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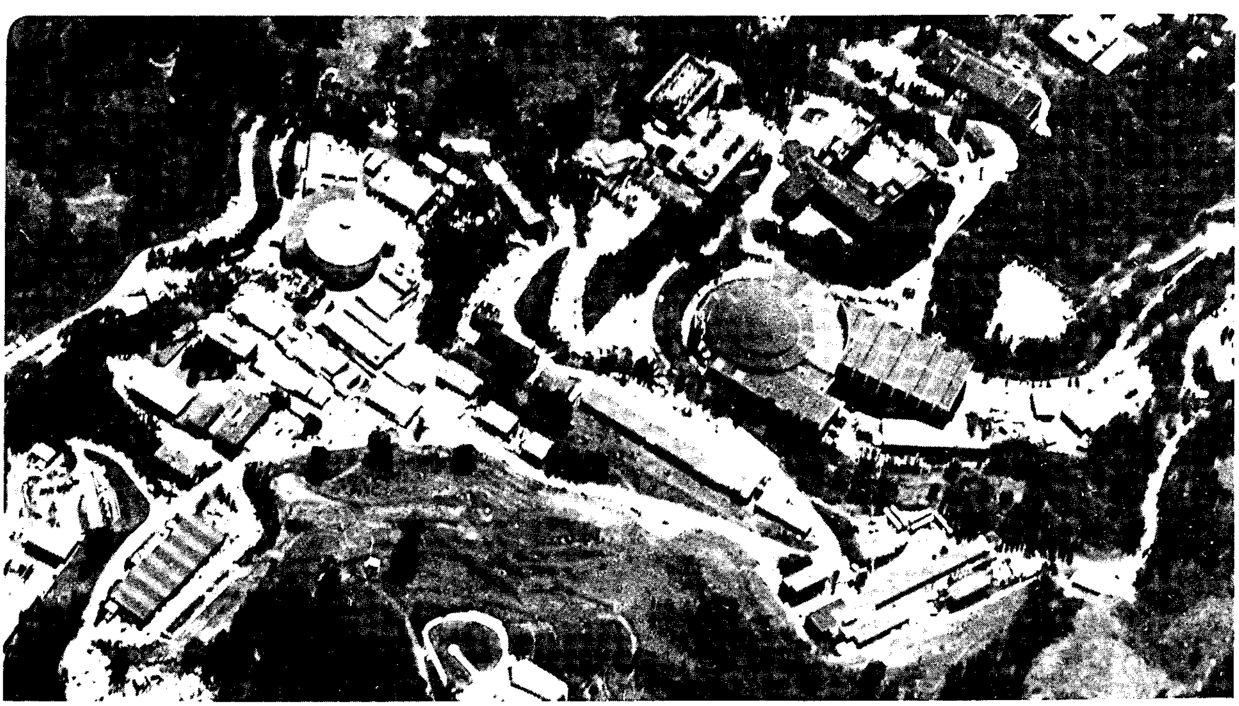

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NEUTRINO MASS *

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ABSTRACT

An introduction is given to the search for evidence of neutrino mass.

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‡This is a very–highly abbreviated version of the talk given at the Conference, meant primarily to call attention to the new developments mentioned in the talk, and to give references to some of the neutrino mass literature.

From the standpoint of the grand–unified theories, it is natural for neutrinos to have non–zero masses.[1] However, we know experimentally that, at most, the neutrino in each generation is much lighter than the associated charged lepton and quarks. The most popular explanation of this relative lightness is the "see–saw mechanism." This predicts that each neutrino mass M_ν obeys a "see–saw relation" of the form $M_\nu M \approx$ [Typical quark or charged lepton mass]^2, where M is a very large mass scale. Very importantly, the see–saw mechanism also predicts that neutrinos are their own antiparticles. A recent variation of the see–saw picture is a model which is constructed to account for the observed lightness of the electron relative to the W boson, but which then automatically predicts the see–saw relation $M_{\nu_e} M \approx M_e^2$, where M is once again a heavy mass scale.[2]

Unfortunately, even if one accepts the see–saw mechanism, gauge theories do not predict neutrino masses in detail. Indeed, with reasonable variations of the parameters in the see–saw models, one can obtain neutrino masses from 10^{-11}eV to 10^{+11}eV. Considering how small the neutrino masses may be, it is important to try to find ways of observing them even if they are much less than 1eV.

