Briefing:

Sodium Atoms Trapped With Laser Light

Researchers at AT&T Bell Laboratories have reported the first operational optical atomic trap. With a tightly focused laser beam, they are able to confine 500 nearly motionless sodium atoms in a volume of 1000 cubic micrometers for a few seconds. Moreover, as videotape images dramatically demonstrate, the laser beam can be moved without spilling the atoms, thereby acting as a microscopic pair of tweezers for manipulating the particles. The optical atom trap complements a magnetic trap demonstrated last year at the National Bureau of Standards.

Much of the interest in trapping traces to the notion that slowly moving particles confined to a small region of space are ideal subjects for ultrahigh-resolution spectroscopic investigations unencumbered by the troublesome Doppler and other effects. On the practical side, the accuracy of frequency standards and atomic clocks, which suffer from the same deleterious effects, might some day be improved substantially.

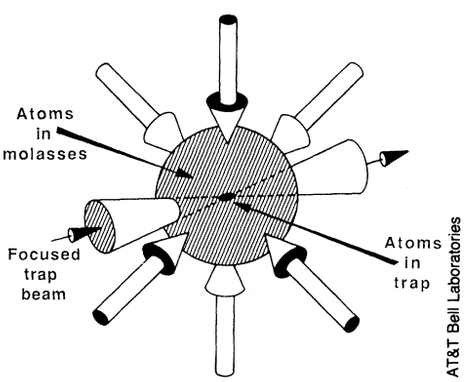
Steven Chu, John Bjorkholm, Arthur Ashkin, and Alex Cable, who made the optical trap work, also emphasize the capability of observing the details of collisions between the ultraslow atoms, the atoms and surfaces, and so on. In principle, for example, the ability to manipulate atoms means that such phenomena as molecule formation when two or more atoms are placed in close proximity could be scrutinized. There is also the possibility of examining the extreme quantum behavior that ultraslow atoms are expected to exhibit. In the realm of quantum statistics, at higher densities of trapped atoms, which the researchers expect to achieve with refinements to the present trap, a fundamental type of phase transition called a Bose condensation might be observed.

The history of optical traps stretches back many years, but the single-beam laser trap used in the Bell Labs experiment was proposed more recently by Ashkin in 1978. It is well known that, averaged over a large number of photons, light exerts a net pressure on atoms in the direction of the light beam that is due to the momentum imparted to the object when a photon is absorbed. In this way, it is possible to stop the atoms in an atomic beam by irradiating them head on, a technique called laser-cooling. (Since velocity and kinetic energy are related to temperature, researchers in the field tend to convert these quantities to the equivalent temperature, hence the term "cooling.")

Trapping is due to a quite different force that manifests itself only when there is a gradient in the intensity of the light. Laser beams generally have a Gaussian or some other intensity profile, so they naturally have a radial gradient, which is enhanced by focusing. Focusing also generates a longitudinal or axial gradient because the intensity is greatest at the focal point. As Ashkin points out, there are several ways of thinking about how the trapping comes about. One explanation is that the intense electric field of the focused laser beam lowers the energy of the ground state of the atom (optical or a-c Stark effect). Since the energy is lowest where the light is most intense, there is a potential well or trap at this location.

Focused laser beams are part and parcel of many atomic physics experiments, so at first sight trapping would seem hard to avoid. However, with a depth (expressed as a temperature) of 0.1 K or less, the potential well of an optical trap is so shallow that atoms moving at their usual thermal velocities of several hundred kelvins have far too much kinetic energy to even notice it. For this reason, it is crucial to slow down the atoms by the technique of laser-cooling.

At Bell Labs, the researchers actually used a two-stage cooling technique. After conventional laser-cooling of sodium atoms in a pulsed atomic beam that cooled particles to a temperature about 1/100 of the initial value, the atoms were irradiated by a pair of collimated, counterpropagating laser beams along each of three mutually perpendicular axes (see drawing). The three-dimensional cooling creates what the experimenters call an optical molasses in which the atoms move very sluggishly. In particular, they are very quickly cooled to a temperature of 0.00024 K, a record low temperature for a gas. The atoms remain in the roughly spherical molasses region (1 centimeter in diameter) for about 0.5 second before escaping.



