ν_e} and $I^{\circ}_{\nu_e}$ are the solar neutrino fluxes detectable and expected in the absence of oscillations and

$$\delta = \sum_{i=1}^{n} |U_{ei}|^4 . \tag{4}$$

For maximum mixing, as is well known [14,15], the value of δ is equal to

$$\delta_{\min} = \frac{1}{n} . \tag{5}$$

In the case we are interested in when we know $|U_{en}|^2$ from reactor experiments, the maximum intensity decrease corresponds to

$$\delta_{\min} = \frac{(1-|U_{en}|^2)^2}{n-1} + |U_{en}|^4 . \tag{6}$$

If $|U_{en}|^2 \ll 1$ we have

$$\delta_{\min} \simeq \frac{1}{n-1} \tag{7}$$

as is to be expected. What do equations (6) and (7) mean from a practical point of view? Suppose, we have three types of weak-interacting neutrinos and no sterile states. The maximum decrease of the neutrino solar flux to be expected in this case is two and not three (as it would be expected according to (5)). If there are oscillations to sterile states, the mass eigenstates are six Majorana neutrinos [15] and the maximum decrease is now five (instead of six). Clearly the interest in further solar neutrino experiments (Ga – Ge, ...) would certainly not decrease if reactor (or accelerator) experiments demonstrate the existence of low amplitude neutrino oscillations.

Few further remarks are appropriate.

1. The full body of other information on the problem at issue also does not contradict the above picture. As a matter of fact, in addition to the papers which give hints for points i), ii) and iii) we have in mind the limits on the oscillation parameters obtained in ref. [2-7] and the limits on the probabilities on neutrinoless double β-decay [16].

2. In principle, the close masses $m_1, m_2, \ldots m_{n-1}$ might be placed not only at the 30 eV ITEP mass value but at smaller values (including zero). If they were crowded around 30 eV, mass difference $|m_n - m_1|$ would be only about 10^{-2} eV. If the masses $m_1, m_2, \ldots m_{n-1}$ were closed to zero, then $|m_n - m_1| \simeq 1$ eV.

3. If one oscillation corresponding to a definite value of Δm^2 and a small amplitude were observed in reactor experiments, our scenario would make it probable that in accelerator oscillation experiments one would see the same value of Δm^2 but not necessary the same amplitude.

4. The present note is not meant to be an argument in favour of the above points i), ii) and iii). It is rather a way of thinking about solar neutrino investigations which would be appropriate, should some reactor (or accelerator) experiments indicate the presence of a small amplitude oscillation. As far as maximum amplitude oscillations of very large lengths are concerned, conditions for their existence based on plausible symmetry requirements have been discussed in ref. [17].

5. It is easy to extend our consideration on solar neutrino experiments to the more general case when it is known that in reactor (or accelerator) experiments more than one small amplitude oscillations have been observed; for example in the case of two small amplitude oscillations the maximum decrease of detectable solar neutrino intensity corresponds to $\delta_{\min} \simeq 1/(n-2)$. Under the assumption that in solar neutrino experiments only maximum amplitude oscullations can be revealed this would mean that, for example if $n = 3$, solar neutrino oscillations are detectable only if there exist sterile states.

In conclusion we would like to thank warmly V.Khovansky for useful discussion of the latest reactor data.

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Реакторные опыты и проблема солнечных нейтрино

Обсуждается вопрос о том, какое /обусловленное осцилляциями нейтрино/ максимальное уменьшение потока нейтрино от Солнца было бы в случае, если в реакторных /или ускорительных/ экспериментах наблюдались бы осцилляции нейтрино с малой амплитудой.

Работа выполнена в Лаборатории ядерных проблем ОИЯИ.

Препринт Объединенного института ядерных исследований. Дубна 1984

Bilenky S.M., Pontecorvo B. E2-84-153
Reactor Experiments and Solar Neutrino Problem

The question about the maximum decrease of the detectable solar neutrino flux, related to neutrino oscillations, is discussed for the case when reactor (or accelerator) experiments indicate the presence of small amplitude oscillations.

The investigation has been performed at the Laboratory of Nuclear Physics, JINR

Preprint of the Joint Institute for Nuclear Research. Dubna 1984