inum catalysts. In the hot field of surface chemical physics, Kroto says, "there's no doubt that Dave King is a leading scientist."

Culture change

King hasn't forsaken his thriving research career. He works 4 days a week here in a stark room (bare walls, empty bookshelves) at the Department of Trade and Industry's Office of Science and Technology before decamping to Cambridge to spend Fridays with his research team. "When I took this job," he says, "I made it a condition that I could keep doing research."

King has inherited a hot seat in the science adviser post. In the last several months, uncertainties over health risks posed by bovine spongiform encephalopathy (BSE), genetically modified crops, the measles-mumps-rubella vaccine, and depleted uranium armaments have dominated in the newspapers—issues all overtaken by the grim vigil on the foot-and-mouth disease outbreak. In this unsettling context, King says, "science has hardly been out of the news." The string of crises has posed a huge challenge, he says: "The single biggest problem is public confidence in science."

Part of the solution is ensuring greater transparency in the way policy-makers take scientific advice, King argues. He describes the recent Phillips Commission report on the government's fumbling of the BSE crisis as "an invaluable audit" and gives May credit for having anticipated many of the report's recommendations: "He could clearly see what needed to be done in response" to the fiasco. In the past, King says, his predecessors and each ministry's chief scientist were discouraged from being forthcoming about risks, no matter how negligible, posed by new technologies. The new policy, King says, is that "you have to come straight out with it and say what you know about the risks ... and what your decisions are and why you took those decisions."

King holds up the 1-year-old Food Standards Agency as the "flagship" effort to change the culture within the government. By holding meetings in public and posting minutes to the Web, he says, the agency "is spearheading this whole notion of engaging with the public in the decision-making process." But although everyone across government has bought into this idea, he claims, "it takes quite a while before people actually behave, on each occasion, according to the new culture." An important part of his job, he says, will be to ensure that this culture change takes hold: "I'm keeping a very watchful eye on it."

Among his core constituents, a preeminent concern is salaries. Not surprisingly, King, a former president of the Association of University Teachers, believes these must be raised. "When we advertise a top position in a top university in the U.K., we ought to judge whether salaries are being paid properly by looking at the people who apply," he says. King concludes that many departments are failing to attract the best applicants and says he will fight to double top salaries. (The salary scale for university lecturers—comparable to assistant and associate professors in the United States—currently tops out at just under 40,000 pounds a year, or $57,000). But all levels of scientists are underpaid, he insists. As a former department head, King says, "one of the most upsetting things for me was year after year watching the brightest crop of graduating students not going into careers in science" but opting instead for high-salary careers in finance, for example.

King promises that his initiation into the world of British science policy "won't last much longer." One of his main priorities after the election, he says, will be to shore up energy research, from biomass to fusion. "We need ... to be working very, very hard on future energy scenarios," he says.

Observers are watching to see how King's tenure will differ from May's. Although both grew up outside the United Kingdom, each brings to the table entirely different people skills. "Bob May is the outback Australian," says Gibson, a former colleague of King's at the University of East Anglia, "whereas Dave is more the smooth, sherry-drinking type, although he tells me he doesn't drink sherry now." That King has managed to sustain this illusion is another sign that, as a student of surfaces, he should easily grasp the contours of the political world as well.

–KIRSTIE URQUHART AND ANDREW WATSON

Andrew Watson writes from Norwich, U.K.

CONDENSED-MATTER PHYSICS

Doing the Bose Nova With Your Main Squeeze

In Bose-Einstein condensates, dancing atoms merge into a chorus line. Now physicists are teaching them some new steps

