Nuclear Evidence That Neutrinos Have Mass

Several long-standing problems in astrophysics may now be resolved

Three physicists from the University of California at Irvine have found evidence that neutrinos have mass. Neutrinos are those elementary particles called ghostly and elusive because they interact only by way of the feeblest of the three forces affecting elementary particles, the weak force, and because they were thought to have no rest mass. If the findings hold up (related experiments are ongoing in the United States and Europe and new ones will surely be starting up), the implications of massive neutrinos will be greatest in the field of astrophysics where at least three long-standing problems could be explained. The discovery apparently will not cause extensive revision of elementary particle theories.

The experiment by Frederick Reines, Henry Sobel, and Elaine Pasierb of Irvine actually did not detect a neutrino mass directly. The investigators found a phenomenon called neutrino oscillations, in which neutrinos of one type transformed into different types as they raced through the air at nearly the speed of light. But existing theories for neutrino oscillation require that neutrinos have mass. Some of the consequences for astro- and elementary-particle physics follow from the oscillation effect and others from the existence of neutrino masses.

Measurements were made at the Du Pont Company's 2000-megawatt Savannah River nuclear reactor, which has a long history of neutrino physics. Reines and the late Clyde Cowan first directly detected the existence of neutrinos there in 1956. In the present case, the reactor acted as a source of neutrinos of a particular type having energies of 10 million electron volts or less. (Neutrinos belong to the class of the lightest elementary particles called leptons: electron, electron neutrino, muon, muon neutrino, tau particle, tau neutrino, and the corresponding antiparticles. The type of neutrino coming from the reactor was an antielectron neutrino.)

The neutrinos collided with deuterium nuclei in a 268-kilogram pool of heavy water, where two types of reactions could occur. The first produces two neutrons, but only if the neutrinos leaving the reactor stay antielectron neutrinos. The second, which produces a single neutron, occurs whether the neutrinos change identity or not. Helium-3-filled proportional counters detected the neutrons, thereby allowing the ratio of double-neutron and single-neutron events to be determined. The expected value of the ratio could also be calculated from theory. As Reines explained at the Washington, D.C., meeting of the American Physical Society late in April, the ratio of ratios (experimental ratio to theory ratio) should be 1 unless the antielectron neutrino was turning into some other type during its 11.2-meter-long travel from the reactor to the detector. The observed value was 0.43 ± 0.17, which is a 3.2 standard deviation effect. Further experiments at Savannah River and elsewhere will be needed to confirm the finding.

There are reasons for both skepticism and optimism. On the skeptical side, a 6-month-long experiment using the 57-megawatt research reactor at the Institut Laue-Langevin in Grenoble, France, by physicists from the California Institute of Technology, the Technical University of Munich, and the Institut Laue-Langevin has found no evidence for neutrino oscillations, according to Felix Boehm of Caltech. The group measured a different quantity (positrons emitted when neutrinos collide with hydrogen nuclei) than the Irvine researchers, however, and interpretation of the results depends on certain other data that are currently in dispute. The Irvine ratio of ratios technique is much less sensitive to this uncertainty.

On the optimistic side, there are numerous reports of an as yet unpublished experiment by researchers at the Institute of Theoretical and Experimental Physics in Moscow who used an entirely different technique to obtain a mass for neutrinos. The experiment measures the characteristics of the electron emitted when tritium (hydrogen-3) decays. Previous attempts, notably by a Swedish group some years ago, failed to find any effect traceable to neutrinos having a mass. Now the Soviet investigators have determined a neutrino mass in the range 12 to 40 electron volts, according to Carlo Rubbia of Harvard University. (The mass of an electron is 511,000 electron volts.) American physicists are eagerly awaiting publication of the work so as to judge first hand what are now only secondhand reports.

The consequences of neutrino oscillations and neutrino masses seem to be greatest in questions of concern to astrophysicists. Three are of particular interest:

1) *Solar neutrinos*. Theoretical models of fusion reactions in the sun lead to predictions of the flux of neutrinos striking the earth. Careful measurements by Ray Davis of Brookhaven over several years have found only about one-third the predicted number. Davis's experiment is sensitive only to electron neutrinos, which are the type emitted by the sun. If electron neutrinos were turning into muon and tau neutrinos on their way to the earth, a good deal of the discrepancy between theory and experiment would be reconciled, although John Bahcall of the Institute for Advanced Study cautions other effects may also be important.

2) *Missing light in galaxies*. A fundamental parameter in astronomy is the mass to luminosity ratio of astronomical objects. A continuing problem for astronomers has been to explain why the ratio for galaxies is much larger than that for nearby stars and why the ratio for clusters of galaxies is much larger than that for individual galaxies. The explanation must involve matter that does not emit radiation. If the mass of neutrinos was in the range from 5 to 20 electron volts, says Gary Steigman of the Bartol Research Foundation, neutrinos would tend to be more tightly gravitationally bound to larger objects than smaller ones in just the right way to account for the missing light.

3) *Evolution of the universe*. In a Big Bang model of the universe, the universe could keep expanding forever or it could reach a point of maximum extent and begin contracting back to its starting configuration of an infinitely dense point. Although not all astrophysicists are in agreement, probably more agree than not that the total amount of mass in the universe is insufficient to reverse the present expansion. If, however, neutrinos, which are thought to be roughly as numerous in the universe as photons, had a mass of about 100 electron volts, then the added mass would be sufficient to cause the universe to contract eventually. As Reines says, this would have a profound effect on the way we think about the cosmos and our place in it.

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