Collection:
Green, Max: Files, 1985-1988
Folder Title:
Science
Box: 21

ITEMS OF SPECIAL INTEREST

CURRENT NEWS
SUPPLEMENTAL
SPECIAL EDITION

SUPERCONDUCTORS

SUPERCHALLENGE
THE RACE TO EXPLOIT SUPERCONDUCTORS

WASHINGTON POST 17 MAY 1987 Pg. 1

Discoveries Spur Showdown Of Technological Titans

Will Japan Reach the Marketplace First?

By Michael Specter
Washington Post Staff Writer

For months, Bertram Batlogg's life has been one part adrenalin and two parts obsession. A physicist at AT&T Bell Laboratories, he has struggled frantically to comprehend the smallest subatomic workings of a material that may one day transform modern life.

Batlogg has become a haggard monk, devoted to the limitless potential of high-temperature superconductors. His cluttered lab is strewn with discarded wafer boxes—plastic coffins for materials that don't work. He has tried hundreds of ways to unlock the secrets of these new substances. And he is not alone.

Since last year, when two

CHALLENGE...Pg. 2

CHEMICAL & ENGINEERING NEWS
1 MAY 1987 Pg. 18

Superconducting SQUID works at 81 K

The first superconducting electronic device that operates above the temperature of liquid nitrogen (77 K) has been made at the NBS laboratories in Boulder, Colo. The NBS device is a high-temperature version of the superconducting quantum interference device, or SQUID, which can measure magnetic fields with exquisite sensitivity. It operates at 81 K. The SQUID, which uses yttrium-barium-copper oxide superconductive material, was fashioned by physicist James E. Zimmerman and coworkers Ronald Ono

SQUID...Pg. 2

DEFENSE WEEK 18 MAY 1987 Pg. 7

Changing The Face Of Defense

BY DAVID J. LYNCH

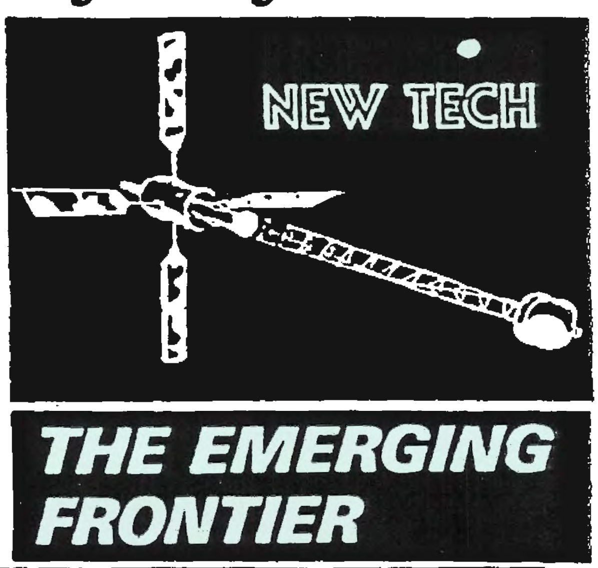
A series of stunning scientific breakthroughs over the past five months has landed researchers on the threshold of widespread use of superconducting materials in everyday life and opened the door to futuristic weapons with incredible capabilities.

The latest advance was announced May 11 by a team of IBM researchers in New York. IBM's scientists said they had demonstrated a ceramic superconductor able to carry 100 times more electric current than had previously been thought possible.

IBM's discovery was a giant step toward eliminating one of the major hurdles preventing practical applications of superconductors—limits on the level of current carried. Despite the progress, key questions remain, including at what temperature the materials will perform and whether they are durable enough to be used in manufacturing.

Superconductors are so named because electricity travels through them without meeting any resistance. As a consequence, the new materials are much more efficient than conventional means of carrying current. Scientists expect superconductors to lead to entirely new ways of generating and storing power, smaller and faster operating advanced computers and a host of

DEFENSE...Pg. 2



Herbert J. Coleman, Chief, Current News Analysis & Research Service
(SAF/AA) 695-2884

DEFENSE...CONTINUED

other developments which can now only be guessed at.

"If we can translate the laboratory findings into industrial products, it will revolutionize everything," said Kosta Tsipis, of the Massachusetts Institute of Technology.

To no one's surprise, the military is also keenly interested in the new technology. Officials at the Defense Advanced Research Projects Agency (DARPA) plan to set aside $10 million over the next three years to investigate ways to process and fabricate the new ceramic superconductors for use in weapons of the future.

The Office of Naval Research will carry out the DARPA-funded research. ONR's Robert Pohanka said he expects to receive research proposals from scientists this month. The final ONR program blueprint could be ready by July, he said.

Pohanka said IBM's most recent breakthrough has given new impetus to the Pentagon's research. "It's a tremendous advance...It makes applications much more feasible," he told *Defense Week*. Pohanka said he was enthusiastic about potential military uses of the new devices. Many of the specific applications are highly classified, he said, but possible uses include more sensitive space sensors, high speed compact computers, and electromagnetic guns.

As research breakthroughs have mounted in recent months, Air Force officials pumped an extra $1 million into a separate superconductor research program run by the Air Force Office of Scientific Research. That program, headed by Harold Weinstock, now has an annual budget of roughly $3 million.

Superconductors are also being eyed eagerly by backers of the Strategic Defense Initiative. "There's a very good possibility they will make the Star Wars initiative much more practical," said Milton Copulos of the Heritage Foundation. Superconductors could provide the cheap, efficient surge power needed for rapid fire ground-based battle lasers, Copulos said.

The SDI Organization's innovative science and technology office, together with the Rome Air Development Center at Hanscom air base in New York, has allocated $1.5 million to see if superconductors can be used to develop better infrared detectors for space-based defense, Weinstock said. SDIO is expected to increase spending on its superconductor research any day, he added.

According to some scientists, space may be the most promising area of near term superconductor applications. The reason is temperature, the key variable with the new materials. Until recently, superconductors have required extreme cooling with expensive liquid helium. That charactertistic alone ruled out widespread use. But in recent months, proceeding at virtually breakneck speed, scientists improved the materials so that they required the much less expensive liquid nitrogen. At that level, the materials could operate easily in the chilly reaches of space.

Looking ahead, there also have been reports of materials requiring only as much cooling as that provided by average household freezer. Some scientists said that, by the end of the century, superconductors will operate at room temperature.

While defense officials are confident that superconductors have the potential to revolutionize warfare, a number of tough technical hurdles remain. "People don't yet fully understand the physics of the materials that have been shown to operate at very high temperatures," said Robert Cooper, the former head of DARPA. Cooper said, for example, it is unclear how the ceramic superconductors can be used in manufacturing.

Eric Leiber, of the American Chemical Society, agreed. "We need a better understanding of the theory...this is black magic days. It's a total mystery."

One of the more highly touted uses for superconductors has been in electromagnetic guns. But the ceramic material may not be up to the job, according to John Pike, of the Federation of American Scientists. Pike said the ceramic substance would undergo considerable stress from the magnetic field created within the railgun. "It's far from clear this stuff will ever work," he said.

Others are more sanguine. "Once you know it's possible, it's a very small step to doing it. The fundamental breakthrough has occurred," said Copulos. Added IBM spokesman Gerald Present: "Nature's not standing in our way. It's just our cleverness in fabricating the material."

ONR's Pohanka said the brittleness of ceramics probably can be overcome.

CHALLENGE...CONTINUED

IBM physicists discovered ceramics that could carry electric current without energy-wasting resistance at higher temperatures than thought possible, thousands of scientists—in the United States and elsewhere—have virtually lived in their labs.

Advances have been so rapid that scholarly journals, the normal route of scientific communication, have been left in the dust. Iowa State University has established an on-line computer newsletter to keep scientists in the field up to the minute. Breathless phone calls carry rumors across the country, and meetings of obscure physics societies have attained the status of rock concerts.

The excitement is so widely shared because a practical, high-temperature superconductor could revolutionize almost all uses of electricity. If practical, superconductors also will become the basis for a gargantuan struggle, first between the United States and Japan, over ways to exploit the new invention. Nobel Prizes seem certain for some researchers. Huge profits are likely for more. And a significant advantage in global economic competitiveness awaits the country that masters the field first.

Almost every use of electricity suffers from resistance—an unavoidable phenomenon inside conventional wires and other conductors that turns part of any flow of electrical energy into useless heat. Superconductors eliminate all waste, making old uses of electricity more efficient and offering new uses that were impractical or impossible with ordinary conductors.

The pace of discovery has been exhilarating. But for American scientists involved, success has been tempered by deep frustration. Having led the way in the dramatic race to understand the new materials, most of them wonder whether the

CONTINUED NEXT PAGE

SQUID...CONTINUED

and James Beall. Several weeks ago, IBM announced a SQUID made of similar materials that operates at 68 K (C&EN, May 11, page 7). Previously, such devices were made from metallic materials that became superconductive—and hence useful—only at temperatures near absolute zero. The new high-temperature SQUID makes applications, such as the measurement of electrical signals in the brain, more convenient and cheaper.

CHALLENGE...CONTINUED

United States will be the first to bring its inventions to market.

"For American science there has never been a better time," said Batlogg, sifting through stacks of phone messages from colleagues reporting advances. "It's thrilling. But I suspect the first products will be from Japan. Whenever individual efforts count, we have been leaders. Yet, when it comes time to turn ideas into products, we are lost."

To illustrate his concern, Batlogg waved a recent special issue of the Japanese Journal of Applied Physics, a glossy book packed with new research. American physicists were astonished last month when their Japanese counterparts handed out 1,000 of the volumes free at a conference in California.

"They managed to put this together almost before we published a word," he said, smiling wanly. "We all wonder, will the Japanese do it again?"

The fears are not without foundation. After inventing many of the marvels of modern technology, including the videocassette player, the color television and the computer chip, American companies watched helplessly as industry from other countries shoved them out of the markets they created.

After years of seeing foreign competitors capitalize on Yankee ingenuity, many U.S. scientists regard the effort to develop high-temperature superconductors as a final chance for the United States to reclaim technological supremacy.

"Scientists see this as the last industrial moment," said Frank Y. Fradin, a physicist at the Argonne National Laboratory near Chicago. "We need to grab it and hold on tight. If we don't pursue this one, we have to wonder what America wants to pursue. I mean, how many times do we have to get kicked in the teeth?"

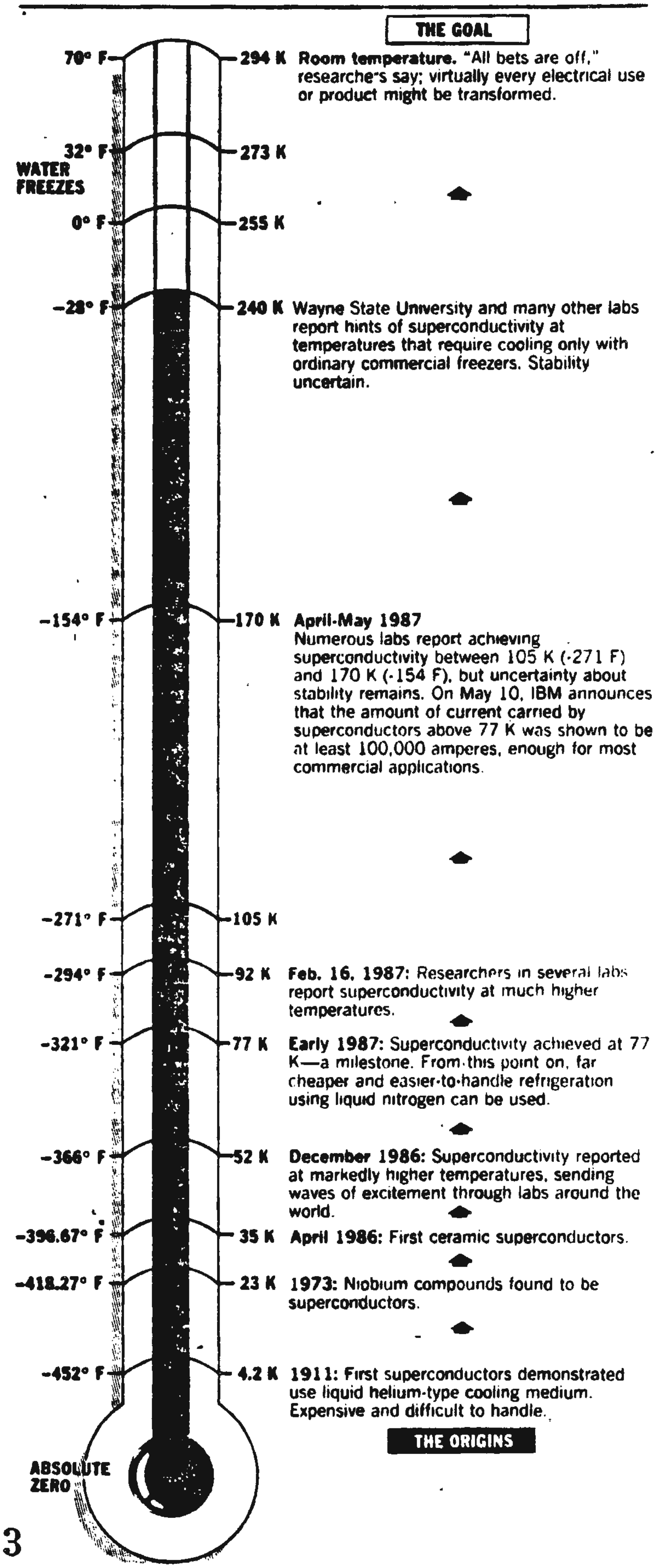
He would not be asking the question if the stakes were not so high. The new ceramic superconductors that many feel will one day carry electrical current at room temperature could open a world of tiny, super-fast computers, high-speed trains that cruise on a cushion of magnetism, efficient electric automobiles and long-distance power lines that waste no electricity.

The new materials hold the

CONTINUED NEXT PAGE

THE WARMING TREND

ACHIEVING SUPERCONDUCTIVITY AT EVER-INCREASING TEMPERATURES



CHALLENGE...CONTINUED

promise of transforming everything that runs on electric motors, from hair dryers to power plants. The day when any of that will be possible is still far off, but until last year it was only science fiction. Now, in the fierce drive to fashion the new ceramic compounds into wires, tapes and thin films that can carry electricity, the reality edges closer each day.

Government officials and company leaders are excited, but many hedge their optimism. With eyes transfixed by the bottom line, corporate America has resisted the urge to join the battle with all its might.

All parties, however, are aware that U.S. companies will be forced to compete not only among themselves but with an unfettered consortium from Japan that has marked superconductor production as a national goal.

