"Now, let's suppose there is a hole in the remnant, a leak," says Rees. "The plasma will all squirt out the hole at almost the speed of light." Thus the jet. In fact, he says, "essentially all the power of the central pulsar comes out in the jet." That power is estimated to be about 10^{41} ergs per second, which also happens to be roughly the optical luminosity of the supernova as a whole. Thus, the numbers are reasonable: a jet would have the right velocity and the right amount of energy to produce the companion source that we see.

"Now," says Rees, "Why is there a hole?" One possibility is that Sanduleak $-69°$ 202 may have had a binary companion star, he says. (Most stars do.) "The ejecta from the explosion would have been blocked in that direction, and you would have had a shadow—a conical region where there is no ejecta. Then, as the companion moved away in its orbit, you would have been left with a hole."

Rees is the first to agree that the jet model needs to be tested against new data. In particular, if the companion is the leading edge of a jet then it will move further and further away from the supernova as time passes. Moreover, the jet will slow down as it goes. (The velocity of known astrophysical jets decreases inversely with the distance they have traveled.)

One such test may well come from the new observations of the supernova made by Nisenson, Papaliolios, and Karovska at the end of May. Reducing the data and creating the image will take a month or more, they say. But assuming that the companion is really there—and a new confirmation of its existence is critically important—then the new images should clearly show whether it has moved. ■ M. MITCHELL WALDROP

Four Groups Build More Efficient Atom Traps

Hydrogen, sodium, and cesium atoms can now be cooled and stored for up to 20 minutes with some combination of a laser, a magnetic field, and a helium dilution refrigerator

ULTRAHIGH-resolution spectroscopy, atomic clocks of unprecedented accuracy, detailed studies of the kinetics of atomic collisions, and observation of unusual quantum phenomena are some of the things that physicists expect from the ability to confine atoms for long times in a nearly motionless state at temperatures much less than 1 millikelvin (mK). During the past 2 years, researchers have shown they can hold up to 100,000 sodium atoms for a second or two, thereby demonstrating the feasibility of atom trapping.

Now four groups have built more efficient traps that can hold substantially larger numbers of atoms for durations of 2 minutes or longer, times that are much closer to those needed for some of the experiments envisioned. Moreover, investigators have extended the variety of atoms confined from sodium, heretofore the fruit fly of atom trapping, to hydrogen and cesium, which should broaden interest in the techniques. At the moment, the confinement record is held by a Massachusetts Institute of Technology (MIT) group, which held 5×10^{12} hydrogen atoms for 20 minutes in a magnetic trap.

At MIT, Thomas Greytak and Daniel Kleppner have been interested for many years in an unusual form of hydrogen gas called spin-polarized hydrogen. Normally, hydrogen atoms combine quickly to form hydrogen molecules. But, if the electronic spin angular momenta of the atoms are aligned in a magnetic field, the Pauli exclusion principle prevents the formation of molecules. Physicists are interested in spin-polarized hydrogen because of its statistical properties. When the spins of the electron and the proton are taken into account, the net atomic spin is either 0 or 1, making the atom a boson.

According to quantum statistical mechanics, at high densities and low temperatures, a system of noninteracting bosons undergoes a phase transition with the jargon name Bose-Einstein condensation. Here, condensation does not mean formation of a liquid but refers to a special quantum condition in which nearly all the bosons occupy the same quantum state—the one with the lowest energy. Physicists believe that the condensed state of spin-polarized hydrogen will be a viscosity-free superfluid similar to liquid helium-4 below 2.18 K, which is also thought to be a Bose-Einstein condensed state. But hydrogen remains a gas, even at 0 K and as the simplest atom it may also be easier to study in detail than helium. On the practical side, it has been proposed that spin-polarized hydrogen could be the basis for an improved hydrogen maser, and it could be a source of polarized protons in high-energy physics experiments.

Achieving an appropriate combination of high hydrogen atom density and low temperature has not, however, been possible up to now because of so-called three-body collisions involving two spin-polarized hydrogen atoms and a third atom in the gas at high densities or on the walls of the refrigerator at low temperatures. The three-body collisions permit the formation of hydrogen molecules. Harald Hess, who is now at AT&T Bell Laboratories, devised a magnetic trap for spin-polarized hydrogen. The idea is to keep the density low enough to avoid three-body collisions in the gas and to insulate the atoms from the wall magnetically while the temperature is decreased.

