MEETING BRIEFS

In Pittsburgh, Physicists Get Down to the Nitty-Gritty

While some physicists ponder the grand design of the universe, others delve to the atomic scale. That microrealm was the focus of most of the 5300 researchers specializing in biological and condensed-matter physics and in materials science who gathered in Pittsburgh two weeks ago for the annual March meeting of the American Physical Society (APS). Among the more than 5000 papers presented at the meeting were descriptions of building and measuring micromagnets, making atomic movies, and studying sand grains for clues to why some dunes roar.

World's Tiniest Magnets

Everybody has a standard. For biologists, the fundamental building block is the cell. For physicists studying magnetism, the magnetic domain serves a similar purpose. It's a microscopic region of a magnetic material within which the spins of all the electrons line up in the same direction, and just as organisms contain a multitude of cells, magnets—even those that clamp photos to a refrigerator—typically contain thousands of magnetic domains. And like biologists, who often explore the mechanisms of life by examining individual cells, magnetism researchers have been striving to study the behavior of magnets so small that they contain only a single magnetic domain.

At the APS meeting, IBM physicist Andrew Kent described early results from a new technique for making and studying one-domain magnets—results that seem to undermine received wisdom in this area, and could prove useful in designing better magnetic storage technology. Researchers have long known that there are two possible orientations of electron spins: up and down. Past studies suggested that when electron spins in a domain change directions they all make the jump simultaneously.

Yet when Kent and his colleagues used a scanning tunneling microscope to fabricate magnetic grains as small as a hundred atoms across, they found evidence that the electron spins in these particles don't always flip in unison. This lack of synchrony could influence the long-term stability of a domain's orientation. Because data that is stored on a magnetic disk or tape is written in the orientation of magnetic regions, "the implication is that the long-term stability of your data is not as good if the domains within [the magnetized regions] are unstable," says Kent.

Though Kent stresses that the results are preliminary, they are consistent with a theoretical prediction made last year by Hans Braun of Simon Fraser University in Vancouver, British Columbia. Magnetism researchers had calculated earlier that if all the electrons in a domain flip in unison, then the amount of energy needed to drive the flip should be proportional to the volume of the magnet. But if the electrons don't change in lockstep, Braun calculated, then the energy needed to flip a one-domain magnet would be proportional not to the magnet's volume but only to its cross-sectional area. The upshot, says Kent, is that it can take a considerably smaller amount of energy to flip the orientation of these magnets.

Testing that prediction was no simple task. Researchers looking at small magnets have traditionally been forced to rely on naturally occurring magnetic grains, and collecting particles of just the right shape to test the hypothesis proved difficult. So Kent and his colleagues David Awschalom at the University of California at Santa Barbara and Stephan von Molnár at Florida State University turned to new nanofabrication techniques, which enabled the group to build iron magnets measuring just nanometers across that had exactly the right shape. They did so by depositing individual layers of magnetic material only a few atoms thick. "The beauty of [this technique] is that you can tailor the size of the magnets in a very clean way to look at the size dependence of the phenomenon," says Awschalom.

To determine the energy needed to flip their minimagnets, the team fashioned a microcircuit designed to measure the magnetic field of the magnets. They then applied an external magnetic field in the opposite direction, and used their microcircuit to gauge when the external field overcame the field of the micromagnets and flipped them around. By testing magnets that had various combinations of volume and cross-sectional area—resembling everything from tree stumps to nails—the researchers were able to show that cross section was a key influence over field strength, a result that neatly confirmed Braun's prediction.

While that finding may one day help industry researchers design more stable magnetic recording systems, such tiny grains are not likely to become a standard unit for storing information. That's because such tiny magnets are unstable for another reason: temperature changes, says Sheldon Shultz, a physicist at the University of California at San Diego. "When you make the storage bit [too] small, it is subject to thermal fluctuations and it loses its value as storage," he says. But even if these tiny magnets have no future in industry, their career in science is just beginning.