The call has gone out for the creation of a "Copper Oxide Valley" based on key elements of the new materials, to rival California's Silicon Valley.

"We are all beginning to realize that as much fun as it is to invent something, it does no good if Japan makes it," said John J.M. Rowell, head of solid state science for Bellcore, the research arm of the seven regional Bell operating companies.

"If AT&T—which invented the laser—has to go to Hitachi to buy them," he continued, "there is clearly something wrong."

For many in the bedraggled army of physicists, chemists, ceramists and materials experts at university, government and industrial labs across the country, the feverish work rate has left little time for fear or failure.

The obsession has turned physics labs into volunteer fire stations, with punch-drunk scientists spelling each other when overcome with fatigue. Families have been forsaken, other projects forgotten.

"We are probably eating more fast food right now than any other work force in America," said Lowell Wenger, professor of physics at Wayne State University.

At IBM's expansive research facility in Yorktown Heights, N.Y., showers once reserved for scientists completing leisurely jogs are now used mostly to revive the weary.

Clothed in ripped cardigans and tattered jeans, even senior researchers look like perpetual graduate students. The endless hours have given many the appearance of raccoons, with deep rings surrounding their eyes.

The race began in a much more leisurely fashion last year.

The first to notice that a new compound of barium, lanthanum, copper and oxygen was superconducting at 30 Kelvin—or 30 degrees Celsius above absolute zero (minus-459 degrees Fahrenheit)—were J. Georg Bednorz and K. Alex Mueller of the IBM Research Lab in Zurich in April 1986.

Although incredibly cold, that temperature was much higher than any previously recorded for materials that act as superconductors, suggesting the phenomenon could have common applications.

The international physics community took almost a year to pick up and improve on the brittle new compound, in part because people could not believe what was happening.

"It was such a radical change that I couldn't accept it at first," said Paul C.W. Chu, a superconductivity expert at the University of Houston, whose lab produced a compound in February that became superconducting at 98 Kelvin (minus-253 Fahrenheit). "That's when the insanity began."

By March 18, when more than 1,000 people packed into a ballroom of a New York hotel for a hastily scheduled all-night session on the new materials, the mania had taken root.

"It was a bizarre cult scene," said one participant. "It reminded me of the ultimate 'Star Trek' convention."

Scientists are pushing the limit on every level. Theorists are trying to determine how the new materials let electrons race through them undisturbed by normal resistance. Chemists and materials experts, have turned back to their bible—the Periodic Table of Elements—trying in thousands of ways to concoct superconductors that work at ever higher temperatures.

And with a mind toward practical applications, dozens of labs are working on wires and films thin enough to deposit on computer chips.

Despite the frantic excitement of the scientists, the labs where much of the work occurs are immaculate and shrouded in silence.

At IBM, raw materials are stored and protected against the air in a white antiseptic "clean room." Nearby, 18 huge vacuum systems—sporting spit-shined gaskets and flashing computer monitors—stand ready to help convert bulk materials to films so thin that a stack of thousands could hardly be noticed by the human eye.

Until last week the two biggest questions about the new materials were: Could they work within the economical and practical reaches of room temperature, and can they carry enough electrical power to be useful?

The second problem seemed the toughest until IBM stunned scientists by announcing last Sunday that it had increased carrying capacity—the ability of the materials to carry electrical current—100 times, to 100,000 amperes per square centimeter. That is the difference between enough power to excite scientists and enough to help run computers and trains.

The elements in the new superconducting compounds—mostly yttrium, barium, copper and oxygen—are easy to find and cheap enough for most labs to purchase. The liquid nitrogen used to cool the substances is cheaper by far than beer, and has replaced coffee as the most common fluid in many American labs. By comparison, the liquid helium used until now to cool conventional superconductors is rare, expensive and difficult to handle.

The elements—powders stored in special "dry boxes"—come in plastic buckets. To make the bulk materials, chemists working with mortar and pestle simply grind the powders by hand into pellets and bake them for hours at extremely high temperatures. The ovens are called arc furnaces, and the process is so simple it can be duplicated in most labs.

From there, however, the process becomes more difficult. It is essential to pull useful wires, usually by drawing a slender copper tube and pouring the material inside. Chemists take minute amounts of the newly baked ceramic crystal and cram it—often using microscopes as if they were doctors in delicate surgery—into the sheaths.

CONTINUED NEXT PAGE

WASHINGTON POST 18 MAY 1987 Pg. 1

A Current of Change for Motors, Computers

By Boyce Rensberger
Washington Post Staff Writer

Not since the days of Thomas Edison a century ago have the possible uses of electricity held such promise as is offered today by the scientists of superconductivity.

Imagine a train floating on a cushion of magnetic force as it hurtles almost frictionlessly across the country as fast as a plane.

Imagine supercomputers several times faster and more powerful than today's biggest, but much smaller and cheaper.

Imagine everything that runs on electric motors, from ships and subways to refrigerators and wheelchairs, being powered by motors half the size, half the weight, half the cost and using half the current of today's versions.

Imagine a device that can read signals shuttling among individual

SUPERCHALLENGE

THE RACE TO EXPLOIT SUPERCONDUCTORS

brain cells, or more powerful atom smashers, or fusion reactors that generate power from virtually inexhaustible fuels, or practical electric cars, or many other highly specialized machines and instruments valuable to scientists, engineers and manufacturers.

Imagining such things has become an almost daily preoccupation of many participating in or witnessing the current explosion of advances in the development of new superconductors—materials that conduct electricity without resistance, without waste—in the form of heat—and the deleterious side effects inherent in all ordinary conductors.

Freed of the resistance inherent in all ordinary conductors, electricity becomes what might be called superelectricity, a form of energy that can do many old jobs better and cheaper and many new jobs that are impossible with ordinary electricity.

The key to superelectricity is the kind of wire it is sent through. Hook an ordinary copper wire to an or-

CONTINUED NEXT PAGE

CHALLENGE...CONTINUED

"At this point the whole process is an awful lot like making a cake," said Roger Koch, one of the IBM physicists who worked on developing the powerful new films. "You play around with the recipe until you find something you like. If it fails, you try something else."

Serendipity, genius and intuition have combined to produce a string of remarkable achievements, including discovery of the bulk materials, fabrication of wires and most recently, the growth of pure crystals.

"I never thought I would live to shout 'Eureka,'" said William J. Gallagher, an IBM physicist whose team made the first pure crystal of the new materials by accident.

"It was April Fools' Day and we were heating the stuff up, trying to make a film," he said. "When we got it out and looked at it, we were shocked."

"We pulled the stuff out of the furnace and put it under the microscope," said Bob Sandstrom, a member of the team. "What we saw had no flaws; it was perfect," he said.

Most scientists say that perfectly pure crystals are essential for further progress. When superconducting elements fuse with tiny grains of other material, their power is greatly diminished.

The crystal they made was smaller than the period at the end of this sentence. But the team was successful in making other samples, which will aid their colleagues in trying to determine exactly how these oxides become superconductors when cooled by liquid nitrogen.

Following the pattern that has emerged since the materials were first discovered, physicists jumped to the phones, and within hours the field was aware of the latest breakthrough.

Different laboratories are trying to break the new materials down to the smallest possible levels to understand them. Scientists feel that a better knowledge of the most fundamental properties of the new compounds will help improve them.

At Bell Labs, scientists are taking the smallest grains of the mixture and attempting to bond them to other materials. Then, using electronic probes smaller than a bee's stinger, they attempt to see what materials work well together.

Every time they make a new sample, the Bell researchers wire it to a voltage meter and plunk it in a cup of liquid nitrogen. If the resistance drops to zero on the digital meter, they proceed to slice it into little bits to explore its inner workings.

"We are working seven days a week, trying every way to make it better, different and stronger," said M. Brian Maple, professor of physics at the University of California at San Diego. Tediously plodding through the periodic table of elements, substituting neighbors of the elements that now work, Maple and others are trying to find a way to push the temperatures higher.

Higher temperatures are the key to widespread economical use. Although liquid nitrogen, which boils at 77 Kelvin (minus-320 Fahrenheit) will immediately be useful for several applications, including medical diagnostic machines and cooling some huge supercomputers, the true prize will go to those who can develop superconductors that work at room temperature.

Because the research is relatively simple and the potential payoff so great, hundreds of scientists will likely remain tethered to their labs for some time to come.

"How can you walk away from a brilliant little baby?" asked Robert A. Laudise, director of physical and inorganic chemistry research at Bell Labs. "We need to make it grow. Will the U.S. be the first to exploit the new superconductors? I think we have learned some lessons, I really do. I can tell you one thing. If we even stop to catch our breath, the Japanese will make us regret it. And we have had plenty of regrets in the past."

NEXT: Superelectricity

CHANGE...CONTINUED

dinary battery or generator and you get ordinary electricity with all its disadvantages. Hook one of the new superconducting materials up to the same source of ordinary electricity and what flows through the material is superelectricity.

The difference is that the atoms of the superconducting material are linked into an array that organizes the electricity—a flow of individual subatomic particles called electrons—into a coherent form of paired, or yoked, electrons that can travel inside the material without the usual resistance that steals energy and turns it into heat.

Superconduction has been known since 1911, but until recently it only occurred if the conducting material was chilled almost to "absolute zero," 460 degrees below zero Fahrenheit. At or near that temperature, any metal becomes a superconductor. In recent months, however, scientists have found a new class of materials, special kinds of ceramics, that become superconductors at much higher temperatures, such as a mere 280 below zero.

While still chilly, this temperature is far easier and cheaper to achieve and makes it reasonable to think of uses that would have been impractical with the old superconductors. So successful have researchers been in finding materials that become superconductors at warmer and warmer temperatures that some even dare to imagine they may find a room-temperature superconductor, needing no refrigeration to achieve its wonders.

If that should happen, most researchers agree, the range of applications would be almost unlimited and the world might witness a revolution comparable to that wrought by ordinary electricity in the 19th century.

One prominent exception would be Edison's electric light. Without the resistance that produces the heat to make the bulb's filament glow white hot—the very thing superconductors eliminate—light bulbs wouldn't work.

"This has been the most exciting time. I've never seen anything like it," said Philip W. Anderson, Princeton Nobel laureate and leading authority on superconductivity phenomena and theory. "Three months ago, I would have said all this talk about applications was overblown. Not any more. It isn't going to happen right away, but I can see some new things coming."

Anderson said he foresees the development of a new kind of brain analyzer, far superior to the electroencephalogram (EEG), which could follow the paths of nerve signals inside the human brain harmlessly and possibly help study and diagnose a variety of mental disorders.

It could work because nerve impulses are tiny electrical currents that, like all currents, produce a magnetic field in the space around them. One of the devices that scientists already have made from old superconductors is an extremely sensitive magnetism detector. Such devices can be made microscopic in size and arrayed in large numbers over a person's head to pick up evidence of nerve conduction that a computer could construct into a detailed picture of mental activity.

Similar detectors, made of the old metallic superconductors, already are used in today's nuclear magnetic resonance imaging machines, but cheaper superconductors should reduce the currently high cost of these devices.

Perhaps the simplest application of superconductivity to envision is energy storage:

Imagine a ring of superconducting wire. Feed an electrical current into the ring. Disconnect the power source. Superelectricity will continue to flow around and around the ring indefinitely. Experiments with metallic superconductors showed the current would persist, chasing its tail around the ring at the speed of light, for at least 100,000 years. In an ordinary wire, the current would die away, consumed by resistance, in less than a second. Connect wires to the superconducting ring and the stored electricity will flow out again, ready for use.

A giant version of such a device, using the older, colder and costlier superconductors, already is in use in Tacoma, Wash., where it levels out fluctuations in a conventional electrical power line by taking in up to five megawatts during peaks of supply and releasing the energy when the supply dips.

Because the Tacoma device uses the older superconductors, it must rely on expensive liquid helium to chill the coils to 452 (4.2 Kelvin) degrees below zero Fahrenheit. Because ceramic superconductors work when chilled with relatively cheap liquid nitrogen, the use of such energy storage systems may spread, cutting the need to build new power plants as long as existing ones can charge up superconducting coils at night to help meet the daytime power demand.

A more glamorous use, already developed in prototype, is the magnetically levitated train, or maglev. Experimental maglevs, some running at more than 300 mph, have been tested in Japan, Britain, France and West Germany. They use electromagnetism two ways—first to lift the train off the ground, and then to push it forward. Superconductivity is not essential to the concept, but its increased efficiency—making more magnetism for a given amount of electricity than conventional electromagnetism—makes the idea more practical.

Magnetic levitation is a phenomenon any child can demonstrate with toy bar magnets lined up to repel one another. Orient the magnets vertically in a channel to keep the top one from sliding off and you have a maglev device.

To lift an entire train, all you need is more powerful magnets. Wind an electric wire around an iron bar, put a current through the wire and the flow of electricity induces electromagnetism in the iron. Superconducting wire would make the magnet even more powerful for the same amount of electricity.

To lift a train, mount big enough electromagnets in the floor of each car and lay a slab of superconducting material in the roadbed. One of the properties of superconductors is that they automatically repel magnetism. The magnetism coming out of the train floor is reflected back up as a repelling force.

To propel the train, you need a series of electromagnets in the roadbed or at the sides of the channel in which the train runs and a similar series built into each car. The magnets are switched on and off and their poles reversed in just the right time to exert simultaneous pushes and pulls, both in the same direction, on

CONTINUED NEXT PAGE

WASHINGTON POST 18 MAY 1987 Pg. 10

How Does Superconductivity Work?

Theories Don't Fully Explain Why Electrons Pair Off

By Boyce Rensberger
Washington Post Staff Writer

To put it briefly, nobody knows for sure how superconductivity works. A theory put forth 30 years ago when the phenomenon was hardly more than a laboratory curiosity may explain the old metallic superconductors but, experts now say, it does not explain the new ceramic superconductors. Still, the phenomenon is not entirely a mystery.

To understand superconductivity, one must first understand old-fashioned ordinary conductivity. In simple terms, electricity is the flow of electrons, the subatomic particles that carry electrical charge, through the spaces between atoms of a conductor.

In ordinary conductors, the electrons move as individuals; in superconductors they move as linked pairs. The pairing, all theories agree, is what allows the electrons to travel without encountering the resistance that traps lone electrons and converts their energy into wasteful heat.

Some experts explain the pair advantage by analogy with people walking. Somebody walking alone may stumble and fall, but if that person is holding hands with a second person, the link makes each more stable and able to keep walking.

