Physics

Ivars Peterson reports from Indianapolis at an American Physical Society meeting

Fresh evidence of neutrino mass

Created by nuclear fusion reactions inside stars and left over from the Big Bang, neutrinos are both abundant in the universe and extremely difficult to detect. Usually thought to have no mass, these elusive subatomic particles barely interact with other forms of matter.

Last year, researchers using the liquid scintillator neutrino detector at the Los Alamos (N.M.) National Laboratory reported experimental data suggesting that neutrinos actually have a mass, albeit a small one (SN: 2/11/95, p. 85). Now, the same team has obtained additional evidence that strengthens this claim.

Because neutrinos constitute a large fraction of the number of cosmic particles, these findings have important implications for understanding the composition and evolution of the universe.

According to the standard model of particle physics, neutrinos come in three varieties: the electron neutrino, the muon neutrino, and the tau neutrino. Each of these also has an antimatter counterpart.

The Los Alamos experiment involved firing high-energy protons into a water target to produce subatomic particles called pions. Pions decay into muons and muon neutrinos, and the muons, in turn, transform into positrons, electron neutrinos, and muon antineutrinos. A tiny fraction of the neutrinos collide with atomic nuclei in a nearby detector, which consists of a large tank of mineral oil surrounded by an array of photodetectors. These rare collisions generate electrons and other charged particles, which leave trails of light in the liquid.

Carefully screening 3 years' worth of data, the researchers identified 22 events that involved electron antineutrinos, which were not predicted by standard theory. Their presence is "very strong evidence" that a muon antineutrino can transform itself into an electron antineutrino through a hypothetical process that theorists call neutrino oscillation, says Fred J. Federspiel of Los Alamos.

According to theory, such transformations can occur only if the particles involved have a mass. In this case, the findings suggest that the muon antineutrino or the electron antineutrino has a mass of at least 0.2 electronvolt. By comparison, an electron has a mass of about 511,000 electronvolts.

If this experimental evidence proves solid, the findings indicate that neutrinos could represent a significant addition to the calculated mass of the universe, though not enough to halt its expansion.

Federspiel and his coworkers expect to collect additional data over the next 2 years. Independent experiments are also needed to confirm the neutrino oscillations. "The situation is by no means wrapped up yet," Federspiel notes.

Uranium fission spawns exotic nuclei

Exploiting a new method for studying the fragments resulting from the fission of uranium, researchers have identified more than 100 types of unstable nuclei rich in neutrons. Though known to be generated routinely in nuclear fission reactors, these short-lived nuclei had never previously been observed.

This experiment represents "the first direct observation of every single type of isotope produced in fission," says Monique Bernas of the Institute of Nuclear Physics in Orsay, France.

A chemical element is characterized by the number of protons in its nucleus. Isotopes of an element differ in the number of neutrons present in the nucleus. About 270 stable isotopes are known to exist on Earth. During the 5 decades since the discovery of nuclear fission, physicists have identified more than 400 unstable isotopes among fragments produced by the splitting of uranium nuclei.

To complete this list, Bernas and her coworkers used a particle accelerator at the Society for Heavy Ion Research in Darmstadt, Germany, to accelerate uranium ions to 80 percent of the speed of light. In flight, the uranium-238 nuclei break up into two main fragments, which can then be identified before they decay into other isotopes on their way to reaching a stable combination of neutrons and protons.

Because the fragments move at nearly the uranium beam's velocity and because they are totally stripped of electrons, "the fission products are much easier to detect than in previous experiments," Bernas explains.

The new, neutron-rich isotopes, all for the elements between vanadium and ruthenium in the periodic table, don't survive for long. Their half-lives range from 20 to 700 milliseconds.

"The new method opens up a wide field for nuclear structure investigations," Bernas says. For example, researchers can now study nickel-78, which contains 28 protons and 50 neutrons. These numbers of protons and neutrons correspond to an unusually stable nuclear arrangement.

The production and investigation of exotic nuclei allow theorists to test models of how nuclei are put together. Such information also serves as a check on astrophysical theories concerned with the creation of elements in supernova explosions and the abundance of these elements in the solar system.

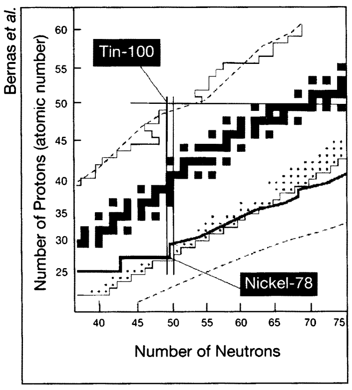

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Chart of isotopes created by the fission of uranium-238. Solid squares represent stable isotopes; dots indicate newly discovered, unstable nuclei. Nickel-78 and tin-100 are known as doubly magic nuclei because they contain just enough protons and neutrons to form completely filled outer layers, or closed shells, of particles in the nucleus.

Measuring the gravitational constant

The news that three respected research groups had independently produced values for the strength of the gravitational force (G) that disagreed significantly with the currently accepted number and with each other created a considerable stir last year (SN: 4/29/95, p. 263). Now, researchers have proposed several new experiments, employing a variety of techniques, to try to resolve these surprising discrepancies.

Riley D. Newman and his coworkers at the University of California, Irvine are preparing a measurement of G in which a thin quartz plate hangs by a fiber between a pair of vertical copper rings. The plate is free to oscillate between the rings, causing the fiber to twist and untwist. The researchers determine G by measuring the change in oscillation frequency when the pair of rings is rotated 90°, for example from a north-south to an east-west orientation.

One unique feature of this approach, Newman says, is that the pendulum can operate at a temperature of 4 kelvins, chilly enough to eliminate thermal effects that could affect the measurement. The Irvine team hopes to run the experiment in a former Nike missile bunker near Hanford, Wash.

Jens H. Gundlach of the University of Washington in Seattle also plans a measurement of G that involves a suspended quartz plate. In his scheme, however, the oscillating pendulum is mounted on a slowly rotating platform, and a set of eight specially located spherical masses replaces the copper rings. As the platform rotates, the masses exert forces on the pendulum that would ordinarily make it speed ahead or fall behind the platform's motion. A feedback mechanism adjusts the platform rotation to match the pendulum's motion, and the scientists measure the platform speed.