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Mr. Grant R. Cameron
649 Silverston Ave
Winnipeg, Manitoba
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Dear Mr Cameron,

Thank you for your letter, I am glad you were interested by the presentation on superconductors.

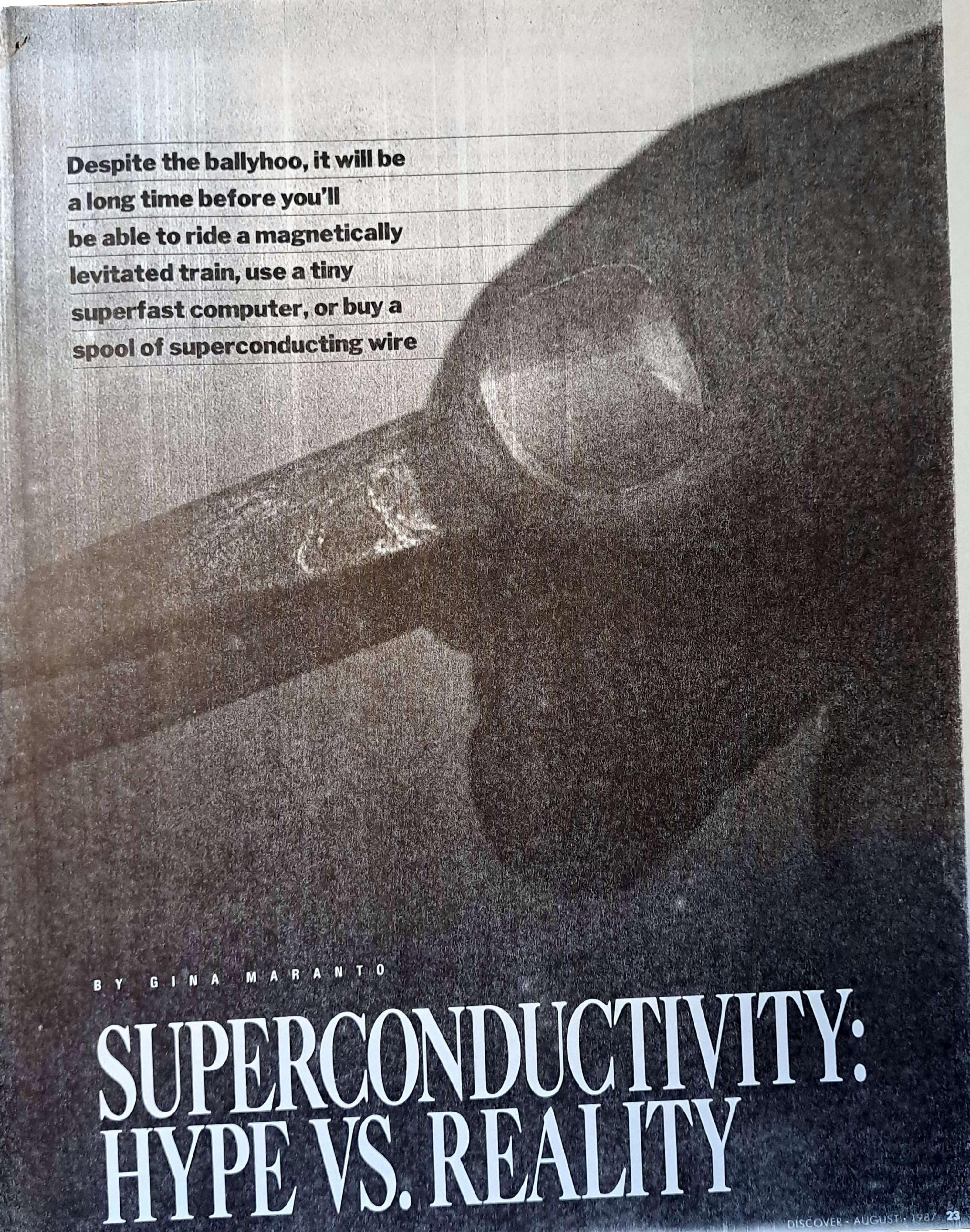
I enclose an article on superconductors which you may find of interest. This gives you some references which you could follow up.

I have done very little work in the area used on the stealth bomber, so I could only be of assistance in very general terms.

Yours sincerely,

M. Sayer

M.Sayer
Professor of Physics



Despite the ballyhoo, it will be a long time before you'll be able to ride a magnetically levitated train, use a tiny superfast computer, or buy a spool of superconducting wire

B Y   G I N A   M A R A N T O

SUPERCONDUCTIVITY: HYPE VS. REALITY

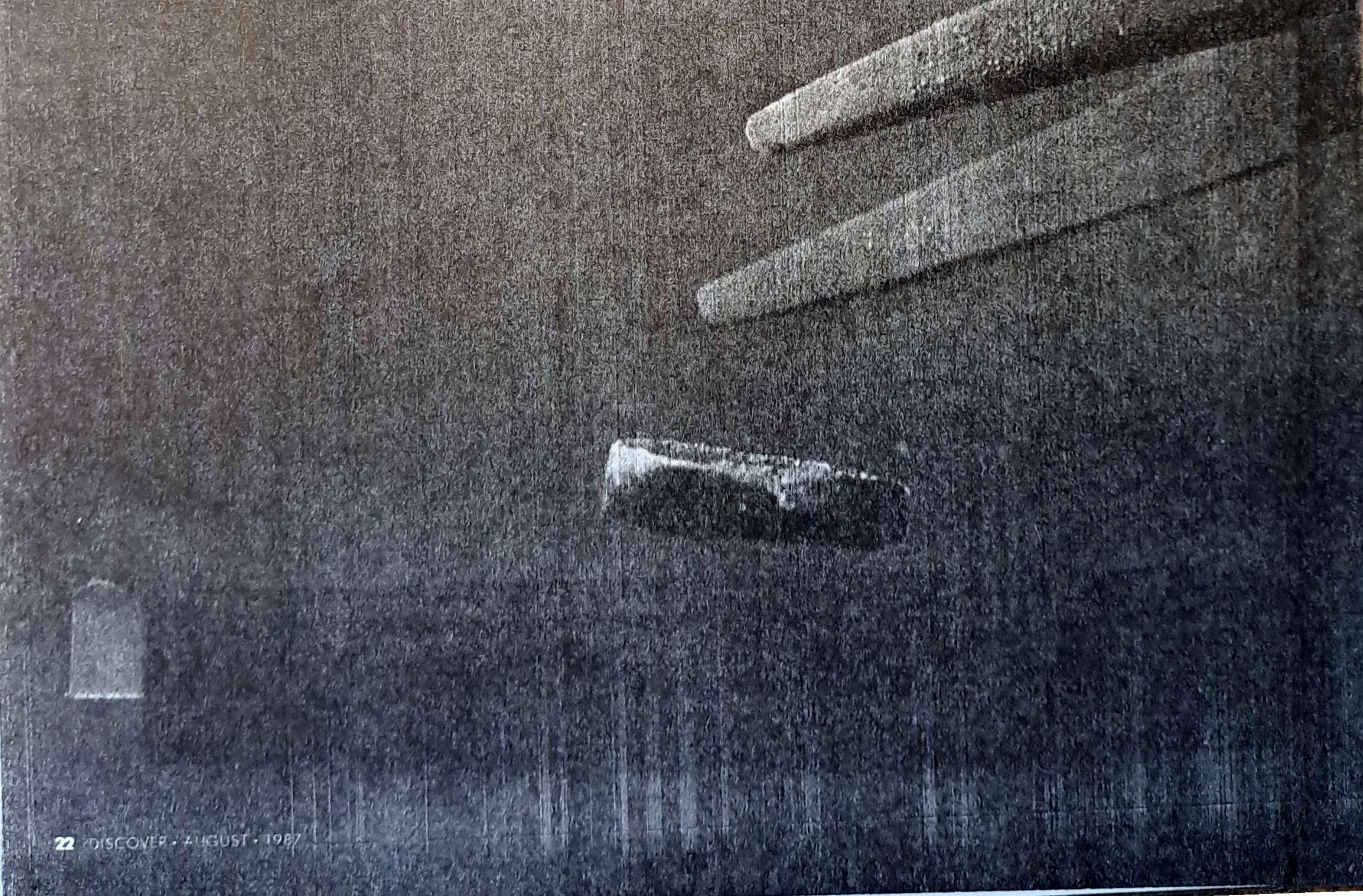
When, in 1972, our family moved from the dreary East to Tarzana, in sunny southern California, my brother and I decided to cover the roof of our house with solar cells. Fossil fuels seemed to be running out, and we wanted to do our bit for conservation. After a foray to the library, though, we scrubbed our grand plan: what we had in mind would have set us back about $300,000.