In real conductors, resistance comes from

CONTINUED NEXT PAGE

CHANGE...CONTINUED

the train. As a wave of magnetism moves down the roadbed, switched on and off like the lights on a movie marquee, the train becomes a magnetic surfer.

Superconducting electromagnets also are being eyed for use in nuclear fusion reactors. The problem is to confine a controlled fusion reaction without physically touching the subatomic particles being fused. The "magnetic bottle," a powerful magnetic field of a certain shape, is one answer, and superconducting electromagnets promise the most efficient way of achieving this.

Many scientists say such large-scale applications probably are far off, but they suggest that smaller-scale uses—as in generators and electric motors for a variety of uses—probably will come sooner. Both devices contain electromagnets and the strength of the magnet affects the output of the device. Some electrical engineers estimate that for any given use, a superconducting electric motor probably would be half the size of today's versions.

Coming even sooner could be superconducting supercomputers. John M. Rowell, a solid-state physicist with Bellcore, the research arm of the seven regional Bell operating companies, sees this as the first major application of ceramic superconductors outside the laboratory.

Superelectricity offers a solution to the chief problems of today's biggest computers. Thousands of microscopic transistors and other components are now so tightly packed on chips that, even at the light currents that flow in them, heat buildup from electrical resistance is a serious problem, threatening to damage the chip material.

Computer engineers would like to pack components even tighter because the speed of computers is now limited by the inability of electricity to travel faster than the speed of light. There is a measurable delay in a computer doing millions of operations per second as the machine must idle while an electrical impulse travels even a fraction of an inch. Tighter packing, however, would make the heat problem intolerable.

Heatless superconductivity is the answer.

According to Rowell, that answer is likely to come in three steps. The first will be superconducting wires simply to connect one chip to the next. Eliminating this source of heat will let designers put chips closer together. The second will be supercomputing wires within a chip, allowing still closer packing.

The third step could be a revolution in computer technology comparable to the introduction of semiconductors—the elimination of semiconductors and the advent of the Josephson computer.

"This would be a completely different kind of computer," Rowell said, "something people could only dream about for a long time."

The Josephson effect, predicted in 1962 by Brian D. Josephson and confirmed experimentally by Rowell and Anderson, is a phenomenon that occurs where two superconductors are separated by a very thin insulator.

When the currents are right, the electron pairs of superelectricity will "tunnel" through the insulator, forming a weak supercurrent across the gap. By manipulating the currents on either side of this "Josephson junction," such a device can be made to do everything semiconducting transistors do—much faster and without making heat. Josephson junctions are the fastest switch known and switching is another thing that slows down computers.

Japanese computer scientists already have constructed all the necessary components for a Josephson computer using the old metallic superconductors, but they have not yet tested large-scale integration of the components onto a single chip.

"Not many of us thought the future was going to come this fast," said Brian Schwartz, a superconductivity specialist at the National Magnet Laboratory. "Some of us would have said, not too long ago, that superconductivity wasn't much more than a laboratory curiosity. You won't find many saying that now."

NEXT: From lab to market

WASHINGTON POST 19 MAY 1987 Pg. 1

A Cautious Eye on the Bottom Line

By Philip J. Hilts
Washington Post Staff Writer

John Hulm is caught between the bottom line and the future. The director of corporate research and planning at Westinghouse, he knows a great deal about superconductors and the possibilities they offer. But he is also a prudent corporate manager who isn't yet sure that anything profitable can soon be made with this still-emerging technology.

"I have never seen the country so hysterical about a new technology," Hulm said in an interview. "It's puzzling and a little dangerous. We are creating expectations that may not be realized."

Those expectations are huge. Superconductors—materials that allow a resistance-free flow of electricity—could change the way we live. Ultimately they may alter every product that now uses electricity, and create many that don't exist. Already, scientists talk of using them to make table-top computers more powerful than today's biggest machines, magnets and wires that would allow for the loss-free storage and transmission of electric current, and new types of compact, high-powered electric motors. Obviously, if any of these dreams are plausible, there are huge profits to be made.

"I am in the position of being one of the few voices

SUPERCHALLENGE

THE RACE TO EXPLOIT SUPERCONDUCTORS

speaking caution when others are rushing ahead," said Hulm, 64. "I have been accused of being too old, set in my ways, unable to see this for what it is."

In fact, he is one of the country's leading researchers in the field. He marvels at the enthusiasm of American scientists who are pushing this new technology for-

CONTINUED NEXT PAGE

SUPERCONDUCTIVITY...CONTINUED

impurities in the material that trap wayward electrons and the natural vibrating motion of atoms that may bring them into the path of an electron zipping through.

Electrons are fundamental particles that orbit the nuclei of atoms. Because electrons have negative charges, most remain tightly bound to the positively charged nucleus.

If the nucleus has enough positive charges to hold all its electrons, the material is an insulator. If some electrons are so weakly held that they easily come loose and can travel through the material, it is a conductor.

This much is agreed. The controversy is about the mechanism that creates electron pairs. Having like charges that repel one another, electrons form pairs not by sticking together but by remaining at a distance while linked by what physicists concede are the strange phenomena of quantum mechanics. An "exchange force" binds the electrons so that each "knows" what the other is doing and the pair behave as if physically bound.

Also agreed is the idea that electrons form pairs as a result of the arrangement of atoms in the superconductor. Both old and new materials are crystals, meaning their atoms are locked in a regular, three-dimensional lattice—something like stacks of egg cartons with each egg an atom. All atoms vibrate in place, moving more violently with increasing temperature but constrained by their attraction to adjacent atoms. (If the temperature gets high enough, the atoms break free and the crystal melts.)

Under the old theory, electron pairs form like this: When the first electron passes between two atoms in the crystal lattice, the positively charged atoms are pulled slightly toward the negative electron. In the brief moment after the electron moves on but before the atoms spring back to their normal positions, they create a region with more than the usual amount of positive charge and a second electron is drawn into the space.

Thus linked, the electrons continue as a pair, the wake of the first smoothing the way of the second. If the atoms are properly spaced in the material and their natural vibration is slowed enough by low temperature, masses of electrons may move in cadence with the atomic vibrations, eliminating all resistance.

Experiments with ceramic conductors show lattice vibration alone does not cause the electrons to pair and a new theory is being discussed.

There is evidence that the peculiar layered structure of the ceramic crystals automatically causes pairs of free electrons to form when atomic vibration is reduced by relatively little cooling. The search for a room-temperature superconductor, then, may depend simply on making a crystal lattice that does not need to be cooled to achieve spontaneous electron pairing.

BOTTOM LINE...CONTINUED

ward, offering the prospect of a revolution in the uses of electricity.

But he is not prepared yet to tell the senior management at Westinghouse to invest tens of millions of the company's dollars in efforts to exploit a still-uncertain technology.

The situation reminds him of the tale of the broker standing in line to get into heaven. After a long wait, the broker stood on a soapbox and announced that gold had been discovered in hell. The stampede began, opening the line ahead of him to get to the pearly gates. But after a moment, the broker jumped down and joined the parade toward hell. When asked why, he said, "Well, there just may be something to it."

Will American industry be able to exploit the head start U.S. scientists have achieved in the race to this new scientific frontier? Many are convinced that the answer is no. Most of the 20 officials of American companies interviewed for this article expressed doubt that American firms will win a commercial contest with Japan to exploit superconductors.

There are some optimists. Lewis Branscomb of Harvard University, formerly a vice president for research at IBM, said he believes American firms can rise to the challenge. "If U.S. companies fail now, the corporate managers will have proved they are as obtuse as people say they are. That is the experiment we are doing. Can they take advantage of a big technology push?"

Dr. Kent Bowen, engineer and industrial expert at MIT, said it is time for vision to overtake wisdom, and to move ahead rapidly. "The downside of this is so bad that we have got to risk something substantial," Bowden said. "We have got to run ahead now, as if we knew all the answers already."

But Hulm at Westinghouse isn't prepared to run so fast. As a corporate manager, he feels he must try to gauge his speed and time his leap of faith into the superconducting future. And it is the industrial managers, not the academic experts, who will determine how the United States does in the forthcoming superconductor sweepstakes.

"The sticky part for us comes when we don't get a lot of products out quickly," Hulm said. "They say, 'Hey, you are spending so many dollars, over so long, where are the products?' You know, we are not the worst at Westinghouse. We have invested money in R and D [research and development]. I don't think it's enough, but we have done it . . . .

"You have to understand these things relative to quarterly earnings. Following quarterly earnings induces extreme caution at the top levels of companies . . . . There is such a pressure for earnings in the short range. I hate to lay the whole blame on Wall Street, but they've got a hand in it. My counterparts in Japan seem to have a much longer time to account for themselves."

That kind of caution contributes to doubts about America's prospects in this contest.

"I am skeptical. I am concerned. I do not yet see any effort on the scale I judge to be merited if the scientific claims are valid," said Bobby Ray Inman, former intelligence official and now a leader of experiments in industrial cooperation. "Superconductors are a pretty interesting technology to look at. If even part of the hype is true, there will be an enormous impact," he said.

Theodore Geballe, director of the materials research center at Stanford University, said, "There is some chance we will do what is necessary to compete. But if you wanted me to bet, I'd say the chances are less than 50-50 that we would dominate in the competition."

Kumar Patel, director of research, materials sciences and engineering for the Bell Labs at AT&T, said: "I have a fear about this. I am sensitive to the fact that we as a nation have done a lot about encouraging research and that we haven't done very much about engineering applications," which are responsible for pressing scientific finds into commercial products.

A few hundred researchers, mostly in industry, are working on the new superconductors full time. Perhaps several hundred more are working part time.

After hurried efforts to push more money into the effort, the government this year may invest $29 million in superconductor and materials research. Industry, scrambling as well, may add several times that amount.

IBM, for example, has an estimated 75 to 100 researchers looking at superconductors; AT&T has more than 40; Du Pont and General Electric have 20. Somewhat smaller companies—but still directly affected by the new technology—have reported mostly "exploratory efforts" involving one or a few researchers who

CONTINUED NEXT PAGE

FEDERAL CONTRACTS REPORT
1 JUNE 1987 Pg. 1017

• **R&D:** An essential ingredient in the development of superconductor technology will be the long-term commitment by the federal government to foster private research and development, panelists told the House Science, Space, and Technology Committee. Despite successes in the emerging field of superconductor technology, it will be 10-15 years before to produce the first limited benefits of energy efficiency in the commercial marketplace, the witnesses said at a briefing held May 27 for legislators and their staffs. Superconductors are ceramic and/or metallic devices that are void of virtually all resistance to electrical currents. Funding for such programs will be central to the future successes of superconductor research, according to Nelson Milder, who is on the staff of the House Science Committee. Milder said there already is a tug-of-war for funds between so-called large science projects and smaller research efforts, such as superconductors. As a result, he suggested also that the federal government work with Congress to develop some method of centralizing federal and private sector efforts in such high-technology projects.

Creation of some sort of centralized government planning and monitoring organization will be essential to ensuring that the United States is successful in both developing this new technology and, equally important, marketing its uses, according to self-described futurist Joseph Coates. Narain Hingorani, of the Electric Power Research Institute, echoed Coates' statements and said that when his group has worked on specific goal-oriented projects with federal agencies and private industry, there have been numerous successes in relatively short periods of time. He said that if such federal and private sector cohesion exists on superconductor research, "we could have a profound effect" on the American energy marketplace. Paul Brown and Ken Klein of the Energy Department agreed that superconductor technology will unlock tremendous potential, but these benefits will not emerge for another 15 years at best.

BOTTOM LINE...CONTINUED

keep track of advances made by others. Celanese Research of Hoechst Celanese, Owens-Corning and Sprague Electric are examples.

Overall, the United States appears to be making a sufficient investment to do the laboratory work that will work out what the new materials may do. But it is inadequate for the next step, taking the new-found rules of nature and manipulating them to make products. Hundreds of millions of dollars and well-coordinated programs are needed to compete for the engineering-to-marketplace prize, according to industrial research directors.

AT&T's Patel is among those who believe that only a coordinated industry effort led by the federal government can make America competitive in this race to commercialize superconductors. "I've been telling anyone who will listen. There are a number of us making noise. So we will be heard, at least," he said.

Art Sleight, one of the premier researchers in superconductors and Du Pont's research manager for advanced materials, said, "I doubt that this country can effectively compete with Japan if we don't cooperate with each other in ways that we haven't done in the past."

"I have not seen anything to give me optimism," said Inman, head of Westmark Systems in Austin, Tex., a firm devoted to buying small electronics companies and making them competitive. "I have spent the last five years learning how much impact accounting rules have on development and competition. They create an unwillingness to jump quickly. If you do jump, invest money, and the work doesn't go right, you take a hit on earnings right down to the bottom line. This causes a tendency to go slow. The whole system discourages major surge efforts.

"In Japan, there are totally different standards. They don't do quarterly reports. The banks sit on the boards of directors. They expect to recover their costs over much longer times .... The kind of rules and protections we have built into our system to protect against crashes, manipulation of the market, monopolies, and so on—when we're in the international market rather than domestic—become difficulties.

"The typical strategy we have evolved here is to try to grab a secret, go to market with it cautiously and get the most of it. The approach is not how to place yourself to grab a market share over the long haul," he said.

Hulm of Westinghouse has worked on superconductors most of his professional life, and has won awards for achieving high-temperature superconductors more than a decade ago.

His company, like many others, is well-positioned to make something of the new discoveries. Westinghouse has built a generator using older superconducting technology, and has done considerable work in microelectronics and in making high-tech wire—each of which could be crucial in superconductor development.

Also, Hulm's researchers have the fever. "It is very unusual, but all the scientists here are unanimous in wanting to push this technology faster now. Often researchers will say, 'Well, I don't know, I'm worried about this difficulty or that one.' Not this time," Hulm said. "The researchers will do anything. They'll work nights and weekends, they'll leave their wives for you. They don't care about the money. They just want a chance to work."

Hulm has reassigned as many researchers as he can under his current budget. He has asked other divisions in the company for help. His research team includes 20 scientists working full or part time.

But moving from basic research, in which the United States has a clear lead, to engineering and development is "a different kettle of fish," Hulm said.

It is the engineering that takes both vision and money. So far, Hulm is not ready to declare to the top brass that this is a breakthrough technology.

"You've got to make money, after all. How can I justify making a new generator?" he asked, when there is no profit in making generators old or new because the demand for electricity is too low. "As much as we may like to pursue our own scientific bent, we have to do something useful for the company."

Hulm also sees an array of tough technical problems. The materials are extremely brittle and so far can carry enough electrical current only in crystal form. Each difficulty, while possible to overcome, is serious and can soak up years of time and money.

