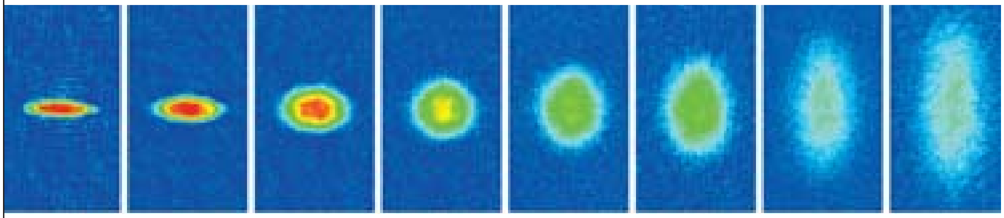
PHYSICS

The Next Big Chill

PHYSICISTS CLOSE IN ON A NEW STATE OF MATTER **BY GRAHAM P. COLLINS**



SUPERFLUID? An ultracold gas of lithium 6, initially compressed in a thin cylinder, expands radially when released—a result that is suggestive of superfluidity but is not conclusive. The sequence runs from 0.1 to 2.0 milliseconds after the release.

JOHN E. THOMAS *Duke University*

It occurs in objects as diverse as superconductors, atomic nuclei and neutron stars. Several research groups are in a race to recreate it in the laboratory in microscopic specks of ultracold gas. If they succeed, it will enable experimental studies of processes that have heretofore been the domain of theorists. "It" is a superfluid state of matter predicted to occur when quantum particles that normally shun one another pair up and behave en masse as a single body of fluid.

This superfluid state involves a broad class of quantum particles called fermions. According to quantum mechanics, all particles in nature are either bosons or fermions. The distinct characters of these two classes become most accentuated at very low temperatures: Bosons sociably gather all in a single quantum state, forming a Bose-Einstein condensate. Fermions, in contrast, act as individualists, no two occupying the same quantum state. As things cool, fermions increasingly occupy the lowest energy states, but they stack up one to a state, like people crowded onto a narrow flight of stairs. This state, in which most of the lowest energy states are occupied by one fermion each, is called a degenerate fermi gas.

In 1999 Deborah S. Jin and Brian DeMarco of JILA in Boulder, Colo., produced the first degenerate fermi gas of atoms in a tiny cloud of potassium atoms in a magnetic trap. But such a degenerate gas is only half the story. In similar degenerate systems that occur in liquid helium 3 and among electrons in superconductors, something new happens—some of the fermions form up in pairs called Cooper pairs. These pairs, which are bosonic, then form a superfluid state very similar to a Bose-Einstein condensate: in helium 3 it is responsible for the liquid's superfluid properties; in a superconductor it allows the resistanceless flow of electricity.

Can such a superfluid state be made in the gaseous fermion systems? Theory predicts that atomic Cooper pairs usually will form only at a temperature much colder than that required for degeneracy, a temperature that seems beyond the reach of experiment at the moment. Recently, however, an alternative method was suggested, based on the fact that Cooper pairing depends on not just the temperature but also the interaction between the atoms. So instead of making the gas colder, why not increase the interaction? Nature has fortuitously provided a convenient way to adjust the interaction—by applying a magnetic field of just the right strength to create what is called a Feshbach resonance, which generates a powerful attractive or repulsive interaction between the atoms. (An attractive one is needed for Cooper pairs to form.)

In late 2002 a group led by John E. Thomas of Duke University used these techniques with lithium 6 atoms to produce results highly suggestive of superfluidity. The trapped gas formed a thin cylinder, and when the trapping laser beams were turned off, the gas expanded radially to form a disk shape—very little expansion took place along the axis of the cylinder. Such anisotropic expansion had previously been predicted to be a hallmark of the superfluid state.

As the Duke group pointed out, however, other effects can also generate such anisotropic expansion. Indeed, experiments conducted earlier this year by Jin's group and by Christophe Salomon and his co-workers at the École Normale Supérieure in Paris have exhibited similar anisotropic expansions in situations where a superfluid cannot be present.

A technique for directly detecting the Cooper pairs or the superfluid is needed. Jin, as well as Wolfgang Ketterle's group at the Massachusetts Institute of Technology, recently reported using radio waves to study the precise states of the atoms in the trapped

A BUNCH OF DEGENERATES

A degenerate gas of fermions occurs in diverse situations, as described below:

- **Superconductors:** The electrons are degenerate and form loosely correlated Cooper pairs, which produce the superconductivity. Something similar must happen in high-temperature superconductors, but that process remains a mystery.
- **Neutron stars:** The refusal of neutrons (which are fermions) to occupy identical quantum states generates a repulsion that prevents the star from collapsing under its own immense weight. A similar repulsion stabilizes the laboratory-made degenerate fermi gases against collapse.
- **Quark-gluon plasma:** As created at the Relativistic Heavy Ion Collider at Brookhaven National Laboratory, the exploding cloud of free quarks (which are fermions) and gluons has properties similar to a gas of fermionic atoms released from the confines of a trap.

degenerate gas; if Cooper pairs were present, the binding energy of the pairs should show up clearly. Neither group saw such signs of Cooper pairs, but both uncovered useful new details of how fermionic atoms interact near a Feshbach resonance.

