Physicists Tackle Theory, Tubes, and Temperature

The American Physical Society held its 1990 March Meeting in Anaheim, California, from 12 to 16 March. Despite its location—just down the street from Disneyland—the meeting focused mostly on the practical side of physics, such as finding applications for tiny tubes made of organic molecules. On the theoretical side, there was some surprising evidence about how high-temperature superconductors work

Anyon Superconductivity?

In an unscheduled talk, AT&T Bell Laboratories physicist Ken Lyons announced some surprising evidence about high-temperature superconductors that may offer insight into why they work. Although scientists have been studying these potentially valuable materials for more than 3 years, so far there is no agreement on a theory to explain why they become superconducting. One intriguing possibility that has been given some support by Lyons' data is that anyons, strange psuedo-particles that exist only in two dimensions, are involved in high-temperature superconductivity. Although Lyons cautioned that the anyon connection is still quite tentative, many scientists at the standing-room-only session were obviously excited by the news.

Since high-temperature superconductors were discovered in 1987, many theories have been suggested to explain them, but so far none has become accepted by even a plurality of physicists. Several theorists have suggested that the key to the superconductors' properties might lie in the two-dimensional planes of copper and oxygen atoms that seem to carry the current in the materials. In line with this thinking, Robert Laughlin of Stanford University proposed that anyons might be responsible for the superconductivity.

The anyon theory, as developed by several scientists, makes a number of predictions about how high-temperature superconductors should behave. Many of these were difficult to test, however, and Lyons' is the first experiment offering solid evidence that anyons may actually exist in high-temperature superconductors. Lyons cautioned that even if anyons are present, that does not necessarily imply they are responsible for the superconductivity of the materials. Nonetheless, his observations, if confirmed, should certainly help discriminate among the competing theories for high-temperature superconductivity.

Anyons are perhaps best understood in reference to fermions and bosons, the two types of particles that are possible in a three-dimensional world. Fermions, which include protons, neutrons, and electrons, are "individualistic" particles—no system can have two fermions occupying exactly the same quantum state. On the other hand, bosons, such as photons, thrive in a crowd—not only can many identical bosons exist, but bosons prefer to be in the same quantum state as the rest of their fellows. Anyons lie somewhere in between fermions and bosons.

The precise definition of anyons is somewhat technical and can only be stated in quantum mechanical terms. Mathematically, fermions, bosons, and anyons are all defined in terms of the quantum wave functions that describe systems of two or more of the particles. If two fermions in a system trade places, the wave function of the new arrangement is equal to -1 times the wave function of the old; alternatively, one can think of the wave function as being rotated $180°$. If two bosons in a system trade places, the wave function remains unchanged, or one can say it is rotated by $0°$ or $360°$.

In an anyon system, on the other hand, when two particles are exchanged, the wave function is rotated by "any" number of degrees. For that reason, Frank Wilczek of the Institute for Advanced Study at Princeton University dubbed them "anyons."

Wilczek first described anyons in 1982. Although as mathematical entities they can exist only in two dimensions, anyons are still able to play a role in the real, three-dimensional world. The reason is that many systems behave as if they are two dimensional. Perhaps the best known example is a two-dimensional electron gas. In some layered semiconductors, the electrons are restricted to such an extremely thin section of the material that they in effect can move in only two dimensions. This can lead to very strange behavior, such as the fractional quantum Hall effect, where charge seems to move in quantities that are fractions of a single electron. Theorists have shown that the fractional quantum Hall effect can be explained by the presence of anyons.

Lyons at Bell Labs tested for anyons in several superconductors by bouncing polarized laser light off of samples of the materials and measuring the polarization of the reflected light. In a 2-month series of experiments completed just 3 days before the meeting, his group tested $YBa_2Cu_3O_7$ crystals and $YBa_2Cu_3O_7$ thin films, as well as $Bi_2Sr_2CaCu_2O_8$ crystals. Although the reflected light was difficult to measure precisely, the researchers were able to show that the polarization of the reflected light was different from that of the incident light in a subtle way.