Atom trap. *Schematic diagram shows the six molasses laser beams and the focused trapping laser beam.*

Trapping occurs when an intense laser beam tuned to a frequency slightly below resonance is tightly focused at some location in the molasses region to make a spot 20 micrometers in diameter and a potential well at the center of 0.005 K. As the theory has it, atoms are trapped for frequencies below resonance, repulsed for those above resonance, and unaffected exactly at resonance. Because the molasses lasers interfere with trapping and vice versa, the Bell Labs investigators switch rapidly between the two modes at intervals of 10 microseconds or less. The trapping is monitored by means of the bright yellow fluorescence emitted by laser-excited sodium atoms. ■

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ADDITIONAL READING

S. Chu, J. E. Bjorkholm, A. Ashkin, A. Cable, "Experimental observation of optically trapped atoms," *Phys. Rev. Lett.* 57, 314 (1986).

Laser-Cooling Mercury Ions Via Beryllium

Scientists at the National Bureau of Standards (NBS) in Boulder, Colorado, have demonstrated a way to slow down or cool ions confined in an electromagnetic trap that overcomes some irksome limitations of the usual laser-cooling technique. The new technique advances the prospects for ultrahigh-resolution spectroscopy of ions and more accurate timekeeping with ion clocks.

Called sympathetic cooling, the method entails the use of two ion species, one of which is directly laser-cooled, while the other is cooled indirectly by means of the Coulomb force between the ions. In an experiment with singly charged beryllium-9 and mercury-198 ions in the same trap, the investigators reduced the effective temperature of the mercury ions to 0.4 K by laser-cooling the beryllium ions.

Because of their electric charge, ions are comparatively easy to capture in traps comprising a combination of static electric and magnetic fields (Penning trap) or simply an inhomogeneous radio-frequency electric field (Paul trap). Although localized in the trap, the ions continue to move about, so that the resulting Doppler broadening and shifting of spectral lines inhibits high-resolution measurements. Laser-cooling dampens the motion effectively, and temperatures as low as 0.005 K and storage times as long as several weeks have been achieved in this way. Early last year, NBS researchers reported making an ion clock, using a radio-frequency transition in laser-cooled beryllium

um-9 ions, that is as accurate as existing cesium atomic clocks, which provide the current time standard.

Unfortunately, in practice, it is not possible simultaneously to laser-cool and make the high-resolution spectroscopic measurements required in clocks of this accuracy. The difficulty is that the electric field in the cooling laser beam changes the frequencies of spectroscopic lines (a-c Stark effect). The researchers therefore had to turn the cooling laser off for about 20 seconds to make a measurement, during which time the ion temperature rapidly rose from 0.1 K to about 30 K, limiting the accuracy of the clock.

A second difficulty stems from limitations in laser technology, which is not yet up to the task of providing intense light continuously across the ultraviolet spectrum. For example, an ion clock based on a microwave transition in mercury-201 is potentially 100 times as accurate as the beryllium clock, but the relevant optical transitions for laser-cooling are in the deep ultraviolet.

In the latest experiment, David Larson of the University of Virginia and James Bergquist, John Bollinger, Wayne Itano, and David Wineland of NBS took a step toward overcoming both obstacles by showing that it is possible to indirectly laser-cool the ion of spectroscopic interest with ultraviolet light generated by frequency doubling a visible laser. The idea is to use two ion species, beryllium-9 and mercury-198 in this case. The beryllium ions are laser-cooled as in the original clock experiments. Any spectroscopic measurements would be done on the mercury ions, whose spectra would be shifted only negligibly by the presence of the laser light.

Actually, there are two reasons why the mercury spectra are largely unaffected by the cooling laser. The first is that the laser light, which is tuned to excite an optical transition in beryllium, is in a spectral region in which mercury is transparent. The second reason for spectral immunity is that, as the experiment demonstrated, the clouds of beryllium and mercury ions are also physically separated in the trap with the mercury forming a ring around the beryllium in the center, so that the cooling laser does not pass through the mercury.

