Scientific Session of the Division of General Physics and Astronomy of the Russian Academy of Sciences (25 March 1992)

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A scientific session of the Division of General Physics and Astronomy of the Russian Academy of Sciences was held on 25 March 1992 in the P. L. Kapitsa Institute for Physics Problems. The following reports were presented at the session:

1. *L. A. Khalfin.* Fate of the universe and the heavy 17-keV neutrino.

2. *V. I. Kudinov and N. M. Kreĭnes.* Metastable photoinduced superconductivity in $YBa_2Cu_3O_{6.4}$ films near the semiconductor-metal transition.

A brief summary of the reports is given below.

L. A. Khalfin. *Fate of the universe and the heavy 17-keV neutrino.*

1. In 1985, J. Simpson reported[1] that he discovered in an investigation of the β-spectrum in the decay of tritium a small ($\approx 3\%$) admixture of a heavy neutrino with a mass of 17 keV to the standard electron-neutrino ν_e. In the same year negative results and criticism of Simpson's work were also published. In 1989, however, J. Simpson and A. Hime published two papers[2] in which they disputed the critical remarks and, moreover, reported new experiments confirming the existence of a 17-keV neutrino in the β-decay of tritium and ^{35}S, but, it is true, with a smaller admixture ($\approx 0.7\%$). The most accurate data for ^{35}S (Ref. 3) gave for the mixing ratio $\sin^2\theta = 0.085 \pm 0.006 \pm 0.005$. In 1990, E. Norman's group reported[4] results which agreed with these data, and what is significant, for a different nucleus (^{14}C) as well as less certain results from an investigation of internal conversion for ^{55}Fe. At the same time, primarily in studies performed with the help of magnetic β-spectrometers, the results for ^{35}S were not confirmed and lower values were obtained for $\sin^2\theta$. A quite complete bibliography of the experimental publications is given in Refs. 5 and 6. The latest results, both positive and negative, were reported at the conference on the problem of the 17-keV neutrino held in Berkeley in December 1991.[7]

2. The existence of such a heavy neutrino (17 keV) seems to be problematic from the standpoint of modern cosmologies, astrophysics, and elementary-particle physics. Positive confirmation of the existence of this neutrino would definitely point toward new physics and, if this neutrino had certain properties, toward new cosmology beyond the Big Bang. The problem is that modern data impose certain restrictions on the properties of the 17-keV neutrino (see, for example, Refs. 5 and 8 and the reports in Ref. 7): A. Cosmology: a) estimate of the age of the universe; b) properties of the relic radiation. B. Astrophysics: a) energetics of the SN 1987 supernova explosion and the neutrino flux; b) properties of red giants; c) density fluctuations and structure formation; d) relic nucleosynthesis; e) the problem of solar neutrinos. C. Elementary-particle physics: a) neutrino mass; b) neutrino oscillations; c) width of the Z^0 boson; d) neutrino-free double β-decay; e) exotic superlight particles (axions, majorons, etc.). Of these restrictions, the most model-independent ones are A a) and b). Namely, using only estimates of the age of the universe (see the absolute estimate[9] obtained by the method of nucleochronology) and the fundamental assumption of modern cosmology concerning the Big Bang, it is concluded (see Ref. 8 for the details) that the 17-keV neutrino should be unstable and its lifetime should be $\leqslant 10^{12}$ sec. Here it is significant that this restriction does not depend on the mixing ratio $\sin^2\theta$. From modern data[10] on the Planck spectrum of the relic radiation, on the basis of the Big Bang cosmology, it follows[8] that the probability of radiative decay of the 17-keV neutrino is $\leqslant 4\cdot 10^{-5}$. According to these two fundamental restrictions, no experiment that has been performed so far is sufficient for solving the problem of the 17-keV neutrino, because none of these experiments gives information about the lifetime of the 17 keV neutrino and the probability of its radiative decay. From this standpoint the negative results only decreased the estimate of $\sin^2\theta$ obtained from the positive results. Other experimental tests are required in order to solve the problem of the 17-keV neutrino (see Sec. 5).

From other, not so absolute, but model estimates, following from astrophysics (B) and elementary-particle physics (C), it follows (Refs. 5 and 8, the publications cited there, and the reports in Ref. 7) that 1) the 17-keV neutrino is a majorana-neutrino, mainly coupled with the ν_τ-neutrino; 2) the μ-meson-neutrino ν_μ is also a majorana neutrino with a mass of either almost 17 keV or in the range 190–220 keV. In this connection the solution of the problem of solar neutrinos by the Mikheev–Smirnov–Wolfenstein effect presupposes the existence of a sterile light neutrino.

3. All currently known experiments on the observation of a 17-keV neutrino are indirect experiments, that is, experiments in which a "kink" (break) is observed in the energy distribution of the electrons in β decay. The kink corresponds to a discontinuity of $d^3N(E)/dE^3$ at the point $E = E_m$ (determined by the mass of the 17-keV neutrino) of the theoretical β spectrum $dN(E)/dE$. The derivative $dN(E)/dE$ is, in turn, related with the experimentally measured spectrum $d\widetilde{N}(E)/dE$ by the integral equation

$$\frac{d\widetilde{N}(E)}{dE} = \int K(E, E')\frac{dN(E')}{dE'}dE', \qquad (1)$$

where $K(E,E')$ is the response function of the spectrometer. Thus the problem of observing a kink in the β spectrum reduces to two inverse problems: a) finding as a solution of Eq. (1) $dN(E')/dE'$ from $d\widetilde{N}(E)/dE$ with known $K(E,E')$

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and b) determining the discontinuity of $d^3N(E')/dE'^3$ from the theoretical β spectrum $dN(E')/dE'$ found in step a). Both problems are typical improperly posed problems (according to Hadamard) and can be investigated on the basis of the statistical approach to the solution of improperly posed problems (see Ref. 11 and the references cited there). In all known experiments the direct problem was actually solved: assuming a definite parametric form for $dN(E')/dE'$, the parametric dependence $d\tilde{N}(E)/dE$ was calculated according to (1) and then the desired parameters (in particular, the mass and mixing ratio of the 17-keV neutrino) were estimated from the experimentally determined $d\tilde{N}(E)/dE$. This approach is obviously suboptimal from the viewpoint of the statistical approach.