Now, 15 years later, the average Tarzanian who wants to unplug his house from the Southern California Gas Company and run his Amana on the sun's rays is still out of luck. While the Japanese have learned how to manufacture low-quality photovoltaic cells cheaply and put them in $1.99 calculators and digital watches, modules of amorphous silicon cells of the sort that could power a house are still too expensive for most people. As for whole cities, says Yoshihiro Hamakawa, a specialist in solar technology at Osaka University, it will be another 15 years before adequate solar arrays, capable of pumping out a million watts or more, are perfected.

Such will probably be the case with the newly discovered and much ballyhooed high-temperature superconductors, the weird metallic ceramics that are being cooked up by researchers in labs around the world. When they're cooled below a certain critical temperature, superconductors offer no resistance to the flow of an electric current. In theory at least, it will run forever without creating heat or in any measure diminishing. What distinguishes the new superconductors from their predecessors is that they have much higher critical temperatures, about 95° Kelvin, or −288° Fahrenheit. (Absolute zero, the absence of all heat, is reached at 0° K, or −459.67° F).

After the now famous "Woodstock of Physics," the all-night jamboree on the new superconductors held at the American Physical Society's March meeting in New York, the *New York Times*, *Business Week*, and *Time* listed the wonders that the new materials might make possible: high-powered electric cars, magnetically levitated trains, tiny superfast computers, and new ways of transmitting and storing electrical energy with barely any loss of power. The secret behind these miracles, the hitherto obscure compound yttrium barium copper oxide (Y-Ba-Cu-O), became as famous as Vanna White. But after the initial hoopla, the excitement over the high-temperature superconductors began to cool. As one scientist says, it's going to be a long time before you can go to the hardware store and buy a spool of superconducting wire.

Promising as they look in



This pellet, made of one of the hot new ceramics, is levitated not by magic but by magnets hidden below. That it responds to a magnetic field is proof that it's superconducting.

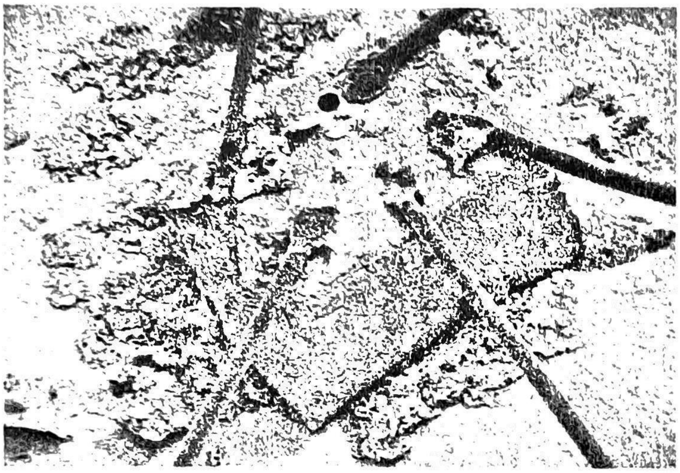
the lab, the new materials may have intrinsic physical limitations. Says Alan Schriesheim, director of Argonne National Laboratory, outside Chicago, which for the past decade has run one of the largest superconductor research programs in the country, "Each application will have its own set of scientific and engineering sticking points, some that will be generic, some unique. Some could be intractable. I don't delude myself that except for military applications the price could be too high to pay."

Because they labored in anonymity and frustration for so long, because the new findings are bound to advance their basic understanding of superconductivity, and because they stand to get more money for research, scientists in the field welcome their moment in the limelight, even as they take issue with the lofty promises made for their work. Says a spokesman at AT&T Bell Laboratories in Murray Hill, N.J., "These advances are exciting, and the scientists here who are involved will tell you that this is the most thrilling thing that's happened to them in their professional lives. But the press has left the general impression that magnetic levitation trains are just around the corner, and they're not." Jack Ekin of the National Bureau of Standards in Boulder, Colo., which has tested twenty or so new superconducting materials, concurs. "I've wanted to see a note of realism injected into the public discussion," he says. "The potential of these materials is great, but the timetable that's been set up by the press is wrong. It will be five years before we see them in thin films in computers, and up to twenty years before we see them in bulk applications," such as magnets or power lines.

Ekin continues, "There's a famous graph: For any discovery, you can plot expectations as a function of time. There will be an initial spike—it goes way up, and then way down as disillusionment sets in. Then there's a long, slow upward curve, as you tackle and begin to solve the intellectual and technical puzzles that the discovery poses. With the new superconductors, we're still near the peak on expectations, but I think we may be about to go down the other side."