"Our company doesn't have a slush fund for research. Everything is planned, including the profits they intend to declare .... Slowly, we're trying to mobilize all the resources we can.

"But our guys want to know how much bottom line they are going to get," he said.

Hulm lived through an earlier scientific revolution that changed the world, the advent of miniaturized electric circuits based on transistors. Westinghouse was involved then, but the company failed to develop and market microcircuits as aggressively as other makers, including the Japanese.

Hulm recalled that Westinghouse had good research and a good product, but was not able to catch the rhythm of the hot new market in the 1970s. Texas Instruments and the Japanese makers of the tiny new circuits put out new, more compact and powerful versions frequently, dropping their per-unit price at an alarmingly fast rate.

"That was the Japanese-style strategy, to put out more and more circuits for less and less money—going from something like a buck a transistor to five bucks for a million transistors—and not worry about immediate profits, but instead to open the market," Hulm said. "As a result, they built the demand up rapidly at the same time their costs were coming down."

Eventually Westinghouse dropped out of that race, and converted its Baltimore microelectronics plant to Defense Department work.

The lesson Hulm draws from that experience is not that it is now time to rush into applications of superconductors, but rather that some inventions cannot be exploited as soon as they are made. If money had been thrown into electronic devices just after the transistor was invented in the late 1940s, he said, that would have been a disastrous mistake. It took more than 20 years from the moment of creation to the time commercial products began to take off, he noted.

CONTINUED NEXT PAGE

WASHINGTON POST 20 MAY 1987 Pg. 1

SUPERCHALLENGE

Last of a Series

Two Different Cadences In the Superconductor Race

U.S. Marshalling Free-Market Forces

By Dale Russakoff
Washington Post Staff Writer

The nation that pioneered the videocassette recorder, the microwave oven, the color television and the memory chip—and then lost them to foreign competition—is once again staking its faith in free enterprise on the next great competitive struggle, the race to take high-temperature superconductors to the marketplace.

"Superconductivity has become the test case of whether the United States has a technological future," said Frank Press, president of the National Academy of Sciences. "[That] future depends on our ability to commercialize our scientific discoveries. If we lose this battle, it will wound our national morale. Everyone will be asking: Here we support science so well, why can't we get products out of it?"

As the competition unfolds this time, many of the Americans on the front lines doubt that free enterprise alone is up to the job. "Looking at it from Cambridge," said Kent Bowen, professor of engineering at the Massachusetts Institute of Technology, "it seems so obvious what has to be done. It's surprising that it hasn't been done already."

Bowen advocates a $100 million federal effort coordinated by one government agency, rather than the present system in which several departments pursue separate courses. Others have called for something like the Manhattan Project that produced the first atomic bomb.

Congress has asked the National Academy of Sciences, the most eminent body of American scientists, to assess the adequacy of the effort. A report is expected by midsummer. Meanwhile, a bipartisan

CONTINUED NEXT PAGE

Japanese Seeking A United Front

By John Burgess
Washington Post Foreign Service

TOKYO—Within weeks after researchers announced development of new superconducting materials that may revolutionize the use of electricity, two Japanese government agencies set about guiding and harnessing another form of energy—the Japanese competitive spirit.

Special committees on superconductors were formed, bringing together top minds from Japan's universities, government and private companies to trade ideas and discuss commercialization and government aid.

Officials in charge of government research funds began reassessing spending plans. Others conferred with laboratories and company executives to keep abreast of the burgeoning research under way in Japan.

"We are working to assure that all this will not be just a fad," said Mitsugi Chiba of the Japanese government's science and technology agency which oversees one of the two superconductor committees. "We want it to be a solid, feet-on-the-ground campaign."

While the United States gov-

CONTINUED NEXT PAGE

BOTTOM LINE...CONTINUED

Once again, Hulm said, he fears that a big investment in commercial exploitation of a new technology may be premature. "If I thought we'd get [superconductors to work at] room temperature, I'd say amen. The potential would be uncovered. It would change everything. That's what I'm hoping for.

"As long as we have to dump that stuff in liquid nitrogen [a chemical that brings temperatures down to the levels at which superconductors now will work], we'll keep it limited to uses people think are so important it's worth the trouble." To Hulm, the possible limitations and snags along the way mean dents in the bottom line.

"That's really it. What can I say to people who say, 'Hey, drop everything and go into this technology?' I can't," he said.

After a pause, he added, "I guess that puts me in the conservative group."

Hulm recalled that as a young man, he too had been a technological enthusiast. Within weeks of the discovery of the transistor, he said, he was ready to plunge into a new world. "I remember saying, 'By golly, that is going to change the world!' "

"With superconducting," Hulm continued, "I don't know, maybe I'm too close to it."

Speaking of faith in technology, he said: "We used to have it. We do believe in it in some things, like health care technology, and it affects everybody."

The Japanese industrial managers, Hulm said, "have more faith in advanced technology than we do. They feel that no matter how far out it seems, if they invest in it, someday they'll get something out of it. Superconducting technology, I suppose, is like that. It is kind of far out."

But he added, "I don't think technology is the only factor here. There is a great sea change of world economic power going on. Maybe there's something to the idea that a country's time comes and goes. I hate to say that I'm discouraged about the future of the U.S."

He paused. "Maybe there is some kind of renewal process . . . . Maybe there is a way to get a second chance," he said.

NEXT: Government aid

US...CONTINUED

coalition in the House and Senate has introduced legislation to create a Japan-style commission of leaders from government, industry and academia.

The proposed commission would oversee the American effort and study such drastic options as breaking down antitrust laws—an idea that alarms a wide range of legal experts—or vastly expanding federal funding in the name of winning the superconductor sweepstakes.

The White House stands firmly against a more centralized federal role in guiding research toward commercial products.

"We have a secret weapon that will overwhelm [the Japanese] process," said William Graham, head of the White House Office of Science and Technology Policy. "We call it the free market. It's far better to let industry make the investment decisions for profit and to let government devote its resources to the basic research and underpinnings. We let each sector operate where it's strongest."

William O. Baker, retired chairman of AT&T Bell Laboratories, was skeptical: "Our government has the attitude the lone inventor in an attic is going to be able to carry on in fine old colonial tradition in international competition. That's exactly backwards."

The American system is characterized by heavy federal aid for basic research, but little or no direct involvement as work moves out of the laboratory into production, except in the case of weapons systems. The system's contribution to basic science, in which the United States leads the world, is unquestioned. For example, a National Science Foundation grant funded the Feb. 16 breakthrough by scientists in Houston and Huntsville, Ala., that brought superconductors into the realm of the plausible—developing materials that conduct electricity without resistance at temperatures much warmer than previously believed possible.

Similarly, in the months since the Feb. 16 announcement, the Energy Department, Defense Department, Bureau of Standards, National Science Foundation and National Aeronautics and Space Administration have shifted $29 million of federal research money into studies of new superconducting materials—significantly more than Japan apparently has spent.

So many departments and subdepartments have joined the field since the Feb. 16 breakthrough that no one in the administration had a precise count last week of how much money was being committed by whom.

The Energy Department, whose national laboratories are conducting $10 million of research on the new materials, has taken responsibility for distributing information, and last week hosted a two-day conference for scientists from government, corporate and university labs. It is cohosting a major White House conference on superconductivity in July.

Energy Secretary John S. Herrington also has put up money for a newsletter reporting latest developments in public and private labs and cataloguing scientific publications from around the world. So far, it is available only to American subscribers. "We're not going to play Uncle Sap," a DOE official said.

While the United States leads the world in basic research, laboratory victories no longer carry the day, and U.S. policy has only begun to respond. "There's a twilight zone between basic research and its application in the marketplace, and it's in that zone that we need to learn to operate," said John H. Gibbons, director of the congressional Office of Technology Assessment.

Concern escalated here following reports from Japan of government-organized councils coordinating efforts by companies, universities and government agencies to find commercial uses for the new superconductors.

This approach, which fostered Japanese dominance of other markets, got under way last December and was in place 11 days after the Feb. 16 announcement that American scientists had broken the superconductivity barrier.

"I would suggest to those who put their ultimate faith in the ability of our private businesses to develop and market this technology that our nation cannot afford to risk losing a leadership role" in superconductivity, said Sen. David F. Durenberger (R-Minn.). "We have to make a se-

CONTINUED NEXT PAGE

JAPAN...CONTINUED

ernment debates the extent of its participation in the superconductor revolution, the Japanese government has already begun to function as facilitator and coordinator, an activist role it has played repeatedly over the years in Japan's drive for preeminence in high technology.

The Japanese government no longer keeps the iron hand on economic decisions that it had through much of the postwar economic advance, and it spends far less in direct government funds on research than does the United States. But it does something that the United States has traditionally shied from as anticompetitive: it coordinates, cajoles and guides its country's industrial development, striving to avoid duplication and increase efficiency.

The Ministry of International Trade and Industry (MITI) controlled the postwar recovery with an authority that was reinforced by control of foreign exchange flows, which could mean life or death for companies. Today, much of that statutory authority is gone, but the ministry and its corps of technocrats retain major influence in the economy. They see it as their duty to decide what the future holds and move people toward it.

Licensing and research grants are prime tools. Important too is "administrative guidance," the formal expression of the ministry's will. Often it has no legal underpinning, but business leaders are loath to defy it. Many agree with MITI's approach, but MITI can find ways to make trouble for those who don't go along.

MITI officials don't like to talk about potential projects, but history provides many examples. From 1962 to 1980, for instance, MITI organized four major thrusts involving computer technology. By far the most famous and controversial was one meant to put Japan on a par with the United States in VLSI—Very Large Scale Integration—production of advanced microchips.

In 1976, with MITI's blessings, the country's major electronics companies established the VLSI Technology Research Association. MITI provided some loans; the companies supplied the rest. The goal was to stop duplicative research and share findings among participants. After spending about $300 million and filing many patents, the project disbanded in 1980 and participants have gone their own ways.

Some studies credit MITI as key to the postwar "miracle." In some cases MITI leadership was clearly crucial—its strongarming of foreign companies to license computer technology in the 1960s is commonly cited—but it has had notable failures too. The Japanese aerospace industry has never taken off despite years of MITI nurturing.

CONTINUED NEXT PAGE

US...CONTINUED

rious commitment to reexamining the benefits that flow from coordinating" the private sector and the government.

Many advocates of more coordination in the United States, including some prominent corporate executives, believe the federal government should organize the dozens of companies seeking commercial uses of superconductors so that certain firms pursue certain potential products, thus avoiding duplication and sharing the high cost and risks of product development.

A range of corporate research directors and government scientists, favoring this approach, have complained in public hearings that federal antitrust laws impede cooperation that could help American firms compete with Japan.

However, corporate culture—not the government—appears to be a roadblock to more cooperation. Amendments to the antitrust laws in 1984 encouraged American companies to conduct joint research and development, all the way to crafting prototypes. The Commerce Department has taken a lead in organizing several consortia; a total of 66 are now operating in the United States.

Some experts believe the law even permits joint production, if necessary for American firms to compete internationally, although it forbids firms from dividing the market, as is occasionally done, with government blessings, in Japan.

"The case just cannot be made that there are significant antitrust impediments," said deputy assistant U.S. attorney General Roger B. Andewelt.

"If American industry thinks it's getting beaten because they're not coordinated, let them coordinate themselves," said National Science Foundation Director Erich Bloch, a former vice president at IBM Corp. "On one hand they want to be entrepreneurs and they want to be independent. On the other hand, they want to be coordinated. I think they're a little schizophrenic."

Another barrier is the reluctance of competitors to pool information.

"If companies cooperate," said Bruce Hannay, former Bell Labs vice president for research, "they'll spend all their time working out rules to make sure nobody gets anything the others don't have. If they agree that when anyone breaks through, everyone breaks through, there's no incentive to push ahead. Competition is the basis of our system."

Officials and experts interviewed for this article agreed on the need for several changes in public policy; some already under way:

- The yawning budget deficit, which has driven up interest rates, greatly discourages risk and investment, according to a range of economists, by raising the cost of borrowing and undermining confidence. The fiscal crunch also rules out a crash federal program, and breeds in-fighting over which technologies to support—superconductors versus semiconductors or atom-smashers, among others.
- The White House and Congress are moving to revise a number of laws that hinder U.S. companies competing in high-technology areas. They seek to close a loophole allowing foreign manufacturers to pirate processes patented in the United States and to ease the antitrust threat to companies that license competitors to use certain patented discoveries. An amendment also is pending to encourage joint manufacturing efforts in the cause of "innovation."
- In the last few years, the National Science Foundation and the Commerce Department have fostered cooperative research linking dozens of companies, universities and government scientists. An executive order by President Reagan last month further opened national labs, and their discoveries, to the private sector.

The theory behind these changes is that the way to move technology from labs to the marketplace is through people—another approach common in Japan.

"It's about time we changed our attitude," Bloch said. "The country is not going to survive if everyone does his own work and nobody talks to each other."

Confusion persists—in government, business, and academia—over the nature of American free enterprise. Many business and government leaders say a Japanese-style system would backfire here,

CONTINUED NEXT PAGE

JAPAN...CONTINUED

MITI opposed the Sony Corp.'s initial licensing of the transistor and Honda Motor Co.'s expansion from motorcycles into cars.

The science and technology agency's committee has more than 100 member organizations. It is holding public symposiums and closed-door meetings between specialists. It is the first time the agency has tried to organize private companies this way, a measure of the awesome potential it believes superconductors hold.

Chiba says the purpose is to put research leaders together and decide what to do. The group might eventually agree to carve up research, perhaps with the government focusing on basic research and companies on commercial development, he suggested.

A second committee, run by MITI, is smaller and less visible. More than 20 senior researchers from companies and government labs belong. So far, it has met in formal session just once, in April. The chief of Tokyo University's program, Shoji Tanaka, briefed the group on a conference in the United States, MITI officials said. Industry researchers expressed views on various materials, the potential for development and possible commercial uses. A working group has convened four times, and bureaucrats and researchers frequently talk informally.

The group keeps MITI informed and exposes top researchers in Japan to a few of their competitors' secrets. "We try to get the researchers to put a little bit of distance between themselves and their companies and to bring in the results of their studies," said Hirokazu Nakaima, an MITI deputy director general. "If they stick too much to the interests of their companies, they will just sit and listen and say nothing."

Direct government money has played a relatively small role in research. The Science and Technology agency put the equivalent of about $22 million at current exchange rates in superconductor studies between 1982 and the present. MITI claims not to know how much it has spent, but calls it small.

