where

$$\Delta m^2 = m^2_{\nu_i} - m^2_{\nu_j} \ . \tag{6}$$

Thus, neutrino-oscillation experiments cannot measure individual neutrino masses, but only differences of masses squared, and indeed these are generally weighted in a more complicated way by lepton-mixing matrix coefficients for the general case where there is mixing among more than just two species. Experimental results are presented as allowed regions on a plot, the axes of which are $|\Delta m^2|$ and $\sin^2 2\theta$. These are often summarized in terms of the upper limit on Δm^2 (the absolute value is usually suppressed in the notation) for maximal mixing, $\sin^2 2\theta = 1$, and the upper limit on $\sin^2 2\theta$ for "large" Δm^2, *i.e.*, sufficiently large $|\Delta m^2|$ that the detector averages over many cycles of oscillation (or there ceases to be any coherence). A more complete discussion is given in the "Note on Neutrino Oscillation Experiments" just before the tables reporting such results.

An important type of experiment is the search for neutrinoless double-β decay, which tests for total lepton number violation such as would result for Majorana-neutrino masses. This process takes place when a nucleus with Z protons and $A = ZN$ nucleons decays according to $(Z, A) \to (Z{+}2, A)e^-e^-$, violating total lepton number by two units. In the case of neutrinos with masses which are sufficiently light, an upper limit on neutrinoless double-β decay yields a correlated upper limit on the quantity

$$\overline{m} = \Big| \sum_j U^2_{1j} m_{\nu_j} \Big| \ . \tag{7}$$

Cancellations may occur in the sum, since U_{1j} is, in general, complex. See Ref. 11 for some recent reviews of searches for neutrinoless double-β decay.

A brief summary of the current experimental situation follows (see previous editions for discussions of various positive claims for neutrino masses and mixing, and their refutations).

1. There is no evidence at present from direct searches for nonzero neutrino masses. These include the endpoint of the Kurie plot in nuclear-β decay for m_{ν_e}, $\pi^+ \to \mu^+\nu_\mu$ for m_{ν_μ}, and certain τ decays for m_{ν_τ} (where, as discussed above, the limits actually apply to the respective mass eigenstates ν_1, ν_2, and ν_3 in these three weak eigenstates). There has been some concern over the fact that the quantity which is actually measured, *i.e.*, the square of the neutrino mass, is negative by several standard deviations for ν_e. This may indicate systematic errors in the measurements which are not understood. A similar situation was noticed recently for the muon neutrino mass squared. Although there is still no resolution of this in the refereed journal literature, it has been argued [12,13] that the reason for this is that the charged-pion mass has been determined incorrectly from pionic x-rays, that this determination is actually ambiguous(!), and that when the analysis is interpreted differently, the charged pion mass is increased so as to yield a measurement of $m^2_{\nu_\mu}$ ($m^2_{\nu_2}$) which is no longer tachyonic but is consistent with zero. See the recent preprint [13] and the more extensive discussion before the m_{ν_μ} and $m_{\pi^\pm}$ Listings.

2. There are no indications of any positive neutrino masses from any of the peak search experiments in π or K decay, or from any experiments on neutrino decays. These set good upper limits on respective lepton mixing matrix coefficients.

3. There are no indications of any positive neutrino masses from nuclear-β decay spectra. The 7-year controversy over the claim by Simpson, Hime, and others of a 17 keV neutrino is finally over, with retractions by these authors of their original claims after very strong refutations by a number of high-sensitivity experiments.

4. Certain positive claims for neutrino oscillations in reactor and accelerator neutrino experiments have either been refuted or retracted, or both (see previous editions for details).

5. There is no indication of Majorana neutrino masses from searches for neutrinoless double-β decay.

6. The situation concerning possible atmospheric neutrino oscillations remains unsettled.

It is generally acknowledged that the strongest indirect evidence for neutrino masses and mixing is the observed deficit in the solar neutrino flux. The pioneering ^{37}Cl radiochemical solar neutrino experiment of R. Davis and his group started in 1967 and, with only one 18-month gap, has been running ever since. Over the years, a deficit in the measure flux of high-energy neutrinos (mainly from the ^{8}B reaction) has been reported [14,15]. The measured flux is about three times less than the flux predicted by theoretical calculations (Refs. 16–18, and other reviews quoted therein; see also Ref. 10). More recently, Kamiokande, a large water Čerenkov detector, has produced independent high-quality measurements of the solar neutrino flux in roughly the same energy range [19,20,21]. Unlike a radiochemical experiment, a Čerenkov detector preserves directional information, and the Kamiokande collaboration has been able to demonstrate that the neutrinos come from the direction of the sun. They have confirmed the deficiency reported by Davis *et al.* The ratio of observed to expected fluxes seen by the Kamiokande group is somewhat higher than that observed by Davis, but is still significantly below unity.

Two experiments are now operating which are sensitive to the lower-energy neutrinos from the main *p-p* burning chain. These are SAGE, the Soviet-American Gallium Experiment [22], and GALLEX, a gallium experiment in the Gran Sasso Underground Laboratory [23,24]. Both of these also report a deficiency in the measured solar neutrino flux. These results are especially important since the flux of the *pp* neutrinos constitutes the dominant part of the solar neutrino flux and is widely considered to be reliably calculable. (This is not to imply that calculations of the high-energy neutrino flux are unreliable, only that they are harder to check. The high-energy part does not arise from the reactions producing most of the sun's luminosity,