PHYSICS

Hydrogen Coaxed Into Quantum Condensate

In 1978, physicists at the Massachusetts Institute of Technology (MIT) hatched an ambitious plan to create a new form of matter. They set out to cool a cloud of hydrogen atoms almost to absolute zero, until they snapped into a single quantum blob called a Bose-Einstein condensate. "We thought it would take 5 years, maybe 8," recalls Tom Greytak, one of the physicists. Twenty years went by and other groups beat them to the punch, with heftier atoms and new laser cooling techniques. The MIT group, however, kept working on hydrogen. And late one night this past June, a phone call from the lab shook Greytak and colleague Dan Kleppner out of bed. They rushed in and at 1:30 a.m. toasted the birth of the tiny superatom with their team. "I was elated," Kleppner says. "It had been such a long siege."

The new achievement, discussed last week at a conference in Washington,* is more than just a heroic example of finishing what you started, says Randall Hulet, a physicist at Rice University in Houston. The MIT team has coerced over 100 million atoms into a single condensate, 10 times more than has been achieved with other atoms, he points out: "For just about any application, more atoms is better." Hydrogen also turns out to be easier to probe with lasers, he adds.

Twenty years ago, hydrogen atoms looked like the only ones that could be made both dense enough and cold enough for the atoms' quantum identities to spread out and merge into a Bose-Einstein condensate. Other atoms seemed likely to solidify as they approached absolute zero, which would heat them up and thwart the condensation. In the 1980s, the MIT group got close with a technique called evaporative cooling. They caged the atoms in a magnetic trap and lowered the walls of the trap so the faster, hotter atoms could escape. "[It's] like lowering one end of a bathtub" to let some of the hot water lap out, Greytak explains.

The problem was that the tub had a hole. Hydrogen only stayed trapped when the spin of its electron and that of the nucleus were pointing in the same direction, giving the magnetic field some purchase. Over time collisions would flip the atoms' spins, and they would leak out faster than they could be cooled. Laser cooling, which slows atoms by bombarding them with photons, offered a faster route toward absolute zero. But existing lasers worked best on heavier atoms. The first condensates were cold clouds of rubidium atoms, sparse enough to avoid solidifying.

Now the MIT team has sped up evaporative cooling with a radio frequency burst that selectively flips the spins of the hotter atoms so they flee the trap. To see if the remaining atoms—now at about 40 millionths of a degree—had condensed, the researchers pulsed them with a laser and measured the light they reemitted. The high density of a condensate would force the atoms' energy levels closer together, lowering the frequency of the reemitted light. At first they saw "the sort of signal only a mother could love," Greytak says. But with improvements it grew convincingly large. "Nothing else could give that feature," Kleppner says.

Because the laser excites a particularly sharp resonance in hydrogen, Greytak says, it should give cleaner pictures of the condensate's structure than researchers have had with other condensates. The laser pulses should also kick out a stream of synchronized atoms—a rudimentary "atom laser," which might one day be capable of etching tiny structures. But the physicists cheering the hydrogen condensate aren't worrying much about practical applications. "We're all delighted at the achievement," says Stanford University physicist Steven Chu, who shared the Nobel Prize for his work with laser cooling. "These guys really started the quest."

–DAVID KESTENBAUM

* 1998 Conference on Precision Electromagnetic Measurement, Washington, D.C., 6–10 July.

CHEMICAL ECOLOGY

Building a Better Bug Repellent

Chemical warfare is nothing new to the hordes of insects that exude noxious compounds to drive away predators. But in the sophistication of their chemical arms factories, squash beetles stand out. Researchers have now discovered that the pupae of these ladybird beetles concoct an arsenal of chemical deterrents with a technique human chemists thought they had a monopoly on: combinatorial chemistry, in which hundreds of different compounds are assembled from the same set of basic chemical building blocks. The finding, reported on page 428 by a group led by Cornell University organic chemist Jerrold Meinwald, is "the first example of natural combinatorial chemistry," says organic chemist Gordon Gribble of Dartmouth College in Hanover, New Hampshire.

The pupae deploy their defensive chemicals in droplets that they secrete from glandular hairs. Ants that attack a pupa and touch the droplets will beat a rapid retreat and try to clean themselves off. To find out what is lurking in the droplets, postdoc Frank Schröder analyzed the secretion with a battery of techniques—nuclear magnetic resonance, high-pressure liquid chromatography, and mass spectrometry—and soon found that the liquid contains an array of complex, large-ring polyamines.

The team discovered that the compounds were formed from simpler subunits called (ω-1)-(2-hydroxyethylamino)alkanoic acids. The pupae seem to have linked the subunits head to tail, in random order and varying proportions, to form scads of rings. "It's very intriguing to see what we do as organic chemists being done in a random, uninformed way," says Yale University's Harry Wasserman. Grad student Jay Farmer synthesized one of the rings, suspended it in a droplet, and found that it deterred ants.

Because the large ring compounds are too heavy to evaporate, they collect in the defensive droplets, where the improvising continues. By analyzing secretions of different ages, the researchers found that over time the rings isomerize (flip bonds) to form compounds with the same molecular formulas but different structures. When combined with newer rings pumped out by the pupa, these isomers add to the potent cocktail that deters predators.

For now, it's impossible to say whether the beetles began this chemical tinkering to yield a bunch of deterrents that could thwart predators better than a single chemical could. "It could be that the beetle doesn't know how to control the process, that it's sloppy," says Meinwald. But that doesn't diminish the finding's importance, says Cornell chemical ecologist Thomas Eisner, a co-author. "It's really pretty nifty" for evolution to have come up with this way of upping chemical diversity, he says. "This one's a keeper," adds May Berenbaum of the University of Illinois, Urbana-Champaign. "This is

THOMAS EISNER

Potent brew. Squash beetle pupae, like those of this close relative, exude defensive chemicals on their glandular hairs.