The Sandman Speaks

Sand dunes are often noisy places, with dune buggies crisscrossing them and kids shouting as they careen down their sandy slopes. But in most cases, when the dune buggies and the kids go home, the dunes lapse into silence. Not always, though. Rare dunes in deserts around the world can raise a racket all by themselves, with no human assistance, roaring like a B-29 or humming like a swarm of bees.

For 1500 years, travelers in the Near and Far East have spun legends around these "booming" or "singing" sands. One ancient folktale explained the sound as the tolling of bells from buried monasteries. Another called it the song of sirens luring desert travelers to a waterless death. At the APS meeting, University of Michigan physicist Michael Bretz unveiled a more down-to-earth scientific explanation: The vocalizing ability of these dunes, he said, is probably due to uncommonly high friction between sand grains.

DAVID R. CRISWELL

Singing sand. Physicists sample a dune for clues to why.

Bretz, Franco Nori at Michigan, and Shigeo Miwa at Doshisha University in Kyoto, Japan, were following up on a clue noted by an earlier leader in the effort to understand booming dunes: British physicist R.A. Bagnold, who in 1954 described one dune in the Sahara that produced "a vibrant booming so loud that I had to shout to be heard by my companion." Studying samples of vocal sands under a microscope, Bagnold found that they tend to contain very little dust or impurities. He also noted that some dunes were noisiest when they had just dried after a rain shower.

Bretz now thinks he knows why: Cleaner sand grains generate more friction. That's because dust and other particles between grains of sand act like miniature ball bearings, reducing friction. And Bretz has evidence that friction is the key to the sand's ability to sing. When Miwa pressed a metal rod into a pile of silent sand, then examined the track of the sand with x-ray pictures, he found that the grains had slipped aside randomly. In a batch of singing sand, however, the rod left fracture, or shear, lines where whole minislabs of grains had shifted together.

Heinrich Jaeger, a physicist at the University of Chicago, called Bretz's demonstrations "pretty convincing evidence that [the sound] has to do most likely with friction." At the same time, Jaeger says, Bretz's presentation begged the question of just how the clingy sand turns motion into sound. Bretz suspects that the collective motion of grains spilling down a booming dune creates a specific pattern of vibrations, and some of those vibrations generate the sound. But Jaeger says that may not be the full answer. By tantalizing his listeners with this new puzzle, he says, Bretz "made everybody's mouth water." A 1500-year-old mystery, after all, can't be expected to yield in a single APS talk.

An Atomic Film Festival

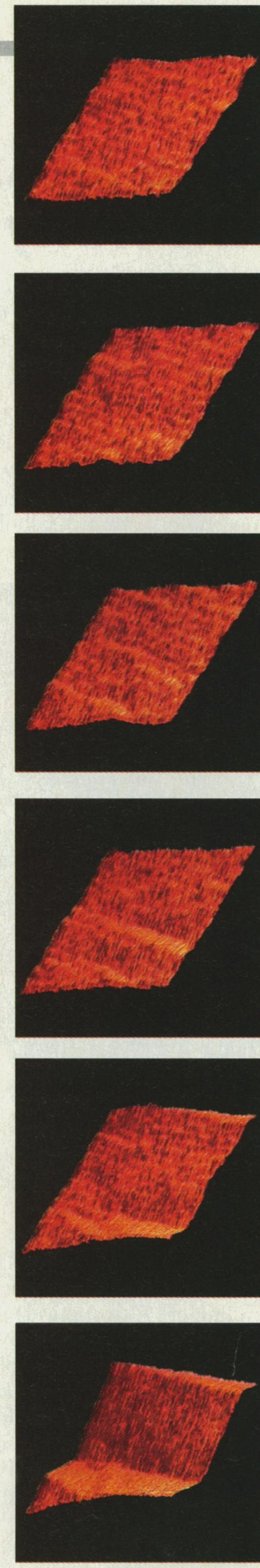
Any moviegoer knows that movement reveals things still images can only hint at. Given that power, it's not surprising that even physicists are catching the moving-picture bug. At the meeting, several researchers showed their latest rushes and described their efforts behind the rolling cameras. But instead of casting Tom Cruise or Glenn Close, these moviemakers cast their features with crowds of atoms. And instead of using lenses, booms, and 35-millimeter film, these scientists are capturing the action with the latest atomic-resolution microscopes—devices with names like STM, LEEM, REM, and TEM.