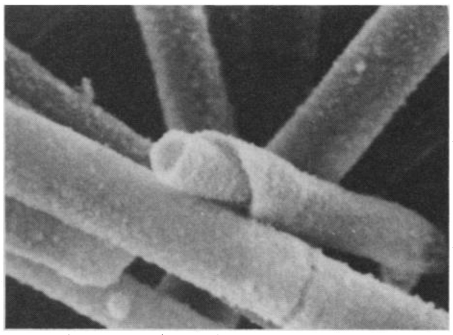
This change in polarization was very surprising, Lyons said, acknowledging that it has been met with "a healthy degree of skepticism." In most materials, when light is reflected directly backward, the polarization will be unchanged because of what is known as time-reversal symmetry. That is, whatever change in the light's polarization is created on the inward path will be exactly reversed on the way back out, and no change in the polarization would be seen. Time-reversal symmetry can be broken when polarized light reflects off a material that has an internal magnetic field. Superconductors, however, push magnetic fields out of their interiors, so theorists assumed that the symmetry would not be broken in superconductors.

To test that the polarization shift was related to the superconductivity of the materials, Lyons' team heated the $YBa_2Cu_3O_7$ samples to remove some of the oxygen and destroy the superconductivity. When the superconductivity disappeared, the shift vanished—the reflected laser light had the same polarization as the incident beam. This implied that the time-reversal breakdown was connected with the superconductivity.

Lyons said he was confident of the results but issued two caveats. Although he knew of no explanation for time-reversal breakdown in the superconductors other than anyons, he said theorists should look for other possible causes. And on the experimental side, he said it was possible that small regions of magnetic, non-superconducting materials could have contaminated his samples and been responsible for the observed signals.

101 Uses for Tiny Tubules

Whenever scientists discover some new material, the first question always seems to be, "What can you do with it?" In 1984, Joel Schnur of the Naval Research Laboratory in Washington, D.C., set out to answer that question for some miniature organic tubes,



Center for Bio/Molecular Science and Engineering

What are they good for? *Time-release capsules, or maybe baseball bats for crickets.*

less than a micrometer across, that colleagues Paul Yager and Paul Schoen had just discovered. Now, Schnur reported at the meeting, he has one application ready to be commercialized—a paint for ships' hulls—and a whole host of other ideas waiting in the wings.

Yager and Schoen had found that if they dissolved certain lipid molecules in alcohol and added water, the molecules would spontaneously arrange themselves in miniature tubes about 0.5 micrometer in diameter and with a wall thickness of only 15 to 30 nanometers. These lipids are similar to the molecules that make up the walls of a cell. Almost immediately, Schnur came up with one use for the tiny tubes. Coated with metal and mixed into an epoxy or ceramic, they would produce a material with electronic properties, such as a high dielectric constant, that would make it quite valuable in microwave components.

Once his team at NRL's Center for Bio/Molecular Science and Engineering learned how to cover the microtubules with a thin coating of metal, Schnur realized that they should have other valuable applications as well. But what? They were "answers in search of a problem," Schnur said. So he went to Ira Skurnick, a program manager in the Defense Sciences Offices at the Defense Advanced Research Projects Agency (DARPA), who called together 30 respected scientists—physicists, chemists, materials scientists, and engineers—to brainstorm on possible uses. After 3 days, they had 600 suggestions, Schnur said, and about 100 were "reasonable enough to be considered."

One idea, for instance, was to align the metal-coated tubes inside a transparent material so that they would reflect light shined upon them. Since the microtubules are much longer than they are wide, small vibrations would cause big wiggles in the reflected light, which could then be easily detected. The result would be an exceptionally sensitive vibration detector.

Schnur and his colleagues at the NRL center have yet to tackle that suggestion or many of the others that came out of the meeting—not for lack of interest, Schnur says, but for lack of time. They have worked on several ideas that seem to have defense applications, and they have nearly finished development on one of them: an anti-fouling paint to be used on ships' hulls. To make the paint, Schnur and Ron Price, a biologist at the center, mix a batch of the microtubules into a slurry that contains tetracycline or another bacteriacide. Capillary action pulls the liquid into the tubes, which are then removed from the slurry, cleaned off, and mixed in with paint. After the paint is applied to a surface, the slow wearing of the paint breaks the tubes and causes them to release the tetracycline. The tetracycline keeps off barnacles in two ways, Price says: by killing the bacteria on which the barnacles feed and by absorbing calcium, without which barnacles will not latch onto a surface.

The center's only test of the paint to date has been on a rudder of a sailboat in Chesapeake Bay. After 9 months, the rudder had no barnacles, Schnur said, while a control rudder coated with the Navy's anti-fouling paint did have barnacles. Further testing is under way at the University of Hawaii and Duke Marine Laboratories.