In fairness, scientists should admit that the press hype grew in part out of their own perfervid reactions: for several months, the superconductor community was caught up in a frenzy. Researchers pulled all-nighters, skipped Christmas vacations, ignored their families. It was the payoff for more than three decades of watching their efforts go pretty much nowhere. In 1953 John Hulm, then at the University of Chicago, had found a material, vanadium-3 silicon, which becomes superconducting when cooled below 17.5° K (−428° F). Within a day, Bernd Matthias, at Bell Labs, had made a material with a similar structure, niobium-3 tin, which became superconducting at 18°K (−427° F). But by 1973 the search for materials with higher critical temperatures (T_C), meaning those that would retain their superconducting properties above 18° K, had yielded only a few with higher T_C's, the best of which, a compound of niobium and germanium, had a T_C of 23.2° K (−418° F).

True, niobium-3 tin and niobium-3 germanium could be bathed in liquid or compressed gaseous helium and kept cold enough to maintain superconductivity, and several labs around the world rigged up prototype engines, maglev trains, and power transmission lines that incorporated these materials. But liquid helium (temperature: −452° F) is too expensive and too difficult to work with to be practical. Doubts began to arise that the holy grail of solid state physics, a "room temperature" superconductor, was really attainable. Says Ching-Wu (Paul) Chu of the University of Houston, who played a key role in the latest round of discoveries, "The pessimists argued that, based on BCS, T_C could never exceed thirty degrees Kelvin."

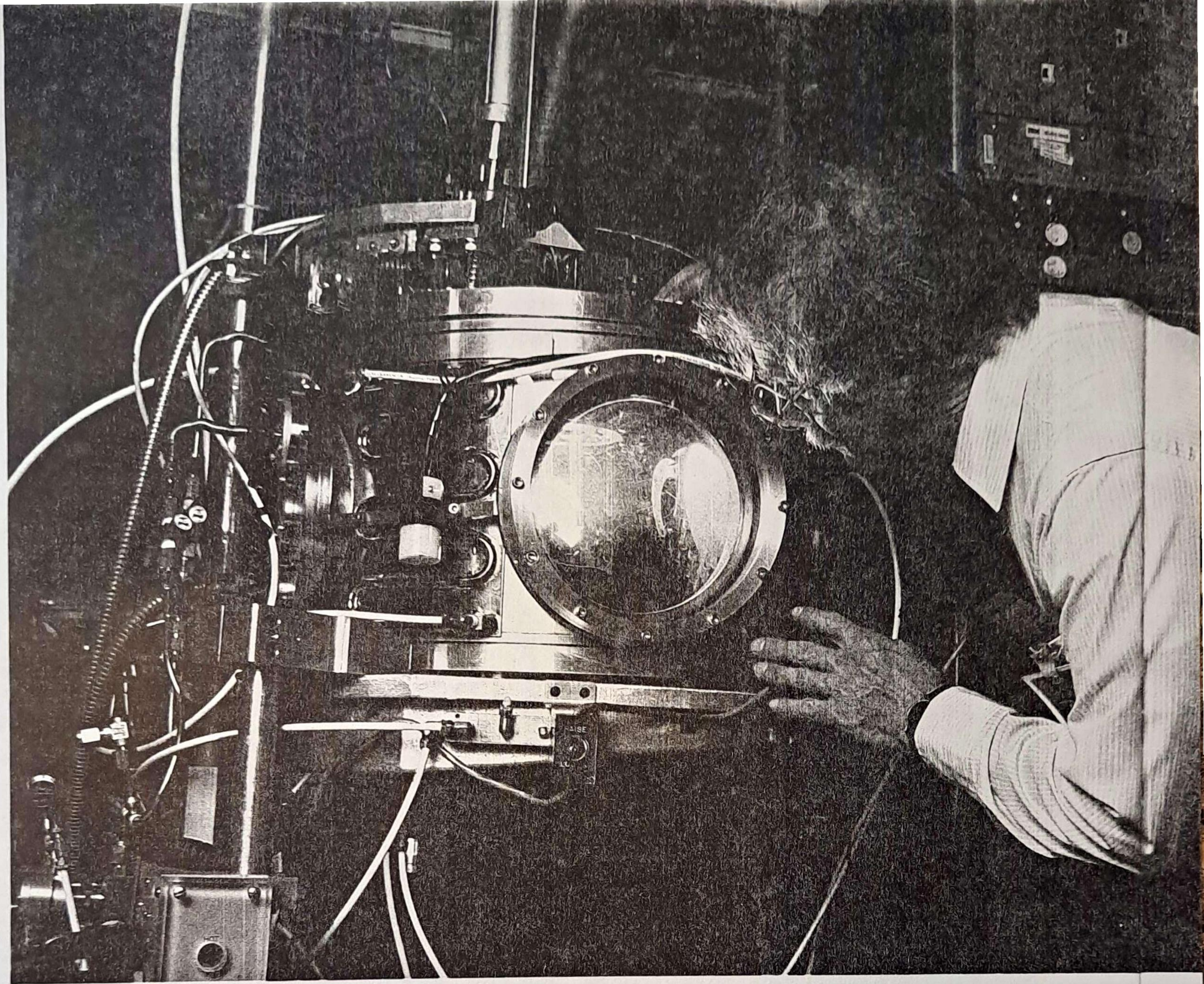


A magnified view of a superconducting crystal of yttrium barium copper oxide. The wires are a thousandth of an inch thick.

BCS refers to the theory that until recently appeared to explain superconductivity. It's an acronym created out of the first initials of the surnames of the three physicists who advanced the theory in 1957, John Bardeen, Leon Cooper, and J. Robert Schrieffer, and won a Nobel for it in 1972. Although the behavior of the new materials has led physicists to question and modify BCS to a certain extent, it probably explains at least some of what goes on.

Putting it simply, the theory says that superconductivity is caused by interactions of the atoms that make up the crystal lattice of a solid with "free" electrons, which aren't attached to a particular atom and are in random motion. (A material's electrical resistance is, essentially, a measure of how effectively the lattice blocks the transit of electrons from one point to another.) When the negatively charged free electrons move past the positively charged lattice, which is flexible, the lattice distorts and sends out vibrations called phonons, or quantized sound waves. Though you can't hear the subatomic commotion, it has a measurable consequence. The phonons cause electrons that usually repel each other to move in tandem, like surfers being carried shoreward by the same wave. This sets up the superconducting state, in which the coupled electrons, known as Cooper pairs (for the Cooper in BCS), move in conjunction with other Cooper pairs through the material without hitting the lattice or dissipating energy.

While BCS offers insights into the atomic behavior of superconductors, it can't predict which materials will be good ones. For that, solid state physicists and materials scientists have generally turned to several rules of thumb formulated after years of trial and error by Matthias. "Matthias said never look at materials that don't have a cubic structure, or that aren't related to known superconductors," says Michael Schluter, a Bell Labs theorist.



"There was also a broad belief that you shouldn't bother looking at oxides."

