ANTIMATTER

Antihydrogen Rivals Enter the Stretch

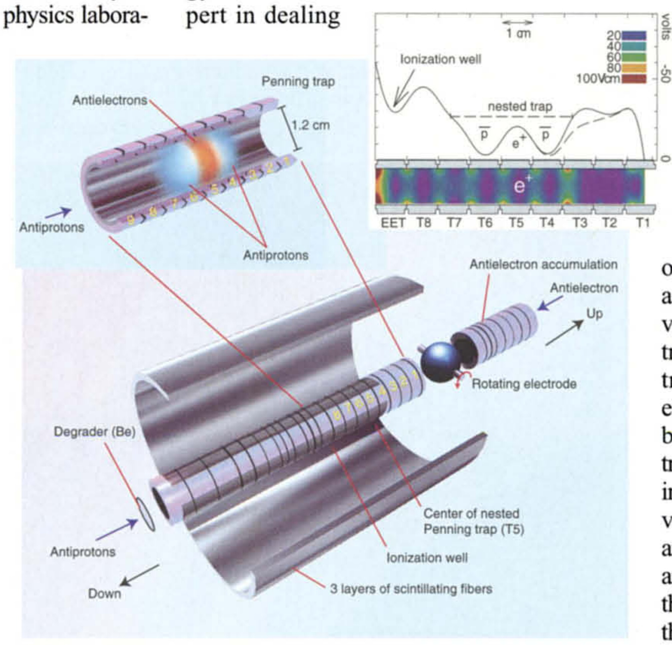
Two teams are vying to probe the properties of mirror-image atoms—a race in which key ideas of physics are at stake

Antimatter, the fuel of countless science-fiction spacecraft, has catapulted into the front pages twice in the past few months. Two rival teams are hot on the trail of antihydrogen, the antimatter doppelgänger of the simplest element, hydrogen. Known as ATHENA and ATRAP, they use similar techniques, nearly identical equipment, and the same particle beam, an antiproton factory at CERN, the European particle physics laboratory near Geneva. Within a month, each announced that it had created tens of thousands of "antiatoms" cold and slow-moving enough to be studied. The results marked the first surge forward in a race to measure antihydrogen's spectrum—a discovery that could rattle the foundations of physics and will likely net a Nobel Prize for whichever team gets there first. Not surprisingly, the competition is intense.

Physicists have known for decades that every bit of matter—whether it be an elementary particle like an electron or composite object like a proton—should have an antimatter equivalent with identical mass and equal but opposite charge. Yet almost all of the known mass in the universe seems to be made out of matter rather than antimatter. Some underlying asymmetry must have led the cosmos to "prefer" matter to antimatter. To learn more, physicists around the world have been waiting for someone to trap and study antihydrogen: the simplest antimatter "element," an antielectron bound to an antiproton in a combination that nobody has ever spotted in nature.

The ATHENA and ATRAP teams are fighting to be the first to analyze antihydrogen's properties. Their goal is to make and then capture enough to measure its spectrum, the wavelengths of light it absorbs. Scientists think that antihydrogen's spectrum should be identical to hydrogen's. If it's not, a key principle in physics known as CPT symmetry will have to be discarded, forcing a drastic revision of physicists' understanding of subatomic particles.

As the two groups close in on that prize, the rivalry is heating up. "There's been some friction between them, and I'm regretful that there has been," says Daniel Kleppner, a physicist at the Massachusetts Institute of Technology and an expert in dealing with cold hydrogen. "It may diminish each other's pleasure of discovery." But Kleppner stresses that the tension shouldn't detract from the real story: the production of significant amounts of cold, slow antihydrogen. "The fact that both groups have gotten antihydrogen is a major accomplishment," he says. "The friction shouldn't deflect from their achievements."



Going negative. "Antiatom" traps use sandwiched potentials (inset) to bring oppositely charged particles together.