Schnur suspects that his new paint may turn out to be commercially competitive, but first, the costs of the tubules will have to come down. The lipids now cost $6800 a pound from the supplier, and after being coated with metal, the finished tubes would sell for around $8000 per pound. If the new paints are to be competitive, the cost of the microtubules must drop below $600 a pound, Schnur says, but this should happen easily with increasing demand.

Once the paint gets to market, Schnur will certainly have plenty of other applications to consider, but one in particular has already caught his fancy. The microtubes, someone suggested, would make perfect baseball bats for crickets. It could be the start of a whole new industry.

Brrr! How Cold Is It?

Measuring temperature is something that most researchers take for granted. After all, thermometers exist that are accurate to within a fraction of a degree for most temperature ranges. But determining the temperature of a sample that is close to absolute zero—the point at which all molecular motion stops—is another matter altogether. Normal thermometers can do the job about as well as a yardstick can be used to measure a paramecium.

Indeed, it is so difficult to accurately measure ultra-low temperatures that until this year the international standard of temperature did not even extend below 13.81 K, or 13.81 degrees above absolute zero. This standard is the one used in government standards laboratories across the world to set their own thermometers. Without a scale below 13.81 K, low-temperature researchers had no commonly agreed upon benchmark in this range and no guarantee that their temperature measurements were congruent.

Now that has changed. ITS-90, the new international temperature scale that was released 1 January, goes down to 0.65 K. And improvements in low-temperature thermometry are coming so fast that this scale may be obsolete in a few years. As reported in a symposium on thermometry, researchers now feel confident that they can determine temperatures as low as 0.01 K.

ITS-90, which was developed by the Bureau of Weights and Measures, an international organization located in France, replaces a scale instituted in 1968. The new standard is more accurate than its predecessor, but the most striking difference is in how closely it approaches absolute zero.

"The reason [the earlier scale] didn't go lower was that there was no suitable thermometer for the range from 5 to 13 K and no good way of calibrating it," explained Billy Mangum, a physicist from the National Institute of Standards and Technology who spoke at the thermometry session. To extend their range below 13 K, researchers tried a number of things, Mangum said, and eventually they settled on a constant volume gas thermometer. This device makes use of the fact that if an ideal gas—a gas in which the individual atoms do not interact—is kept at constant volume, the gas's pressure is exactly proportional to its temperature. Although the helium used in the thermometer is not an ideal gas, researchers know its deviations from the gas law quite precisely. By measuring the pressure of the helium, they can determine its temperature to within a few millikelvin.

But the constant gas volume thermometer is itself limited in range because, as the temperature drops, it is harder and harder to keep helium gas from becoming liquid. ITS-90 uses the constant gas volume thermometer from 3.0 to 24.5561 K but, below 3 K, another device must be called into play.

This is a vapor pressure thermometer, which measures temperature by its effect on the pressure at which helium boils. As any cook knows, water boils at a higher temperature when air pressure is lower—100°C will start the pot bubbling in Honolulu but not in Denver. Helium does the same thing, although its boiling point is much lower—4.2 K at 1 atmosphere. By varying the pressure of a helium sample and watching when it boils, one can calculate its temperature, again to within a few millikelvin.

Below 0.65 K, the vapor pressure thermometer is not accurate enough to be included in ITS-90, but researchers have several new methods to take the lower limit closer to absolute zero. Robert Soulen from the Naval Research Laboratory described a "noise thermometer" that determines temperature by measuring the level of electrical noise in a resistor. Cooling a resistor decreases the random molecular movement that causes this noise, so the level of noise offers a way to gauge the temperature.

Another measure, described by William Fogle of the standards institute, involves the melting point of helium-3, which is a solid at low temperature and high pressure. By decreasing the pressure until the helium-3 melts, a researcher can determine the sample's temperature. A third method depends on measuring an object's magnetic susceptibility—how easily its electrons align their spins with an applied magnetic field—as a function of temperature.

All three techniques give an accurate measure of temperature down to about 0.01 K, said Lawrence Rubin of the Massachusetts Institute of Technology, who added, "that's about as low as you can go and everyone will agree with you." The international temperature scale will probably be amended to reflect this increased range sometime in the next few years, he added.

Above 13 K, ITS-90 is more accurate than the 1968 scale, mainly because it no longer uses thermocouples. A platinum resistance thermometer is used between 13.8033 and 1234.93 K. As platinum heats up, its resistance to an electric current increases; the temperature can be inferred from resistance. Above 1234.93 K, a radiation thermometer measures the temperature of an object by examining the frequency and magnitude of the radiation it emits.

