NOBEL PRIZES

Awards for High-Energy Molecules and Cool Atoms

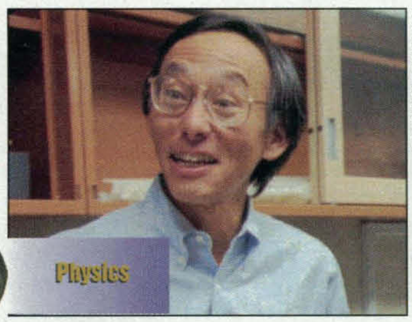
Three physicists who developed techniques for cooling atoms to near absolute zero won this year's physics prize. The chemistry prize went to three researchers for groundbreaking work on key enzymes involved in the body's cellular energy cycle. The champion of the hypothesis that infectious proteins underlie a class of degenerative brain diseases won the physiology or medicine prize earlier this month (*Science*, 10 October, p. 214).

Masters of Atom Manipulation Win Physics Prize

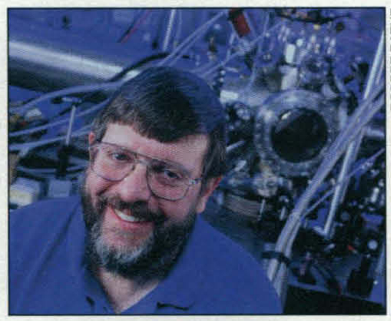
At the end of the last century, physicists were locked in a debate over whether atoms really existed or were creatures of theory. Near the end of this century, atoms are not only real; they are so commonplace that physicists cool, trap, bounce, and toss them with the facility of microscopic jugglers. That facility is due in no small part to techniques developed by three masters of atomic manipulation who have been awarded the 1997 Nobel Prize in physics. These masters showed how atoms could be chilled to millionths of a degree above absolute zero and trapped by bombarding them with laser light.

Work by the three recipients—Steven Chu of Stanford University, Claude Cohen-Tannoudji of the École Normale Supérieure in Paris, and William Phillips of the National Institute of Standards and Technology (NIST) in Gaithersburg, Maryland—has proved invaluable for basic physics, because the ability to slow and trap isolated atoms allows them to be studied at leisure. It has also led to dozens of applications, including astonishingly accurate clocks, high-precision devices for measuring the pull of gravity, and lasers made of coherent "waves" of atoms. The work has "opened up a new world, a new field," says Daniel Kleppner of the Massachusetts Institute of Technology.

The techniques honored by the prize rely on a few basic facts of optics and atomic physics: Atoms can absorb and reemit photons of light at specific frequencies, and those photons carry momentum. If a laser beam's frequency is tuned just below one of those absorption frequencies, a stationary atom will be nearly oblivious to the light, but if the atom is moving into the beam, the so-called Doppler shift will raise the frequency seen by the atom, like a police whistle heard from a passing car. The atom can then absorb the beam's photons, whose momentum has the effect of tennis balls bouncing off an oncoming basketball.



P. SAKUMA/AP PHOTO



ROBERT RATHE

JACQUES BRINON/AP PHOTO

The light stuff. From above, Chu, Phillips, and Cohen-Tannoudji.

Working with ions rather than atoms, researchers including David Wineland of NIST in Boulder, Colorado, showed in the 1970s that bathing the particles in laser light could lower their velocity in every direction—cool them, in other words. In 1985, Chu and co-workers were the first to use this strategy to chill neutral atoms, which are much harder to control, because static electric fields have little effect on them. Their initial efforts cooled the atoms to 240 millionths of a degree above absolute zero (240 microkelvins). By 1988, Phillips had pushed the temperature down to 40 microkelvins, while also developing better ways to measure it.

Just how cold atoms can get in a bath of laser light depends on how narrow a margin is left between the frequency of the lasers and the frequency absorbed by the atoms at rest. But the lasers can't be tuned too close to a rest frequency, because most absorption windows span a range of frequencies. To get around this limit and push the temperatures even lower than Chu and Phillips had reached, Cohen-Tannoudji and others showed how to exploit narrower "windows within windows," created by absorption processes that become apparent only in the presence of intense light.

Still more recently, Cohen-Tannoudji and his group have come up with tricks to keep the windows open for moving atoms but close them entirely for stationary ones, leading to even colder temperatures, down to a fraction of a microkelvin. "It's exciting to see how far one can go," says Cohen-Tannoudji.