In 1983 J. Georg Bednorz and Karl Alex Müller of IBM's Zurich Research Laboratory came on the scene. Outsiders to the tight little world of superconductivity, they conducted their investigations intuitively—and quietly. Says Bednorz, "We didn't tell anybody what we were doing because we would have had difficulty convincing our more knowledgeable colleagues that what we were doing wasn't crazy."

Müller says the idea of looking for superconductivity in the class of ceramics called perovskites occurred to him while sitting in the garden of a medieval monastery in Erice, Sicily, in the summer of 1983. Later he chanced upon an intriguing paper by Claude Michel and Bernard Raveau of the University of Caen in France: in a ceramic compound, which should have impeded current or acted as an insulator, the chemists had found signs of electrical conductance. (Chu also saw the paper but paid it little heed.)

In any project," says Müller, "you always need a certain kick of luck." Theirs was Bednorz's decision, in following up the French lead, to alter the chemists' method of preparing the compound. Instead of simply mixing the powdery oxides of lanthanum, barium, and copper, he dissolved them in water first. Then he let the particles settle out of solution, and heated them at about 1,800° F. The fired material had a sandwich-like structure, with layers of lanthanum and barium atoms alternating with layers of copper and oxygen atoms. When Bednorz ran a current through it, its resistance dropped precipitously at about 35° K (−396° F) and vanished altogether at 13° K. Superconductivity had set in far above the highest T_c ever recorded.

After rechecking the astonishing results for several months, Müller went public and was essentially dismissed. "They thought, 'Alex is getting a bit old,' " he says. The Bednorz and Müller paper, published in a German journal, *Zeitschrift für Physik*, elicited only mild interest among superconductor researchers in the U.S. Their response, says Gordon Pike of Sandia National Laboratories in Albuquerque, was "Gee, that looks interesting."

That ho-hum attitude persisted at a long-scheduled symposium on superconductors during the meeting of the Materials Research Society in Boston last December—until the fourth day. That afternoon Chu arose to give his talk. Half-

way through, almost in passing, he mentioned that his lab had looked at Müller and Bednorz's work and verified the resistance drop of the lanthanum compound.

During the comment period, Pike recalls, Koichi Kitazawa, a member of Shoji Tanaka's team at the University of Tokyo, "got up in an excited state with two Vu-Graphs in hand and came to the front and projected them. I think he'd been planning to keep the findings under the table for a while, but Chu forced his hand."

Not only had Tanaka's team confirmed the drop in resistance; it had also seen the so-called Meissner effect, the one

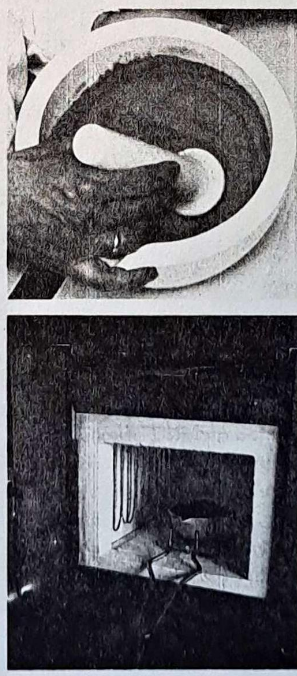
IBM's Gerald Cuomo observes a beam of ions *(interior view, above)* depositing a thin superconducting layer on a sliver, or substrate, of sapphire.

true sign that a material is in a superconducting state. The effect refers to a superconductor's ability to exclude, or repel, a magnetic field, and it underlies a trick that has often been performed in recent months, even by high school science students, in which a small piece of superconducting material is released above a magnet and remains suspended in mid-air.

In the flurry of activity that followed the symposium, Tanaka's group and researchers at Bell Labs quickly identified which phase of the Swiss material was superconducting. Then, in a series of inspired experiments, Chu and his team, along with Maw-Kuen Wu at the University of Alabama at Huntsville, succeeded in raising the T_C to 57° K (−357° F) by the end of December, and then, by replacing lanthanum with the rare earth yttrium, to 93° K (−292° F) on Jan. 28.

At first glance, the new superconductors seemed ridiculously easy to make. During the APS meeting in March, scientists had rattled off the basic recipe: mix lanthanum, barium, and copper oxides, grind them up, stick them in a furnace with oxygen, and next day, *voilà!*, a superconducting soufflé. But a few weeks later, scientists began to recognize complexities. These would have to be dealt with if the materials were to become anything more than a laboratory curiosity. On April 30, Robert Laudise, director of materials research at Bell Labs, testifying before the House Republican Research Committee's Task Force on High Technology and Competitiveness, said, "We're going to have to learn how to do ceramic processing with a kind of finesse and control that we haven't been capable of before."

The new materials would have to be tailored for each application, and that daunting task would fall on the shoulders of engineers. For integrated circuits, they would have to learn how to make thin films, only fractions of a micrometer thick, capable of carrying currents as high as a million amperes per square centimeter. For power transmission lines, which require more current-carrying capacity, they would probably have to learn to make tapes that can endure considerable tension and bending without developing the minute cracks that impede the flow.



Shake and bake: grinding up the ingredients—yttrium, barium, copper—at Bell Labs *(top)*; cooking them at Argonne at 950° C.

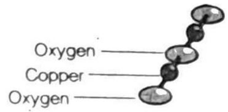
Superconducting niobium-3 tin is prone to such cracking, and it took scientists at Brookhaven National Laboratory on Long Island ten years to perfect a method for incorporating it into a tape that could be wound into a cable for a prototype superconducting power transmission line.

Magnets call for miles of wire: How to make flexible wires from ceramics, which are intrinsically brittle? (The pliable films that researchers waved around at the APS "Woodstock" meeting were "green," meaning they hadn't yet been fired to their final hardness.)

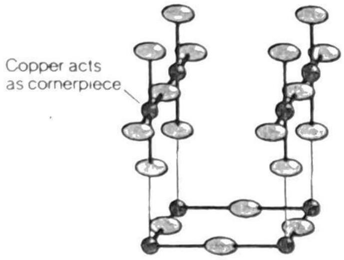
Given enough time and money, say ceramists, such hurdles can probably be cleared. IBM has already developed a way of coating objects of a variety of shapes with the superconducting materials by spraying them on in the green state, and IBM ceramists and others have been experimenting with different methods of making wire. In one, devised by AT&T researchers, barium, yttrium, and copper oxides that have been only partially reacted are packed into metallic tubes a quarter of an inch in diameter, which are then drawn through a series of ever smaller dies to produce wire eleven mils (.011 inches) in diameter. Argonne's Schriesheim anticipates that developing a commercial wire will take about five years. Argonne has received a contract from the Department of Energy (DOE) for such a project, which it plans to carry out with two other national research facilities, Ames

SUPERCONDUCTIVITY'S TINKERTOY WORLD

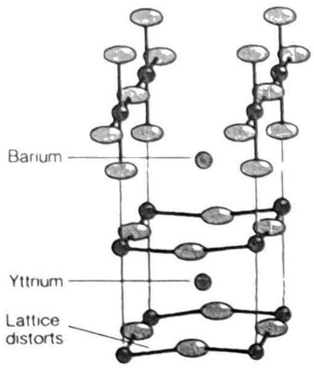
Best known of the new superconductors is a ceramic called yttrium barium copper oxide, whose crystalline structure is shown schematically here. Ceramics usually impede electrons, so how the new material works is being investigated by scientists comparing its conducting and non-conducting states.