The evidence concerning M_{ν_e} coming from studies of tritium beta decay is discussed in these Proceedings by Wilkerson. Interestingly, the upper limit on M_{ν_e} derived from studies of the arrival times of the neutrinos from supernova 1987A[3] is of the same order as the upper limits reported by several tritium experiments.

Evidence of neutrino masses smaller than 1 eV can be sought by searching for the flavor oscillation of neutrinos for which $L(km)/E(\text{GeV}) > 1$. Here L is the distance travelled by the neutrinos between production and detection, and E is their energy. Among the neutrinos with $L/E > 1$ are some of those produced in the atmosphere by cosmic ray protons, and detected in underground detectors. These cosmic–ray neutrinos are generated largely through the reaction [cosmic ray p] + [Air] $\rightarrow \pi + \ldots$, followed by $\pi \rightarrow \mu\nu_\mu$, and then by $\mu \rightarrow e\nu_e\nu_\mu$. (We shall not distinguish between a ν and a $\bar{\nu}$.) Obviously, this chain of reactions produces neutrinos in the ratio $\nu_\mu : \nu_e = 2 : 1$. Of course, if one does not detect all cosmic ray neutrinos, but only those in a certain energy range, then the ratio of detected muon neutrinos to detected election neutrinos need not be $2 : 1$, but one should be able to correct for this effect. Now, the Kamiokande–II collaboration has reported that the observed $\nu_\mu : \nu_e$ ratio does not agree with theoretical expectations.[4] For charged leptons produced by the cosmic ray neutrinos in the detector with momenta in the range (200 – 700) MeV/c, the observed anomaly is $R \equiv (\nu_\mu : \nu_e)_{observed}/(\nu_\mu : \nu_e)_{expected} = 0.5 \pm 0.1$.[5] *Conceivably*, this anomaly is due to neutrino oscillation. For example, it could be due to oscillation between ν_μ and ν_τ, with a large mixing angle, and with a neutrino mass (carried by a neutrino mass eigenstate) between 0.03 eV and 0.6 eV.[6] This mass is large enough to allow the neutrinos to oscillate between their production and detection, but not so large as to violate bounds from other experiments. It should be noted, however, that the theory of $(\nu_\mu : \nu_e)_{expected}$ is undergoing further analysis, and the value of R may change.[7]

With the discovery of the Mikheyev–Smirnov–Wolfenstein effect, we have learned that future observations of solar neutrinos may provide evidence for neutrino masses in the range between 10^{-4} eV and 10^{-2} eV. Such masses are, of course, even smaller than those probed by studies of cosmic ray neutrinos.

The most sensitive test of whether neutrinos are their own antiparticles remains the search for neutrinoless double beta decay, the nuclear process $(A, Z) \rightarrow (A, Z+2) + 2e^-$.[8] Barring exotic mechanisms, this process can occur only if neutrinos are their own antiparticles. Needless to say, it has not as yet been seen, although the somewhat related rare process $(A, Z) \rightarrow (A, Z+2) + 2e^- + 2\bar{\nu}$, which can occur whether or not neutrinos are their own antiparticles, has been seen in the laboratory.[9] The observation of neutrinoless double beta decay would imply not only that neutrinos are their own antiparticles, but also that at least one of them has a mass large enough to be sought in other types of present–generation experiments.[10]

In summary, there are good theoretical reasons to look for neutrino mass, but the neutrino masses may be much smaller than 1 eV. Thus, experiments which are sensitive to tiny masses are of great interest. The see–saw mechanism suggests that neutrinos are their own antiparticles, a possibility which is best explored, so far as we now know, by searching for neutrinoless double beta decay.

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