QUANTUM MECHANICS

The Subtle Pull of Emptiness

There's no such thing as a free lunch—except in quantum mechanics. Classical physics—and common sense—dictates that the vacuum is devoid not only of matter but also of energy. But quantum mechanics often seems to depart from common sense. A paper in the current issue of *Physical Review Letters* describes the first successful measurement of the ultimate quantum free lunch: the Casimir force, a pressure exerted by empty space.

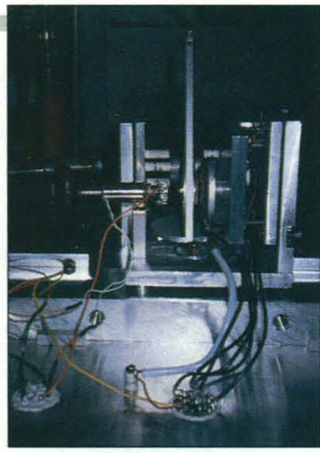
The measurement, by physicist Steven Lamoreaux of Los Alamos National Laboratory, confirms the strange picture of the vacuum conceived in the 1920s by pioneering quantum physicists Max Planck and Werner Heisenberg. Even at absolute zero, they asserted, the vacuum is seething with activity. This "zero-point energy" can be thought of as an infinite number of "virtual" photons that, like unobservable Cheshire cats, wink in and out of existence—but should have a measurable effect en masse. That's what Lamoreaux has now shown. "We're excited; it confirms a very basic prediction of quantum electrodynamics," says Ed Hinds of the University of Sussex in the United Kingdom.

For decades after Planck and Heisenberg described the zero-point energy, physicists preferred to ignore it. It's infinite, and to a physicist, "infinity's not a very useful quantity, so we get rid of it," says Charles Sukenik of the University of Wisconsin.

But an early clue that these infinite fluctuations can't be ignored came in 1948, when researchers at the Philips Laboratory in the Netherlands were studying the van der Waals force—a weak attraction between neutral atoms. At long distances, the van der Waals force weakened unexpectedly. Philips scientists Hendrick Casimir and Dik Polder found that they could explain the weakening when they pictured the force as resulting from correlated zero-point fluctuations in the electric field, which would propagate from atom to atom at the finite speed of light. Because of the lag, the chance that the atoms would feel each other's fluctuations while they were still correlated would fall off at longer ranges. This weakening, called the Casimir-Polder effect, was first accurately measured in 1993, by Hinds, Sukenik, and their colleagues.

Casimir had also realized that the zero-point energy should reveal itself more directly, as a very weak attraction between two surfaces separated by a tiny gap. Provided the gap was small enough to exclude some of the virtual photons, the crowd of photons outside the cavity would exert a minute pressure.

To measure it, Lamoreaux positioned two gold-coated quartz surfaces less than a micrometer apart, one of them attached to a torsion pendulum while the other was fixed. The surfaces created a "box" that allowed only virtual photons of certain wavelengths to exist inside it. Outside the box, a full complement of virtual particles was merrily winking away. The infinite zero-point energy on the outside of the box outweighed the infinite (but smaller) zero-point energy inside, forcing the surfaces together.



Conjuring act. Two closely spaced surfaces, one on a torsion pendulum, coax force from space.

By counteracting this subtle attraction with piezoelectric transducers, which exert a force when a voltage is applied to them, Lamoreaux was able to measure the force. The result: a value of less than 1 billionth of a newton, agreeing with theory to within 5%.

Hinds and others say the experiment should help physicists accept that the subatomic world is every bit as weird as quantum mechanics predicts. "We feel in our hearts that we really do understand how things work—even something as peculiar as vacuum fluctuations," says Hinds. Adds Sussex physicist Malcolm Boshier, who was on Hinds's Casimir-Polder team: "This is one of those experiments that is going to wind up in all of the textbooks."

–Charles Seife

Charles Seife is a writer in Scarsdale, New York.

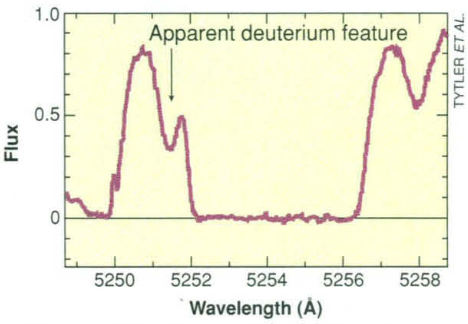
COSMOLOGY

Clouds Gather Over Deuterium Sighting

CHICAGO—Three floors below the ballroom where Craig Hogan spoke at the 18th Texas Symposium on Relativistic Astrophysics, held here from 15 to 20 December, a pair of old headlines in a showcase illustrated the perils of drawing conclusions from limited data. Not that there was any resemblance between the topic chosen by the University of Washington, Seattle, astronomer—the amount of deuterium in the early universe—and the 1948 presidential election. But Hogan found himself in much the same position as the *Chicago Daily Tribune* the day after its famous DEWEY DEFEATS TRUMAN banner: Faced with new data, he graciously withdrew an earlier conclusion.

