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.

going into my chemical ecology class next fall," she says. This mix-and-match approach might also have a practical payoff, says Gribble: It could be used against pests someday, "much like we use DEET to repel mosquitoes."

The hunt is now on for other insects that use such sophisticated chemistry. "Once you find something, it's going to turn up all over the place," Meinwald says. Considering that fewer than 5% of insects have even been identified, let alone studied chemically, Eisner says, "I revel in the thought that insects are the great frontier."

–LUIS CAMPOS

Luis Campos is a summer intern at *Science*.

ARCHAEOLOGY

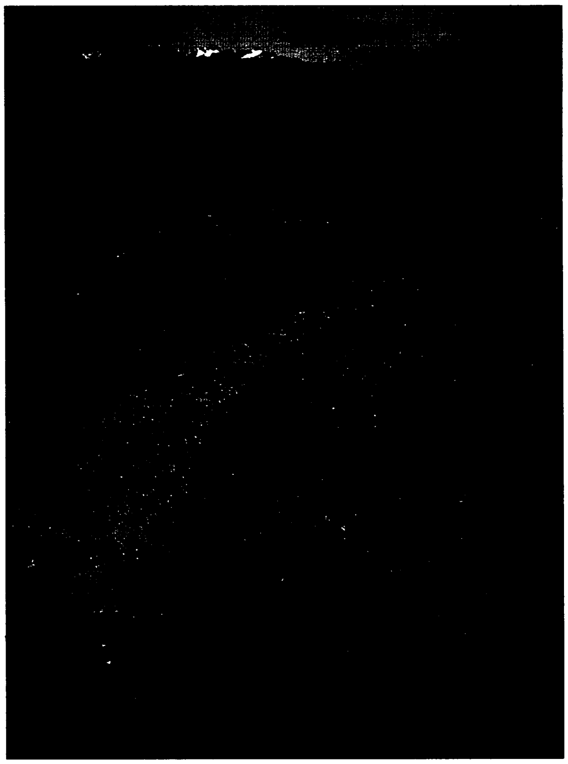
Green Farming by the Incas?

Many of us once liked to think that ancient peoples lived in harmony with the land, but that romantic notion withered in the 1990s, as studies showed that many civilizations overfarmed the land, damaging their livelihood as well as their environment. Now, however, a sediment record and archaeological evidence from a high South American valley suggest that one ancient people, the Incas, used conservation practices such as canals, terracing, and perhaps even tree planting so successfully that they actually restored degraded farmland. Those same tactics may work to help Peruvian farmers today, says botanist Alex Chepstow-Lusty of the University of Cambridge, England, co-author of the new findings. "We're convinced the [early Inca] built the ideal cultivation system for the highlands," says another co-author, archaeologist Ann Kendall.

The findings, appearing last month in *Tiahuantinsuyu*, an annual compilation of Andean archaeology, and in the journal *Mountain Research and Development*, are based on an 8-meter core taken from a small, dry lake at the bottom of the 3300-meter-high Patacancha Valley in southern Peru and on nearby archaeological digs. Although the evidence is centered on this intensely studied valley, the researchers think the findings apply to other parts of Peru, where abandoned Inca canals and terraces still cover nearly a million hectares.

The lowest layers of the core, radiocarbon dated from 2000 B.C. to A.D. 100, paint a picture of a pre-Incan land cleared and intensively farmed. The team found high levels of pollen from ambrosia, a daisy-like weed that flourishes in disturbed soil, and from pasture grasses and quinoa, an ancient food crop. The core also shows repeated spikes of inorganic sediments flowing into the lake—a sign that soil washed off the hillsides during floods. And the archaeological record suggests that farmers of the time built only rudimentary terraces. By A.D. 100, a cooling climate—and possibly degraded soil—reduced farming in the valley, but erosion continued, says Chepstow-Lusty.

Then about A.D. 1000, shortly before the Inca took over, a suddenly warmer and drier climate was accompanied by an enormous increase in pollen from the alder tree *Alnus acuminata*, a nitrogen-fixing species that thrives on eroded soils. The signature of soil erosion plummeted, and pollen and seeds from maize and other crops appeared.



ANN KENDALL

New life from old terraces. Incan terraces and canals once helped restore degraded land and may help farmers today.

At just this time, excavations in the valley point to the beginning of a systematic effort to farm the area with soil-sparing techniques, says Kendall, who directs the Cusichaca Trust in Bellbroughton, England, a rural development project that revives ancient farming practices. The Incan system included a well-built 5.8-kilometer canal to bring in water from streams and lakes at higher altitudes, says Kendall; it had layers of well-fitted stones, sand, and clay, and drop structures to distribute the flow evenly to the plots. Terraces proliferated—so many that Kendall speculates "people may have literally dragged the soil that had fallen into the valleys and riverbeds back to the hillsides" to build them. "What prompted people to say, 'OK, let's build thousands and thousands of terraces' is anyone's guess," says Chepstow-Lusty. "But when they found it worked, they kept developing it."

Excavations of nearby dwellings suggest that as the terraces were built, the valley's population quadrupled to modern levels of about 4000, showing that the land was able to support more people with less damage, says Kendall. *Alnus* trees persist in the pollen record too, even though the growing population apparently relied on the trees for firewood and building. (Excavated buildings have *Alnus* door lintels and roof beams.)

The trees may originally have spread because of the warmer climate, but the researchers suggest that there must have been a system for conserving them, and that they would have stabilized soil on the steep slopes. "There were so many people that the very fact there were any trees left means they did something," says Kendall. Indeed, chroniclers writing shortly after the Spanish conquest in the early 1500s report that the Inca had had a strong tradition of tree planting; *Alnus* cultivation was overseen by the emperor himself, and illegal woodcutting and burning was punishable by death. After conquest, the terraces and trees went into decline. *Alnus* now grows only in a few remote ravines.

Some researchers are skeptical that the Inca consciously practiced agroforestry. "One core doesn't clinch the case for active management," says Alan Kolata, director of the Center for Latin American Studies at the University of Chicago. Still, he agrees that other features of early agricultural systems, such as terraces, probably did conserve soil and boost crop production.

Moreover, some of these ancient tactics may still be practical. The Cusichaca Trust has funded a project in the Patacancha Valley to excavate terraces and then rebuild them with old methods. Since 1995, local families have rebuilt the canal and replanted 160 hectares of old terraces in potatoes, maize, and wheat. They report that the terraces produce well and use less fertilizer than other lands. "These people [had] hundreds of years to learn what worked on the land and what didn't," says University of Florida, Gainesville, geographer Michael Binford. "If we pay attention to what they did, we might just learn something."

–KEVIN KRAJICK

Kevin Krajick is a writer in New York City.