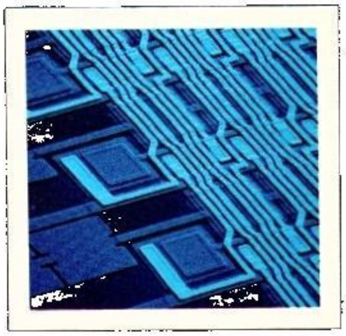
Edison would have loved the new electricity

COLD CURRENTS

BY STEVE AARONSON

When metals are supercooled, they change in almost magical ways. Those changes, already used in a few specialized applications, will soon make most of technology obsolete.



In the near future we may see: a supercomputer in a one-inch cube; trains that ride like surfboards on waves of energy; magnetic bottles strong enough to hold a bit of starfire; wire that can carry all of New York City's electricity in a single cable; guns powerful enough to shoot a satellite into orbit; and instruments that can sense magnetic changes in your brain while you read out of

The supermagnets of Fermilab's particle accelerator were made on the 1,400-ton press shown at left. The small photo above shows a Josephson junction microchip.

PHOTOGRAPHS BY
DAN McCOY

one of your favorite books or magazines.

All these breakthroughs require the ability to squirt electricity through a wire without resistance and without losing any of it, an elusive property called superconductivity. Nature has been dangling it in front of us for more than 70 years, since students of the Dutch scientist Heike Kamerlingh Onnes noticed that a thread of frozen mercury suddenly loses all resistance to electricity when it is cooled to about four degrees above absolute zero (−459°F). Physicists have been trying to explain superconductivity ever since.

Compared to the temperatures at which superconductivity appears, our room-temperature world is a seething caldron. In physics, heat represents disorder: the random collision of atoms. It is this constant chaos that causes mercury in a thermometer to expand and rise in its tube. Without heat, however, the physical world has perfect, harmonious order.

Think of the atoms in a room-temperature metal as defensive linemen in a football game, moving rapidly and bumping into the other players. Then imagine how easy it would be to score a touchdown if the defensive players were frozen in place. All the offensive players could run at top speed into the opposite end zone. Such, more or less, is superconductivity.

It has been 24 years since three scientists at the University of Illinois—John Bardeen, Leon N. Cooper, and John Robert Schrieffer—managed to explain what Onnes and his students had observed. In 1972 they shared a Nobel Prize for their "BCS" theory of superconductivity. A few years later the Soviet physicist A. A. Abrikosov discovered that there are two types of superconductors, one of which can be made into supermagnets far stronger than any that had ever been built. These gargantuan electromagnets are now becoming a standard feature of high-energy particle accelerators.