ILLUSTRATION: CAMERON SLAYDEN/SCIENCE; GRAPH SOURCE: ADAPTED FROM GABRIELSE *ET AL., PHYSICAL REVIEW LETTERS*

Until a few months ago, the smart money was on ATRAP. Its leader, Gerald Gabrielse, a physicist at Harvard University, was the recognized expert in the field of trapping and cooling antiprotons. "He was the first person to do atomic physics with antiprotons, he figured out how to cool them, and he did a marvelous measurement of the [lack of] mass difference between antiprotons and protons," Kleppner says. "So I view him as having opened up the field." Others on the 15-member ATRAP team had worked on the experiment that first made hot antihydrogen at CERN in 1995. The new team quickly started racing toward cold antihydrogen production.

But ATRAP was not the only horse in the race. ATHENA, led by CERN's Jeffrey Hangst, had access to the same beamline, the Antiproton Decelerator (AD) at CERN, which takes protons created at near the speed of light down to about 10% of that speed. Drawing on years of experiments with AD's predecessor, LEAR, both groups settled on electromagnetic bottles known as Penning traps to cool antiprotons down to about 4 kelvin, confine them with antielectrons, and induce the two to combine.

ATHENA and ATRAP follow the same basic recipe for antimatter. Each gets its antiprotons from AD and its antielectrons from a radioactive sodium isotope that emits the particles as it decays. Each captures the antiprotons, cools them to a few kelvin, and shoots them and the antielectrons into opposite ends of a trap where they can mix.

The traps—meter-long cylinders that corral the particles with electromagnetic fields—face a daunting challenge: Because antiprotons and antielectrons have opposite charges, a potential that captures antielectrons repels antiprotons and vice versa. That makes it difficult to build a single trap that can hold both of them, because a trap that appears like a valley to an antielectron looks like a hill to the antiprotons. To bring the particles together, both teams use a trap within a trap—in effect, two hills framing a valley (from the antielectrons' point of view) or two valleys flanking a hill (from the antiprotons' point of view) (see figure). When an antielectron binds to an antiproton (something that occurs with only a handful of the thousands of cold antiprotons in each shot), the resulting neutral antiatom can no longer be easily controlled by electric or magnetic fields. It escapes the trap and floats away.

That's where the big differences start. To tell that they've created antihydrogen, the ATHENA physicists look for gamma rays that are produced when an antihydrogen atom is annihilated by collisions with ordinary matter. By subtracting the background gamma rays from their total count, they can estimate the number of antiatoms. Gabrielse's ATRAP team, by contrast, lets the untrapped neutral antihydrogens float into an additional trap, which tears apart the antihydrogen atom. The team then counts the liberated antiprotons as they annihilate on contact with ordinary matter. As a bonus, the ionization trap also yields information about how tightly the antielectron is bound to the antiproton.

The race for the spectrum began with a false start last year, when ATRAP succeeded in cooling antiprotons together with antielectrons but couldn't prove that it had made the particles combine. This September, the underdog ATHENA drew first blood in the duel for antihydrogen. It announced in *Nature* that it had produced an estimated 50,000 slow-moving antihydrogens (*Science*, 20 September, p. 1979).

"ATRAP was leading the way in technology over time. ATRAP was always ahead," says Steve Rolston, a physicist at the National Institute of Standards and Technology in Gaithersburg, Maryland. "Coming in second was a shock." Gabrielse acknowledges that he was taken aback. "It surprised me when they got the paper published, but such is life," he says. At first, he expressed some reservations about ATHENA's results—it can be easy to mistake background events for antiatoms—but he concedes that ATHENA probably created antihydrogen. "They're honest people and did a fairly careful job," he says. "Right now, I presume they have seen antihydrogen atoms."

But Gabrielse was poised to strike back. In October, ATRAP released a paper that will be published in *Physical Review Letters* that goes beyond ATHENA's work: Not only does it claim the production of about 170,000 cold antihydrogen atoms, but it begins to analyze their properties. With its ionizing trap, Gabrielse's team confirmed predictions that the antielectrons would occupy a high "orbit" around their antiprotons, placing the antihydrogens in a loosely bound, high-energy "excited" state.