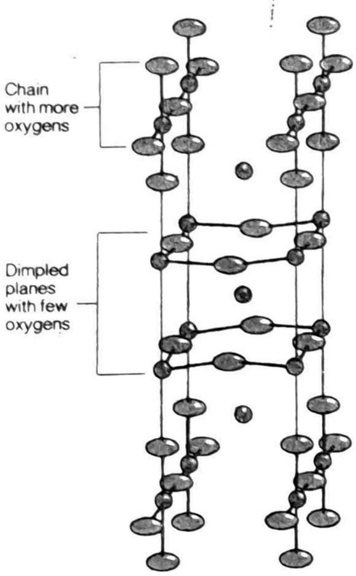
1 The crystal is formed out of a latticework of atoms that resemble Tinkertoys. The key building blocks are oxygen and copper atoms that alternate in sequence.



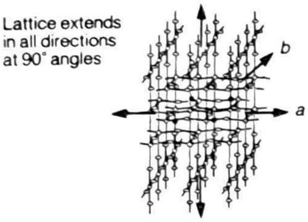
2 The copper atoms act as cornerpieces for the lattice, which branches out at 90° angles, here forming the top of a three-dimensional "cell."



3 Suspended inside these cells are alternating ions of barium and yttrium. Since both have charges, they exert a pull on the oxygen atoms nearest them, somewhat distorting the lattice.



4 The sequence of barium and yttrium repeats itself throughout. The regions around the yttrium have fewer oxygen atoms and are called dimpled planes, because the lattice is distorted. The regions around the barium, called chain regions, have more oxygen atoms.



SOURCE: IVAN SCHULLER ARGONNE NATIONAL LABORATORY

Research Center, at Moffett Field, Calif., and Brookhaven. But Chu has doubts about the endeavor. "Even if wires can be made," he says, "it isn't clear that they will be able to carry a large current or will have the necessary mechanical strength for some applications." In magnetic fields of, say, two million gauss, which is about standard for a large magnet, the mechanical forces are enormous, and a wire of the new superconducting materials would have to be tough to withstand them.

Other obstacles may be insuperable—for instance, keeping the new materials superconducting. Ceramic minerals in the earth's crust have held up for eons, and man-made ceramics survive the harshest conditions (high temperature furnaces are lined with them, and the space shuttle is sheathed in them). "Most ceramics are stable because their electrons are bound up in covalent bonds," says Frank Fradin of Argonne, which means that adjoining atoms share pairs of electrons. "But these new materials aren't natural, and they seem to have something in their chemistry that makes them unstable." To wit: a chunk of fired Y-Ba-Cu-O that's put in a glass of water overnight will dissolve. Completely. This seems to happen because, as one scientist puts it, "the oxygen wants to come in and out." Chu says that when impure Y-Ba-Cu-O is immersed, the barium oxide reacts with the water to form barium hydroxide and then barium carbonate. Perfect crystals might not react in this way, he says, but no one yet knows how susceptible to moisture the material is, and whether devices made from it would have to be coated with an impermeable substance to prevent deterioration.

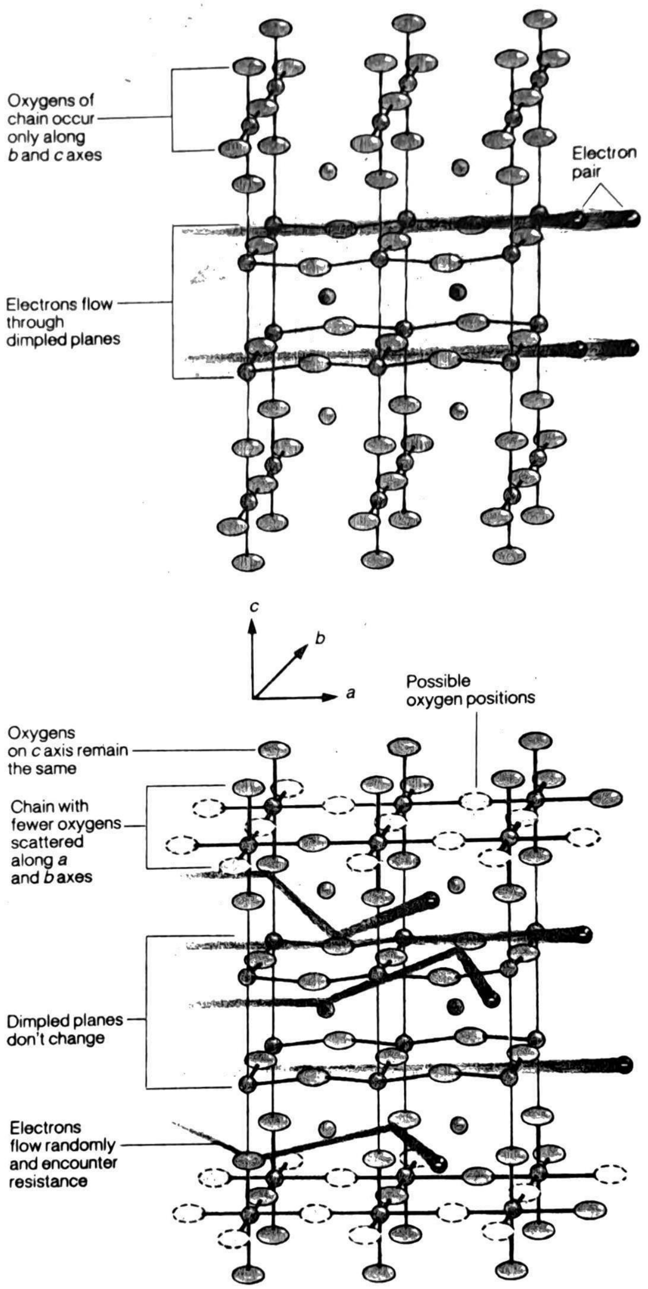
Chuck Oberly, of the Aeropropulsion Laboratory at Wright-Patterson Air Force Base near Dayton, voices the fear that most haunts research-

Chu with samples of his current success

ers around the country. "It isn't clear," he says, "that the materials are ideal for high-current-density applications [like maglev trains, transmission networks, or energy storage coils], and until people publish their serious data, no one is really going to be able to figure out the limitations." Says Ekin, "The critical current densities in these bulk materials aren't high. This is a common shortcoming in all the materials we've seen."