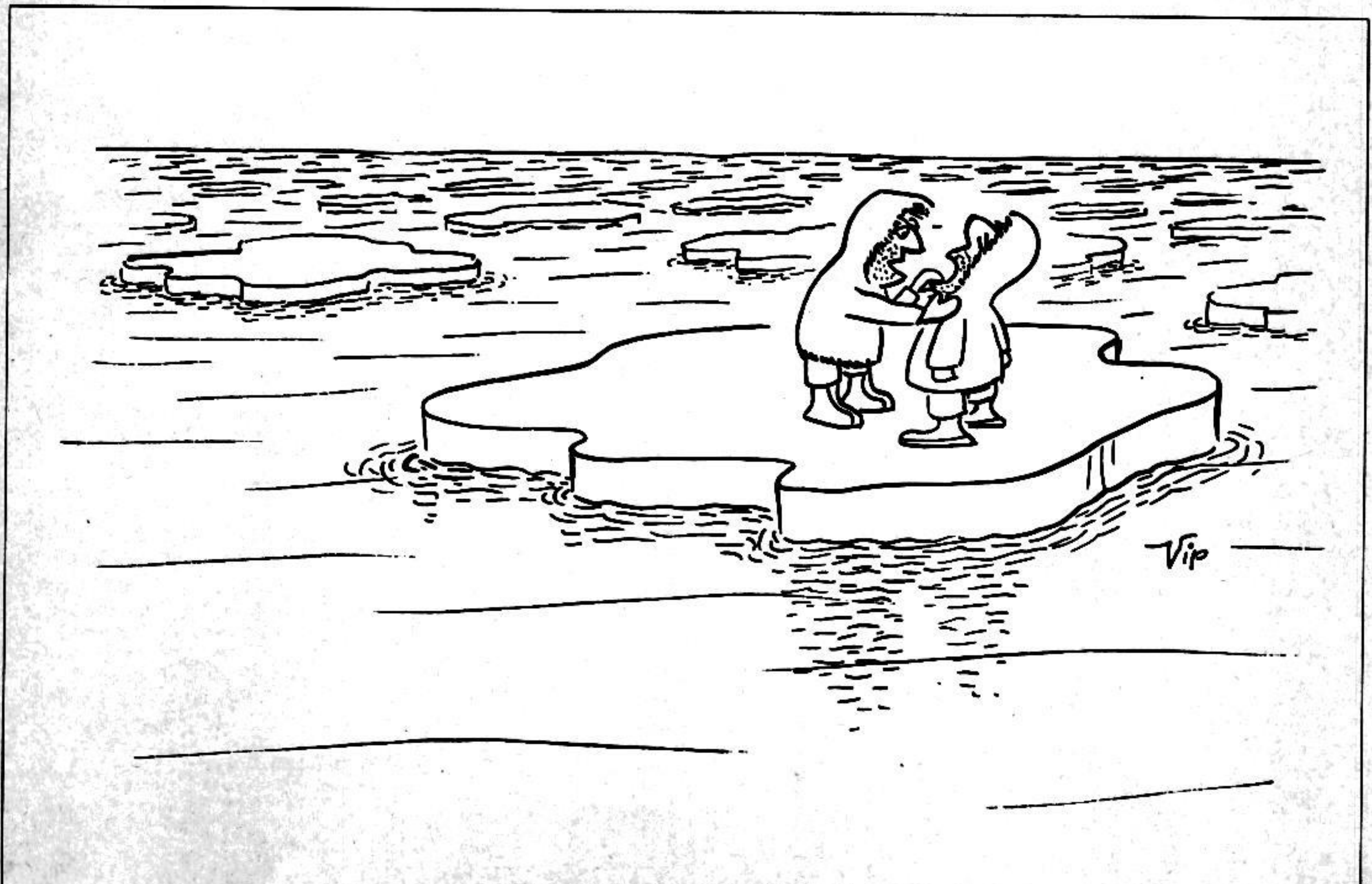
Yet superconductivity still has not found its way into widespread use. The reason is simple: Despite intensive work at laboratories throughout the world, the highest temperature at which any known material becomes a superconductor has risen less than 20 degrees since 1911; it is still only 23 degrees Kelvin.

All superconductors must be chilled continuously in liquid helium. And helium is scarce and very expensive. The best sources of helium are underground gas deposits in the south-central United States. However, when the natural gas is extracted, the helium is usually allowed to escape into the atmosphere. If this waste continues, the natural helium deposits might be exhausted by 1990. The best hope for a replacement source would be the development of fusion-power plants, which would produce pure helium as a by-product.

In the past few years we have begun to see possible solutions to this problem of temperature. We may soon discover materials that become superconductors at room temperature. "At that point," says the Russian physicist V. L. Ginsburg, "ordinary electromagnets with nonsuperconducting coils would almost go out of use." In his view, "the problem of preparing high-temperature superconductors takes second place in its technological importance only to the establishment of thermonuclear [fusion] reactors."

A possible breakthrough came in 1965, when Dr. William A. Little, of Stanford University, in California, suggested that organic molecules might sometimes behave as superconductors. "It occurred to me," he explains, "that if nature wanted to protect the information contained in, say, the genetic code against the ravages of heat and other external influences, the very stable, low-energy state of superconductivity would be well suited for the purpose." His hunch now seems to offer our best hope of creating a practical superconductor.

Room-temperature superconductivity would open "a whole new world of science and technology," Dr. Little believes. "Hovercraft of the future might use it to carry passengers and cargo above roadways of superconducting sheet, moving like flying carpets on magnetic fields, without friction or wear. We might even ride on magnetic skis down superconducting slopes and ski jumps. Many fantastic things would become possible."



"Don't worry; it's just a cold sore."

Large superconducting magnets could propel railroad cars in a worldwide subway system, called Planetran. Such a train could travel from New York City to Los Angeles in about 90 minutes. Each car could carry supermagnets to float it on a magnetic field. A recent Rand Corporation report estimates that Planetran "will use only a few percent as much energy per passenger-mile as an airplane. Coast-to-coast energy costs are less than $1 per passenger." Japan National Railways has already tested a prototype magnetic-levitation train that uses supermagnets to lift the car off the track.

