Material Witnesses: APS Meeting in Cincinnati

More than 3000 physicists descended on Cincinnati from 18-22 March for the American Physical Society's March meeting, which focused on materials. Some of those materials—such as semiconductors—already have a host of applications. Others—including buckminsterfullerene, more commonly known as "buckyballs"—make interesting science now and could prove technologically useful later. But the discussion in Cincinnati didn't by any means confine itself only to materials. It also touched on lighter topics, such as why laser light brakes when it passes through a glass of milk, and how a new generation of microscopes based on light—of all things—might just outpace their high-tech competitors.

Buckyballs: A Little Like Basketballs—Only Smaller

One topic at the Cincinnati meeting was so hot that an evening session starting at 7:30 p.m. was still going strong at 1 a.m.: buckminsterfullerene, or C60, known affectionately as "buckyballs." One reason for the excitement is that this was the first session on buckyballs at a major physics meeting since last September, when researchers found a way to make the elusive molecule in quantities large enough for study. That breakthrough touched off intense competition to find the first uses for buckyballs, reminding some in the field of the rivalry over high-temperature superconductors.

While chemists are hoping to base a whole new class of chemicals on the buckyball structure (much as there is a class of chemicals based on the benzene ring), physicists are probing the physical properties of C60 with tools such as infrared and x-ray spectroscopy, nuclear magnetic resonance, and scanning tunneling microscopy. High on their agenda, as hundreds of participants at the late-night session heard, is the question of how buckyballs pack in a crystal. The answer seems to be: something like a basketball, but not exactly.

Those in the field emphasize that the potential uses of buckyballs remain strictly in the blue-sky category. But, says John Weaver of the University of Minnesota, the exotic nature of the molecule should lend itself to many interesting uses, especially in electronics, where they might, for example, be combined with other materials in more efficient semiconductor chips. He is starting to test the water by adding charges to the molecules, and by exploring the compatibility of C60 with other materials.

Although applications are still far off, there's plenty of competition to bring them closer. A lot of that competition is between AT&T and IBM. Researchers at both industrial giants are studying the properties of buckyballs in crystalline form, because understanding how buckyballs behave in solids will be key to applications. And part of the key to how they behave in solids is the shape of the individual buckyballs.

In 1985 Richard Smalley of Rice University theorized that C60 has the 20-sided icosahedral form of a soccer ball. That hypothesis was confirmed last year, when quantities of the stuff became available. But researchers still didn't know whether buckyballs would pack together cleanly like polygons—the face of one right against the face of another, leaving no space—or more like a pile of basketballs, leaving spaces between. Now work at both IBM and AT&T has helped to provide an answer. "It turns out to be like packing basketballs," says AT&T's Robert Fleming, who played a key role in the discovery.

In his talk to the APS meeting, Fleming says he first thought C60 might pack into the unusual structures known as quasicrystals, which form in patterns forbidden by ordinary crystallography laws. "Instead they play a trick by rotating and ignoring their icosahedral structure," he says. That is why, when they form a crystal, they are able to behave like basketballs. Researchers at IBM and AT&T say these observations of buckyball structure agree remarkably well with computer simulations created recently by Jerry Bernholc and colleagues at the University of North Carolina. Bernholc's team is now simulating the structure of buckyball crystals at different temperatures.

While physicists have been looking at solid structure, Rice's Richard Smalley, who presented first at the evening session, is studying the birth and death of buckyballs. He says he now understands the complex mechanism by which this unusual molecule forms. C60 is created in any soot-producing flame, he says, but most of the molecules burn up in the same flame that created them. Blasting with lasers, he says, brings on a more dramatic death. "It first evaporates, then shrinks, and finally explodes."

How much of this stuff exists in nature? Smalley's work might suggest that buckminsterfullerene is too delicate to survive in quantity anywhere outside the laboratory. But to Donald Huffman, buckyballs seem hardy enough that they probably show up somewhere in nature. Huffman—who was largely responsible for last fall's buckyball breakthrough—and his colleagues at the University of Arizona are searching for buckyballs on earth, in meteors, and in the interstellar dust.

