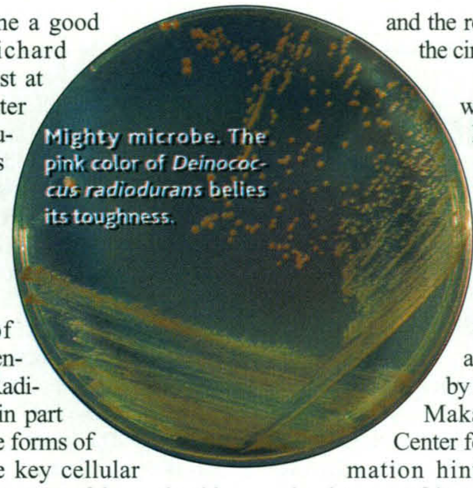

Mighty microbe. The pink color of *Deinococcus radiodurans* belies its toughness.

that, "TIGR has done a good job of it," says Richard Alm, a microbiologist at Astra Research Center in Boston, Massachusetts. Now, the team's analysis is revealing the surprisingly conventional nature of the microbe's radiation defenses.

One element of these defenses is an enzyme called MutT. Radiation damages cells in part by generating reactive forms of oxygen that oxidize key cellular compounds, including some of the nucleotide building blocks of DNA. These oxidized nucleotides can cause faulty DNA replication, but MutT protects against such mutations by helping rid the cell of the oxidized nucleotides. Most organisms have a single MutT gene, but with 20 MutT-like genes, *Deinococcus* is capable of "removing a whole lot of oxidative products," White said.

The sequence also offers a clue to how *Deinococcus* repairs the numerous breaks that radiation induces in its DNA. This repair requires that the microbe put the fragments back together in the right order. In 1995, Michael Daly and Kenneth Minton, molecular microbiologists at the Uniformed Services University of the Health Sciences, Bethesda, Maryland, had suggested that the microbe, which usually carries multiple copies of each of its three chromosomes, rebuilds the copies in parallel. This would be possible, they proposed, if the chromosome copies were aligned. The nearby fragments of one copy could thus provide information missing from the other, and complete chromosomes could be assembled (*Science*, 24 November 1995, p. 1318).

But the genome seems to support a different picture, which first began to emerge when Daly did experiments with artificial DNA inserted into *Deinococcus* chromosomes. He showed that the fragments form circles before they build reconstituted chromosomes. When White and his colleagues realized that the *Deinococcus* genome contains some several hundred repeating stretches of DNA, they wondered whether these repeats were involved in making circles during repair.

One possibility is that early in repair, a repeat at the end of a fragment loops around and links to one at the opposite end, forming a circle and thereby protecting the broken ends of the DNA. Alternatively, these stretches of repetitive DNA may help keep DNA fragments from copies of the same chromosome close by, enabling them to link up more readily and eventually reconstitute a full chromosome. But, Daly cautions, "it's early days," and the roles of both repeats and the circles are still unclear.

Why the organism would have evolved this Phoenixlike ability to rebuild itself after radiation exposure has been a mystery, but its lifestyle and its genome offer some clues. Desiccation damages DNA, and an analysis of the genome by Daly, Minton, and Kira Makarova of the National Center for Biotechnology Information hints that *Deinococcus* gained some of its all-round toughness by adapting to harsh, dry environments.

The researchers showed that *Deinococcus* has genes for at least three desiccation-resistant proteins that thus far have been found only in plants. It also has other genes usually seen in eukaryotes and not in bacteria. "It seems whole families [of genes] were transferred [from other species]," Makarova suggested, although more sequenced genomes will be needed to confirm this.