Helium-bathed superconductors are finding their way into specialized uses. IBM, for example, has spent $100 million to develop computers based on a superconducting switch invented 20 years ago by a Cambridge graduate student named Brian Josephson. Because it uses superconducting materials, the Josephson junction is hundreds of times faster than ordinary solid-state circuits, consumes much less power, and can be crammed more tightly onto tiny silicon chips. Computers based on the junctions would be enormously powerful.

The Josephson junction is also used in an instrument that can detect incredibly small magnetic fields: the SQUID (*s*uperconducting *qu*antum *i*nterference *d*evice). Geologists are using SQUIDs to help discover whether the earth has a solid core, and physicists are using them to test Einstein's theory of general relativity. On one of its first regular flights, the space shuttle will carry a SQUID so sensitive that it will be able to detect a snail crawling on the moon. The SQUID will watch for changes in the way an almost perfect sphere of quartz spins on its axis. On a tiny scale, the experiment will duplicate changes in the rotation of Mercury that were predicted by Einstein's theory.

So sensitive a SQUID can easily differentiate the tiny magnetic changes caused by electrical activity in the brain. Soon they may be used to control machines by thought. Researchers at New York University already claim they can tell whether someone's thumb or little finger has been pricked simply by monitoring the brain's magnetic field. Other medical researchers are using SQUIDs to keep watch on the heart's magnetic field. Such work offers a dramatic new chance to identify neurological and cardiac disorders before they become life-threatening.

Doctors are also using powerful electromagnets with coils of superconducting niobium-alloy wire in a process known as nuclear magnetic resonance (NMR) imaging. NMR works by pumping energy into atomic nuclei in the body and measuring their magnetic fields as they return to normal. NMR can view cross sections of the body, like X rays, and also permits three-dimensional mapping. But what NMR produces is not a mere image but a detailed chemical analysis of the tissues. And doctors think NMR is much safer than X rays.

The first NMR scanners used superconducting magnets, though today's models usually do not. Still, "superconductivity will ultimately be indispensable in NMR," according to Dr. Raymond Damadian, of the State University of New York's Downstate Medical Center, who did the first NMR scan of a human patient.

NMR scanners with superconducting magnets might give doctors a quick, simple way to identify cancer, heart disease, pneumonia, and even brain disorders. Such machines might trace the effects of drugs on human tissues and help locate the chemical causes of disease. Hand-held NMR scanners might even allow doctors to check their patients' health routinely in their office.

One of the first commercial applications for large superconducting magnets probably will be to purify water, mineral ores, and foods. In 1962 Dr. Henry H. Kolm and his associates at Massachusetts Institute of Technology devised "high-gradient magnetic separation" (HGMS) to collect iron-meteorite fragments from the bottom of ocean trenches: A supermagnet sifted through tons of sediment and retained the iron particles. Since then the process has been adapted to remove pollution-causing impurities from coal and to refine kaolin, a white clay used to coat glossy paper.