At MIT, Hess collaborated with Greg Kochanski, John Doyle, Naoto Masuhara, Kleppner, and Greytak of MIT in implementing the scheme. With an appropriate combination of magnet coils, it is possible to generate a static magnetic field with a minimum value in a specified region of space. In a large magnetic field, atomic hydrogen has four relevant quantum (hyperfine) states, according to the four combinations of parallel and antiparallel orientation of the electron and proton spin angular momenta relative to the field. Once in the trap, the atoms with electron spins parallel to the field are attracted to the minimum, whereas those with antiparallel spins are ejected, giving a sample of spin-polarized atoms. The investigators actually went a step farther and retained only those atoms with both electron and proton spins parallel to the field, further reducing the already small but still significant probability of two-body collisions resulting in molecule formation.

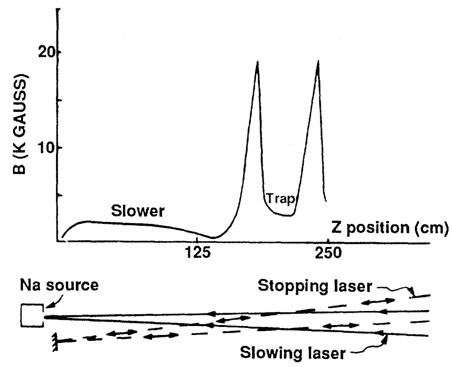
The maximum depth (expressed as a temperature) of the trap with magnetic fields of 0.87 tesla was 580 mK, so that the atoms had to be cooled with a helium dilution refrigerator before they could be trapped. In the present experiment, the trapped atoms were at an estimated 40 mK.

In their experiment, the investigators initially trapped 5×10^{12} atoms and retained a significant fraction of them for 20 minutes by this means. In the future, they hope to increase the density and lower the temperature to less than 1 mK and thereby observe the Bose-Einstein condensation or other distinctly quantum phenomena that occur in collisions at ultralow temperatures. One way that Hess has proposed to achieve lower temperatures is by deliberately reducing the magnetic field once the atoms are trapped, making it easier for the most energetic atoms to escape. This method is called evaporative cooling.

An older but highly effective method of atom trapping is to use laser cooling to slow down sodium atoms prior to trapping. The principle behind laser cooling is that an atom in a beam is slowed down by the momentum imparted to it when it absorbs a large number of photons from a laser shining in the opposite direction. Although the atom receives another kick when it radiates a photon on relaxing from the excited to the ground state between each absorption event, the net momentum imparted after many emissions is zero and does not interfere with the cooling process.

At MIT, a group headed by David Pritchard and including Vanderlie Bagnato, Gregory Lafyatis, Alexander Martin, Eric Raab, and Riyad Ahmad-Bitar has succeeded in holding 10^9 laser-cooled sodium atoms in a magnetic trap for 2.5 minutes. The larger number of stored atoms and the longer trapping time, as compared to the previous experiments, are due to two factors: continuous loading of the trap with atoms for a second or so as opposed to single-shot pulses of less than 1 millisecond, and a much improved vacuum associated with the liquid helium refrigeration of the superconducting magnets that form the trap.

In brief, a beam of sodium atoms emerged from an oven at a temperature of 550°C. The atoms were slowed by the light from a dye laser emitting yellow light. Upon reaching the trapping region, the atoms were nearly "stopped" by a second dye laser whose light passed through the atomic beam at a slight angle, struck a mirror, and returned for a second pass through the atoms. Pritchard calls this arrangement a one-dimensional optical molasses. With the frequency of the laser tuned slightly below that for absorption by stationary atoms, because of the Doppler effect, atoms moving in either direction along the axis of the beam in the trapping region will absorb light and be slowed and trapped. The temperature of the stopped atoms was less than 2 mK. In the original Bell Labs three-dimensional optical molasses with three mutually orthogonal laser beams reflected from mirrors, motion



MIT magnetic trap. *(Top) Profile of the magnetic field that traps sodium atoms longitudinally. (Bottom) Arrangement of sodium source, cooling or slowing laser, and stopping laser. [From* Phys. Rev. Lett. *58, 2194 (1987)]*

in any direction was damped and a still lower temperature obtained.

The MIT trap comprised two magnets: a solenoid confined the atoms in the axial direction, and an octopole provided the transverse or radial confinement. The trap depth was 120 mK and nearly constant over its cylindrical volume of 4-centimeter diameter by 25-centimeter length. As with the hydrogen atoms, the trapping occurred because of the energy-lowering interaction between the magnetic field and the sodium atoms when they were in a particular spin-polarized quantum state. Sodium is a more complicated atom than hydrogen, however, and the number of quantum states in a magnetic field is much larger. Fortunately, the laser-cooling process itself, which took place in a weak magnetic field, prepared the atoms in the proper spin-polarized state for trapping.