"What's really so dramatic is that you can have such marvelous control over these atoms," says Kleppner. By adding spatially varying magnetic fields to the cooling setup or making use of other optical forces, he notes, Phillips, Chu, and others showed how to trap the atoms once they are cooled, holding them steady for lengthy experimentation.

Out of those successes has come an explosion of new science. In 1995, Eric Cornell of NIST and the University of Colorado in Boulder and colleagues used laser cooling along with other techniques to make atoms so cold that they formed a Bose-Einstein condensate, in which their quantum-mechanical waves all overlapped to create a strange new state of matter (*Science*, 14 July 1995, p. 152). Phillip Gould of the University of Connecticut at Storrs and others are playing atomic billiards: studying how atoms behave when they collide at extremely low velocities. "The only way to [do] that is with laser cooling," says Gould.

Chu and co-workers are also putting chilled atoms to work by kicking them out of a laser trap. Timing the atoms as they rise and fall in an "atomic fountain" gives the most precise measurements of Earth's gravity ever made. Oil companies are now using the device to search for deposits, which are marked by tiny dips in local gravity, says Chu.

At NIST in Boulder, researchers are turning a similar fountain into an atomic clock that should eventually be accurate to one part in 10^{16}. An atomic clock's accuracy depends on how long the atoms can resonate within a microwave cavity, says Tom Parker of NIST, and the atomic fountain boosts that time from the tens of milliseconds of standard technology to a second or so. In fact, a team in France has already built a fountain clock that keeps time to a few parts in 10^{15}, says Parker. "There's much more to come," says Chu. "Most of the applications, I didn't dream of in 1985."

–James Glanz

Chemistry Prize Taps the Energy of Life

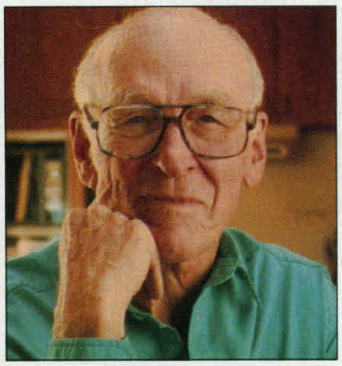
Every day our cells synthesize multikilogram quantities of a power-packed molecule known as adenosine triphosphate (ATP), a cellular fuel that drives processes ranging from the firing of nerve cells to muscle contraction. Last week, this year's Nobel Prize in chemistry went to three researchers for their "pioneering work" on enzymes that create and burn this ubiquitous compound. American Paul Boyer and Briton John Walker shared half of the $1 million prize for deducing the remarkable molecular machinery of an enzyme called ATP synthase, which catalyzes the production of ATP. Danish physiologist Jens C. Skou took the other half of the prize for his discovery of another enzyme that's the body's biggest ATP user.

Researchers identified ATP synthase in 1960, in cellular power plants known as mitochondria where ATP is constructed. A series of enzymes inside these fuel cells break down energy-rich compounds formed by the metabolism of nutrients, liberating energy that's used to pump hydrogen ions across a membrane inside the mitochondria. The pumping leaves an internal region with a relative shortage of hydrogen ions. In the early 1960s, British biochemist Peter Mitchell proposed that hydrogen ions streaming back through the membrane somehow cause ATP synthase—which is bound into the membrane—to create ATP.

By the 1970s, researchers had determined that ATP synthase consists of three sets of protein assemblies: a wheellike structure lodged in the mitochondrial membrane, a rod with one end fixed to the wheel's hub, and a large cylinder that wraps around the other end of the rod and sticks into the internal region of the mitochondria. Several labs subsequently showed that ATP is created at a trio of sites on the cylinder, and that the rod plays a key role in turning on the catalytic activity at these sites. But again, the underlying mechanism was mysterious.

Boyer, a biochemist at the University of California, Los Angeles, put the pieces of the puzzle together. He theorized that hydrogen ions cause the wheel to spin as they pass through the mitochondrial membrane back to the central region, much as rushing water turns a water wheel. Because the rod is attached to the wheel, it spins too, causing the other end to rotate within the stationary cylinder. This rotation slightly alters the structure of the trio of active sites within the cylinder, causing each in turn to snag the building blocks of ATP, synthesize a molecule of ATP, and release it.