Besides defining the thermometers, ITS-90 also provides "fixed points" for calibrating the thermometers. For instance, the triple point of water—the unique temperature at which water can be a solid, liquid, or gas—is used to define the point 273.16 K, or 0°C. Other fixed points include the triple point of hydrogen at 12.8033 K, the triple point of neon at 24.5561 K, and the freezing point of silver at 1234.93 K.

Finally, ITS-90 provides formulas for interpolating between the reference points. The resistance of platinum, for example, varies almost linearly with temperature, but not quite. The scale gives scientists a standard way of transforming resistance measurements into temperature readings.

■ ROBERT POOL

Fiber Fracas at FASEB

Scientific arguments over the merits of a high-fiber diet—oat bran in particular—have simmered for a while. But recently they burst into flame, sparked by an article in the *New England Journal of Medicine*. Researchers at Harvard Medical School wrote in the 18 January issue that oat bran has no special power to lower cholesterol and therefore presumably no effect in preventing heart disease. That brought oat bran's champions to a boil, criticizing the Harvard study's design and findings. But the porridge is about to get even thicker.

At the annual meeting of the Federation of American Societies for Experimental Biology (FASEB) next week, both sides will find the issue complicated by a study done by Louisiana State University's Maren Hegsted. Hegsted's study, which is being prepared for publication in the *American Journal of Clinical Nutrition*, finds that the response to dietary fiber is quite individualistic: some people experience a reduction in cholesterol, others don't.

With several apparently contradictory studies on hand, the FASEB organizers have chosen to devote an entire session to dietary fiber and its effects—a session that promises to be exceptionally lively. And the questions are so compelling that other papers on fiber have been scattered throughout the program. Indeed, the FASEB press office has called a press conference highlighting the work of five fiber researchers who will be presenting papers at the meeting.

The paper that touched off the latest round in the debate came from a research group led by Frank H. Sacks. Sacks and his Harvard colleagues set out to test some conventional wisdom. Evidence gathered over the last two decades suggests dietary fiber has a modest—but real—effect on lowering cholesterol, and that water-soluble fiber, such as that found in oat bran, is the most effective.

In Sacks' study, 20 healthy volunteers with serum cholesterol in the normal range were given, successively, supplements of high-fiber oat bran muffins or low-fiber Cream of Wheat. The conclusion was that "high-fiber and low-fiber dietary grain supplements reduce serum cholesterol levels about equally, probably because they replace dietary fats."

Fiber's defenders shot back. Eliot A. Brinton, a biochemical geneticist at The Rockefeller University, told *Science*: "I am appalled. The Harvard study is embarrassingly poorly designed to answer the questions they wanted to answer." One thing that bothers Brinton is that Sacks' study included people with normal serum cholesterol, rather than those with elevated cholesterol, who may have abnormal metabolism.

Sacks acknowledges that the question of what oat bran does for people with elevated cholesterol is important—and he says a recent study finds oat bran doesn't do anything special for that group, either. The study, by nutritionist Wendy Demark-Wahnefried of Syracuse University and her colleagues, published last month in the *Journal of the American Dietetics Association*, tested a high-fiber diet on 68 patients with high cholesterol. The conclusion of that study was that some of the effect of oat bran was due to replacement of fat, as Sacks had found.

But Demark-Wahnefried doesn't think that's the whole story. "There is evidence that something else is going on" that helps reduce cholesterol, she says.

Which may set the stage for nutritionist Hegsted of Louisiana State. She plans to tell FASEB attendees that her study differs from previous ones not only in finding an individualistic response to high levels of fiber, but also in finding that rice bran can lower cholesterol. Yet the fiber in rice bran, unlike that in oat bran, is insoluble in water—hence a different mechanism may be at work.

So what gruel does this leave for the nutrition conscious? One lesson may be that there aren't any miracle preventatives for disease, and that less faith should be placed in diet fads. Jon A. Story, a nutritionist at Purdue University, says fads—including the oat bran craze—put too much emphasis on "diet and disease, rather than on diet and health. Diet should not be disease prevention. Rather, one should eat for optimal health."

That prescription might stimulate those at the FASEB meeting to attend another intellectually nutritious session: "Psyllium: The Latest Fad Grain" by Merry Yamartino of the University of Massachusetts.

■ ANNE MOFFAT

Anne Moffat is a free-lance writer based in Ithaca, New York.