So far, the sympathetic cooling is not 100% efficient; that is, the laser-cooled beryllium ions have a temperature about 1/10 that of the mercury. The researchers conjecture that the interaction may be weakened by the spatial separation that results from the rotating motion of the two ion clouds. The cooling of the mercury occurs by a long-range Coulomb interaction that Bergquist described to *Science* as a "gentle collision."

Finally, an intriguing application of sympathetic cooling may be the storage of antimatter, antiprotons in particular, in an electromagnetic trap. It appears difficult to cool antiprotons directly because there is no atomic structure and hence no resonance. An alternative is to load electrons and antiprotons into the same trap. The electrons cool themselves by emitting radiation as they circulate in the trap (radiation damping). The cold electrons could then sympathetically cool the antiprotons. ■

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ADDITIONAL READING

D. J. Larson, J. Bergquist, J. J. Bollinger, W. M. Itano, D. J. Wineland, "Sympathetic cooling of trapped ions: A laser-cooled two-species nonneutral ion plasma," *Phys. Rev. Lett.* **57**, 70 (1986).

RNA Plasmid Discovered In Maize Mitochondria

Research on RNA continues to turn up surprises, the latest being the discovery of apparently independently replicating single- and double-stranded RNA species in maize mitochondria. Because these RNA molecules are unrelated to the DNA of the mitochondrial genome, their discoverers, Patrick Finnegan and Gregory Brown of McGill University, Montreal, have called them RNA plasmids.

Grant Heilman Photography

"These plasmids represent a novel type of inheritable element in organelles," note Finnegan and Brown. Their origin is currently obscure, but the McGill researchers are in the process of cloning and sequencing the four new RNA molecules they have found. The sequences may reveal some hint of their origin, if for instance they contain telltale remnants of viruses or transposable elements. The identification of any protein-coding regions would also be of considerable interest.

There are in fact four different mitochondrial DNA (mtDNA) variants in maize that are known as S, C, T, and N, the first three of which result in defective pollen production. So far the newly identified RNA plasmids have been recovered only from the S type. Restriction to the S strain implies that the plasmids are of fairly recent origin, having arisen since the divergence of the S, C, T, and N varieties.

Finnegan and Brown made their discovery when they were looking for differences in mtDNA transcription activities among the four types. Previous research has revealed a number of other biochemical differences, including patterns of restriction fragment polymorphisms and protein profiles. It therefore seemed possible that the mitochondrial genomes might manifest characteristic transcription products. The McGill researchers did not expect to find the production of RNA molecules that were apparently unrelated to the mtDNA sequences.

Moreover, this new RNA was generated in the presence of actinomycin D, which blocks the transcription of RNA from DNA. These RNA's, apparently, were made off RNA templates.

The first such RNA's they found were relatively short, measuring 900 and 850 nucleotides, the former being double-stranded and the latter single-stranded. At about one-tenth the concentration of these molecules were two longer species, measuring 2850 and 2150 nucleotides, the first being double-stranded and the second single-stranded.

In hybridization experiments, Finnegan and Brown were able to show no sequence relation between the four new RNA molecules and the mitochondrial genome itself. There was, however, some relation within the group of newly discovered RNA's: "complementarity exists between at least one of the [double-stranded] RNA's and the 850-base single-stranded RNA." The obvious interpretation, and the one that Finnegan and Brown currently favor, is that the two single-stranded species represent transcripts of the double-stranded molecules.

If this interpretation is correct, then presumably the RNA plasmids in some way harness mitochondrial RNA polymerases to their own requirements, as the plasmids themselves appear to be too small to encode such an enzyme. Unless, of course, the RNA molecules act as their own polymerases, which these days is not beyond the bounds of speculation. ■ ROGER LEWIN

ADDITIONAL READING

P. M. Finnegan and G. G. Brown, "Autonomously replicating RNA in mitochondria of maize plants with S-type cytoplasm," *Proc. Natl. Acad. Sci. U.S.A.* **83**, 5175 (1986).