In theory superconductivity will last indefinitely, but in practice it's a somewhat precarious state, since three critical parameters must be met. If a superconducting material is subjected to temperatures, magnetic fields, or currents that are too high, it will change state, sometimes even becoming a semiconductor or an in-

AN ORDERLY FLOW VERSUS ELECTRONIC CHAOS



SUPERCONDUCTING

Because of its structure, the yttrium-barium-copper-oxide lattice creates an anisotropic, or lopsided, electronic environment. Electrons seem to flow only through the planes. And although they would ordinarily repel one another, they manage to move together in a process called Cooper pairing. Possibly it's the oxygen-rich chain that creates conditions that enable one electron to follow another electron. Scientists are looking for clues to this strange behavior by examining the material in its non-superconducting state.

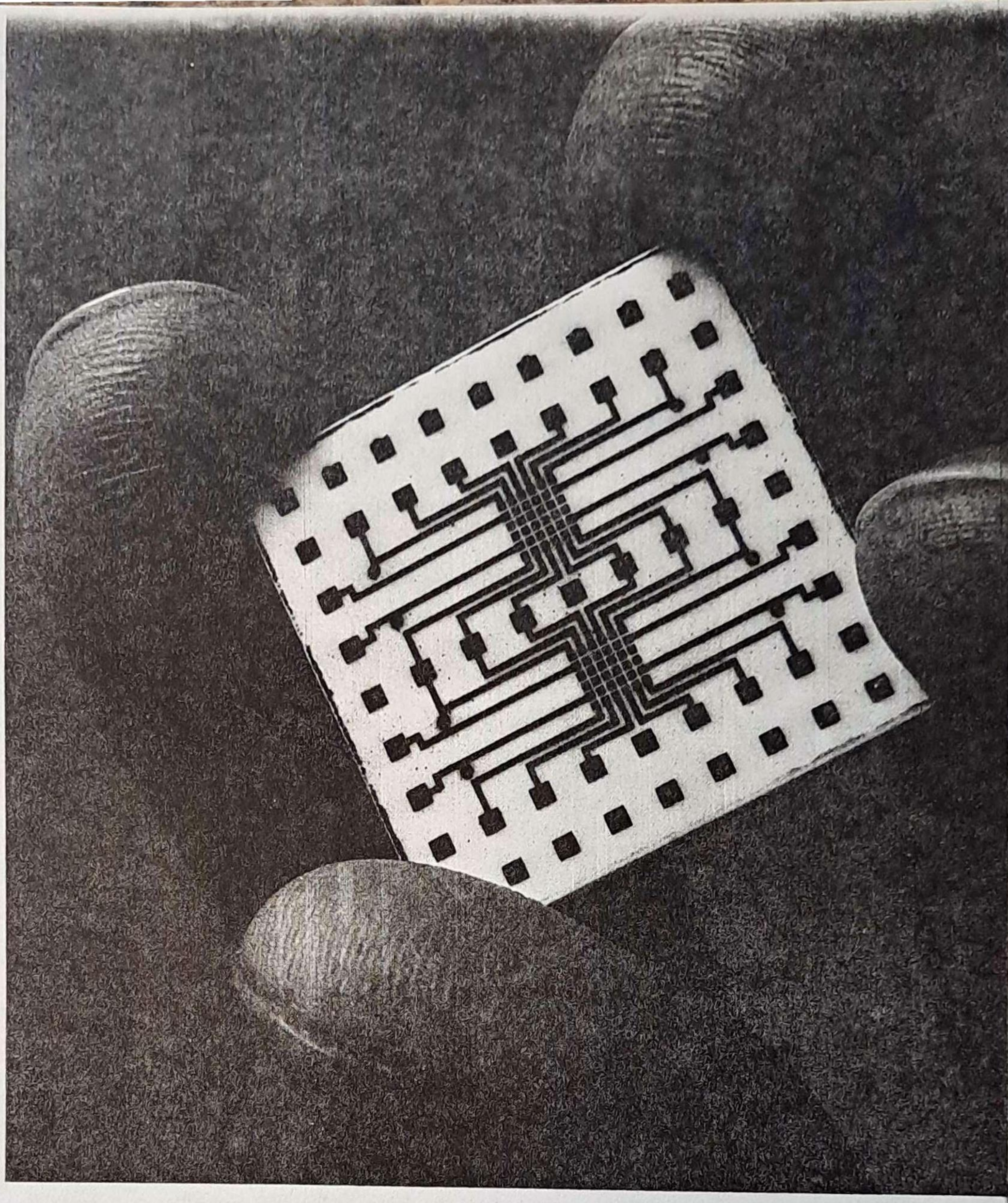
NON-SUPERCONDUCTING

When the material isn't superconducting, electrons move in every direction, colliding randomly with the vibrating atoms of the lattice. This slows them down, saps them of energy, and heats up the lattice (a process called resistance). The crucial difference may be that in the non-superconducting state, some oxygens in the chain disappear from the lattice, while others scatter along the *a* and *b* axes. Whether it's the number of oxygen atoms or their scattered positions that accounts for the chaotic electron flow, scientists are unable to say.

sulator. (The cut-off points are known as the critical temperature, the critical field, and the critical current.) While the new materials have high critical temperatures, they don't rate as well in the other areas. Ekin says that in bulk form, meaning any form other than a thin film, the materials as they're now made begin to lose their ability to carry current in a magnetic field with a strength of 10 to 100 gauss. This poses no insurmountable difficulty if the materials are used in applications in which only small fields are generated, such as transmission lines and computers. But most magnets operate in the 10,000-to-100,000 gauss range. Even in the absence of a field, the bulk materials have low critical current densities, typically about 200 amps per square centimeter. The highest critical current density in any bulk material that had been tested by May at AT&T was 1,000 amps/sq. cm. Says Ekin, "We're still trying to figure out why the figures are so low."

The best bet is that the orientation of the crystals in the bulk materials is responsible. This suspicion grew out of work by scientists at IBM's Thomas J. Watson Research Center in Yorktown Heights, N.Y., who announced in May that they had succeeded in making a thin film of Y-Ba-Cu-O with a critical current density of 100,000 amps/sq. cm. IBM got that high reading from epitaxial films, or those in which most of the crystals have their long axes at right angles to the plane of the film. "This makes you think," says Ekin, "that if all the crystals could be lined up in bulk material, its current-carrying capacity would probably be high too. I think the problem is solvable, because of the IBM results. The question is, how are we going to orient the crystals in bulk?" Any process for doing so is likely to be expensive and delicate, and before engineers can tackle the problem, they'll need to know a great deal more about the basic characteristics of Y-Ba-Cu-O.

