Creeping to a Critical Point

Probing a liquid-vapor interface in a microgravity setting

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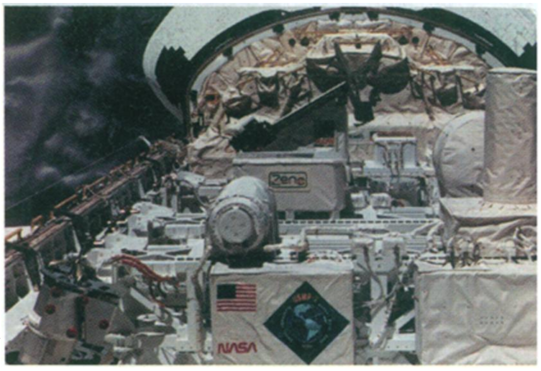
NASA

View of space shuttle Columbia's cargo bay, showing where the Zeno apparatus was housed on its 1994 flight into space.

When the space shuttle Columbia touched down at NASA's Kennedy Space Center in Orlando, Fla. on March 9, it returned a remarkable instrument to Earth. Designed to monitor laser light scattered by a dense, compressed gas teetering on the brink of turning into a liquid, this precision apparatus had operated continuously in space for more than 14 days.

During this time, researchers had relayed dozens of instructions to the equipment, controlling the temperature of an ultrapure, high-pressure sample of xenon to millionths of a degree. By taking advantage of a setting in which the effects of gravity do not obscure details of a material's activity, they could bring the xenon sample excruciatingly close to its critical temperature—the point at which its liquid and gas phases coexist and blend into one.

Robert W. Gammon of the Institute for Physical Science and Technology at the University of Maryland in College Park and head of the research team dubbed this project the Zeno experiment in honor of the philosopher of ancient Greece who pondered the paradox of traveling a finite distance in steps that become vanishingly small.

The recent shuttle experiment represented the culmination of years of work by a large group of scientists, students, engineers, and technicians at the University of Maryland, NASA's Lewis Research Center in Cleveland, Ball Aerospace in Boulder, Colo., and several other organizations.

"No other microgravity instrument has logged as many hours as the Zeno experiment," says R. Allen Wilkinson of the space experiments division at Lewis. "It's gone through two launches and two landings, and it's gone through hundreds of hours of operation in orbit and more than 10,000 hours of testing on the ground.

"That's an impressive reliability record," he insists.

The data provided by this instrument brought researchers closer to a fundamental understanding of what happens when materials change from one phase to another, whether from gas to liquid, from ordinary conductor of electricity to superconductor, or from nonmagnet to magnet.

In particular, Gammon, project scientist Jeffrey N. Shaumeyer of Maryland, and their team observed with unprecedented clarity xenon's behavior as the gas hovered within microkelvins of its critical temperature of 289.72 kelvins, or about 16.7°C.

The physical state of a material depends on its temperature and pressure. For instance, at sea level pressure on Earth, water exists as a liquid at temperatures between 0°C and 100°C. When the temperature goes above 100°C, it changes phase to become a vapor. During this phase transition, the material's density decreases considerably.

By increasing the pressure, it's possible to raise water's boiling point while increasing the vapor's density. At sufficiently high temperature and pressure, the difference in density between the liquid and vapor phases diminishes to zero. At temperatures within millikelvins of this critical point, the fluid fluctuates rapidly between liquid and vapor, creating density waves.

These density fluctuations scatter light, making the fluid appear milky instead of clear and colorless. This phenomenon is known as critical opalescence.

On Earth, it's difficult to observe the details of these fluctuations because the fluid's own weight compresses part of the sample, distorting the waves. In orbit, where the apparent force of gravity is only one-millionth as strong as it is on the ground, such distortions disappear.

For their experiment, Gammon and his team used a sample of pressurized xenon only 100 micrometers thick. By shining laser light into the sample, they could monitor how the density fluctuations scattered light, making the sample look like a twinkling star.

As the sample temperature approaches the critical point, "those twinkles get slower and slower and more and more intense," Gammon says.

By watching these trends, the researchers could readily monitor how closely the xenon had crept to its critical state as they slowly and systematically manipulated the temperature. They had to be extremely careful not to step through the critical point itself.

"If we had made a temperature error and gone through too large a step too quickly, we would have messed the sample up," Gammon says.

On its first shuttle flight, in March 1994, the instrument allowed the researchers to make measurements to within 100 microkelvins of the critical temperature.

"The outstanding performance of the Zeno instrument during the mission gave a fine demonstration of the possibility of making high-precision materials measurements in low gravity, as well as the power of a flexible, ground-commanded experiment," the research team concluded in its report on the first run.

Two years later, having learned how to control temperature changes considerably more carefully, the researchers put the Zeno experiment back on board space shuttle Columbia for a second try (SN: 3/16/96, p. 165).

"For 14 days, we worked our way up to more and more intense fluctuations, and on the last day, we scanned across and actually saw the transition more sharply than I have ever seen it," Gammon says.

Beyond the transition, as the sample cooled further, it began breaking apart into separate phases, with drops of liquid forming within the vapor and pockets of vapor forming within the liquid to create a kind of fog.

"The transition was really there, right where we projected it would be," Gammon observes. "We could locate the transition to about 10 microkelvins.

"You can't see it this way on the ground," he says. "It was a delightful conclusion to the 2-week experiment."

There are no more flights planned for the Zeno experiment. To get even closer to the transition point and to get more detailed data, the researchers need more than 14 days in space: It takes longer than that for tiny temperature differences across the sample to even out. "We're still struggling with equilibration issues in the microgravity environment," Wilkinson notes.

"There's more to be learned," he adds. "But the experiments would be very difficult and require a lot more time." ☐