While some researchers mine the *Deinococcus* sequence for clues to the microbe's capabilities, others have been looking for ways to exploit its hardiness. At the meeting, Minton described the success of Daly's group in providing *Deinococcus* with genes that allow it to detoxify a common environmental contaminant—mercury. Daly and Hassam Brim in his lab showed that neither the mercury-altering genes nor another set of newly added genes for breaking down the chemical toluene interfere with the microbe's resistance to radiation. The engineered *Deinococcus* might thus serve to detoxify sites doubly contaminated with chemicals and radioactive wastes. "If we can take mixed waste and reduce it to a [pure] radiation waste, then we can handle it," explains Marvin Frazier, a microbiologist with the U.S. Department of Energy.

White is eager to see his supermicrobe go to work. "It's able to withstand a lot of environmental insults," he emphasizes. "This is going to really be an industrially relevant organism."

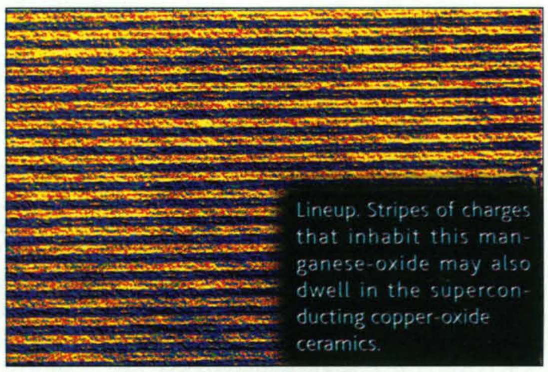
–E.P.

PHYSICS

Could Charge Stripes Be a Key to Superconductivity?

Seen in ceramic superconductors, stripes are confounding many theorists but exciting a few as a possible clue to how these materials work

Takashi Imai wears his stripes reluctantly. Like hundreds of other physicists around the world, Imai has been struggling to understand how an odd family of ceramics manages to conduct electricity without resistance at unprecedentedly high temperatures. Along with most other physicists studying high-temperature superconductivity, he was inclined to discount an idea that has hovered at the fringes of the field for several years—that charges percolate back and forth through these materials in a series of stripes, a few atoms wide, creating a landscape that helps current flow effortlessly through the material in all directions.


Lineup. Stripes of charges that inhabit this manganese-oxide may also dwell in the superconducting copper-oxide ceramics.

"I was very skeptical [of the stripe theory]," says Imai, a young assistant professor at the Massachusetts Institute of Technology. The evidence for the stripes was patchy, and the theory "looked too simple to be true." But that was before last summer, when Imai and his students began running a set of experiments for months on end that showed clear hints that charges were indeed running in defined lanes. By November, the group knew they were onto something big and resolved to double check every detail. "We kept running experiments 24 hours a day, 7 days a week. I skipped Thanksgiving and Christmas to keep taking data," he says, adding casually, "This is a competitive field."

Competitive is an understatement. Deciphering the mystery of high-temperature superconductivity has been the prime ob-

CREDITS: (TOP) TIGR; (BOTTOM) S. MORI ET AL., NATURE 392, 473 (1998).

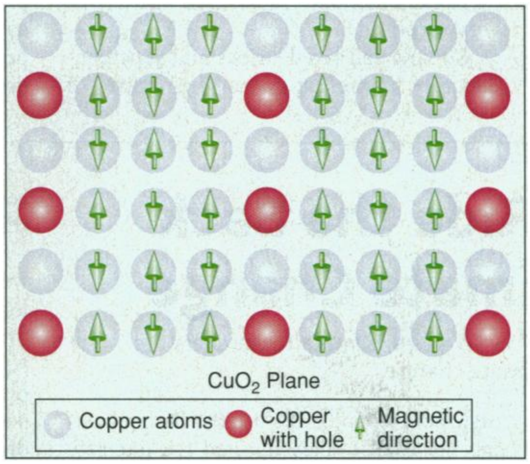
session among condensed matter physicists since 1986, when the first superconducting ceramics were discovered. A definitive answer remains elusive. But Imai's discovery along with a couple of other recent reports is giving stripe proponents a big boost. At meetings around the world, "one of the main themes we're seeing is stripes," says John Kirtley, a superconductivity researcher at IBM's T. J. Watson Research Center in Yorktown Heights, New York. "More and more people are starting to believe it."