Despite all the papers and press conferences, the new superconductors remain mysterious. Y-Ba-Cu-O, it's known, is highly anisotropic—it conducts electricity more easily in one or two directions than in others. This seems to be due to its crystal structure, which is orthorhombic, or, as IBM's Robert Laibowitz says, "long and rectangular like a box of Fig Newtons." It also conducts electricity predominantly in the copper-oxygen regions sandwiched between yttrium and barium layers, both in one-dimensional chains and two-dimensional planes. The yttrium and barium, or any of the elements that have been substituted for them, donate electrons for Cooper pairing but are otherwise far from the superconducting action. Somehow, the copper-oxygen



Brookhaven engineer Thomas Muller wraps protective foil around the end of a superconducting cable. At right, superconducting lines have been etched on ceramic, showing how the new material might be used in integrated circuits.

bond is critical, but no one can say quite why. And, somehow, impurities in the ceramic structure may play a role. At the APS meeting, theorist Philip Anderson of Princeton asked, "What has zero resistance when it's so darn impure? This material is extremely impure and extremely random." Admits Fradin, "We don't understand why these materials work."

Even if basic researchers can unravel the structures sufficiently for engineers to proceed, and engineers can find ways around the inherent shortcomings of the new materials, the basic question remains: Are the recent breakthroughs in superconductivity going to lead, as some have said, to a worldwide technological upheaval that will make the Industrial Revolution look like a failed palace coup?

Take power transmission: Will we ever see the day when losses are cut to zero? "The idea that there can be lossless power transmission is a myth," says Kenneth Klein, director of the DOE's office of energy storage and distribution. Narain Hingorani, vice president and director of the electrical systems division at the Electric Power Research Institute, the electric utility industry's research arm, agrees. "You're always going to have some loss," he says. "There's literally no such thing as zero loss, although there can be practically zero loss."

Transmission losses now run about ten per cent nationwide (not twenty per cent, as has been widely reported), says Klein. About four per cent occurs over long-distance power lines, the other five or six over shorter lines, like those that run from utility poles to houses. But superconducting cables wouldn't be loss-free either, since they would have to be cooled: Brookhaven researchers figured that a niobium-3 tin line would need a refrigeration station every ten miles and the new materials would need about the same. Refrigeration takes power, and power that gets eaten up in cooling counts toward total power losses, just as power lost because of the resistance of copper wire does. Superconducting systems also require transformers, which are the leaky joints in any transmission system.

In the power industry, no one measures the efficiency of a system solely in terms of how much power it loses. Rather, it's measured by weighing capital costs—how much has to be spent to build the system versus the cost of power, including generation and waste. Says Eric Forsyth, chairman of Brookhaven's accelerator development department, "The amount of loss in a system isn't set by the technology but by the operating costs." When utilities try to decide what's most economical, they don't compare conductor to conductor, but system to system.

Even a room-temperature

conductor requiring no refrigeration would involve major expenditures, since power companies would have to replace existing overhead copper cables with new, underground superconducting lines. Consequently, Klein says, the new superconductors are more likely to be used to improve system reliability and stability. Underground superconducting cables would be less susceptible to the vagaries of weather, for instance, and wouldn't generate magnetic fields. They could also carry more power than conventional underground cables in a smaller space: a pipe about eight inches in diameter could carry up to 2,000 megawatts.

In the long run, says Forsyth, "something like a superconducting system will go in, but it's big stuff and bloody expensive. Still, oil will run out, and so will coal eventually. We'll have to do more with less. Slowly, we've got to replace the Victorian-designed world we live in with a new one. I can't believe that in five hundred years we'll still have linemen stringing up things that were designed a hundred years ago." Hingorani, too, is hopeful that the new research will yield technology that will improve power transmission. "But it will take ten years," he says, "before the materials get to the point where they'll be commercially viable, and another ten years before they're integrated into the systems, which are highly complex."

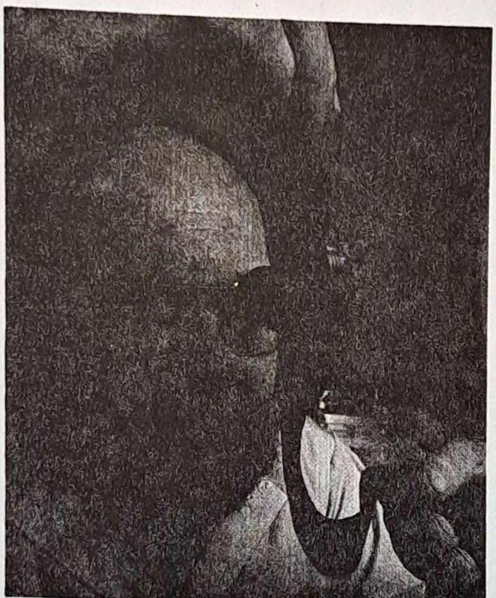
The story is likely to be the same for other large-scale applications as well, from giant coils for power storage to power sources for space vehicles. John Rogers, a group leader at Los Alamos National Laboratory in New Mexico, thinks that "the potential payoff is so tremendous that people will jump on the new superconductors" for power storage. Rogers and others at Los Alamos have studied the feasibility of using the older, lower T_c superconductors in energy storage coils several football fields in diameter and more than 27 yards high for storing energy from power plants during off-peak hours so that it could be tapped at peak times. A 1985 study by Klein's DOE office showed that a coil with a diameter of 1,100 yards could handle the power from a 1,000-megawatt, 5,000 megawatt-hour superconducting magnetic energy storage plant. "If this could be done," says Rogers, "it might save the cost of building new power plants." The new materials would have to have current densities like that of the IBM film, though, and would have to be fairly cheap. "We just have to wait and see whether the engineers can create materials that are reliable," Rogers admits.

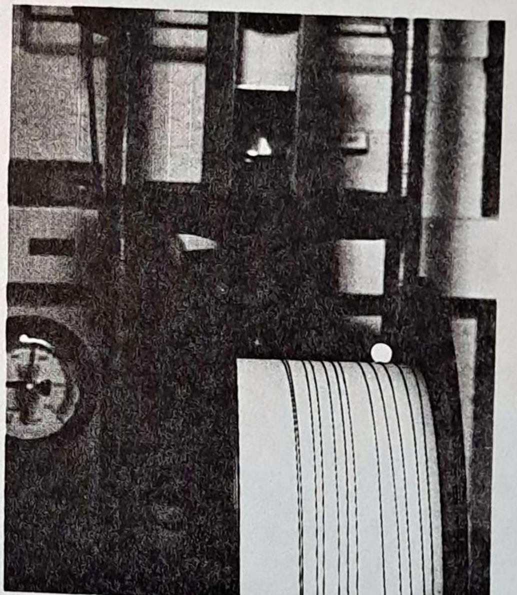
It's still too early for the new superconducting materials to be incorporated into the design of NASA's space station. "All new technologies have to be proven before they find their way into a spacecraft," says Cosmo Baraona, a senior project engineer at NASA Lewis Research Center. Aerospace engineers take this conservative view because their responsibility is to design and build machinery that has the least chance of failing. But, says Baraona, "I've no doubt that some piece of space hardware will take advantage of the high-temperature superconductors in the future—after all, the space station is being built for a thirty-year lifetime, so it could be retrofitted. More likely, these materials will find their way onto something like the laser battle station for SDI, if it's ever built." (Presumably, the SDI office is keeping a close watch on developments, because any space-based directed-energy weapon, or even one on the ground, would draw enormous amounts of energy, and superconducting magnetic energy storage devices would eliminate the need for a constant supply.)