"It was a startling new idea," says Joseph Robinson, a professor of pharmacology at the State University of New York (SUNY) Health Science Center in Syracuse. It wasn't Boyer's only one: He and his co-workers found that rather than using energy to link chemical building blocks together, as most enzymes do, ATP synthase uses energy to bind the building blocks to the enzyme and kick out ATP molecules once they have formed. The formation of ATP itself doesn't require excess energy in the special catalytic environment of the enzyme, but it takes considerable energy to pry the molecule loose so that it can be put to use elsewhere. "It's a beautiful little molecular machine," says Boyer.



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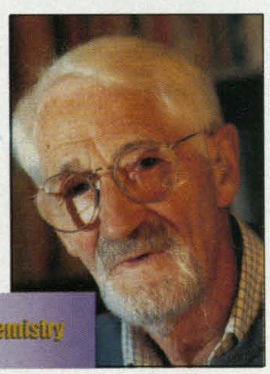

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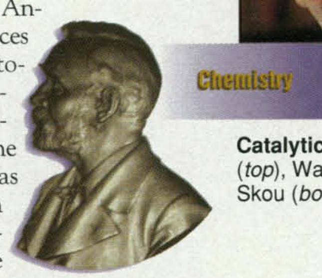
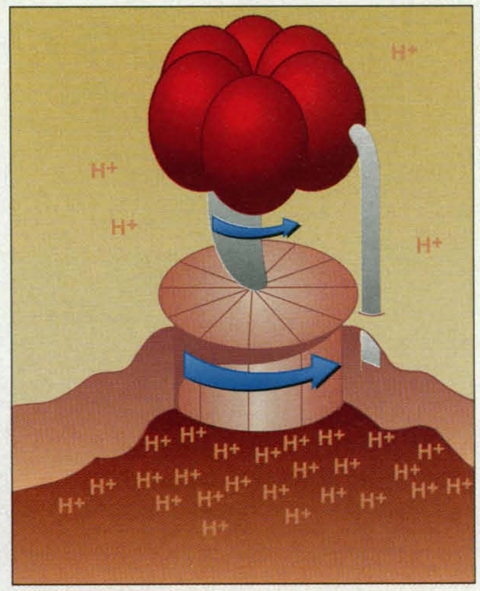


Catalytic insight. Boyer (*top*), Walker (*middle*), and Skou (*bottom*).

In 1994, Walker and his colleagues at the Medical Research Council Laboratory of Molecular Biology in Cambridge, United Kingdom, verified some of Boyer's theories by using x-rays to create an atomic-scale map of the catalytic portion of the enzyme, made up of the cylinder and rod. The resulting three-dimensional (3D) structure "had a tremendous effect," allowing researchers to see exactly how the enzyme's mechanism worked, says Robinson's SUNY colleague Richard Cross.

But despite this progress, ATP synthase hasn't yet yielded all its secrets. Researchers have yet to determine just how the rush of hydrogen ions through the membrane spins the enzyme's wheel. "That's the $64,000 question," says Robert Fillingame, a biochemist at the University of Wisconsin, Madison, whose own group is racing to determine the atomic structure of that part of the molecule.



P.D. BOYER/UCLA/THE NOBEL FOUNDATION

Molecular machine. Hydrogen ions streaming through cell membrane spin wheellike structure and attached rod, altering catalytic sites in cylinder at the end of the assembly.

Skou, at Aarhus University in Denmark, approached the fuel cycle from the other end. In 1957, he discovered the first enzyme that uses energy stored in ATP to pump ions across cell membranes. Researchers already knew that ions were often more heavily concentrated on one side of a cell membrane than another, "but people didn't know how the transport of those ions was accomplished," says Robinson.

Working with cell membranes from crab nerves, Skou discovered that an enzyme in these membranes was breaking down ATP when sodium and potassium ions were both present in the surrounding medium. After a series of tests in which he systematically altered the concentration of these ions and watched their effect, Skou surmised that an enzyme in the membrane pumps sodium out of cells and potassium in. Skou's enzyme, known as sodium, potassium–ATPase, uses about one-third of all the ATP the body generates to shuttle these ions back and forth, an activity essential for nerve signal firing as well as a host of other cell functions. Hundreds of related ATP-using transport enzymes have since been discovered.

Like ATP synthase, however, the detailed workings of this ATP-burning enzyme are still shrouded in mystery. Researchers have worked out the protein's amino acid sequence, and they know which regions are embedded inside cell membranes and which are not. But it's proving hard to grow crystals to determine the 3D structure. And without the structure, says Skou, "we still do not understand fully how this machine works."

–Robert F. Service