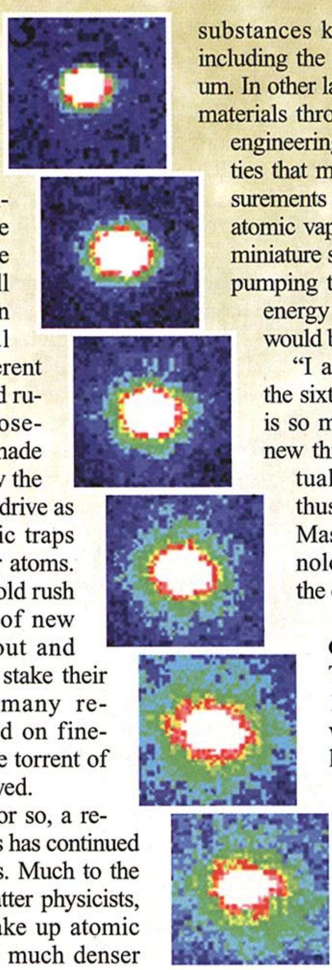
Six years ago, researchers in Boulder, Colorado, hit the physics jackpot when they created a new state of matter. By trapping a wisp of rubidium atoms and cooling them to a few hundred billionths of a degree above absolute zero, the physicists managed to get all the atoms to lock together in one quantum mechanical state—as uniform and coherent as a single particle. The frigid rubidium vapor, the first Bose-Einstein condensate (BEC) made out of an atomic vapor, threw the physics community into overdrive as labs raced to build magnetic traps and create colder and colder atoms. Since then, the condensate gold rush has slowed as easy veins of new physics ore were mined out and fewer physicists came in to stake their claims. More recently, many researchers have concentrated on fine-tuning their gadgetry, and the torrent of preprints and papers has slowed.

Yet within the past year or so, a remarkably diverse set of results has continued to amaze the atom wranglers. Much to the satisfaction of condensed-matter physicists, the tenuous vapors that make up atomic BECs turn out to resemble much denser substances known as quantum fluids—including the classic superfluid, liquid helium. In other labs, researchers are putting the materials through some weird contortions: engineering them with quantum properties that might lead to ultraprecise measurements of distance or time; imploding atomic vapors at will to create a kind of miniature supernova or "Bose nova"; and pumping their atoms so full of internal energy that less uniform substances would be instantly destroyed.

"I am truly amazed that even in the sixth year of BEC research, there is so much excitement and so many new things happening, both conceptually and experimentally," enthuses Wolfgang Ketterle of the Massachusetts Institute of Technology (MIT), leader of one of the early groups to achieve BEC.

Quantum fluid tricks

The history of BECs began in 1937, when Pyotr Kapitsa, working in Moscow, cooled liquid helium below its 4.2-kelvin boiling point and discovered an astonishing



Star quality. Collapsing rubidium-85 condensate ends with a burst like a tiny supernova.

CREDIT: C. WIEMAN ET AL./JILA

thing: At 2.17 kelvin, the boiling stopped and the liquid became calm again, but it had no viscosity. All trace of resistance to fluid flow had vanished; Kapitsa had discovered the first superfluid. With the jiggling from thermal energy removed, theorists explained, the wave functions of all the atoms had locked together. The helium fluid had undergone Bose-Einstein condensation down to a common quantum state.

Since then, liquid helium has been the lab rat for many experiments in condensed-matter physics. One of the key findings was that superfluids break up into tiny whirlpools when they are rotated. The vortices are strikingly long-lived. In theory, without viscosity to stop them, they could persist forever. For many physicists, this vortex phenomenon is the acid test for superfluidity. "Superfluidity has many manifestations," says Ketterle, "but for many people vortices are the most direct evidence."

When the much more rarefied atomic BECs came along, physicists wondered whether they would pass that test. Over the past year or so, most have concluded that they do. Late in 1999, groups at JILA in Boulder and the Ecole Normale Supérieure in Paris directly observed superfluid whirlpools in BECs. They created the vortices by using a laser beam, in effect as an optical spoon to stir up the condensate. As the stirring speed increases above a critical velocity, they found, a hole forms in the condensate as the quantum fluid spins around it—just as it does in liquid helium. By dragging a laser beam through a condensate, Ketterle and his group at MIT confirmed that the beam moved without resistance, again just as in a superfluid.