But believing in the reality of the charge stripes is one thing; conceding that they have anything to do with superconductivity is something else entirely. The new evidence has by no means quenched the debate about the stripes' significance; indeed, it seems to show the stripes remaining fixed in the material like the stripes on a flag—a behavior that nearly everyone agrees should kill superconductivity, not promote it. As David Pines, a superconductivity theorist at the University of Illinois, Urbana-Champaign, and the Los Alamos National Laboratory in New Mexico, puts it, "There may be some evidence for stripes. But that doesn't say in any way, shape, or form that this helps produce superconductivity."

Seeing stripes. Early support for stripes came primarily from theorists, who were struggling to understand how the electrical and magnetic behaviors of the ceramic superconductors interact. The superconducting ceramics all share a layered structure, with sheets of copper and oxygen atoms sandwiched between layers of other atoms, such as yttrium, barium, strontium, and lanthanum. Each of the oxygen atoms in the copper-oxide sheets harbors an even number of electrons, which have "spins"—magnetic orientations—pointing in alternate directions. The alternating spins cancel each other out, so the atoms carry no net spin. The copper atoms, by contrast, have an odd number of electrons, and thus have an excess electron spin, giving these atoms a net magnetism. In these materials, opposite spins attract: When one electron's spin points up, its neighbor prefers to point down. Adjacent copper atoms do their best to align in opposite orientations, creating an alternating up-and-down pattern.

This large-scale pattern tends to hamper the movement of free charges, which are introduced when researchers dope these "cuprate" materials with other atoms. Added to the lanthanum-based cuprate as a dopant, strontium atoms replace lanthanums, which normally donate electrons to the electron-hungry atoms in the adjacent copper-oxide planes. But strontium has one less electron than lanthanum to donate. The upshot is that copper atoms wind up with electron vacancies, or "holes." These holes, it turns out, can percolate through the material, carrying a positive charge but no spin.

In the early 1990s, theorists such as Vic Emery at Brookhaven National Laboratory (BNL) in Upton, New York, and Steven Kivelson at the University of California, Los Angeles, realized that as holes moved around, they would change the lattice of spins in the material. As a hole moves to a new copper atom, that atom's spin moves to the hole's previous location, disrupting the orderly up-down arrangement of spins. "That costs energy and tends to frustrate the movement of the holes," says BNL experimental physicist John Tranquada.



Holed up. Positively charged "holes" collect in stripes to avoid interacting with the alternating pattern of magnetic "spins" on neighboring rows of copper atoms.

SOURCE: J. TRANQUADA/BNL

Stripes could form as the holes' way of getting around this restriction, he explains. Add enough holes, he says, and "if they clump together in a stripe then they can move along that stripe more easily without moving any spins." The regions in between, meanwhile, hang onto their favored "antiferromagnetic" order of up, down, up, down spins.

Though hints of stripes in the cuprates went back to the early 1990s, researchers had been unable to get a good look at them. Tranquada and his BNL colleagues suspected that the stripes were elusive because they were moving around, blurring their signature in the data. So the BNL group looked for a way to fix them in place. They added neodymium to a superconducting ceramic made with lanthanum, strontium, copper, and oxygen, in hopes that this dopant would alter the shape of the lattice just enough to keep the stripes from moving. The researchers then hit their sample with a beam of neutrons, which can probe the fine-scale magnetic structure of a material: Neutrons have an intrinsic spin that interacts with—and can reveal—the spins of electrons. The neutron scattering data suggested that these ceramics do indeed have stripes of magnetic order alternating with stripes rich with electrical charges.

