PHENOMENA

The Coldest Place in the Universe

Physicists in Massachusetts come to grips with the lowest possible temperature: absolute zero **BY TOM SHACHTMAN**

WHERE'S THE COLDEST SPOT in the universe? Not on the moon, where the temperature plunges to a mere minus 378 Fahrenheit. Not even in deepest outer space, which has an estimated background temperature of about minus 455 F. As far as scientists can tell, the lowest temperatures ever attained were recently observed right here on earth.

The record-breaking lows were among the latest feats of ultracold physics, the laboratory study of matter at temperatures so mind-bogglingly frigid that atoms and even light itself behave in highly unusual ways. Electrical resistance in some elements disappears below about minus 440 F, a phenomenon called superconductivity. At even lower temperatures, some liquefied gases become "superfluids" capable of oozing through walls solid enough to hold any other sort of liquid; they even seem to defy gravity as they creep up, over and out of their containers.

Physicists acknowledge they can never reach the coldest conceivable temperature, known as absolute zero and long ago calculated to be minus 459.67 F. To physicists, temperature is a measure of how fast atoms are moving, a reflection of their energy—and absolute zero is the point at which there is absolutely no heat energy remaining to be extracted from a substance.

But a few physicists are intent on getting as close as possible to that theoretical limit, and it was to get a better view of that most rarefied of competitions that I visited Wolfgang Ketterle's lab at the Massachusetts Institute of Technology in Cambridge. It currently holds the record—at least according to *Guinness World Records 2008*—for lowest temperature: 810 trillionths of a degree F above absolute zero. Ketterle and his colleagues accomplished that feat in 2003 while working with a cloud—about a thousandth of an inch across—of sodium molecules trapped in place by magnets.

I ask Ketterle to show me the spot where they'd set the record. We put on goggles to protect ourselves from being blinded by infrared light from the laser beams that are used to slow down and thereby cool fast-moving atomic particles. We cross the hall from his sunny office into a dark room with an interconnected jumble of wires, small mirrors, vacuum tubes, laser sources and high-powered computer equipment. "Right here," he says, his voice rising with excitement as he

Brrright idea: Wolfgang Ketterle (in his M.I.T. lab above) hopes to discover new forms of matter by studying ultracold atoms.

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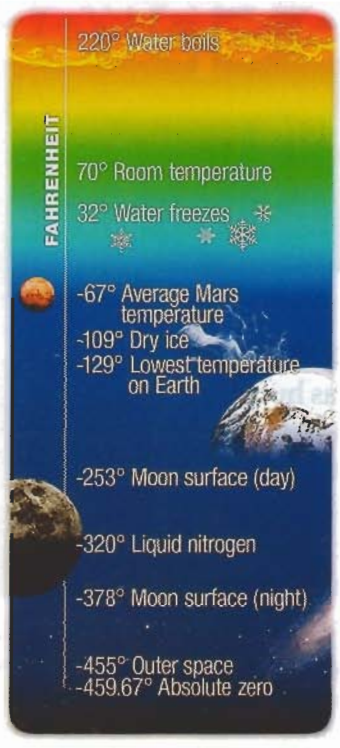
points to a black box that has an aluminum-foil-wrapped tube leading into it. "This is where we made the coldest temperature."

Ketterle's achievement came out of his pursuit of an entirely new form of matter called a Bose-Einstein condensate (BEC). The condensates are not standard gases, liquids or even solids. They form when a cloud of atoms—sometimes millions or more—all enter the same quantum state and behave as one. Albert Einstein and the Indian physicist Satyendra Bose predicted in 1925 that scientists could generate such matter by subjecting atoms to temperatures approaching absolute zero. Seventy years later, Ketterle, working at M.I.T., and almost simultaneously, Carl Wieman, working at the University of Colorado at Boulder, and Eric Cornell of the National Institute of Standards and Technology in Boulder created the first Bose-Einstein condensates. The three promptly won a Nobel Prize.

Lene Vestergaard Hau (in her Harvard lab) generates ultracold matter to slow and even stop beams of light.

Ketterle's team is using BECs to study basic properties of matter, such as compressibility, and better understand weird low-temperature phenomena such as superfluidity. Ultimately, Ketterle, like many physicists, hopes to discover new forms of matter that could act as superconductors at room temperature, which would revolutionize how humans use energy. For most Nobel Prize winners, the honor caps a long career. But for Ketterle, who was 44 years old when he was awarded his, the creation of BECs opened a new field that he and his colleagues will be exploring for decades.

Another contender for the coldest spot is across Cambridge, in Lene Vestergaard Hau's lab at Harvard. Her personal best is a few millionths of a degree F above absolute zero, close to Ketterle's, which she, too, reached while creating BECs. "We make BECs every day now," she says as we go down a stairwell to a lab packed with equipment. A billiards-table-size platform at the center of the room looks like a maze constructed of tiny oval mirrors and pencil-lead-thin laser beams. Harnessing BECs, Hau and her co-workers have done something that might seem impossible: they have slowed light to a virtual standstill.



How cold is it? Though scientists have come close, they don't expect to achieve absolute zero.

The speed of light, as we've all heard, is a constant: 186,171 miles per second in a vacuum. But it is different in the real world, outside a vacuum; for instance, light not only bends but also slows ever so slightly when it passes through glass or water. Still, that's nothing compared with what happens when Hau shines a laser beam of light into a BEC: it's like hurling a baseball into a pillow. "First, we got the speed down to that of a bicycle," Hau says. "Now it's at a crawl, and we can actually stop it—keep light bottled up entirely inside the BEC, look at it, play with it and then release it when we're ready."

She is able to manipulate light this way because the density and the temperature of the BEC slows pulses of light down. (She recently took the experiments a step further, stopping a pulse in one BEC, converting it into electrical energy, transferring it to another BEC, then releasing it and sending it on its way again.) Hau uses BECs to discover more about the nature of light and how to use "slow light"—that is, light trapped in BECs—to improve the processing speed of computers and provide new ways to store information.

Not all ultracold research is performed using BECs. In Finland, for instance, physicist Juha Tuoriniemi magnetically manipulates the cores of rhodium atoms to reach temperatures of 180 trillionths of a degree F above absolute zero. (The Guinness record notwithstanding, many experts credit Tuoriniemi with achieving even lower temperatures than Ketterle, but that depends on whether you're measuring a group of atoms, such as a BEC, or only parts of atoms, such as the nuclei.)

It might seem that absolute zero is worth trying to attain, but Ketterle says he knows better. "We're not trying," he says. "Where we are is cold enough for our experiments." It's simply not worth the trouble—not to mention, according to physicists' understanding of heat and the laws of thermodynamics, impossible. "To suck out all the energy, every last bit of it, and achieve zero energy and absolute zero—that would take the age of the universe to accomplish."

TOM SHACHTMAN *is the author of* Absolute Zero and the Conquest of Cold, *the basis for a future PBS "Nova" documentary.*

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