This high-energy state complicates the task of taking antihydrogen's spectrum. An antihydrogen in a highly excited state won't absorb the wavelengths of light that physicists are so interested in. To get much information, physicists have to coax the antiatoms back down to their ground state—a slow process compared with the seconds it takes to mix the antiprotons and antielectrons. Thus, the teams will have to trap a lot of antihydrogen for minutes, hours, or even longer before they can get a reasonable spectrum. Existing equipment might not be up to the job, says Rolf Landua, a physicist on the ATHENA team.

Another problem is that the teams' source of antiprotons has just dried up. The current run of CERN's beamline just ended, so both teams will have to wait until next year to resume the race. And the budget problems at CERN (*Science*, 29 March, p. 2341) will interfere with their scramble to collect antihydrogen. "[AD] will be shut down for 1 year, which is a huge disappointment," says Gabrielse. "Without antiprotons, it's hard to make progress."

For now, frozen neck and neck, the rivals can only plan their next round of experiments, fine-tune their equipment, and wait. Says Gabrielse: "I would give a lot for one more week of beam time." **–CHARLES SEIFE**

GRADUATE STUDENT UNIONS

Labor Seeks Fertile Ground On Ivy-Covered Campuses

Graduate student unions aren't a new phenomenon at state universities. But their presence at elite private schools is raising the ante for scientists

CAMBRIDGE, MASSACHUSETTS—When graduate students at Cornell University in Ithaca, New York, overwhelmingly rejected joining the United Auto Workers (UAW) last month, they scotched what would have been only the second student union at a private U.S. university. A week after the 24 October vote, UAW organizer Joan Moriarty, a Ph.D. candidate in labor economics, still shakes with anger as she recounts the bruising 18-month battle for the hearts and minds of her 2300 colleagues, two-thirds of them in science and engineering fields. Fierce opposition from Cornell's president, a vocal antiunion student group, and reports that some faculty members had warned their grad students that a "yes" vote could jeopardize their careers swung the vote against the union, she believes. However, others say that organizers erred by pushing for a vote before they were ready and hooking up with UAW. "It was a setback, not a defeat," she asserts, tearfully vowing to continue the fight.

Stand up and be counted. A federal labor official explains the rules before the recent vote by graduate students at Cornell University.

Whatever happens at Cornell, Moriarty won't be alone. Similar organizing efforts are being waged on dozens of U.S. campuses. No longer exclusively blue-collar, unions also represent some 40,000 graduate students at 27 universities around the country. Unlike their counterparts in many countries, U.S. graduate students often carry heavy teaching loads—spending 20 hours or more a week on duties only tenuously related to their graduate training. Their unhappiness over pay, benefits, and job-related working conditions—as well as nonfinancial issues such as inadequate grievance procedures and career counseling—has been red meat for union organizers. Although teaching assistants still dominate most union bargaining units, research assistants (RAs) are becoming more prominent in the wake of a 2000 ruling by the National Labor Relations Board that RAs perform "work" apart from pursuing their degree requirements.

Ironically, there is a dearth of rigorous, academic research on how graduate student unions affect academia, notes Elaine Bernard, a labor educator who heads the Labor and Worklife program at Harvard University. Earlier this month, her program joined with a network of labor economists to put on a 2-day meeting here to explore scientific workforce issues, including the rise of graduate student unions and the status of postdocs, a traditionally downtrodden class of researchers who have begun to improve their status through cooperative rather than confrontational tactics (see sidebar). The network is funded by the New York City–based Alfred P. Sloan Foundation, which has a long-standing interest in the health of the U.S. scientific work force.

What's at stake. The first graduate student union was established at the University of Wisconsin in 1969. Most have been formed in the last decade, however—and none without a fight. The early conflicts took place at public universities, which are governed by state labor laws that are often more receptive to unionization. The battleground has now spread to private institutions. One of the longest running, and most bitter, fights is being waged at Yale University, where administrators have steadfastly refused to recognize the AFL-CIO–affiliated Graduate Employees and Students Organization (GESO)

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