4. The parametric form of $dN(E)/dE$ was determined, in particular, according to the standard theory of mixing of neutrinos. This theory is based (see, for example, Ref. 12) on the assumption that the mass states of the neutrinos are stable. As we have already underscored, modern cosmology rejects this possibility and the theory of neutrino mixing must be constructed for unstable neutrinos. This was done in Ref. 13, where the results of the general theory of a multilevel unstable physical system with breaking of a discrete symmetry were employed (see Ref. 14 and the references given there to earlier publications). The new mixing theory predicts new effects, whose strength is proportional to the overlapping of the mass distributions of the unstable neutrinos, which, in particular, in the case when the ν_μ and ν_τ masses are degenerate (see Sec. 3), is not small. In the standard mixing theory the phenomenological mixing ratio $\sin^2\theta$ is an independent parameter. In the new theory, however, the mixing ratio is not arbitrary and is limited by the unitarity relation (the analog of the Bell-Steinberger unitarity relations). It is significant that this unitarity relation was derived without using the Weisskopf-Wigner (W.-W.) approximation, and it shows that the mixing ratio is very sensitive to the tails of the mass distributions, and not only to the masses and widths, as in the W.-W. approximation.

5. It is natural to consider direct methods for solving the problem of the existence of the 17-keV neutrino and checking its expected properties (see Sec. 3): 1) experiments on oscillations of neutrinos of different flavors and 2) measurement of the momentum of the daughter nucleus in β decay, which would make it possible to reduce the three-particle problem of β decay to a two-particle problem (see the reports Refs. 15 and 16). According to Ref. 17, the necessary experiments on oscillations are expected no earlier than 1995; implementation of the second method is no less problematic. In Ref. 18 a surprising method is proposed for investigating neutrino physics, in particular, neutrino oscillations: investigation of the nonexponential terms[19] in the decay laws of β-active nuclei as well as unstable particles (for example, π and K mesons), whose decay products include neutrinos. We present one result for the decay law $L(t)$ for $\pi\rightarrow\mu+\nu_\mu(|\nu_\mu\rangle=\sqrt{a_1}|\nu_1\rangle+\sqrt{a_2}|\nu_2\rangle+\sqrt{a_3}|\nu_3\rangle$, $a_1+a_2+a_3=1$, $m_1\leqslant m_2\leqslant m_3$):

$$L(t)\approx\exp[-2\Gamma m_\pi+(m_\pi^2+p^2)^{-1/2}]$$

$$+\frac{2}{\pi}\frac{1}{t}\exp[-\Gamma m_\pi+(m_\pi^2+p^2)^{-1/2}$$

$$\times\sum_{i=1}^{3}\frac{a_i\Gamma}{(m_\pi-m_\mu-m_i)^2+\Gamma^2}\sin\left(\frac{m_\pi^2-m_\mu^2-2m_\mu m_i-m_i^2}{2p}t\right)$$

$$+\frac{2}{\pi^2}\frac{1}{t^2}\sum_{i\neq j}^{3}\sum^{3}\frac{\Gamma^2a_ia_j}{[(m_\pi-m_\mu-m_i)^2+\Gamma^2][(m_\pi-m_\mu-m_j)^2+\Gamma^2]}$$

$$\times\cos\left[\frac{(m_i-m_j)(m_i+m_j+2m_\mu)}{2p}t\right].\qquad(2)$$

In Eq. (2) p is the momentum of the π meson, m_π and m_μ are the masses of the π and μ mesons, and $(2\Gamma)^{-1}$ is the lifetime of the π meson. This expression holds for $t\geqslant 2/(m_\pi-m_\mu-m_1)$, and the standard nonexponential terms of order t^{-2}, not containing oscillation factors, have been dropped. Terms containing sin in Eq. (2) would make it possible to determine the neutrino masses m_i (as an alternative to the second method), while terms containing cos reproduce the oscillation terms (as an alternative to the first method). Although these nonexponential terms are small, detection of the decay law $L(t)$ requires only detectors for the nuclei and strongly interacting particles; no very complicated detectors for weakly interacting neutrinos are required. The expression (2) was derived for stable neutrinos. For unstable neutrinos it follows that the expression (2) is not valid for $t\gg t_{cr}$, where t_{cr} is determined by the lifetime of the neutrino. A more accurate expression for $L(t)$ can be obtained[20] on the basis of the theory of cascade decay[21] beyond the W.-W. approximation. This expression makes it possible to obtain information not only about the neutrino lifetime but also about the amplitudes of neutrino decay, in particular, into decay channels with exotic superlight particles, without directly detecting these decay channels.

6. If the lifetime of the 17-keV neutrino turns out to be less than 10^{12} sec, then the existence of this neutrino will make it necessary to go beyond the standard theory of elementary particles, but it will not affect the Big Bang cosmology. If, on the other hand, the lifetime of the 17-keV neutrino turns out to be greater than 10^{12} sec and (or) the probability of its radiative decay turns out to be greater than $4\cdot10^{-5}$, then the Big Bang cosmology is incorrect, i.e., our ideas about the past, present, and future of the universe are wrong. All depends on the results of future experiments: There are no theoretical laws absolutely forbidding the existence of a 17-keV neutrino.

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