Pairing up. Encouraged by the result, Emery and Kivelson went further. They proposed that fluctuating stripes not only help charges flow through these ceramics but are crucial to high-temperature superconductivity itself. One hallmark of superconductivity is that electrical charges—either electrons or holes—skate through the material in pairs rather than singly, which keeps them from scattering off atoms in the lattice. And a major challenge in high-temperature superconductivity theory is explaining what promotes this pairing.

Emery and Kivelson think it's the stripes. By confining charges to narrow regions, the magnetic barriers in effect raise the energy of the holes. To lower this energy, the holes work to spread out. Single holes can't readily manage the task. But by pairing up, the holes can work together to modify the arrangement of spins in the barriers and tunnel through, lowering their overall energy. Once formed, the pairs can move effortlessly through the material as a supercurrent.

Theorists, who tend to favor their own pairing theories, have been slow to embrace this picture. And nearly everyone, including Emery and Kivelson, agrees that stripes should kill rather than promote superconductivity unless they can meander through the material like a winding river that often changes course. Due to a quantum mechanical effect, a fixed, parallel arrangement of stripes would conspire to pin down all the charges in the material, creating an insulator. "Just about everyone would agree that if you really localize the charge in stripes, you will not get superconductivity," says Tranquada.

Fortunately for stripe proponents, several early reports did find evidence of fluctuating stripes in the lanthanum-based cuprates. More support came from work reported last fall in *Nature* (8 October 1998) by a team of U.S. and British researchers led by Herb Mook, a neutron scattering expert at Oak Ridge National Laboratory in Tennessee, which also suggested fluctuating magnetic stripes in a different superconductor, made from yttrium, barium, copper, and oxygen, or YBCO. And even Tranquada's initial experiment could be taken as support for the idea that fluctuating stripes favor superconductivity. When the group added neodymium to pin down the stripes, the temperature at which the lanthanum-based material superconducted dropped sharply, from around 38 K to just a few degrees above absolute zero.

But other experiments have begun to muddy this pretty picture and suggest that fixed stripes may not always be superconductivity killers. In work recently submitted to *Physical Review B*, a team of Japanese and U.S. researchers looked at a lanthanum-copper-oxide crystal with excess oxygen added as the dopant, a material that has the highest superconducting temperature of any lanthanum-based compound. The team's neutron scattering results clearly showed the presence of static stripes. The inescapable conclusion, says team member and MIT physicist Robert Birgeneau, is that "superconductivity and static magnetic order [fixed stripes] can coexist."

Now comes Imai's latest result, which underscores that puzzle. Because neutrons are strongly sensitive to the magnetic spins on the copper atoms, most neutron scattering work had revealed just the arrangement of magnetic spins in superconductors, leaving investigators to infer the charge stripes. Imai, however, has traced the charges themselves in the high-temperature superconductor lanthanum-strontium-copper-oxide. In a technique called nuclear quadrupole resonance, the team pulsed radiofrequency waves at the material and tracked the magnetic response, which indicated the spins of the copper nuclei. But nearby electrical charges also affect the magnetic signature, which allowed the researchers to piece together the location of the charges as well. Imai says the results, which have been submitted to *Physical Review Letters*, support the presence of "quasi static" stripes, largely fixed in place. "I didn't expect we'd see this phenomenon," says Imai. "So I was very surprised."

So how can fixed stripes and superconductivity be present in the same hunks of ceramic? One possibility, says Princeton theorist Philip Anderson, is that any seemingly fixed stripes and superconductivity may be confined to separate regions of the material. Emery suggests another: The stripes aren't completely fixed after all, but meander about an average position. His reading of the recent data suggests that "there is some movement there," he says.