Like the rest of the world's, Japanese superconductor research plodded along until late last year, after scientists at an International Business Machines Corp. laboratory in Switzerland published a paper concluding that superconductors could be made from ceramics and function at less-cold temperatures than metallic ones. Suddenly, even room-temperature superconductors seemed within range.

Tokyo University Associate Professor Koichi Kitazawa, a specialist in superconductors, recalls that he initially tossed the IBM paper aside, feeling its ideas were basically wrong-headed. But he passed it to a graduate student in physics, who one day

CONTINUED NEXT PAGE

US...CONTINUED

because it conflicts with America's culture of independence.

But a cursory look at federal tax laws or government procurement patterns reveals that the U.S. government is not above nurturing an array of private activities. Said Press: "People like to say we don't have an industrial policy, but we do. We have 12," one for each Cabinet department.

Given the American culture of competition, former Bell Labs chairman Baker called government efforts to promote cooperation woefully inadequate. "Hopeful and well-intentioned and about 20 years too late," was the way he put it.

The race with Japan also is short-sighted in Baker's long view—"another narrow idea of mutual exclusion." If superconductivity has as much potential as most believe, he said, why not develop agreements combining American science and Japanese engineering so that both countries share the vast new wealth and make new technologies available to the world more quickly?

"The human race hasn't really caught up with the idea of what cooperation in science and engineering can do for the general strength of the planet," he said. "That's what war is—the irrationality of the human race.

"Agony will be the main thing that changes it," he said. "If we keep burning the forests and tearing the ecology apart, contaminating air and oceans, the agony will build up enough so we'll have to cooperate. The trickle of rationality is what we all work for—to help the human condition."

JAPAN...CONTINUED

approached him and asked for permission to try it out in the lab "and make a joke of it."

The student, 26-year-old Hidenori Takagi, found it was no joke at all. On Nov. 13, he and another student found signs of reduced magnetism in the material they were making, a crucial sign that the paper's findings were valid.

"I was astonished, deeply moved," Takagi recalled. "I doubt I'll ever have such a feeling again." Takagi reported his findings to a professor, who told him to buy a bottle for a celebratory toast. A half-dozen researchers raised glasses together.

Since then, the lab has been racing full-throttle, with Chiba and other researchers often passing the night there. "At the very busiest times, I'm not really sure where my home is," he said.

The university's announcement that it

CONTINUED NEXT PAGE

The U.S. Research Program: Where the Money Comes From

The United States' strong suit in technological competition is its support for basic research—that early stage of scientific discovery that explores the basic rules of nature, long before the exploitation for profit begins.

The search for the mysteries of high-temperature superconductors is no exception. Since the breakthrough in superconductivity research Feb. 16, 10 departments and sub-departments have committed $29 million of their budgets to exploring the properties and potential of the newly discovered materials. These commitments have evolved with little coordination among departments. A reporter had to call scientists at six agencies and the White House to get a full accounting.

President Reagan has radically changed the priorities for government-financed research and development. In 1980, 47 percent of $29.8 billion of R&D obligations went to defense, and the rest to civilian projects. This year, the estimate is 70 percent for defense, out of $59.2 billion.

Basic research—the kind of exploration under way in the new superconductors—is still concentrated in nondefense projects (89 percent). The United States will spend about $1 billion on basic research this year, compared with $540 million in 1980. Here is the breakdown for the new superconductors:

DEPARTMENT OF DEFENSE

over $11.5 million

Air Force Office of Scientific Research: Studies of thin-film superconductors and potential uses in sensors, electronics and other areas. ($3.5 million)

Defense Advanced Research Projects Agency: Contract for research aimed at applying superconductors to computers, sensors and other devices. ($10 million over three years, $3 million in 1987)

Office of Naval Research (up to $3 million)

Naval Research Laboratories ($1.5 million)

Strategic Defense Initiative Organization: Research on infrared sensors. ($500,000)

National Security Agency: Classified research. "You'll never find out what that is," said a department official.

DEPARTMENT OF ENERGY

$10 million

Research at national laboratories and DOE-funded universities to examine why new materials become superconductors at relatively high temperatures, and how to increase their limited capacity for carrying electrical current. (DOE also is spending $15 million on low-temperature superconducting magnets and fusion devices.)

NATIONAL SCIENCE FOUNDATION

$6.6 million

Grants to universities for research on high temperature superconductors ($5 million), interdisciplinary research efforts at the agency's materials research labs ($1 million) and small grants for researchers with ideas for processing the new materials into rods, wires and tubes ($600,000).

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

$750,000

NASA National Aeronautics and Space Administration

Research grants to universities, with a goal of using superconductors in space, where low temperatures are easily attained.

COMMERCE DEPARTMENT

$150,000

Bureau of Standards: Measurement science to insure the precision of numbers, properties of materials and measurements being used in research.

JAPAN...CONTINUED

had confirmed the IBM study had touched off a frantic wave of research. The giants of the Japanese electrical industry jumped in with more personnel and money.

"We didn't have to apply the whip," said Minami Ichikawa, an MITI superconductor specialist. "The companies were off and running on their own."

Records were set, only to have competitors report they had been broken a few days later. On April 2, for instance, Toshiba announced it had fashioned a superconducting wire that works at 93.7 degrees Kelvin, or minus 294 degrees Fahrenheit. The Kelvin scale is based on absolute zero at which all molecular motion stops, or minus 459 degrees F. On April 7, Mitsubishi Electric Corp. said it had found a material that worked at 95 Kelvin and would carry larger currents than previous materials.

"If you come to this lab at midnight, or 3 a.m.," said Kitazawa of Tokyo University, "you'll see students working." Estimates of 100 Japanese labs in the race are heard in the industry here, although no one knows. Many, however, are doing primitive work that simply tries to duplicate accomplishments of others.

April's edition of the English-language Japanese Journal of Applied Physics carried 84 articles on superconductivity. Several public conferences in large halls in Tokyo have become the same hectic sellouts seen at similar events in the United States.

In the long run, Japan's approach to superconductor development could be heavily influenced by attitudes common in society here that while competition is good, harmony, stability and predictability can be just as desirable.

As of last year, the government was overseeing 427 cartels, ranging from major industries in decline, such as aluminum, to barber shops (the government establishes a minimum price for a haircut). Japan has antitrust laws much like those of the United States, mostly put in place during the U.S. occupation after World War II. But they are enforced less vigorously and with no sense of moral crusading. Laws for promotion of specific industries often give antitrust exemptions.

Japanese offer their superconductor achievements in recent months as proof that their companies excel without government guidance. Japan has historically borrowed foreign technology, they say, but this time may be different. "In the United States, it is Bell Labs and IBM, the premier labs, that are working on superconductors," said Dr. Michihiko Nagumo, a Nippon Steel Corp. research director handling the materials. "It is an honor to be competing with them."

Many Japanese believe that even if they lose in the basic research, they can come from behind in a more important race—to commercialize the discoveries. Japan's list of achievements here is daunting—the VCR, the transistor, the color TV. So, too, in capital items like power generators, machine tools and broadcast equipment.

"By concentrating on the development of consumer technology and not wasting money and the country's best brains on military technology, Japan has been able to accomplish more than other industrialized nations in many areas," think-tank researcher Kishida Junnosuke has written.

Bred in an educational system that stresses memorizing and unshakable loyalty to teachers, Japanese researchers often falter in the creative leaps needed for breakthroughs in basic science. But they excel at the personal touch, and the trial-and-error drudgery, required to convert abstract processes into products. The Japanese also accord a greater status to engineers who choose manufacturing over research than does the United States.

Much of the Japanese corporate culture breeds success in commercialization. Companies here usually operate at low profit margins, with the paramount goal of long-term market share. They are quicker than American companies to modernize factory equipment, aided by low interest rates. Workers in big companies know they have lifetime job security and thus don't fight productivity-increasing automation as Americans often do. Universities graduate more engineers than the United States and companies are packed with them. Many Japanese chief executive officers are engineers.

The Japanese still believe they must fight their way to the top of the world order. They are taught that theirs is "a poor island nation with no resources." Despite burgeoning affluence, the country retains the feisty spirit of an upstart.

Now more than ever, Japan is on the lookout for new technology. The 70 percent rise of the yen since September 1985 has destroyed the world competitivity of many mainstay export industries. "The Japanese company is saying, 'Gosh, the iceberg we're standing on is melting,' " said James C. Abegglen, a consultant and author on the Japanese business world.

Still, the Japanese say that world domination in superconductors is not their goal; one country could not possibly control a field as vast as this one may be. "A type of nationalism is being injected since ceramics became the focus," said Dr. Hiroyasu Ogiwara of Toshiba Research and Development Center. "I don't understand it."

MITI said Japanese labs have been quick to share their findings in the new field. It called for a chain of conferences here and in the United States to stay in touch. And if a big foreign company can produce a Japanese-speaking researcher who can hold his or her own with those on the MITI committee, Nakaima said, there could be a seat waiting. But so far, he said, none has inquired.

Superconductors offer avenues for finding submarines

By Frank Elliott

Recent breakthroughs in superconductivity are leading the Navy to reappraise a submarine detection technology that it once dismissed as not worth the effort.

Superconductivity is the transfer of electricity without resistance, and corresponding loss of power, from the material through which the current passes.

In theory, a submarine detection system made with superconductive materials could be thousands of times more sensitive than today's sensors. Any signal, however slight, would reach the system's operators. And it could take less power to run the system. If successfully integrated into a new generation of sensors, superconductivity could revolutionize anti-submarine warfare.

But with super-sensitive superconductors come other significant problems that complicate submarine detection, as the Navy has discovered.

Dewars and water

Several years ago, a specially equipped P-3 Orion anti-submarine patrol plane flew out over the Atlantic Ocean off the Southeastern United States. The airplane carried an experimental magnetic detection device inside a Dewar flask, a giant thermos bottle used for storing super-cooled liquid gases. In this case, the Dewar flask contained liquid helium at 452 degrees below zero Fahrenheit.

At a pre-designated spot over the ocean, the Dewar flask was lowered on a cable below the airplane until it was skiing atop the water. Engineers and scientists inside the P-3 then began to read instruments that told them if the new detector could find the magnetic signature of a submarine lurking underwater. What they found was that the detector only worked when it was extremely cold, hence, it was surrounded by liquid helium in the Dewar flask.

According to scientists familiar with the experiment, the detector found the submarine. But it was so sensitive that it also found lots of metal objects that had nothing to do with submarines. The Navy filed away the results and pursued the matter no further. It simply was not practical to outfit every submarine patrol plane with frigid magnetic detectors in Dewar flasks. Thus ended one of the Navy's first efforts to enlist superconductivity in the cat-and-mouse world of submarine hunting.

Until 1973, the only way to achieve superconductivity in electronic devices was to freeze them in liquid helium to temperatures approaching absolute zero: 459 degrees below zero Fahrenheit, the temperature at which all molecular motion ceases.

Then researchers found that niobium compounds became superconductors at 418 degrees below zero Fahrenheit; still so cold as to require liquid helium. But early this year, researchers announced that a special ceramic material became superconductive at only 321 degrees below zero. A small difference perhaps, but at this temperature liquid nitrogen — much cheaper and mush easier to handle — could be used to chill the superconductor.

Since then, announcements have come rapid-fire of new breakthroughs in materials that become superconductors at even warmer temperatures. The warmest thus far is 9 degrees Fahrenheit. Many scientists predict superconductors at room temperature, a technology that will revolutionize society.

Sailors and SQUIDS

The Navy will be among the first to experience this revolution because one of the easiest applications of superconductors is a device scientists call a SQUID, said Tom Stefanick, an anti-submarine warfare expert for the American Federation of Scientists.

SQUID stands for superconducting quantum interference device. In layman's terms, a SQUID senses the minutest changes in the earth's magnetic field — such as the change caused by a submerged submarine gliding unseen below the waves.

The Navy's main way of finding enemy submarines is by picking up their noise. But Soviet submarines have been getting progressively more quiet. Navy officials know the day is coming when submarines will be too quiet to be heard over the static noise of the open ocean.

But SQUIDs offer the Navy an alternative: finding submarines by detecting their magnetic signature. The experimental device in the Dewar flask was an early SQUID.

For years the Navy has used magnetic detection for ASW. These magnetic detectors — mounted on P-3 and S-3 anti-submarine planes — pinpoint a submarine after it has been found with other sensors. But today's magnetic detectors can only find submarines within about 330 yards.

The SQUIDs, Stefanick said, will let the Navy made magnetic sensors "that are likely to be three orders of magnitude more sensitive than today's sensors. An order of magnitude is logarithmic, so when we say three orders of magnitude it means 3,000 times more sensitive."

But such sensitivity gains do not transfer directly. "Magnetic signal strength falls off as the cube of the distance," Stefanick said. So in practical terms, whereas today's devices can detect magnetic changes at 1,000 feet, he said, a SQUID might increase this to 10,000 feet.

Roger Coch, a scientist at IBM Corporation's Watson Research Center in Yorktown, N.Y., described a SQUID as "a loop of superconducting material, 100 microns by 100 microns." At two places on this loop, the superconductivity of the material is suppressed. This lets the loop convert magnetic sensitivity into voltage that can be measured, Coch said.

IBM tested a SQUID in April, Coch said. "It wasn't a very high performer, but it demonstrated the potential" for them, he said.

IBM is not alone. Recently, two physicists with the National Bureau of Standards reported making a SQUID that works with liquid nitrogen at the bureau's Boulder, Colo., laboratory.

Referring to the Navy's SQUID experiment with the Dewar flask, Coch said, "It so much easier to use these new materials that the Navy may have to reassess its opinion" of their usefulness for anti-submarine warfare.

Problems and prospects

But first, said Donald Polvani, a physicist with Westinghouse Electric Co., "You have to have some way of

CONTINUED NEXT PAGE

DEFENSE NEWS 1 JUNE 1987 Pg. 1

DoD Consolidates Efforts In Superconductor Work

By GEORGE LEOPOLD
Defense News Staff Writer

WASHINGTON — With advances in superconductor research being reported nearly every week, the Defense Department is planning to consolidate its own research efforts as it seeks to develop new materials and processing techniques that could yield applications ranging from compact ship propulsion systems to improved sensors.

Pentagon officials, who decline to provide details about the coordination effort, say it is part of a larger government plan to develop an integrated research program to exploit superconductor technology that permits electricity to pass through materials unimpeded by resistance.