Several teams have recently studied the formation of loosely bound two-atom molecules in their gases. "We hope that we can turn [the molecules] into Cooper pairs," Ketterle says. And in August theorist Yvan Castin and his co-workers at the École Normale Supérieure suggested just how that might be done: first let the molecules Bose-condense, then adjust the Feshbach resonance. If that is true, experimenters are just two steps from their goal.

HEALTH

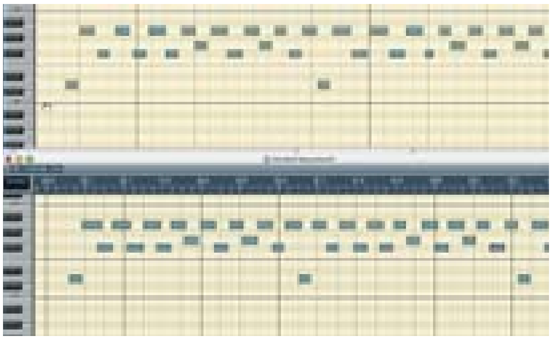
Musical Medicine

A HIGH-TECH PIANO TREATS A REPETITIVE STRESS DISORDER

BY W. WAYT GIBBS

My left forearm twinges as I sit down at Kathleen M. Riley's piano. An hour of scribbling notes and two days of working on a laptop computer have inflamed my repetitive stress injury, an ailment common among journalists—and musicians. In fact, hardworking musicians can develop a much more severe condition, known as focal dystonia, which cramps the hands so badly that it often ends a promising career. Injections of botulinum toxin can relieve dystonia for some, but the effect lasts only a couple of months.

I never had a career at the piano. But I have played Haydn's Sonata No. 50 more than 100 times over the past 20 years and at one point had even committed much of it to memory. What is unnerving me, in part, is the computer attached to the Yamaha Disklavier piano that will record just how I touch each key. Also unsettling are Riley's refereelike gaze and the video camera trained on my left hand. But mainly my trepidation is fed by a gloomy certainty that that sore hand will lag through the opening bars. As indeed it does: what should be a quiet, perfectly even motif of sixteenth notes comes out as a skewed, off-tempo jangle.



PIANO ROLL of author's performance shows notes that are inconsistent in spacing and duration (*top*) and subsequent improvement (*bottom*).

Riley, a music technologist and dystonia therapist at New York University, can help. By linking the instrumented instrument with software and a precisely synchronized video recording, she has turned the piano into a medical machine. The system captures the time and velocity at which each note is struck and released. Even more important, it captures the position of the performer's hands, arms and body. Bad habits—slouching, angled wrists, rigid forearms, raised elbows—can over years of playing contribute to focal dystonia.

"Athletes are coached about how to hold and move their bodies," Riley says. "But musicians rarely get that kind of instruction from their teachers. And unlike athletes, musicians tend not to warm up before practicing, take breaks to rest, or stretch out afterward." Riley, who so far has helped five musicians ease their dystonia, uses the computer's "piano roll" display of a performance to detect which fingers are cramping in certain passages. The synchronized video reveals unhealthy postures and overly tense muscles. Riley then coaches the musician to play in ways that allay the cramps.

After a minute of the Haydn sonata, for example, she stops me and rewinds the video. As the Disklavier replays my performance—the keys moving themselves, ghostly—she points to the monitor. "See how your left wrist drops?" It is half an inch lower than my right wrist, forcing the left hand to cock upward and its fingers to flatten. "Also, you are sitting much too close," she says. "Your left elbow and wrist are locked, so your forearm is full of tension."

Riley has me move the bench six inches, arch my back to shift forward my center of gravity, and straighten and raise my wrists so that the piano keys, rather than my sore joints, bear the weight of my arms. I play the passage again, and she brings up both record-

IT GETS STUCK IN YOUR HEAD

The stress injury called dystonia appears to originate in the brain, not the muscles. "If you do an MRI on someone with focal dystonia," says Edgar E. Coons of the Center for Neural Science at New York University, "you see a change in the parts of the brain that receive touch and motor feedback for each finger. Those zones are normally physically separated in the brain. But in people with dystonia, the regions merge." Curiously, the cramping and rigidity of focal dystonia often disappear during everyday activities but resurface as soon as the musician starts to play.

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