The MIT investigators believe that both the number of trapped atoms can be increased substantially by at least a factor of 100 and their temperature can be lowered perhaps to the microkelvin range. The main limitation on the number of trapped atoms at the moment—the excitation of atoms in the trap to the wrong quantum state by light from the slowing laser—is not a fundamental one. Moreover, among many other physicists, Pritchard has proposed a laser-cooling scenario that makes use of an additional radio-frequency source that theoretically could cool sodium atoms to 0.01 mK.

In an optical trap, lasers do both the cooling and the confining. A trap that a Bell Labs group demonstrated last year consisted of three-dimensional optical molasses to cool the atoms and a single focused laser beam to confine them. The trapping mechanism relied on a type of force quite different from that doing the cooling. When there is a gradient in the light intensity, according to the optical Stark effect, an atom can lower its energy by moving toward the region of highest electric field. A single focused laser beam has a region of maximum intensity in both the axial and transverse directions.

Much more debatable has been the proposition that optical trapping could also be accomplished by means of the momentum transfer that causes laser-cooling. Physicists call this force spontaneous because the atoms decay to the ground state by spontaneous emission or fluorescence after absorbing light from the laser. The force associated with the optical Stark effect is called stimulated because the laser drives both the excitation and decay transitions. By containing up to 10^7 sodium atoms for 2 minutes, a Bell Labs–MIT group has now shown that optical trapping via the spontaneous force is possible. Somewhat ironically, the researchers estimated the depth of their spontaneous-force trap to be 1 K, about ten times that of the stimulated-force trap previously reported.

The problem with the spontaneous force is that with static laser beams alone there is no way to generate the energy well needed for a trap. Atoms trapped in one direction are eventually ejected in another, even in optical molasses. Last year, Pritchard, Raab, and Bagnato of MIT joined with Carl Wieman and Richard Watts of the Joint Institute for Laboratory Astrophysics (JILA) and the University of Colorado to show theoretically that a trap could be made if the internal structure of the atoms could be manipulated in such a way that they were to absorb light differently according to their position in the trap.

Mara Prentiss, Alex Cable, and Chu of Bell Labs teamed with Raab and Pritchard of MIT to develop and implement an idea suggested originally by Jean Dalibard of the Ecole Normale Supérieure in Paris. The idea, as applied to the Bell Labs optical molasses apparatus, was to immerse the setup in a weak magnetic field, whose magnitude changed linearly from positive to negative with position across the trap. According to the Zeeman effect, each quantum state of a given spin angular momentum is split into a number of substates, whose energies depend on the strength of the field, so that the energies of the substates are reversed from one side of the trap to another. The last ingredient was the use of circularly polarized light—left circularly polarized for the beam in one direction and right circularly polarized in the other for each of the three orthogonal axes of the molasses. Circularly polarized light causes transitions only between certain Zeeman substates.

To see how the trap works, consider what happens in one dimension. Since an atom can absorb laser light only when its frequency matches the energy between appropriate Zeeman substates and when it has the correct polarization, the net effect of all these factors is that an atom on the left side of the trap, for example, absorbs light preferentially from the beam coming from the left and therefore pushing it toward the center, whereas an atom on the right absorbs more light from the opposite beam. The net force on the atoms is toward the center and is provided by the same lasers that cool the atoms to about 0.5 mK.

A different approach that also makes use of circularly polarized light is being tried on cesium atoms at JILA by Wieman, David Sesko, and Carol Tanner. In preliminary experiments, trapping has been demonstrated, but the number of atoms and confinement time are still low. An additional wrinkle is the use of low-cost infrared laser diodes rather than comparatively expensive visible dye lasers. Making optical trapping less costly undoubtedly enlarges the number of researchers who might want to try their hand at this kind of experiment.

The JILA researchers exploit the phenomenon of optical pumping. One form of optical pumping is normally a complicating factor in laser cooling. It arises because of the existence of a hyperfine splitting in the atomic ground state; that is, the energy is different when the electron and nuclear spin angular momenta are parallel and antiparallel. During cooling, the laser excites atoms in only one of the hyperfine states, but the atoms can decay back to either state. The result is that the atoms quickly end up in the wrong state and can absorb no more light, so that cooling stops. If two beams of unequal intensity are used, one to excite each hyperfine state, the stronger beam will end up doing the optical pumping.