"We've been working together for months," to coordinate DoD superconductor research, acknowledges Ted Berlincourt, director of Pentagon research and laboratory management. Through a Pentagon spokeswoman, Berlincourt added last Thursday that "details on superconductor coordination are still being worked out."

Donald Gubser, head of a recently formed superconductor research committee at the Naval Research Laboratory here, says the DoD effort will likely include representatives of the military services, the Defense Advanced Research Projects Agency and the Strategic Defense Initiative Organization. A source at the Defense Advanced Research Projects Agency confirmed last Thursday that the agency is participating in the coordination effort.

Gubser, who also heads the metal physics branch of Naval Research Lab's condensed matter and radiation sciences division, says the Pentagon superconductor program probably will focus on high-speed electronics rather than electrical devices like storage magnets and electric motors.

In April, Berlincourt's boss — Ronald Kerber, deputy undersecretary of defense for research and advanced technology — identified high-temperature superconducting materials as one of several "special technology opportunities" to be pursued in the Pentagon's Conventional Defense Initiative. Kerber said a small, but unspecified amount of money would be devoted to superconductor research.

The Naval Research Lab, which formed a superconductivity committee on May 14 that could serve as a model for the Pentagon, is investigating new materials processing and fabrication techniques needed to produce high-temperature ceramic superconductors for both electronic and electrical devices. These efforts include development of thin films for microscopic electronic devices and thicker coatings to make high-capacity transmission lines and storage magnets.

Superconductivity occurs when materials are cooled to very low temperatures, slowing molecular motion.

In the last two weeks, university and industry researchers have reported evidence of superconductivity at increasingly higher temperatures. Paul Chu, a University of Houston physics professor and a leading superconductor researcher, reported finding a material that lost all resistance to electricity at minus 54 degrees Fahrenheit, or 225 degrees Kelvin.

Last week, Energy Conversion Devices Inc. of Troy, Mich., said it had found evidence of superconductivity at nine degrees Fahrenheit, or 260 degrees Kelvin.

In order to exploit superconductivity, however, experts say methods must now be found to turn processed materials into wires for electrical transmission or thin films for computer chips. The Naval Research Lab and industrial researchers recently reported the development of a "thermal spraying" technique to produce thicker current-carrying superconducting coatings for practical electrical devices.

Gubser of the Naval Research Lab says $1.3 million in internal funds have been redirected to its superconductivity committee, which consists of representatives of its materials science, condensed matter and radiation sciences, chemistry and electronics technology divisions. The laboratory also hopes to attract external research funding.

Along with the quickening pace of superconductor research and the huge potential scientific payoff, Gubser thinks research dollars can also be attracted because, for the first time, technological breakthroughs came after the implications of superconductivity were already known. "All the applications are waiting there," he stresses.

Gubser adds he has made three trips to the Pentagon thus far to brief Navy officials on research efforts.

A superconducting compound *made from yttrium barium copper oxide is suspended above three magnets at a temperature of 77 degrees Kelvin, or 321 degrees Fahrenheit. The device, developed by the Naval Research Laboratory, demonstrates the Meissner effect, or expulsion of a magnetic field.*

NATURE Pg. 263
28 MAY - 3 JUNE 1987

UK superconductivity

London

Moves to organize a coordinated strategy between Britain's industry and universities for research into high-temperature superconductors have been initiated by the government's chief scientific adviser, Mr John Fairclough. Representatives of the Cabinet office, the Department of Trade and Industry (DTI) and the Science and Engineering Research Council (SERC) met on 12 May and were due to meet again last week. DTI is expected to meet industrial research directors soon.

Professor Laurie Challis, chairman of the SERC physics committee, says "This is a very hopeful sign which implies that the government is recognizing that this is a special area needing special financial treatment." S.L.H.

SUBMARINES ... CONTINUED

cancelling out the noise, or increased sensitivity won't do you any good."

Stefanick explained: "The problem with any detection device is not just sensitivity, but finding a signal that's embedded in noise." The more sensitive the detector, the more clutter it picks up. "A lump of ore might look like a sub," he said.

"The increased sensitivity will help, but it will only help if you solve the signal-to-noise problem," Stefanick said, "because that's the fundamental limitation."

There are two kinds of noise, Stefanick said. Spacial noise refers to magnetic signals picked up by variations in the earth's magnetic field, such as the lump of submarine-imitating coal. Temporal noise refers to temporary changes in the magnetic field, such as magnetic storms in the out atmosphere caused by solar flares.

"So one of the things you have to do is pick out a signal from the spacial and temporal noise," Stefanick said. A stationary sensor could be calibrated to ignore spacial noise, he said, but it would be troubled by temporal noise unless it was paired with other, nearby sensors.

And an airborne sensor would be vulnerable to spacial and temporal noise, he said.

But the news isn't all bad. Polvani said, "One of the nice things about superconductors is you get this sensitivity in a very small package." Stefanick said, "A SQUID device is one of the easiest devices to build."

"What you have now is a new understanding of the material and the science," he said. "But there's a long way to go...to engineering something that would work and is affordable. Superconductivity may give you the ability to build some of these devices within cost constraints.

"Putting a more sensitive magnetic anomaly detector on airplanes is probably well within sight," Stefanick said. "But it is hard to tell how that will change the whole ASW picture."

But naval analyst Norman Polmar, thinking of abilities yet unknown that superconductivity will make possible, says flat-out, "Superconductivity could change the face of anti-submarine warfare."

An Oxygen Key to the New Superconductors

First it was the physicists, then the chemists, and most recently the materials scientists and ceramists who have hastily included in their annual meetings symposia on the new high-temperature, ceramic superconductors. Below are briefings from the 1987 Spring Meeting of the Materials Research Society (MRS) that was held in Anaheim, California, from 21 to 24 April, 1 week before the American Ceramics Society's conclave in Pittsburgh.

With the initial wave of euphoria now past, the atmosphere in Anaheim was decidedly more professional than that of the now fabled "Woodstock of Physics" that was part of the American Physical Society's March Meeting in New York City only 5 weeks before. Nonetheless, perhaps 1500 materials researchers listened to 69 scheduled papers and several late walk-ons that were crammed into a 2-day symposium. With a martial strictness, cochairs Michael Schlüter of AT&T Bell Laboratories and Donald Gubser of the Naval Research Laboratory kept the talks to the allotted 10 minutes each.

Except for an impassioned presentation by Juei-Teng Chen of Wayne State University, who sought to convince listeners that a group there had seen clear signs of superconductivity at 240 K, which is ambient temperature during a cold night on the northern plains, no significant indications of room-temperature superconductivity were reported. The most skeptical view was that of Theodore Geballe of Stanford University, who suggested that some of the unreproducible signs seen in several laboratories could be due to something other than superconductivity, as similar effects disappeared in Stanford samples with repeated cycling between room and liquid-nitrogen temperature.

If there was one theme at the symposium, it was that oxygen is the key to the family of rare-earth–based ceramic materials now in hand that remain superconducting up to about 100 K.

Where the Oxygen Vacancies Are

It was already apparent at the American Physical Society's March Meeting in New York that the new superconductors are members of a family of compounds having the generic composition $RBa_2Cu_3O_{7-x}$. R stands for yttrium or one of the lanthanide rare earths, and x is a number less than 1 whose value depends on the method used to prepare the material. Researchers also agreed that the structure of the compounds is something called a triple-layer perovskite with some oxygen sites vacant, but they disagreed on which sites.

Now, with the aid of neutron and x-ray diffraction and high-resolution electron microscopy, investigators are converging on a common interpretation that indicates the simultaneous presence of two- and one-dimensional characters in the electrical properties. The figures (page 1065) show the triple-layer structure derived from neutron diffraction studies at Argonne National Laboratory by researchers from Argonne, the Illinois Institute of Technology, and Western Michigan University. At least five other groups in Canada, France, Japan, the United Kingdom, and the United States have reached the same conclusions from independent neutron experiments. Neutrons are more sensitive to oxygen than x-rays and therefore provide a comparatively unambiguous picture of where the oxygen atoms are.

To understand the structure, first consider a perovskite cube with a copper atom at each corner and oxygen atoms on each of the cube edges. Leave the center unoccupied for the moment. Then join three cubes together, placing a barium atom at the center of the top and bottom cubes and a rare earth atom at the center of the middle cube. The unit cell of such a structure is tetragonal with three orthogonal axes and one lattice constant considerably larger than the other two, which are equal. The ideal compound has nine oxygen atoms per unit cell, but the missing oxygen atoms lower the number. The vacancies also distort the structure slightly so that it just barely becomes orthorhombic with the two once equal lattice constants now slightly different.

Locations that researchers now favor for missing oxygen atoms include the sites in the central rare-earth plane and half the sites in the top and bottom copper planes (left figure). These vacancies shift the composition to $RBa_2Cu_3O_7$. Donald Capone, who presented Argonne's structure at the MRS meeting, noted that a so-called Rietveld refinement of the neutron diffraction data for an yttrium-containing compound whose composition was optimized for superconductivity yielded a value of 6.81 oxygen atoms per unit cell of the triple-layer structure; that is, 81 of every 100 unit cells contained 7 oxygen atoms, whereas 19 contained only 6. Capone said the extra 0.19 vacancy per unit cell was also on the top and bottom copper planes. Moreover, the two copper planes adjacent to the rare-earth plane are "dimpled" because the oxygen atoms relax toward the now mostly empty rare-earth plane.

The oxygen vacancies in the rare-earth plane give the structure an electronically two-dimensional character. Theorists calculate that electrons flow mainly in copper and oxygen orbitals, and these orbitals are only continuous horizontally as a result of the missing oxygen atoms in the rare-earth plane. If the oxygen vacancies in the top and bottom copper planes are ordered, so that they lie on opposite sides of the unit cell, an additional one-dimensional aspect to the electronic structure emerges because the copper-oxygen orbitals can form continuous chains in these planes in only one direction. However, in the dimpled copper planes, the orbitals remain continuous in two dimensions (right figure).

Although neutron diffraction directly shows the ordering of the oxygen vacancies, supporting evidence also comes from electron microscopy. Abbas Ourmazd of Bell Labs showed high-resolution electron micrographs at the symposium taken by him and colleagues at Bell Labs and at Arizona State University. As compared to the heavier metal atoms, the light oxygen atoms do not scatter electrons strongly enough to be directly visible, but ordered oxygen vacancies could be inferred from a series of micrographs on samples of different thickness.

Vacancy Ordering and Superconductivity

There is strong evidence that the crucial effect of oxygen vacancies on both the superconductivity and the structure of $RBa_2Cu_3O_{7-x}$ is their ordering, which gives rise to linear chains of copper and oxygen atoms (see previous briefing). As Jean-Marie Tarascon of Bell Communications Research (Bellcore) summarized it at the MRS symposium, what is important for superconductivity is not only how much oxygen there is but where it is.

X-ray and neutron diffraction experiments in conjunction with other studies at Bellcore and elsewhere indicate that the number of oxygen atoms per unit cell can be easily varied over a wide range from about 6.1 to 6.9, according to the oxygen pressure in the

CONTINUED NEXT PAGE

OXYGEN ... CONTINUED

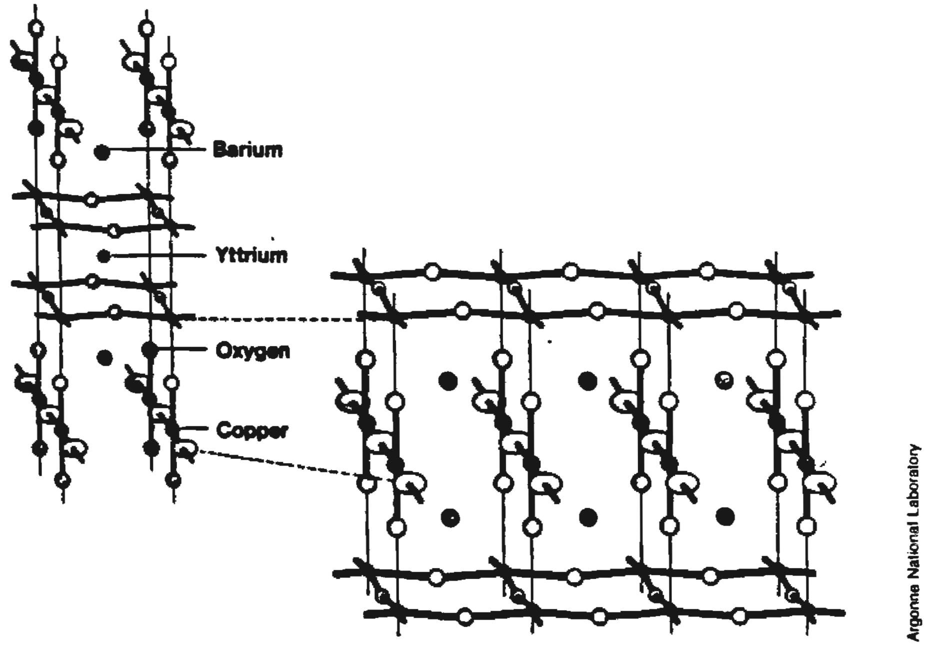
high-temperature furnace during preparation of the compound. Moreover, the concentration can be reversibly lowered and raised simply by, for example, first removing from and then reinserting oxygen atoms into the linear chains by means of high-temperature heat treatments (annealing) in vacuum and in air. The number of oxygen atoms strongly influences the critical temperature for superconductivity of these compounds, as well as their crystal structure.

Begin the story with the by now well-known insensitivity of the critical temperature to the specific rare earth. Researchers have succeeded in making superconductors with every lanthanide rare earth except cerium and praseodymium and uniformly have obtained critical temperatures around 90 K. The Bellcore group reported lattice constant measurements on a series of compounds with different rare-earth atoms and found in every case that the structure was orthorhombic. Tomoaki Yamada of the Nippon Telegraph and Telephone (NTT) Corporation in Tokyo presented very similar findings.

When the Bellcore investigators then vacuum-annealed their series of compounds, they found that all had become tetragonal. The tetragonal structure was associated with a decrease in the number of oxygen atoms and a decrease in the critical temperature. In the case of a compound containing yttrium, the critical temperature for superconductivity dropped from 91 K when the number of oxygen atoms per unit cell was 6.8 to 55 K when the vacuum annealing reduced the number to 6.6. Interestingly, the NTT researchers could only make their lanthanum-based compound with a tetragonal structure and found a similarly reduced critical temperature near 50 K.