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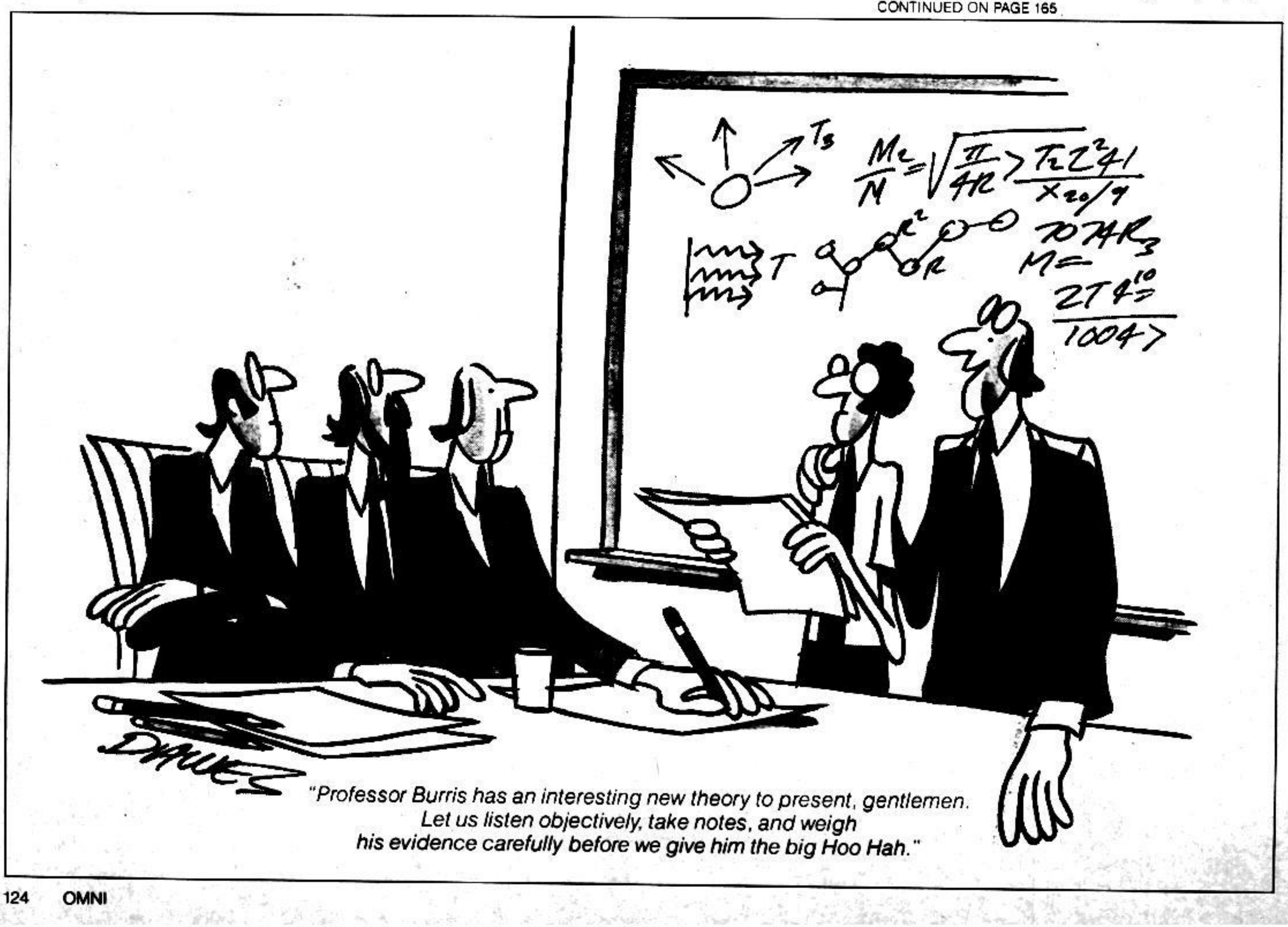

"Professor Burris has an interesting new theory to present, gentlemen. Let us listen objectively, take notes, and weigh his evidence carefully before we give him the big Hoo Hah."

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(The clay accounts for probably half the weight of this magazine.)

The process can also separate nonmagnetic materials that tend to stick to a magnetic "seed" compound. There are many of them. For instance, some polluted rivers and lakes could be purified by seeding the water with iron oxide, to which certain bacteria adhere, and then pumping the water through a barge-mounted magnetic separator.

But the most important use of superconductors will be in generating and distributing power. Fusion generators will rely on them. Peter N. Haubenreich, of the Oak Ridge National Laboratory, in Tennessee, says, "In the sun, gravity holds the reacting mass together. On Earth, the chief hope for practical man-made solar energy depends on the use of strong magnetic fields to effect confinement." Enormous superconducting magnets are the obvious choice for this duty.

They might also help us extract more useful energy from burning coal and oil. Magnetohydrodynamic (MHD) generators produce electric power directly from the burning fuel by passing the hot, conductive combustion gases through a strong magnetic field, much as an ordinary dynamo works by moving a conductive wire through a magnetic field. MHD generators capture about half the energy in the fuel—15 percent more than a dynamo. Again supermagnets might be instrumental in making this technology practical.

And even conventional power plants could benefit from them. Westinghouse is now building the world's first commercia generator using supermagnets. Eugene J Cattabiani, the corporation's executive vice-president, says, "Annual fuel savings for a single large plant of one million kilowatts would be equal to the energy in more than one hundred thousand barrels o oil." Such energy-saving generators could begin to replace present models by the early 1990s.

Superconducting cables might cut the cost of distributing that power. Even a sma one can carry enormous amounts of electricity. A single cable less than two fee across could supply all of New York City' electrical needs. Because of this tremendous capacity, supercables may allow u to locate power plants far from the citie they serve. This would cut the cost of shipping fuel to the plant and might even mak it easier to find sites in rural areas for nuclear generators.

Because of the bulky cooling equipmen and rivers of liquid helium they need supercables must be placed underground Their tunnels will be expensive, but the may have several other uses: Light-wav communications links, freight systems and pipelines for oil, water, gas, and wast disposal could all run through them, an several companies could share the costs.

