IN OLD AND NEW EXPERIMENTS, THE 17-keV NEUTRINO GOES AWAY

For more than a decade now, experiments in high-energy physics have yielded very few real surprises. Far from being a reproach to the experimenters, this state of affairs is a testament to the encompassing success of the standard model of the elementary particles that took its definitive shape in the 1970s. In the early 1980s the heavy vector bosons, $W^{\pm}$ and Z^0, that mediate the weak interactions were found just about where they were expected, and the millions of Z^0s created since then have confirmed the predictions of the standard model in spectacular detail.

But one needs occasional surprises. The fond hope is that some unforeseen discovery will point the way to a grand unification beyond the thriving, but manifestly incomplete, standard model. A particularly enticing surprise was the 17-keV neutrino, first reported by John Simpson (University of Guelph, Ontario) in 1985. After several other experimenters failed to confirm Simpson's extraordinary find, the heavy neutrino was recalled from moribund slumber by a series of apparent confirmations in 1990–91. (See PHYSICS TODAY, May 1991, page 17.) The discomfiture of the theorists at the prospect of reconciling this indigestibly heavy morsel with standard ideas of particle physics and cosmology was more than compensated by the excitement and promise it engendered.

Now, two years later, the 17-keV neutrino is once again moribund, though not everyone is ready to declare it dead and buried. In the last 12 months the heavy neutrino has been dealt five severe blows. Two of them are null results from innovative new experiments, and the other three are reanalyses and expansions of experiments that had previously reported results favoring the existence of a 17-keV neutrino. The reanalyses can serve as cautionary tales underlining the late Gary Feinberg's dictum: "Science is hard," I heard him lament at a Columbia seminar when someone pointed out an error in an argument he was making.

Starting with Simpson's first reports of a small admixture of 17-keV neutrinos in the β decay of tritium, all the experiments have looked for telltale kinks 17 keV below the end points of the electron energy spectra for various β decays. If neutrinos have zero or negligible mass, the maximum electron energy in a β decay (ignoring the very small nuclear recoil) is Q, the mass difference between the parent and daughter nuclei. If *all* β-decay neutrinos had a nonvanishing mass M, the endpoint of the electron energy spectrum would be $Q - M$. But in the quest for the 17-keV neutrino one is looking for evidence of a heavy neutrino that makes its appearance in about one β decay event in a hundred, irrespective of the decaying nuclear species. In that case one expects to see an essentially normal β spectrum ending at Q with a 1% admixture of a second spectrum that ends 17 keV lower. The most visible indication of such a superposition would be a kink 17 keV below the maximum of the otherwise smooth spectrum.

Spectrometers vs crystals

The experiments since 1985 fall into two broad catagories, characterized by how the energies of the decay electrons are measured: magnet spectrometer or solid-state detector. It has been a frustrating aspect of this field that all the evidence *for* the 17-keV neutrino has come from experiments that employed solid-state detectors. No spectrometer group has ever reported seeing a spectral kink. Indeed, skeptics have suggested that the 17-keV signal is some sort of solid-state artifact. Simpson, in turn, has argued that the *ad hoc* shape-correction fits required for the magnetic spectrometer data tend to wash out evidence of the spectral kink.

Last April, Hirokane Kawakami's group at the University of Tokyo reported the results of the first magnetic spectrometer experiminent that convincingly circumvents the problem of arbitrary shape corrections by virtue of very high statistics.[1] With limited statistics, most experiments can't just look for an obvious kink in the β spectrum; they must try to fit the spectral shape over a large energy range, with and without a putative heavy neutrino. But the Tokyo group, with its high statistics, had the luxury of doing a "direct kink search" by fitting very narrow energy bins of the observed β spectrum. Finding no kink at 17 keV below the end point or anywhere else, Kawakami and company set an upper limit of 0.1% on the admixture of a heavy-neutrino component in the β decay of ^{63}Ni.

In those solid-state experiments in which the detector is physically separate from the β-decay source, one has to worry about electrons scattering on their way to the detector. An Argonne–Berkeley collaboration headed by Stuart Freedman has sought to allay this concern by employing a solenoidal magnetic field, in place of the usual collimators and baffles, to guide the electrons from the experiment's sulfur-35 source to the silicon-crystal detector. Their results, published in January, give no evidence of a heavy neutrino.[2] The group impressively demonstrated that its apparatus was sensitive enough to detect a 1% heavy-neutrino component by adding to their source, and then detecting, a 1% radioactive contaminant that simulated the spectral effect of a 17-keV neutrino.

"The Argonne null result came as a shock when I first heard of it last summer," concedes Simpson's protege Andrew Hime. It was Hime who, together with Nick Jelley, did the experiment at Oxford in 1991 that was the strongest evidence for the 17-keV neutrino in its heyday.[3] "Now they had the same kind of ^{35}S source and silicon detector as our Oxford experiment," Hime told us, "and yet they saw nothing." The only real difference was the Argonne experiment's magnetic transport system.

Bouncing off baffles

At the Moriond workshop on massive neutrinos at Les Arcs in the French Alps in January 1992, Leo Piilonen (Virginia Polytechnic Institute) had reported a Monte Carlo analysis that he and his VPI colleague Alexander Abashian had carried out to study the effects of scattering in the Oxford experiment. They had concluded that scattering off baffles designed to screen the detector from stray electrons in the Oxford apparatus might well have been responsible for a spurious 1% heavy-neutrino signal. "I didn't pay much attention to this critique at the time," Hime told us. "We hadn't included scattering off the baffles in fitting our data because we knew that scattering at the detector itself was a much bigger source of electron energy degradation. That's something we *had* included in our fits and shown that it had no effect on our 17-keV signal. And besides, Simpson and I had seen the same 17-keV signal in a variety of earlier experimental geometries at Guelph that had nothing to do with baffles. But after Freedman's result I knew I had to take a serious second look."