In the 1 March 1996 issue of *Astrophysical Journal Letters*, Hogan and his then-graduate student Martin Rugers had analyzed a gas cloud so far away that it likely contains material fresh out of the big bang. They concluded that it holds about one deuterium atom for every 5000 hydrogen atoms. That was a startlingly high value, because the more of this hydrogen isotope that emerged from the big bang, the lower the universe's total density of other ordinary matter must be (*Science*, 7 June 1996, p. 1429). Hogan and Rugers's value implied a universe so rarefied that it could barely contain the ordinary matter astronomers have observed by other means. But now, Hogan told the audience, a team led by David Tytler of the University of California, San Diego (UCSD), has obtained "clearly superior" data on the same cloud and failed to find the clues that had led Hogan and Rugers to their conclusion. "What we thought was a smoking gun of … [high] deuterium is not there."

Limin Lu, an astronomer at Caltech who has made similar measurements and who heard talks by Tytler and Hogan at the symposium, agrees: "The case for high deuterium is basically gone." That may remove a puzzling discrepancy with values nearly 10 times lower, which Tytler and colleagues had measured in two other gas clouds. But Hogan's concession—unlike the *Chicago Daily Tribune*'s—isn't the last word, because some astronomers maintain that Tytler's own measurements are not airtight.



Down on deuterium. In this spectrum—the shadow of a distant gas cloud—a crucial peak in the apparent deuterium feature has vanished.

All sides in this dispute are using a single weapon: the 10-meter Keck Telescope on Mauna Kea, in Hawaii. Its light-gathering power allows astronomers to record the "shadows" cast by gas clouds billions of light-years away in the light of brilliant quasars at even greater distances. How much light the clouds absorb—and at which wavelengths—holds clues to their composition. But deuterium and the far more abundant hydrogen in the clouds have such similar spectral signatures that disentangling the two is a delicate, not to say risky, task.

The first widely reported deuterium measurement appeared in a 1994 *Nature* paper by Antoinette Songaila and Lennox Cowie of the University of Hawaii, along with Hogan and Rugers. They had studied a cloud along the line of sight to the quasar known as Q0014+813. Based on the depth of a small notch in the spectrum next to a deep well of hydrogen absorption, this group reported the 1–5000 ratio of deuterium to hydrogen atoms—but only as an upper limit. The reason for their caution, they explained, was the possibility that a small, nearby "interloper" cloud of hydrogen might be drifting through the line of sight to the main cloud. The motion of the interloper could have shifted its absorption spectrum by just enough to mimic all or part of a deuterium feature in the main cloud.

In their later *Ap. J. Letters* paper, however, Rugers and Hogan concluded that this ratio could be interpreted as a firm value rather than just an upper limit. They had reanalyzed the same data and found a sharp spike of reduced absorption in the center of the apparent deuterium feature. The spike split the notch into two narrower features that looked even more like the fingerprints of deuterium. Rugers and Hogan concluded that they were seeing the shadows of high deuterium in two separate clouds. "The spike was the thing that made us think it was [purely] deuterium," says Hogan.

But when Tytler and UCSD's Scott Burles and David Kirkman observed the same cloud with the Keck on two nights in early November, they saw no spike at all. In retrospect, say researchers close to the project, the spike may have resulted from a technical glitch in the reanalysis. What's more, the UCSD team found that the entire notch had shifted slightly, moving it away from the frequency expected if it were caused only by deuterium. A small interloper cloud may be at least partly responsible for the hints of high deuterium after all, say researchers who have read the group's preprint.