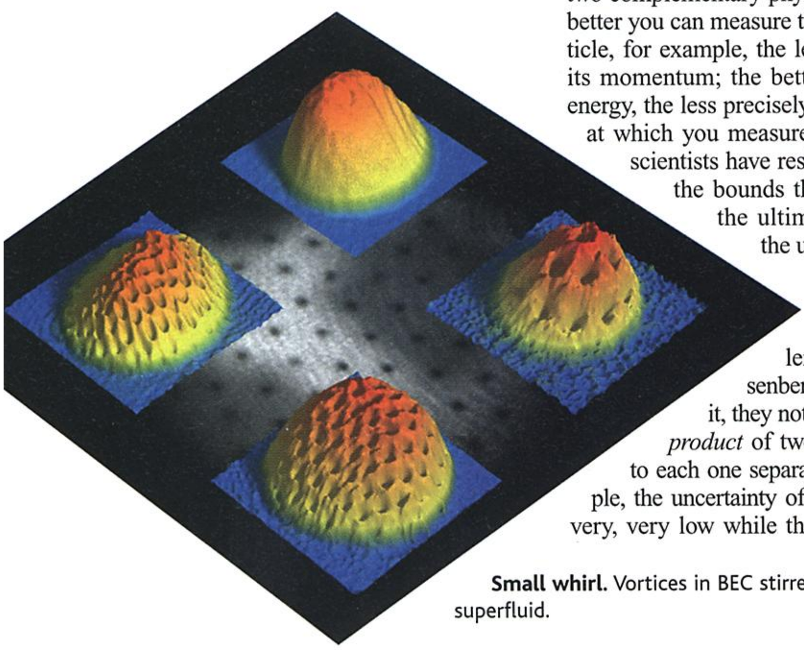
Recently, BEC researchers have nailed down more elaborate superfluid phenomena. In the laboratory of Jean Dalibard at the Ecole Normale Supérieure, researchers have created impressive arrays of vortices. As they stir more vigorously, more and more vortices appear, packing themselves into lattices that look strikingly like the arrays of magnetic vortices observed in superconductors—another example of outlandish quantum behavior at extremely low temperatures. Ketterle's group has taken the creation of vortex lattices the farthest to date. In a paper published online today by *Science* (www.sciencexpress.org), they report that they have spawned highly ordered arrays of more than 100 vortex lines, lasting as long as 40 seconds. "If you want to see superfluid motion, you are looking for something persistent," Ketterle explains. "We can watch the vortices make 50,000 rotations. In a classical gas, these would be completely damped out." Meanwhile, Eric Cornell and colleagues at JILA have used a laser to change spinning vortices into doughnut-shaped rings something like smoke rings.

Such experiments have left most physicists convinced that cold atomic vapors behave like superfluids. "Everybody believed that superfluidity was going on in these things," says Bill Phillips of the National Institute of Standards and Technology (NIST) in Gaithersburg, Maryland, "but seeing it unequivocally was something people were looking for."

A helping of fresh squeezed

While some physicists stir BECs, others prefer to squeeze. In many labs, the squeezing is metaphorical—a way of working around the limits to knowledge imposed by Werner Heisenberg's famous uncertainty principle. The principle tells how accurately anyone can hope to pin down the value of two complementary physical quantities. The better you can measure the position of a particle, for example, the less you know about its momentum; the better you measure its energy, the less precisely you know the time at which you measured it. For a century, scientists have resigned themselves to the bounds the principle sets on the ultimate knowability of the universe.

But applied physicists have sought to squeeze lemonade out of Heisenberg's lemons. The limit, they note, applies only to the *product* of two uncertainties—not to each one separately. Thus, in principle, the uncertainty of one variable can be very, very low while the uncertainty of the other is immense. In other words, if you're only interested in one quantity and not the other, you could "squeeze" all the uncertainty into the less pertinent variable and capture the interesting quantity with sublime accuracy. It would be like zooming down the Long Island Expressway in a microscopic sports car: The highway patrol could precisely clock your excessive speed (or momentum, to be more accurate), but they couldn't give you a ticket because they wouldn't know your position.



Small whirl. Vortices in BEC stirred by laser show it's a superfluid.

Physicists who work with photons were among the first to tackle this concept, and much effort has gone into trying to make "squeezed states" with light. By making fluctuations of some desired quantity (such as wavelength) extremely small, they hope to make measurements with great precision—perhaps great enough to detect gravitational waves. "The fly in the ointment is you've got to reliably make these squeezed states," says Mark Kasevich of Yale University, "and it turns out to be very difficult to do that in optical systems."