For all the similarities between the competition over buckyballs and the early research on superconductors, there are some important differences. For one thing, the competition is a shade "less intense," says AT&T's Fleming. Participants in the race to understand and make use of buckyballs also foresee more cooperation and sharing of information than characterized the work on superconductors. Some attribute this collegiality to the fact that neither the applications nor the profitability of buckyballs are as clear as they are for superconducting materials.

In addition, buckyball researchers are being much more cautious in forecasting early applications. "With the high temperature superconductors we got excited at first, but later found there were big barriers to applications," warns Fleming. "We want to start looking now for possible barriers with C60."

Whether those barriers materialize or not, the buckyball story has already made a winner out of Huffman, who worked on C60 for years, trying to make it, isolate it, and determine its structure. At his presentation he offered some folksy advice that may get lost in the current high-stakes race, dominated by scientists at major industrial research labs: It doesn't take big bucks to do science, not everything has been discovered, and it's important to have fun.

Through a Glass—Darkly

Researchers from the United States and Holland say they think they can exploit a phenomenon that was once considered merely annoying: the "multiple scattering" of light waves bouncing off particles and droplets in a solid or liquid. Until now, multiple scattering, which produces a characteristic speckled pattern as light emerges from a solid or liquid, has mostly been thought of as the cause of poor images produced by cloudy lenses. But one day, researchers hope, it could help oncologists locate solid tumors and aid auto manufacturers in locating flaws in cast metal parts.

The key to these very speculative applications was a parallel that an American group and a Dutch one—both of whom presented at the meeting—drew between light scattering in milky fluids and electrons bouncing off impurities in metals and semiconductors. Until recently, neither phenomenon was well understood. But in the last 5 years, electron scattering has finally been better understood. And, since "the physics for the electron and light systems are the same," this understanding has helped unravel the causes of multiple scattering of light, says Shechao Feng, a UCLA physicist who with Patrick Lee of MIT made up the U.S. research team.

Electrons traveling through a metal and photons passing through a fluid can be thought of as waves having a wavelength inversely proportional to the particle's energy. In a metal, electrons undergo multiple scattering if they encounter a barrage of impurities so dense that the distance between obstacles begins to approximate the electron's wavelength. Milk proteins or paint particles can do the same for photons, which is what ultimately leads to the speckled pattern.

While Feng and Lee were doing their work, a team from the University of Amsterdam and the FOM-Institute for Atomic and Molecular Physics was also drawing parallels between light and electrons—but using it for a somewhat different purpose: to explain bizarre observations of laser light going through white paint. Physicist Ad Lagendijk and his colleagues were surprised to find that the paint slowed light down to 10% of its original speed, an effect Lagendijk, at the Cincinnati session, called "spectacular."

He and his colleagues theorized that the light gets held up in the paint because it is actually getting trapped and bouncing around inside individual paint particles; researchers had known for many years that materials can hold up electrons in this manner. When the light does finally get out, a mishmash of waves, all headed in different directions, creates the speckle pattern.

That pattern was once thought to be purely random, but on the basis of their new insights, Feng and Lagendijk have concluded that it is not. On the contrary, the spotted array contains information that can be used to infer quite a lot about the interactions between the light and the material it is passing through. And that information, in turn, is the key to possible applications for multiple scattering. For example, since tumors in living tissue have different properties from the material that surrounds them, they should produce different patterns of speckling. An appropriate light source might make it possible to detect tumors in a completely noninvasive way, says Feng. He adds that multiple scattering also works with acoustical waves, which could be used to detect cracks and defects in metal parts.

"The message is that multiple scattering doesn't have to be bad," he says, "and don't be afraid of speckles." A lot of people at the meeting seem to have heard his message: After he finished his presentation, he attracted quite a crowd of people interested in the possible applications he described.