So Hime, having moved on to Los Alamos, undertook his own Monte Carlo calculation and backed it up with calibration studies of the scattering of electrons from monochromatic β sources off the baffles. These exercises showed that scattering off the baffles was indeed a small but insidious effect. Whereas scattering at the detector added a long but harmless low-energy tail to the monochromatic calibration peaks, the 1% of electrons that scattered off the baffles almost all ended up in the top 20 keV of the low-energy tail, where they could seriously distort the β-decay spectrum. When he now refit the original Oxford data with a model that included scattering at the baffles, Hime found that he got just as good a fit without the 17-keV neutrino as with it. He details all of this painstaking reanalysis in a recent paper[4] that amounts to a retraction of the 1991 Hime–Jelley paper.

Meanwhile, back at Oxford, Jelley, having confirmed Hime's analysis and reconfigured the apparatus, continues to take ^{35}S data. With the offending baffles now rendered harmless, the 17-keV neutrino signal appears to have gone away. The new Oxford results should soon be ready for publication.

The errant guard ring

But what about Eric Norman's experiments at Berkeley? It was Norman's 1990 report of a 17-keV kink in the β-decay spectrum of ^{14}C that really started the renaissance of Simpson's heavy neutrino. Surely scattering couldn't explain that signal away, because in Norman's experiment the radioactive ^{14}C atoms are grown into the germanium crystal that serves as the detector. Simpson's tritium experiments also had the source inside the solid-state detector.

After the report of Norman's initial four-month run, his Berkeley group found 17-keV signals in each of three additional runs of comparable statistics. Just as they were about to publish these new confirmatory results at the end of 1991, the group acquired a sophisticated new data acquisition system that allowed them, for the first time, to discard events by off-line software veto. Because the betas have a range of about 100 μm in germanium, one wants to discard decays that are too close to the edge of the crystal, lest they get out without depositing their full energy. To that end, the Berkeley group had surrounded the detector's fiducial volume with a Ge guard ring designed to veto events too close to the edge.

All the 1990–91 running had been done with just an on-line hardware veto from the guard ring. But now, with the new software-veto capability, the group could take a closer look at events the guard ring was discarding. And what they found was very disturbing; it called all their previous results into question. Far too many events were being vetoed, and there was a peculiar correlation between the energies recorded in the central crystal and in the guard ring. Eventually it was found that the culprit was electronic cross talk between the central detector and the ring.

With the errant guard ring taken out of commission, the Berkeley group took new ^{14}C data throughout 1992 with a software fiducial veto and found that its 17-keV neutrino had vanished. The analysis was completed in February, and this new null result will shortly be published.

Internal bremsstrahlung is another nuclear decay process whose energy spectrum would show a heavy-neutrino kink. In the fall of 1990 Norman reported preliminary evidence of a heavy neutrino in the γ spectrum from the Berkeley group's ^{55}Fe internal-bremsstrahlung source. But the group has just completed a much expanded version of the ^{55}Fe experiment. With statistics high enough to allow a direct kink search that looks for structure in the second derivative of the γ spectrum, the group now finds no sign of a heavy neutrino.[5] One of the authors of this new paper is Igor Zlimen, a member of the Zagreb group that reported in 1990 the first evidence for a 17-keV neutrino in an internal-bremsstrahlung spectrum.

"I guess I owe Sheldon Glashow a bottle of wine," conceded Simpson when he was told that Norman's new ^{14}C results showed no sign of the 17-keV neutrino. Though Glashow may have bet against the existence of Simpson's heavy neutrino, he hedged his bet by writing a paper on how such an object might fit into a modified standard model.[6] "Still it's very peculiar that all those different experimental arrangements should have conspired to give the same spurious signal," says Simpson. "At the moment it appears that only the Guelph results remain to be explained, so we're continuing our experiments."

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References

1. H. Kawakami *et al.*, Phys. Lett. B **287**, 45 (1992).
2. J. Mortara *et al.*, Phys. Rev. Lett. **70**, 394 (1993).
3. A. Hime, N. Jelley, Phys. Lett. B **257**, 441 (1991).
4. A. Hime, Phys. Lett. B **299**, 165 (1993).
5. F. Weitfeld *et al.*, Phys. Rev. Lett. **70**, 1759 (1993).
6. S. Glashow, Phys. Lett. B **256**, 255 (1991).

NEW EVIDENCE CONFIRMS OLD PREDICTIONS OF RETARDED FORCES

Some of the more subtle predictions of quantum mechanics have had to wait decades before experiments were capable of validating them. One of these is the so-called retarded force between charges that are so far apart that it takes a relatively long time for a photon to travel between them. (See the article by Larry Spruch in PHYSICS TODAY, November 1986, page 37.) In the 1940s Hendrik B. G. Casimir and D. Polder (then at the scientific laboratory of N. V. Philips's Gloeilampenfabriken in Eindhoven, the Netherlands) analyzed interactions affected by the finite speed of light. They found that the van der Waals potential between two atoms, which goes as r^{-6}, becomes a potential that varies as r^{-7} when the atoms are separated by distances greater than a few hundred Bohr radii.[1] A related prediction is that the interaction between a neutral atom and a conducting wall changes from an r^{-3} to an r^{-4} potential when the atom is far enough from