The question of the role of structure has been on everyone's mind from the beginning. Donald Capone of Argonne National Laboratory, speaking for an Argonne, Catholic University of Leuven (Belgium), Illinois Institute of Technology group, and Robert Beyers, representing the IBM Almaden and Yorktown Heights Laboratories, reported high-temperature x-ray diffraction studies that showed a transition to a tetragonal structure at about 750 K. Tetragonal material that was then cooled slowly regained the orthorhombic structure and retained a high critical temperature for superconductivity of better than 90 K. However, material that was rapidly cooled (quenched) did not have time to complete the structural transformation. Apparently because of the presence of the tetragonal phase, the transition temperature dropped to 50 K or so.

Similarly, Y. Kubo of the NEC Corporation in Kanagawa, Japan, reported that NEC researchers had found a correlation between the structure, the superconductivity, and the number of oxygen atoms per unit cell from x-ray diffraction measurements on material quenched from several temperatures above and below the orthorhombic-to-tetragonal transition.



High-temperature superconductor: *(Left) The triple-layer perovskite unit cell; (right) expanded view of linear chains of copper and oxygen atoms and dimpled copper-oxygen planes. The oxygen atoms immediately above and below the chains form a "picket fence" that weakly links the dimpled planes separated by barium atoms, but there is no communication between planes separated by yttrium atoms.*

From these results and others, researchers have reached the conclusion that there may be two mechanisms for superconductivity. Critical temperatures of 90 to 100 K are associated with electrons flowing in the linear chains that only exist in the orthorhombic structure, whereas critical temperatures of 50 K or so are due to planar electron flow that is possible in both orthorhombic and tetragonal structures. A particularly direct piece of evidence supporting this idea comes from the Argonne group.

From measurements of the lattice constants just above and below the orthorhombic-to-tetragonal transition, the Argonne investigators concluded that the number of oxygen atoms per unit cell did not change during the transition from one structure to the other. One possibility is that the oxygen atoms simply move. In the tetragonal phase at high temperature, the oxygen atoms in the top and bottom copper planes of the unit cell randomly occupy the available sites. There are twice as many sites as atoms. On cooling, the atoms order in the manner previously described, converting a disordered, two-dimensional planar situation to an ordered, one-dimensional linear one in these copper planes.

Oxygen Isotopes Spell Trouble for Phonons

The ease of moving oxygen atoms into and out of $RBa_2Cu_3O_{7-x}$ provides a convenient way of testing the Bardeen-Cooper-Schrieffer (BCS) theory of superconductivity. At the MRS symposium, Robert Cava, representing a group from AT&T Bell Laboratories, and Donald Morris, speaking for a Lawrence Berkeley Laboratory team, reported similar findings in independent experiments that make it unlikely that the BCS theory in its entirety applies to the 90 K superconductivity in these compounds, which seems to be associated with linear chains of copper and oxygen atoms (see previous briefing).

In the BCS theory, superconductivity results from a second-order phase transition that occurs when certain electrons in a metal find it energetically advantageous to form pairs, known as Cooper pairs. No one disputes that pairing is essential for superconductivity. The specific mechanism by which electrons can lower their energy by pairing is what is at issue. The BCS theory posits an interaction between the electrons and lattice vibrations as being responsible. A negatively charged electron moving through the lattice slightly drags the positive ions in the process, making it easier for the second electron to follow and thereby generating an attractive force between the two.

In applying this general picture to the high-temperature superconductors, theo-

CONTINUED NEXT PAGE

NATURE 21 MAY 1987 Pg. 175

DoE hopes for superconductor cooperation

Germantown, Maryland

RESEARCH by US industry into the new superconductors is gaining momentum, judging by attendance at a meeting at Department of Energy (DoE) headquarters last week. The two-day event was organized to review the efforts of DoE laboratories on the new materials, and to give industrial researchers a chance to show off their own work. Although there is no sign yet of a coordinated national research programme, the DoE is trying to offset worries about Japanese progress by increasing its visibility as a broker for collaboration between universities, national laboratories and industry.

High current densities, recently achieved in thin films grown at IBM's Yorktown Heights laboratory, provided the major scientific interest. Because the ceramics have strongly anisotropic electrical properties, David Clark and his colleagues grew single grains, about a micrometre thick and up to a centimetre long, so that the crystal plane in which electron pairs travel was parallel to the film. The current density achieved across the planes was as much as seventy times smaller.

Panels of industry and university scientists gave their views on research progress and on prospects for superconductor applications. There was a general note of optimism, despite the acknowledged difficulties in making use of the fragile ceramics. Many participants expressed worries about the chemical as well as the mechanical durability of the materials; the oxides absorb water and carbon dioxide readily, changing the oxidation state of the copper atoms and destroying superconduction. But any difficulty was no sooner mentioned than countered instantly with suggestions for remedies. As panellists emphasized, many fairly obvious and straightforward experiments are waiting to be done, as soon as researchers can find the time.

DoE seems to see its purpose as coordination, not direction. Participants generally agreed that industry will find any research applications under its own steam, and that the role the universities and laboratories could best fulfil is to come up with new materials and theoretical underpinning for their properties. Angela Stacy, of Lawrence Berkeley Laboratory, lamented the lack of strength in solid-state chemistry in the United States; gas phase chemistry and reaction dynamics are perceived as being more intellectually exciting. But the idea that DoE might try specifically to encourage research in certain areas was not enthusiastically received by DoE officials at the meeting.

David Lindley

OXYGEN...CONTINUED

rists have focused on lattice vibrations involving oxygen atoms because they are thought to interact particularly strongly with the electrons that flow through copper and oxygen orbitals. The strong interaction makes the Cooper pairs more tightly bound and therefore translates to a high critical temperature, the temperature at which thermal effects break up the pairs. Werner Weber of Bell Labs and the Karlsruhe Nuclear Research Center in West Germany has worked out the details for the ceramic oxide superconductors $La_{2-x}A_xCuO_4$, whose discovery last year launched the current superconductor frenzy. In these compounds, which have critical temperatures up to 40 K, A is an alkaline earth.

Oxygen isotopes are an important consideration because, according to the BCS theory, the critical temperature increases with the frequency of the relevant lattice vibration. The frequency decreases with the masses of the vibrating atoms, however. Hence, replacing the oxygen-16 that is normally present with heavier oxygen-18 should have an observable effect on both the frequency and the critical temperature.

According to Cava, the Bell Labs group was able to incorporate about 75% oxygen-18 in an yttrium-containing compound by means of a cycle of repeated heat treatments at 500°C in vacuum, which removes some of the oxygen from the lattice, and in oxygen-18, which inserts it. The researchers verified the incorporation of the oxygen-18 by observing the expected 4% decrease in the frequency of the oxygen vibration by means of Raman spectroscopy. However, they found no effect on the critical temperature, as measured by the Meissner effect. In a less detailed report, Morris estimated that the Berkeley group had managed to incorporate an even higher oxygen-18 content of 90% by means of a somewhat different technique, but still saw no effect on the critical temperature.

As it happens, the idea of one-dimensional superconductivity in linear chains dates back over two decades. At that time, William Little of Stanford University proposed a specific version of it in organic polymers as a possible route to a room-temperature superconductor. Little's theory is built around an attractive pairing force of an electronic nature, so that no isotope effect on the critical temperature would be expected. Although there is no evidence as yet linking electrons flowing through linear chains in the triple-layer perovskite compounds with Little's mechanism or any of the others that theorists have proposed, the absence of an isotope effect means that alternative models must be seriously considered. ■

ARTHUR L. ROBINSON

HARTFORD COURANT 29 MAY 1987 Pg. C-1

Kaman official says ceramics reality still 10 years off

By ROBERT WATERS
Courant Staff Writer

The development of ceramic superconductors, the dramatic discovery that has been hailed as an energy breakthrough for everything from high-speed trains to military weapons systems, may be some 10 years away from practical applications, an energy expert said Thursday.

Henry H. Kolm, president of a Kaman Corp. subsidiary which is developing a revolutionary anti-tank weapon known as a coilgun for the Army, said he believes the ceramic superconductor will eventually have a heavy impact on his coilgun project as well as similar work he is doing on electromagnetic-powered space vehicle launchings.

"But it may take years before a practical material is available that can actually be used," said Kolm. Asked how long this might be, Kolm replied: 'It might take 10 years."

One of the major stumbling blocks, said Kolm, is "the very sad state" of the American ceramics industry.

Kolm, who is regarded as one of the nation's leading experts in electromagnetic propulsion, said the U.S. ceramics industry has suffered while Japanese ceramics developers have seized world leadership in the technology.

"We need to find a way that the whole [U.S.] industry can collaborate to make something happen," said Kolm.

A unified industry approach was adopted in Japan, he said.

"But in the United States," he said, "it would constitute a violation of antitrust laws."

Kolm said he believes there are only two ways that the United States can accelerate the technology base research that will be necessary to seize the opportunities that ceramic superconductors offer.

"It will be supported by the government in the name of defense or by the industry itself in the name of competition."

Kolm said the Defense Department has acknowledged a definite interest in the new technology. He said he attended a meeting on superconductor technology two weeks ago in Washington, convened by a Pentagon agency known as DARPA — the Defense Advanced ResearchProjects Agency.

DARPA is a low-profile Pentagon office that sponsors research into new technologies. It is sponsoring the revolutionary X-wing aircraft under development at the Sikorsky Aircraft Division of United Technologies Corp. in Stratford.

Kolm said the DARPA session was called to assess the effect of ceramic superconductors but he did not discuss details of the session.

However, Kolm said there is only one federally sponsored group that is active in the technology.

"A committee of the Defense Science Board is the only body that is taking a long, serious, enlightened look at where we stand."

Kolm said no federal money has been made available yet. He said there have been preliminary discussions of funding for programs in the $3 million to $10 million range.

"But the figures being kicked around ... are not sufficient to launch a serious effort."

Kolm praised the major research progress on ceramic superconductors that was announced May 10 by IBM Research Laboratory of Yorktown Heights, N.Y. He noted, however, the ceramic superconductors developed by IBM and others so far lack the size that would be required for large-scale applications such as his coilgun project.

Current ceramic superconductors, he said, are small.

"Everything that has been done so far," he said, "resembles a potato chip more than a wire."

"And you can't build a magnet out of a potato chip," he quipped.

With intensive research, however, Kolm said he believes the technology of ceramics may be combined with some other technology, such as composites, to produce the magnets that will lead to materials that can provide large-scale applications of superconductors.

"There is no question that we are entering the ceramics age," said Kolm.

Kolm, 61, is president of Kaman Corp.'s Electromagnetic Launch Research Inc., a small firm that is based in Cambridge, Mass.

Kolm's coilgun project is working under a 33-month, $8.5 million contract, which was jointly funded by the Army and DARPA last September.

The weapon, which is based on the science of electromagnetic propulsion, will be the free world's first coilgun weapons system, said Kolm.

Kolm has called the coilgun the "greatest discovery since gunpowder." He said the weapon is designed to fire anti-tank projectiles at speeds up to 2.5 miles per second — more than twice the speed of the Army's conventional anti-tank guns.

Kolm is also working on a similar project for electromagnetically propelled space launchings.

Both systems will require massive amounts of electrical power which would be rapidly dissipated in firing, a development that will require charging the systems at a rapid rate, said Kolm.

But electrical storage in ceramic superconductors, which can handle some 100 times more electrical current than the best superconducting materials previously developed, would lose power more slowly.

CHEMICAL & ENGINEERING NEWS 1 JUNE 1987 Pg. 18

Superconductivity at dry ice temperatures

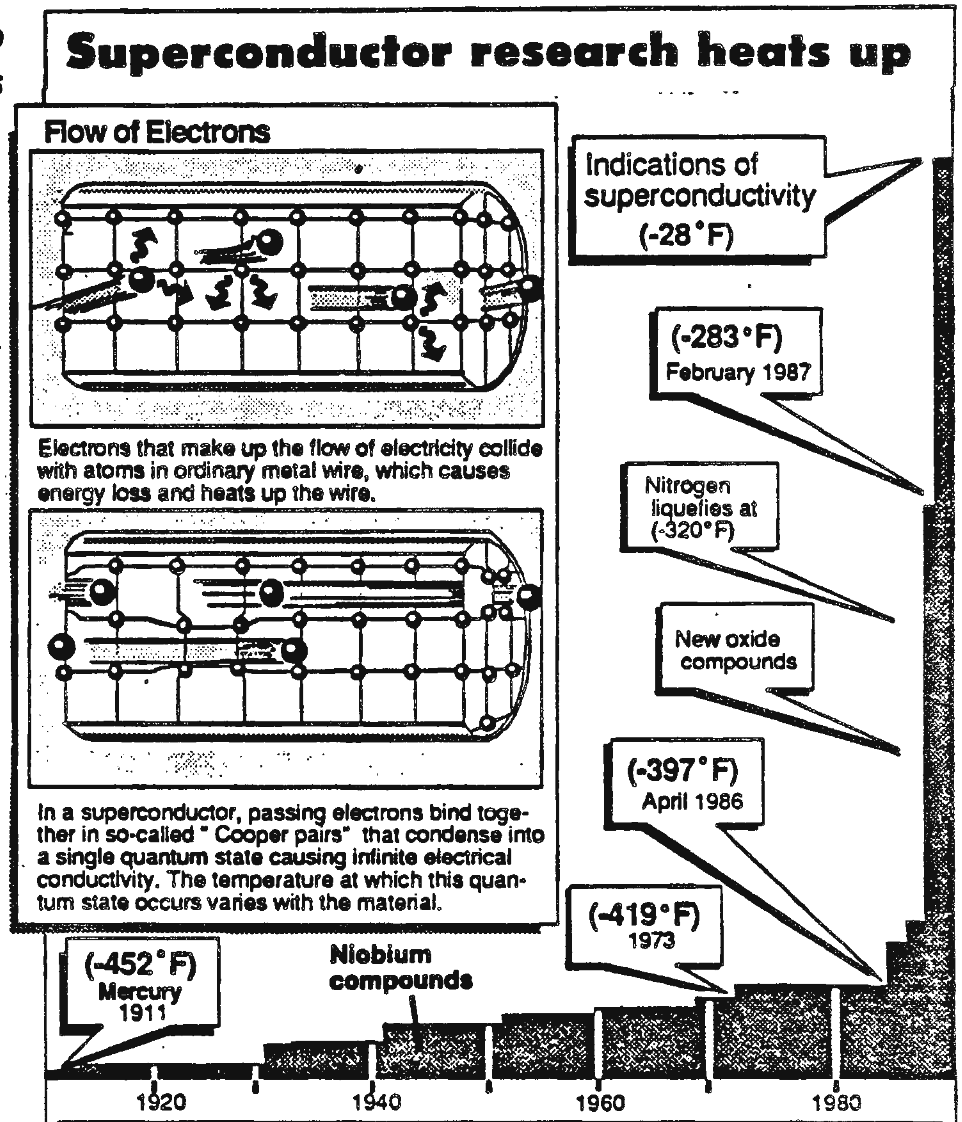
The Texas physicist who was the first to usher superconductivity into the practical and relatively temperate clime of 100 K is on the verge of announcing yet another advance. Ching-Wu (Paul) Chu of the University of Houston and colleagues at Lockheed Corp. and the National Magnet Laboratory in Cambridge, Mass., have been studying a class of ceramic compounds that lose resistance to electricity at 225 K (-48 °C), which is warmer than dry ice. The most reliable sign of superconductivity, though, is a material's ability to exclude magnetic fields. This effect has so far been measured at 225 K in only a tiny portion of Chu's new material, which is composed of several phases. A similar drawback besets researchers at Energy Conversion Devices Inc., who report seeing evidence of superconductivity at 260 K in multicomponent ceramic materials. The composition of these new materials hasn't been revealed. Chu notes that his materials are not completely stable, and the readings are difficult to reproduce. Other researchers also have seen flickers of superconductive behavior at these remarkably high temperatures.