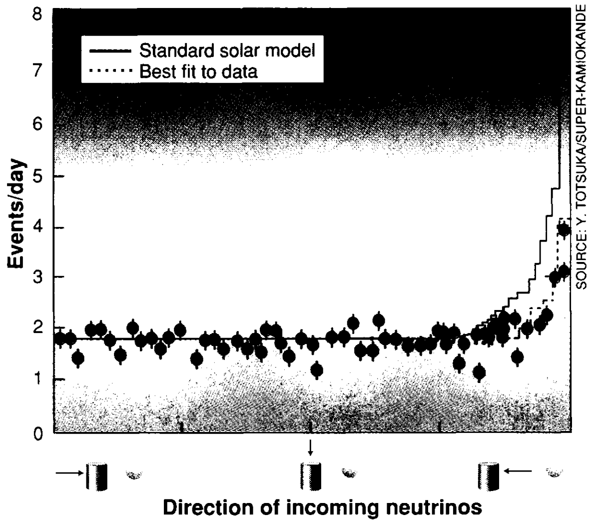
Tytler and co-workers, says E. Joseph Wampler of the National Astronomical Observatory in Japan, "have pretty convincingly shown that the earlier models ... are incorrect, at least in detail." But the real value of primordial deuterium is yet to be determined and could still emerge from this cloud, he says. Cowie, for example, not only raises questions about Tytler's own measurements on a different cloud but says new, unpublished data he and Songaila have gathered on Q0014+813 support their original upper limit. In cosmology as in politics, every headline is subject to change.

–James Glanz

NEUTRINO DETECTION

Japan's 'Super' Site Confirms Deficit

CHICAGO—If neutrinos were precious gemstones, the supply of these elusive particles would scarcely be enough to satisfy holiday shoppers in one of this city's wealthier neighborhoods. But last month brought good news: Japanese researchers reported that the world's largest neutrino detector—a $100 million device located in a mine 300 kilometers west of Tokyo—has begun to collect enough data to satisfy an international clientele. These scientific customers all hope to explain why even the best source of these cosmic messengers—the sun—seems to fall short.



Not enough. Super-Kamiokande is measuring half the predicted number of neutrinos from the direction of the sun.

Speaking at the 18th Texas Symposium on Relativistic Astrophysics, held here on 15 to 20 December, Yoji Totsuka of the University of Tokyo, spokesperson for Japan's Super-Kamiokande detector, said that the count rate at the newly constructed detector confirms a mysterious deficit in the flux of neutrinos from the sun. That deficit, which had been seen in data from Super-Kamiokande's predecessor, Kamiokande, as well as other facilities, is a crucial clue in the quest to determine whether these particles have mass—a question with profound consequences for physics and cosmology.

The data are coming in so fast, says Totsuka, that researchers should soon be able to piece together the neutrinos' energy spectrum, which may help them determine just what causes the shortfall. In just 102 days of running time since April, Super-Kamiokande "has more events than all previous solar-neutrino experiments have gotten in 30 years," says John Bahcall of the Institute for Advanced Study in Princeton, New Jersey, another speaker at the conference. "For me, it's thrilling."

Neutrinos are weakly interacting particles first identified in 1956 after being posited a quarter century earlier to explain aspects of radioactive decay. They are commonly produced in many kinds of nuclear reactions, including those that power the sun and that take place when cosmic rays collide with the upper atmosphere. They come in three "flavors," one of which—the electron neutrino—is easiest to spot with water-filled detectors like Super-K. And according to physicists' standard picture of particles and forces, they are massless.

The solar shortfall, however, could be a sign of neutrino mass. Bahcall, who is not part of the Super-K team, and others have suggested that neutrino mass could allow the easily observed electron neutrinos to "oscillate," or transmute, into one of the other two types as they travel from the sun's core to Earth, eluding detection. Then again, the apparent deficit might reflect an imperfect understanding of the sun's workings.

The details of the shortfall could help physicists choose between these explanations. Like Kamiokande, Super-K detects trails of Čerenkov light given off by electrons after their rare interactions with neutrinos. With 50,000 metric tons of water and 11,200 photodetectors, Super-K is picking up about 10 neutrinos a day from the direction of the sun (see graph). That's only half the number predicted by solar theory and the Standard Model of particle physics, which assumes massless neutrinos. In that respect, said Totsuka, "we have already confirmed the old Kamiokande data. [The detections] are well below the predicted numbers."

Totsuka says the project is now seeking to measure the energy spectrum of the arriving neutrinos. That information, he says, should begin to emerge in a few years, after "about a factor of 5 more data." Well before then, the team also hopes to have data on another neutrino problem: the observed shortfall of one type of atmospheric neutrino.

The results add up to "a beautiful experiment," says Douglas Duncan, an astronomer at the University of Chicago who chaired the neutrino session. And the data promise to keep neutrino-hungry astronomers in a holiday mood for several more shopping seasons.

–James Glanz