As Kasevich and his colleagues report on page 2386, atomic BECs may offer an easier way to the promised land. They've created squeezed states of atoms with BEC inserted into tiny traps formed with walls of light. "We can retroreflect a laser beam and create a standing wave," Kasevich explains, "and that overlaps with the magnetic atom trap to make this corrugated optical potential. Then we can load little condensates into each of these corrugations."

In this experiment, Kasevich says, Heisenberg's trade-off pits the number of quantum particles against the phase of the wave function that describes them. If the number of atoms is well defined, the phase—the point at which the amplitude of the wave crosses zero—should be all over the map. To bring about such a situation, the researchers set the laser at low intensity, allowing the atoms to "tunnel" from one trap to the next. When about 1000 atoms have fallen into the corrugations, they jack up the laser intensity, preventing any further tunneling. Now the numbers of atoms in each well ought to be nailed down—the fluctuations in number negligible.

Are they? To check, Kasevich's group looks at the complementary variable, phase. If it were well defined, Kasevich says, the atomic bunches in each optical well ought to create interference fringes like those that arise from combining laser beams. But "if we make squeezed states, the phase fluctuations should wash out the interference fringes," he notes. When they turn the corrugated trap laser off, the atoms are free to interact and interfere. And indeed, the atomic interference fringes are smudged out, a key sign that the phase is nearly undefined—the hallmark of a squeezed state.

CREDIT: W. KETTERLE *ET AL.*/MIT

Kasevich says such states may offer an alternative to optical squeezed states for ultraprecise measurement. Now that scientists know how to create them, he says, the next crucial step will be to reverse the squeeze, blurring the number of atoms in order to home in on information about the waves. "The physics community is building all of these instruments based on atom wave interference for doing measurements," says Kasevich. "Right now they run at the classical noise limit. If we have good ways of making squeezed states with atoms, we can realize a tantalizing enhancement in sensitivity."

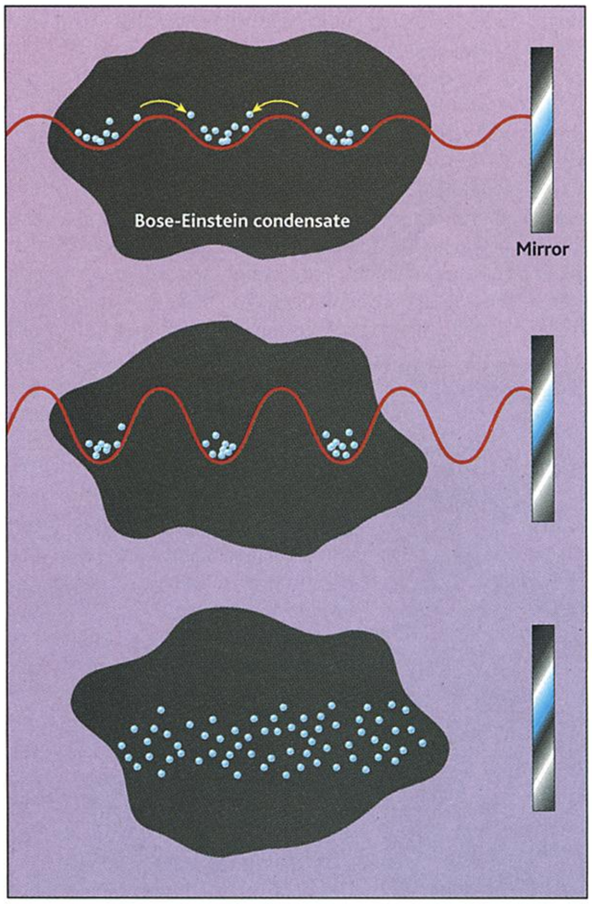
Doing the Bose nova

Meanwhile, at JILA, Carl Wieman and Cornell have been forcing condensates to run squeeze plays for real. By tweaking a BEC cloud with a magnetic field, they triggered a spectacular collapse.

The key was to subvert the BEC's atoms. Most atoms used to make condensates, such as the isotope rubidium-87, slightly repel one another. In the early days of atomic BECs, many researchers thought that only repulsive atoms could form BECs. Theorists believed that a gas of atoms with slightly attractive interactions would instead turn to a liquid or solid when cooled. In 1995, Randy Hulet's group at Rice University in Houston disproved that notion by forming small BECs out of lithium-7, an isotope with slightly attractive atoms. Still, if the number of atoms in the BEC cloud becomes too large, the Texans found, the attractive force wins out, and the cloud implodes.