Supercables become economical only at extremely high power levels—higher, in fact, than we need right now. But if our power use grows as it has for decades, we might need them before the year 2000. And the development of room-temperature superconductors might drastically reduce transmission costs.

Superconducting magnets might help with another long-standing power problem: Most generators are designed to supply power for a hot summer afternoon, with factories and air conditioners running full blast. On a cool autumn evening there is no efficient way to store the extra electricity; most of it is wasted. But superconducting coils can hold current forever. To store power in off-peak periods, stadium-sized coils could simply draw electricity when it is available; the current would flow inside the wire without loss until it was drawn off for use when demand peaked.

There are problems, of course. Very large magnets pack nearly the power of a medium-sized earthquake. To prevent the magnet from tearing itself apart, it must be buried so deep that the bedrock can brace it. As things stand, such enormous magnets would require hundreds of thousands of gallons of liquid helium for cooling, far more than the world's supply.

Yet a prototype storage coil is now being built at the Los Alamos Scientific Laboratory, in New Mexico, and another is being designed at the University of Wisconsin-Madison. Before the year 2000 the descendants of these storage coils will probably enable electric utilities to cut costs, raise their efficiency, and reduce the likelihood of blackouts.

Physicists now are using the world's largest supermagnets to study the basic constituents of matter at higher energies than ever before. They are now designing two particle accelerators with magnetic rings a mile wide. One is to be built at Fermilab, in Batavia, Illinois; the other will be part of the Conseil Européen pour la Recherche Nucléaire, outside Geneva, Switzerland. Each will contain enough superconducting niobium-titanium wire to encircle the equator, and their cooling systems will triple the world's need for liquid helium.

Superconducting guns, called mass drivers, would be quiet, smokeless, safe—and astonishingly powerful. The U.S. Army is now funding the development of a mass driver capable of firing conventional shells, or any other magnetic object, to defend against enemy tanks, missiles, and incoming artillery rounds. Because electromagnets accelerate the projectiles more gently than explosives do, mass drivers might also be used to throw supplies across inaccessible terrain.

Mass drivers may even launch the next generation of space vehicles. Even with the space shuttle, it now costs about $325 to put a pound of payload into orbit, though that may drop to $50 a pound late in this decade. Scientists at MIT believe that very large mass drivers with superconducting magnets might reduce launch costs to about $1 per pound. And launchers on the lunar surface may hurl buckets of ore into orbit for use in constructing space stations. As a first step, Dr. Gerard K. O'Neill is now building a superconducting mass driver at Princeton University, in New Jersey.

An even more spectacular scheme, the Bussard ramjet, devised by California physicist Robert Bussard, would use supermagnets to propel a spaceship to the depths of space. According to Fred R. Fickett, of the National Bureau of Standards, a magnetic "ion scoop," almost a third of a mile wide, would channel space dust and atomic particles from the solar wind into a fusion engine system. A Bussard ramjet might well be our best hope of reaching the stars. Space is so cold that the supermagnets would hardly need to be cooled.

For this reason, supermagnets might also be used in space to shield crews from radiation—or from particle-beam weapons. Military outposts in space could use superconducting storage rings to supply the large pulses of power needed by plasma guns and lasers.

Dr. Little's 15-year-old vision of "flying carpets" and magnetic skis is still only a fantasy, but its prospects for realization are improving. It begins to look as if his theory of room-temperature superconductivity is correct. Just last year Dr. Denis Jérôme, head of a French and Danish scientific team, declared that "superconductivity in organic matter not only exists but has been found." Unfortunately, the material these scientists tested is superconducting only at extremely low temperatures and under high pressures.

But all over the world scientists are working to make practical superconductors a reality. Earlier this year another French team announced that it had probably created an organic superconductor that doesn't require high pressure to function. Soviet scientists are working on a theory of superconducting "exciton mechanisms"; the concept, which involves some kind of communication between electrons, is so new that no one but the physicists who developed it quite understands it yet. And Polish scientists are tracking down what they call "persuasive evidence of the existence of superconductivity at room temperature."

Although a room-temperature superconductor is the ultimate goal, even a partial success would be important. If the critical temperature can be raised by just seven degrees, engineers will be able to cool superconducting cables and magnets with liquid *hydrogen*—much cheaper and more plentiful than liquid helium. Many potential uses for superconductors that are presently pie-in-the-sky would instantly become practical.

One way or the other, a technological revolution is on its way.