Terrestrial neutrinos reappear

Careful experiments in earthbound laboratories may be less exciting than supernovae, but will in the long run be more useful

THE 20 neutrinos that arrived on Earth from the recent supernova have prompted strenuous attempts by physicists and astronomers to extract the microscopic properties of the neutrino from the meagre data. This excitement may have caused some people to forget that laboratory experiments with similar aims have been going on for some time. As a reminder of these long standing efforts, the current issue of *Physical Review Letters* contains two somewhat contradictory contributions to the debate on the neutrino mass.

Physicists at the Institute of Theoretical and Experimental Physics in Moscow (S. Boris *et al. Phys. Rev. Lett.* **58,** 2019; 1987) describe new results which support their claim of 1981 for an electron neutrino mass of 30 eV, but another group (J.F. Wilkerson *et al. Phys. Rev. Lett.* **58,** 2023; 1987), working at Los Alamos National Laboratory, has data that set an upper limit of 27 eV. Experimental errors no doubt allow these two results to be reconciled, but the Los Alamos group hopes soon to increase the sensitivity of its method down to 10 eV, and the technical differences between the two essentially similar experiments are worth reviewing.

The basic idea is appealingly simple. Tritium has a beta decay whose products are a helium nucleus, an electron and an antineutrino, with a total energy of 18.6 keV. To do the experiment, collect some tritium, and record the energies of the electrons that emerge as it decays. Then plot a suitable graph of the number of electrons detected as a function of their energy. If the neutrino is massless, this graph is a straight line intersecting the axis at 18.6 keV, but if the neutrino is massive, the graph turns over and goes to zero at an energy of 18.6 keV less the neutrino's mass. Measuring the endpoint of tritium beta decay thus measures directly the mass of the neutrino.

Two problems arise in putting this idea into practice. Because the neutrino mass is at most a few tens of electron volts, a small fraction of the energy released in tritium decay, any departure from a straight line occurs very close to the endpoint, so good energy resolution and statistics are needed to reveal a turnover in the graph. (Tritium is used as it has the lowest energy release of any beta decay.) The ingenuity of experimental physicists can overcome this problem, but the second difficulty is more pernicious, and involves theory.

The Moscow group used tritium in the form of replaced hydrogen atoms in valine, an amino acid. This was laid on a substrate forming a solid radioactive sample which could easily be inserted into a spectrometer to measure the electron energies. The drawback is that when tritium decays as part of a molecule, it excites molecular vibrations whose energy is comparable in magnitude to the putative neutrino mass. Unless these final state effects can be accurately accounted for, a reliable mass estimate cannot be retrieved from the data.

Calculations of vibrational states in complex molecules are notoriously intricate, and the uncertainties are large. This is why the Soviet claim for a neutrino mass of 30 eV or so has always been treated sceptically — the experimental technique is acknowledged to be excellent, and the results are statistically significant, but the suspicion of systematic errors has never been dispelled.

A similar experiment has been done in Zurich (M. Fritschi *et al. Phys. Lett.* **173**B, 485; 1986), the significant difference being that tritium was implanted in a carbon substrate. The final state effects were calculated on a basis of methane-like molecular vibrations, which ought to be simpler and more reliable than similar calculations on the complex valine molecule. The Swiss experiment yielded an upper limit of 18 eV on the neutrino mass. The contradiction between this and the equally credible Soviet results demonstrates the nature of the problem.

The ideal way to avoid all these incalculable effects is to avoid using molecules, and this is what Wilkerson *et al.* have almost done. Through ingenious design, they have been able to build an experiment to measure electrons from a sample of gaseous tritium, for which the molecular excitations are known to an accuracy of about one electron volt. The great innovation was in finding a way to transport electrons out of the chamber containing the gas so that their energy could be measured by a spectrometer. In their apparatus, tritium gas flows into the middle of a long narrow tube, and is recirculated as it passes out of the ends. The magnetic field of a superconducting solenoid forces the electrons to spiral along the tube to the ends, where they are magnetically focused and transported to a spectrometer. Use of a gaseous source also alleviates two other problems that bedevilled the earlier experiments. Where tritium is bound in a solid sample, energy resolution suffers because electrons can be scattered within the sample itself and off the supporting substrate. In the Los Alamos experiment, internal scattering is reduced and backscattering is absent.

The results reported by Wilkerson *et al.* are derived from only twelve days of data-taking, but already they have arrived at an upper limit of 27 eV with a 95 per cent confidence level. After taking more data since their paper was submitted, they appear to be running up against some systematic errors, but with some refinement of their method believe they can get to a sensitivity of about 10 eV.

The next step will be to work with atomic rather than molecular tritium. Although the two-body final state effects are fairly well understood, they amount to a substantial correction, which it would be easier to avoid. Without molecular correction, Wilkerson says their data indicate a neutrino mass of 15 eV.

A further improvement would be to use solid instead of gaseous tritium, for an easier experimental set-up, but work in this direction at Lawrence Livermore National Laboratory has not produced results so far. The perfect tritium endpoint experiment would measure electrons from bare nuclei, so that even atomic excitations were absent. This in principle would allow errors to be reduced to fractions of an electron volt, but the necessary handling techniques do not yet exist.

This careful and time-consuming laboratory work makes an interesting contrast to the somewhat cavalier calculations of astrophysicists using the supernova data. It is undoubtedly true that the supernova neutrinos would have easily revealed a mass of 100 eV or 50 eV, but beyond that there are differences of opinion. Bahcall and Glashow (*Nature* **326,** 476; 1987) derive an upper limit of 11 eV, but Kolb, Stebbins and Turner (*Phys. Rev.* D, in the press) say that by taking into account all possible sources of error, a reliable upper limit is about 20 eV. In some sense, both results are correct, except that different levels of confidence can be put upon them. The Los Alamos experiment gives an upper limit of 27 eV with 95 per cent confidence or, if you prefer, 23 eV with 90 per cent confidence. The uncertainties and model dependence in the astrophysical arguments (as well as the paucity of data) make comparably precise statements impossible.

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