Wieman and Cornell have discovered that another isotope of rubidium, Rb-85, is even more fickle. In the 28 August 2000 issue of *Physical Review Letters*, the JILA researchers described how they changed its atoms' interactions from repulsive to attractive by using a magnetic field to manipulate a property called the Feshbach resonance. When Cornell and Wieman did that last June, they saw the atomic cloud collapse on itself as the atoms suddenly became attractive. Then came something even more astonishing: When the BEC vapor collapsed, it spit out a tiny blast of hot atoms. Cornell likens the miniblast to the neutrino burst that comes out of a collapsing star during a supernova. In a dying star, fusion reactions create energy that staves off gravitational collapse. When the fusion furnace goes out, however, the star implodes and the infalling mass creates a powerful shock wave that rebounds at the center and blows everything apart—the supernova. The shock wave also drives a huge burst of neutrino emission.

The JILA team thinks something similar is going on with their collapsing BEC. This "Bose nova," as Wieman calls it, even leaves behind a tiny BEC core like a supernova remnant. "We think there is some kind of shock wave phenomenon, but nobody knows the exact mechanism for heating the atoms that are emitted," Cornell says. The Bose nova will now provide a playground for exploring the rich physics of condensate collapse.



Big squeeze. A laser beam bounced off a mirror creates a standing wave that traps atoms from a BEC (top). By hiking the intensity, physicists keep atoms from tunneling out of their pockets (middle). Lack of interference fringes when the laser is turned off (bottom) shows that the BEC's wave function was "squeezed."

More BEC surprises are likely to be on the horizon, as physicists attempt to make condensates of other atoms and molecules. Last month, a group led by Alain Aspect at the University of Paris in Orsay expanded the condensate zoo by returning to the element that began it all: helium. In another paper published online today by *Science* (www.sciencexpress.org), they report that, unlike the atoms in liquid helium, the atoms in the new condensate have been boosted above their lowest energy state. In each of them, one of the two electrons has been kicked upstairs to an excited energy level. Starting with a beam of such "metastable" helium, the physicists slow it down and cork it inside a magnetic trap. Each of the resulting excited electrons carries a whopping 20 electron volts of energy—enough to rip the electrons out of just about anything it touches. So a gas of metastable helium is like a cloud of little flying sticks of dynamite, just waiting to bump into something and detonate.

"It's like a bomb waiting to explode," Aspect says. "When isolated, it will not decay. But if the atom collides with anything except another helium atom with the same spin, it releases its energy." What prevents the Orsay group's metastable helium vapor from self-destructing is that during the Bose-Einstein condensation process all the atoms are put into the same spin state. Every atom has a total spin that is the sum of the spins of the electrons and the nucleus, and they can be lined up just like a bunch of little toy tops or bar magnets. If the spins were all randomly aligned, the gas wouldn't last more than a millisecond. But when the spins are all pointing the same direction, as in a BEC, quantum theory says the internal energy of the metastable helium atoms cannot be released in a collision. Thus the condensate is stable. "This is just absolutely astounding and wonderful," says Phillips of NIST. "People have talked about this for a long time and thought it would never happen. The data look really nice." Researchers at the Ecole Normale Supérieure achieved the same result just a few days later.

What use is a BEC with an insanely high internal potential energy? For one, its atoms can be counted and detected with unheard-of sensitivity. "Metastable helium going into our detector creates a huge signal, and we can even detect a single atom," Aspect says. This means better BEC experiments with fewer atoms. Perhaps more exciting is the potential to use metastable helium BEC as a new kind of laser. According to Aspect, a slight kick in the right way could release the 20-eV energy stored in the helium as light, producing laser emission in the deep ultraviolet.

All in all, researchers say, the future of condensate work appears as vigorous as a vortex in a superfluid. New BEC machines and new condensates such as metastable helium continue to drive the field. "With all that hype in 1995 and 1996, I was concerned that the BEC field [would] not live up to the high expectations," Ketterle says. "It is very exciting to see that BEC is *exceeding* expectations and is still producing surprises."

–DAVID VOSS