'Scopes With a Light

That hottest of hot fields—materials science—has been driven partly by insights coming from scanning tunnelling and atomic force microscopes. To many scientists, it may seem incredible that before these high-tech wonders have even emerged from their infancy they might be surpassed. Their incredulity would deepen if they were told that the instruments that threaten to surpass them are based on the oldest of microscopic tools: light.

Yet by summer, a team of scientists from Oak Ridge National Laboratory told APS meeting attendees, their Photon Scanning Tunnelling Microscope (PSTM) should be available for purchase at a cool $100,000. Right behind the PSTM is the NSOM, AT&T's Near Field Scanning Optical Microscope. Its designers say they haven't set a production date, but, they add, the technology is market ready for about the same price. Since both machines use photons for imaging, they would be very well suited for viewing optical chips and easily damaged materials like living cells—things that neither the scanning tunnelling microscope nor the atomic force microscope do particularly well.

What's revolutionary about these entries is that both of them break the long-standing barrier that has prevented optical microscopes from resolving anything much smaller than the wavelength of visible light. The PSTM can make out detail about a tenth of a wavelength across and trace vertical contours only about one hundredth of a wavelength high, says coinventor Robert Warmack, a physicist from Oak Ridge. "The vertical resolution is the big advantage," he says, "and it doesn't damage the sample with electrons the way the electron microscope and STM can."

Warmack explains that the PSTM works much like the atom-seeing STM. In both instruments, a super sharp probe scans the sample, bobbing up and down with vertical peaks and valleys. The STM gets its topographical information from monitoring a tiny electrical "tunnelling current" while the PSTM reads the intensity of tiny spikes of light making up the "evanescent field." That field, Warmack explains, forms when light coming from below reflects off the top surface of a sample, and a bit of the beam emerges above the surface.

The PSTM can't see the contours of individual atoms the way the STM can, but it does give a close look at many materials that the STM remains blind to—fiber-optic cables and artificial eye lenses, for instance—according to coinventor Robin Reddick of Oak Ridge. He says it could prove valuable for checking the working order of the invisibly fine waveguides that channel light through optical chips the way wires channel electrons.

Reddick adds that the instrument can give more than just topographical contours. He can get it to make fine-scale maps of a chemical composition and other properties by hooking it up with various types of spectrometers. Such combinations could make useful images of biological materials, he says. "We hope the users will think up many more applications."

The Oak Ridge machine may be coming out sooner and may provide excellent vertical resolution, but AT&T researchers are making some aggressive claims for their machine—based largely on its superior horizontal resolution. A new, updated version of the NSOM resolves images smaller than one forty-third of a wavelength, says coinventor Eric Betzig. (The PSTM makers boast about one-tenth of a wavelength.) Taking off the kid gloves, Betzig gives a bare-knuckle appraisal of the competition: "I don't think there's anything the PSTM can do that the NSOM can't do better."

That updated machine is quite an improvement over an older version, which worked by sending a light beam down a 500 angstrom hole in a glass pipette coated with aluminum. The beam scanned over the sample, illuminating only a sub-wavelength piece at a time. A major weakness, explains Betzig, was that light would bounce around the pipette walls and leak through defects in the coating, degrading image resolution and intensity. The improved version sends a beam down a fiber-optic filament, which gives not only a finer resolution but a brighter image.

NSOM lacks the ability to map vertical contours, but Betzig doesn't see that as a handicap. He says he has shown that the new NSOM can make record-breakingly fine observations of hard-to-see structure on both optical and electronic chips, as well as blood and tissue samples. He adds that the NSOM gives an image with better contrast than PSTM could, making it the better tool for biology and medicine. "When the PSTM gives an image that looks like a blob," he says, "we can see real structure."

Not surprisingly, PSTM proponents at Oak Ridge are ready to contest AT&T researchers' derisive comments. And so it will go until the consumers in the laboratories settle the debate by plunking down their precious research dollars for one or the other. ■ FAYE FLAM