The new superconductors will probably be used in computers and related devices at first, if only because the technology is less demanding. Says Schriesheim, "You have to make a decision about how much effort is warranted in each case. It's technically more feasible to develop the new materials for computer applications and riskier to try wire or bulk development. It now looks as though these thin films are potentially closer to reality than anything else."

Many other scientists agree that applications using thin films, such as computers and SQUIDs (for superconducting quantum interference devices), which are extremely sensitive magnetic field detectors that can be used in everything from detecting brain activity to gravity waves, will come first, although the engineering difficulties are manifold. In testing

Bell Labs' David Johnson examines a "green" (unfired) piece of superconducting tape. At right, a wire is being extruded out of an yttrium barium copper oxide. After it's baked it will become superconducting.

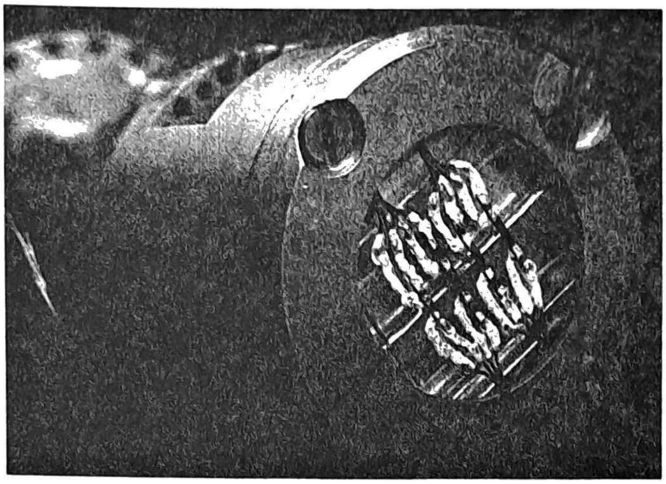




the thin films, IBM patterned some using lithography techniques that are standard in the manufacture of integrated circuits, but the results were less than satisfying. "Where we stand now," says Schriesheim, "is like at the beginning of the transistor or the laser. We can't really foresee how we're going to work out the bugs or what these superconductors might be used for in the future."

With the initial burst of competition for Nobel prizes over, scientists are calling for greater cooperation among labs on basic research. There's still a strong inclination in industrial labs to withhold information having to do with specific devices, but researchers foresee an era of increasing openness that will advance understanding. "As the field is maturing," says Arthur Freeman of Northwestern University, "the scientists are maturing and exchanging information."

When Schriesheim testified before Congress in March, he called on the government to launch a comprehensive program on superconductors that would pull together universities, government labs, and industry. The goal, he says, is "to translate the fruits of basic research into commerce rapidly, to enable the U.S. to be internationally competitive in the field." Neither Schriesheim nor his supporters have clear notions about how to organize such an effort. Something like the Manhattan Project is what they suggest. But the nation isn't at war, and it would be difficult to marshal the drive necessary for such a program. "I don't think we're going to revamp the relationship of government and industry overnight, even if we wanted to—and I'm not conceding that we do," says Donna Fitzpatrick, assistant secretary for conservation and renewable energy at the DOE. "Our position here is that the best we can do at this point is to support research and facilitate the flow of information."



At the National Bureau of Standards superconductors are tested with probes that minimize resistivity at contact points *(top)* and measure currents that tunnel across artificial fissures.

That has been happening. Seven national labs, largely supported by the DOE, have been rapidly shifting money and researchers into superconductors. By mid-summer, Argonne had begun to formulate an overall research strategy, a move prompted in part by the overtures of a number of manufacturers and venture capitalists who want to invest in superconductor projects. In July the White House and the DOE were scheduled to stage a get-acquainted-with-superconductivity conference for industry in Washington, part of a flurry of activity instigated by fears that the Japanese have again outdistanced the U.S.

"Nuclear fusion. Bullet trains. Supercomputers. Cheap power. A superconductor breakthru *[sic]* has hit. If Congress acts now, America keeps the leading edge. If not, Japan may take it," reads a weekly publication of the House Republican Research Committee. Says H. Kent Bowen of MIT, "The bullet train is already out of Tokyo Station! If it reaches Nagoya [the center of Japan's ceramic industry] before the U.S. implements, then we may have lost the race."

On the basic research level, the Japanese don't appear to have the lead. Most of the fundamental advances have been made by Americans, or by researchers in the employ of American companies or universities, and merely duplicated in Japan. But the Japanese government, through MITI, Japan's powerful Ministry of International Trade and Industry, can target areas and direct research in ways that the U.S. is often unable to match. Still, the pace in Chu's lab, for one, has been, by his assessment, "very rapid." In early May his team got signs of superconductivity at 225° K (−54° F), although not with any constancy. The material—Chu wasn't revealing what it was, except to say it's another oxide—is extremely unstable, and, as he told a conference in Berkeley in June, these compounds quickly lose their superconductivity. But when he isolates the superconducting phase of the 225° material, he believes it will be much closer to room temperature superconduction. "In fact," he says, "the onset temperature for the material is *above* room temperature."

Other researchers also claim to have pushed the temperature higher. In June Stanford Ovshinsky and his colleagues at Energy Conversion Devices, Inc. of Troy, Mich., a pioneer in amorphous semiconductors (DISCOVER, November 1984), announced that some regions of their experimental material, a mix of yttrium, barium, copper, fluorine, and oxygen, showed signs of superconductivity at an astonishing 305° K, or 90° F, though other researchers have been unable to replicate these results with similar materials.

Speaking at Drexel University in Philadelphia, Chu was greeted like a rock star. "I believe a material with a very high T_c exists—that's 'believe' like in religion," he told a packed house. "I believe nature has been very kind and given us all these wonderful phenomena to discover. But I don't believe it's so kind as to let us hit everything right the first time." Laibowitz puts it another way. "There's nothing wrong with dreaming," he says, "but now we have to give the engineers a crack." The new superconductors could usher in an age of plenty. Then again, for the time being at least, they could give us plenty of nothing, except dreams. □