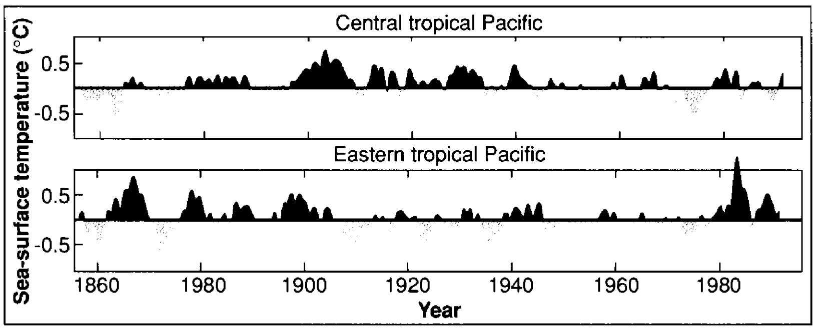
Whatever the answer, it appears that stripes are here to stay. They may be either a key to superconductivity or a false lead devised by nature to throw theorists off the track. To find out, says Pines, researchers now need to show that stripes not only coexist with superconductivity in the same region of material, but that they somehow improve its superconducting behavior. Until someone figures out how to pull off that experiment, the charge stripes will remain a disquieting mystery. –**ROBERT F. SERVICE**

CLIMATE CHANGE

Big El Niños Ride the Back Of Slower Climate Change

After two "El Niños of the Century" in 15 years, climate researchers are finding explanations in long-term climate change

Climate modelers were patting themselves on the back last year after successfully anticipating the arrival of El Niño in 1997. In the spring of that year, dutifully following predictions of a modest event, the tropical Pacific warmed sharply (*Science*, 24 April 1998, p. 522). But then the Pacific asserted its independence, confounding the models by soaring to record-breaking warmth in one of the most severe events of this kind on record—worse than the devastating "El Niño of the century" that struck in 1982–83. By the time it was over in 1998, El Niño–related weather extremes had caused 23,000 deaths and $33 billion in damages around the world. Now, by deconstructing the symphony of longer-term climatic cycles that play out in the Pacific Ocean, researchers have found clues to why these events were so severe.



Synergy. Two of the tropical Pacific's climate cycles turned warm simultaneously in the early 1980s, fueling the 1982–83 El Niño.

SOURCE: ENFIELDS AND MESTAS-NUÑEZ

In two papers soon to appear in the *Journal of Climate*, researchers show that these other, slower cycles of ocean warming and cooling have tended to be at or near their peaks—in some cases unusually high peaks—since the 1970s. By preheating the Pacific, they boosted the intensity of the El Niños.

No one knows what drives these cycles, although some researchers suspect that the past century's global warming may have helped push some of them to the warm side simultaneously. But identifying the cycles at work in a given year could be a first step toward forecasting how powerful a predicted El Niño will be—and ultimately how it will affect weather patterns around the world (see sidebar). "If we are to extract every ounce of predictability from the [climate] system," says oceanographer David Enfield of the National Oceanic and Atmospheric Administration (NOAA), "we must try to understand how the other components work and how they interact with [El Niño] in modifying our climate."

Untangling climate to understand its workings and future behavior takes a record long enough to include repeat performances of a given climate oscillation. Enfield, of NOAA's Atlantic Oceanographic and Meteorological Laboratory in Miami, Florida, and oceanographer Alberto Mestas-Nuñez of the University of Miami found theirs in a 136-year record of sea-surface temperature measured by ships around the globe, just compiled by oceanographer Alexey Kaplan and his colleagues at Lamont-Doherty Earth Observatory in Palisades, New York.

The Miami researchers parsed the complex climatic symphony of the Kaplan temperature record into its component parts. First, they removed the so-called El Niño–Southern Oscillation or ENSO variations themselves, the high-pitched drone of tropical warmings and coolings that return every 2 to 7 years. Next, they removed the bass crescendo of global warming—a trend of nearly half a degree Celsius per century, which may be driven by human activity. Finally, they used a sophisticated statistical technique to separate the remaining melody of the temperature record into several oscillations—a decade or two long and a half degree or more in amplitude—that were being played out in different parts of the ocean.

What they found was more of a cacophony of discordant cycles than a harmo-