None of these instruments is new. What is novel is the speed with which they can click off successive images and convert them into frames of a motion picture. Thanks to advances in computer power and instrumentation, these microscopes can now make images quickly enough to capture successive stages in the movement of atoms across a surface, creating an atomic-scale movie. "We've reached a stage where we can see things move on surfaces with atomic resolution in real time," says Ellen Williams, a physicist at the University of Maryland.

The resulting films promise to deepen researchers' understanding of such things as how surfaces rearrange themselves when they are exposed to high temperature and how atoms freshly deposited on a surface settle into the neighborhood. And that should bolster the ability of electronic device makers to create finely layered structures by depositing different materials atom by atom—a process that is now largely a matter of trial and error. "These movies can give you some feeling for the dynamics of how these materials interact," says Ruud Tromp, a physicist at IBM's Thomas J. Watson Research Center in Yorktown Heights, New York.

The favored camera of these researchers is the scanning tunneling microscope (STM), a device that reads the atomic contours of a surface by scanning a probe over it. STMs paint a picture line by line, so the time it takes an STM to complete an image goes up with the area to be depicted. For a region 100 atoms square, current STMs require about a second, more than 10 times as fast as the STMs of a decade ago. But that's still too slow to capture some of the atomic action. Hence some researchers are turning to faster, albeit coarser, techniques that create images by playing beams of electrons over the sample: low-energy electron microscopy (LEEM), reflection electron microscopy (REM), and transmission electron microscopy (TEM).

Whatever camera they use, the physicists have one advantage over budding Fellinis in other domains: They can alter the screenplay just by changing the temperature. Much of the action on a surface takes place along the edges of the atoms-high terraces, stepped like hillside ricefields, into which even "flat" surfaces are divided. New atoms arriving on a surface generally attach themselves to the edges of terraces, with the rate and pattern of growth varying according to the temperature. To home in on a new kind of action, all the researchers have to do is warm or cool their samples.


BARTELT

A star turn. Atoms rearrange themselves on a silver surface exposed to oxygen. The images were made with a scanning tunneling microscope at intervals of 150 seconds.

At the atomic film festival, LEEM movies by Tromp and University of Maryland physicist Norm Bartelt showed how step edges on a silicon surface fluctuate wildly at 1000°C. The heat, explains Bartelt, dislodges thousands of silicon atoms from terraces and causes them to careen into nearby steps. The cumulative effect of these interactions can make a step edge move by as much as 1000 angstroms per second. The more restrained dramas that take place on these silicon terraces at around 300°C were depicted in STM movies by Maurice Webb, a physicist at the University of Wisconsin. At that temperature, Webb's video showed atoms on a silicon terrace just begin to break away from the surface.

Other researchers turned their cameras on the surfaces of different materials. Among those filmmakers was Laurens Kuipers, a physicist at the FOM Institute for Atomic and Molecular Physics in Amsterdam, who showed STM movies that traced the arrival of atoms on the terraced surface of a gold sample. The step edges of gold (like those of silicon) are made up of straight segments interrupted by corners where the edge zigs or zags by the width of a single atom. Kuipers' movie of gold showed that as newly arrived atoms attach themselves to a step edge, they tend to settle right in the corners of the zigzags.

These sneak previews didn't exhaust the atomic film festival. Other filmmakers presented work showing how conditions other than temperature affect a surface (see sequence of images at left), as well as movies taken with REM and TEM cameras. Tromp left the theater a very satisfied moviegoer. "I am very excited about real-time microscopy," he said. "It is really starting to gain momentum now."

–Robert Service