For optical trapping of cesium, the optical pumping is not between hyperfine states but between Zeeman substates when the atoms are in a constant magnetic field. Circularly polarized beams traveling in opposite directions are each focused to points on the far side of the trap relative to the lasers. Optical pumping of an atom on the left side of the trap, for example, prevents absorption of the more intense light coming from the right but allows it from the weaker light from the left. Similarly, an atom on the right can only absorb light coming from the right. Once again, all the atoms feel a force pushing them toward the center.

All in all, more and more researchers are getting interested in trapping atoms with the result that some of the promised fruits of the technique should be ready for picking in the not too distant future. ■

ARTHUR L. ROBINSON

Study Bolsters Case Against Cholesterol

A new study shows that aggressive cholesterol-lowering therapy can halt the growth of lesions and in some cases shrink them

THE benefits of lowering blood cholesterol levels have become almost gospel over the past few years. Clinical trials, involving thousands of subjects, have shown that lowering blood cholesterol can reduce the risk of coronary heart disease and heart attack. But what has not been clear is the mechanism: Does lowering cholesterol actually improve the condition of coronary arteries that have become clogged with fat deposits, called lesions?

Now new evidence, perhaps the strongest to date, comes from a 2-year trial by David H. Blankenhorn and his colleagues at the University of Southern California School of Medicine.* They report that a drastic reduction in blood cholesterol levels, achieved through an aggressive diet and combination drug therapy, can slow the progression of atherosclerotic lesions and in some cases even shrink them. At last, says Blankenhorn, the mechanism is clear.

The results of this trial, the Cholesterol-Lowering Atherosclerosis Study (CLAS), were reported in the 19 June *Journal of the American Medical Association* and announced with much fanfare at a news conference at the National Heart, Lung, and Blood Institute (NHLBI), which supported the study along with the Upjohn Company. Heart institute director Claude Lenfant hailed the study as "significant new information" that presents "for the first time . . . evidence regarding regression of lesions in humans."

According to Blankenhorn, this study showed a "strong and consistent therapy effect—the first seen in humans at the level of coronary arteries—from cholesterol lowering."

To Robert I. Levy, former director of the heart institute who is now at Columbia University College of Physicians and Surgeons, the study results are "exciting" if not unexpected. "It confirms and extends the factual evidence," he says. "Every new bit of evidence makes the conclusions firmer, but I didn't think they were soft before."

Several primate studies have demonstrated that lesions regress in response to both diet and drug therapy, he and others say. And, Levy adds, previous human trials, including the NHLBI Type 2 Coronary Intervention Study, have clearly indicated that the progression of atherosclerotic lesions can be slowed by lowering cholesterol levels. Human studies have also strongly suggested that lesion regression may occur.

But those earlier human trials were inconclusive, according to Basil M. Rifkind, chief of the lipid metabolism branch at NHLBI, who calls the Blankenhorn study the "first conclusive study with clear-cut results in humans."

One key finding of the new study, researchers agree, is that diet and combination drug therapy can achieve substantially greater reductions of blood cholesterol than previously demonstrated. And that, according to heart institute officials, suggests a larger role for drugs in the future treatment of coronary heart disease, which affects some 5 to 6 million Americans, and perhaps in the treatment of those with elevated cholesterol levels.

The study also makes a strong case, Blankenhorn says, for reducing blood cholesterol to a level below 200 milligrams per deciliter, the level now recommended by both NIH and the American Heart Association. "These findings suggest that the target level should be on the low side of 200—between 185 and 200," Blankenhorn says.

The study was conducted on 162 men, aged 40 to 59, who had previously undergone coronary bypass surgery for treatment of atherosclerosis. (Bypass patients were selected both because they could benefit from cholesterol reduction and because the researchers believed they would be highly motivated to comply with the rather rigorous study requirements.) None of the subjects smoked, although some had previously, and all had blood pressure within normal range, thus eliminating the two other major risk factors for heart disease.

The men were randomly assigned to two groups. Half received the cholesterol-lowering drugs, colestipol and niacin, and were placed on a stringent diet that limited fat intake to 22% of total calories and cholesterol to less than 125 milligrams a day. The other half received a placebo and were

*His colleagues are Sharon A. Nessim, Ruth L. Johnson, Miguel E. Sanmarco, Stanley P. Azen, and Linda Cashin-Hemphill.