ATLANTA CONSTITUTION 26 MAY 1987 Pg. 18

Superconductors trigger scientific gold rush

Thousands scrambling to develop commercial use of new materials

By Robert Lee Hotz
Science/Medicine Writer



For 75 years niobium compounds were used and temperature advancements were small. But in April 1986 use of new copper oxide compounds began to accelerate the temperature climb.

JONATHAN MASSIE/Staff

A gray disc the size of a Roosevelt dime, wreathed in a halo of superchilled liquid nitrogen, is the token of an upheaval in modern physics. It is a superconductor — a brittle ceramic of rare earths and copper oxide that transmits electricity with no waste, at a cost 1,000 times cheaper than ever thought possible.

Ground with mortar and pestle, then fired in an electric furnace, the new superconductors are the product of an alchemy that may transform industry. Their commercial potential already has triggered an unprecedented scientific stampede.

While physicists scramble to explain how the new superconductors work, thousands of researchers in the United States, Europe and Asia have joined the race to push the fragile new materials out of the laboratory and into the marketplace.

Scientists say mastery of the new materials promises to revolutionize the applications of electricity and magnetism, from storage batteries to nuclear fusion. They could lead to high-speed levitating trains, ships powered by supercooled magnetic motors, laptop supercomputers and portable medical imaging machines.

Military analysts believe superconductors may even change the rules of nuclear warfare. Space-based superconducting sensors could easily detect the magnetic trails of submerged submarines and the faint infrared glow of aircraft engines or rocket exhaust. Superconductors could lead to compact particle accelerators suitable for use as orbiting beam weapons.

Innovation feeds global rumor mill

The speed of recent innovation has outstripped the publication schedules of traditional scientific journals.

To stay abreast of research, scientists are turning to computerized newsletters, teleconferences and a global rumor mill. Within 24 hours of the formal announcement in March that researchers had achieved superconductivity at the unprecedented high temperature of 284 degrees below zero, chemical supply houses sold out of the rare earths needed to duplicate the experiment in other laboratories.

Researchers who six months ago could barely attract research funding for superconductor work now are invited lecturers at gatherings of stockbrokers, investment managers and venture capitalists.

"The new superconductors open vistas of tremendous opportunities for the future but there is tremendous work to be done," says Dr. Frank Fradin, director of materials science at Argonne National Laboratory in Illinois.

Superconducting ceramics, for instance, are so brittle they crumble at a touch. No one knows if superconducting wires can carry enough electricity to be useful. Nor is anyone certain the ceramics are strong enough to withstand the magnetic fields they may generate.

Whittling away technical obstacles

The pace of discovery, however, shows no sign of slackening. In recent weeks, several centers have reported progress in overcoming some of the technical obstacles:

■ Researchers at IBM's Thomas J. Watson Research Center in Yorktown Heights,

CONTINUED NEXT PAGE

WASHINGTON POST 23 MAY 1987 Pg. A1

Superconductor Breakthrough Reported Near

By Michael Specter and Boyce Rensberger
Washington Post Staff Writers

A team of American scientists told the National Science Board yesterday that it has developed a new class of materials that shows signs of becoming a superconductor of electricity at temperatures far higher than any previously recorded.

If a practical material could be developed to carry electricity in the higher range, it would broaden the potential applications of a technology seen as a major new arena of global economic competition.

University of Houston physics Prof. Paul C.W. Chu, one of the leaders in creating high-temperature superconductors, reported that his group found a material that lost all resistance to electricity at 54 degrees below zero Fahrenheit, or 225 Kelvin.

This is easily within the range of such ordinary cooling mechanisms as dry ice, inexpensive mechanical refrigeration or even simpler methods.

"That is staggering," Neil Ashcroft, a Cornell University physics professor and a leader in the field, said upon hearing of Chu's report. "Chu is the one who has really been calling the shots. That would be a breakthrough that is truly revolutionary . . . ."

The previous known bests were in the range of 225 degrees below zero Fahrenheit, or 130 Kelvin.

Chu said the new material has not passed all tests required to prove superconductivity but that further work should establish this.

Although the phenomenon of superconductivity has long been known, only in recent months have physicists proved that it is not confined to metals cooled almost to absolute zero, 459 degrees below zero Fahrenheit.

Earlier this year, physicists developed new materials that would become superconducting when cooled to 321 below zero, the temperature of liquid nitrogen, which is relatively cheap.

Practical superconductors promise to revolutionize nearly all uses of electricity by eliminating the waste of power inherent in ordinary conductors and by making new applications practical.

Among the most widely discussed are high-speed trains riding a cushion of electromagnetism, more powerful supercomputers and

CONTINUED NEXT PAGE

GOLD RUSH ...
CONTINUED

N.Y., have demonstrated that a thin superconducting crystal can carry enormous electric currents, up to 100,000 amps per square centimeter — enough for useful applications. Superconducting wire still can carry only a fraction of that.

■ Scientists at Argonne, IBM and AT&T Bell Laboratories in New Jersey have formed the first hair-thin superconducting wires, tapes and thin films. But they are still too brittle to be coiled or formed into the kinds of shapes needed to make cables, magnets or electric motors.

■ Physicists at Georgia Tech have perfected a technique to plate almost any object with a superconducting film, using a process called chemical vapor deposition. With a different process, known as plasma coating, IBM researchers have "spray-painted" layers of superconducting materials onto computer chips. Both techniques may be useful for industrial applications. But neither has yet been demonstrated on a large scale.

"An awful lot of work still stands between us and the marketplace," says Dr. Roger Poeppel, manager of Argonne's ceramics research group. "We may never develop a wire that can carry significant amounts of current. We may have great success in a matter of months."

Dr. Robert Dynes, director of chemical physics research at Bell Laboratories, is equally cautious. "A lot of people are trying to run before they can walk and we can't even crawl yet. The materials issues are still very serious."

A new battleground in world trade

But in April, IBM, whose Zurich, Switzerland, research center first reported the new class of superconductors, announced that its researchers had developed the first practical electronic device using the materials — a sensitive magnetic detector called a SQUID.

Scientists at Argonne and Bell Labs say the crude prototypes of new superconducting magnets and microchips may be ready within the year.

But others say such predictions are built only on hope and enthusiasm.

"I don't believe we can build these new magnets in under a decade," says Dr. John Hulm, vice president of research at Westinghouse Electric Corp., a pioneer in the early development of superconductivity. "There are some fearsome problems from a materials processing standpoint.

"There is a lot of hype. It is fooling the public to say these things are around the corner," he says. "It is going to be a hard slog."

The discoveries have triggered professional rivalries and potential patent disputes, and already promise to become the newest battleground in the competition for international trade.

The National Academy of Sciences recently convened a research team to assess the commercial potential and the National Science Foundation more than doubled its research funding to $6.6 million.

Japan is matching American efforts. Within weeks of the initial research breakthrough, Japan's Ministry of International Trade and Industry began reviewing the commercial potential of superconductors.

Scientists in the United States, Japan and China so far have found a dozen different recipes for the superconducting ceramics.

All are made from powdered copper oxide, barium and yttrium. The chemicals are inexpensive and plentiful. At 22 cents a gallon, the liquid nitrogen necessary to cool them to the temperature at which their resistance to electricity disappears is cheaper than milk or beer.

While some researchers race to patent practical products, other scientists are seeking materials that can become superconductors at ever warmer temperatures.

"The field is exploding. Every week we have a new announcement," says Dr. Alex Malozemoff, who coordinates IBM's high temperature superconductivity materials research program. "It is almost too early to focus on specific applications."

Researchers at Wayne State University in Detroit, the University of California at Berkeley and a number of Japanese universities have reported hints of superconductivity at a relatively balmy 28 degrees below zero.

The ultimate goal is a material that can conduct electricity with no resistance at room temperature.

"We don't know how soon we may find a room-temperature superconductor," says Dr. Mau-Kuen Wu, the physicist at the University of Alabama in Huntsville who helped push the new superconductors across the crucial liquid-nitrogen temperature barrier. "In the meantime, we shouldn't wait."

SUPERCONDUCTIVITY: Current-carrying capacity soars

Researchers at IBM's Thomas J. Watson Research Center in Yorktown Heights, N.Y., have increased 100-fold the current-carrying capacity measured in the new relatively-high-temperature superconducting ceramics. In a specially prepared single-crystal thin film, the researchers measured a critical current density of more than 100,000 amp per sq cm at the boiling point of liquid nitrogen, 77 K. Such a value is "in the ballpark for most practical applications," says IBM spokesman Gerald Present.

The measurement marks yet another milestone in the fast-paced research effort that has surrounded these materials for the past six months. Last November, researchers at the University of Tokyo and at the University of Houston confirmed an earlier report by IBM researchers in Zurich, Switzerland, that certain copper oxide ceramics could conduct electricity with virtually no resistance at temperatures well above absolute zero. Since then, materials scientists in laboratories all over the world have been joining the race to understand these materials and to see if they will really prove practical for hundreds of electrical applications (C&EN, May 11, page 7).

Much of the work so far has focused on raising the temperature at which the materials lose most of their electrical resistance and become superconducting—the so-called critical temperature, or T_c. Many laboratories now have materials with T_cs in the range of 90 to 100 K, temperatures that can be reached fairly economically using liquid nitrogen as a coolant. But practical applications also require materials that can carry a large amount of current and can do so in the presence of a strong magnetic field. Recent work at AT&T Bell Laboratories has shown that the new superconducting materials retain their superconductivity in magnetic fields much stronger than those that destroy this property in present-day commercial superconductors, which work only at lower, liquid helium temperatures.

Now IBM's Praveen Chaudhari, Robert Laibowitz, Roger Koch, Thomas McGuire, and Richard Gambino find that the inherent ability of the new materials to carry high currents is also good enough for commercial use. Not unexpectedly, they find the amount of current the material can carry increases as the temperature declines, so that at 4 K, liquid helium's boiling point, the critical current density for their sam-

CONTINUED NEXT PAGE

BREAKTHROUGH ... CONTINUED

a range of new medical diagnostic devices.

To be considered a true superconductor, a material must show two effects: loss of all resistance to electrical flow and display of the Meissner effect, the ability to repel a magnetic field.

Chu said the new material displayed the Meissner effect only in small regions. Earlier claims of superconductivity at comparably high temperatures lacked evidence of the effect.

Chu said he anticipates that modifications of the material or its manufacturing method could extend the region of Meissner effect to the entire material.

The new material is being developed through a collaboration of Chu's group with others at Lockheed Corp. and the National Magnet Laboratory in Cambridge, Mass.

Chu would not divulge the material's exact composition but said it differs from the general group of formulas that have led others to advances in superconductivity.

Chu said the new materials are not completely stable, sometimes losing superconducting properties if warmed and recooled.

He and other physicists expressed confidence that researchers can overcome this problem.

"Nobody before has been able to get both Meissner effect and zero resistance at the same time," said Brian B. Schwartz, professor of physics at Brooklyn College and a visiting scholar at the National Magnet Laboratory. "We are getting closer [to practical uses] every day."

Since last year, when scientists discovered a class of ceramics that became superconductors at higher temperatures than thought possible, developments in a once-moribund field of physics have occurred almost daily.

Physicists worldwide have raced to make new materials that act as superconductors at increasingly high temperatures.

Until recently, scientists said the two biggest obstacles to developing room-temperature superconductors were attaining the higher temperatures and getting the materials to carry large amounts of current.

Two weeks ago, IBM scientists announced that they had managed to get the ceramics to carry 10 times more current than before, making many applications more likely.

Much work remains to be done, however, for the materials to fulfill their promise. They are brittle and difficult to manipulate. For them to be useful, engineers must find a way to make flexible wires and microscopic films that can be deposited on computer chips.

Physicists working on the problems said they believe that the obstacles can be surmounted.

"The tantalizing thing is that having got it so high, there is no reason it couldn't go higher," Ashcroft said.

NATURE 21 - 27 MAY 1987 Pg. 178

British semiconductor company enters Japan's back door

London

WHILE most of the major US and European semiconductor manufacturers are doing battle with the Japanese, claiming trade malpractice through dumping and demanding greater access to the Japanese market, Inmos, the small British chip company, is selling its products in abundance to Japan.

Such is the group's success in Japan that a new company, Inmos Japan KK, has been formed to exploit what it considers to be an expanding market because of interest shown in the Inmos transputer, a revolutionary microchip design concentrating memory, computational power and communication links on one device.

The international arm of Japan's telecommunications network, KDD (Kokusai Denshin Denwa), has launched the first of the country's designs based on the Inmos device, an image-processing system, developed in conjunction with the image-processing equipment manufacturer Kashiwagi Laboratories.

Japanese interest in the transputer has given hope to Inmos, formed in the late 1970s with government funds to spearhead Britian's entry into a new semiconductor age, that it could break even in this coming year. The group, which has an arm in Colorado Springs in the United States and two in Newport in Wales, has been dogged with controversy, and financial problems. The project consumed more than £65 million in government funds and loans since it began and it was sold, in the autumn of 1984, to the British electronics group Thorn-EMI for £95 million.

The group then had to attempt to survive one of the worst recessions in the global semiconductor market. The group has been rationalized, retaining a development and design presence in the United States and about 400 people, and design and management expertise in Bristol and manufacturing in Newport.

Bill Johnstone

LONDON FINANCIAL TIMES
15 MAY 1987 Pg. 6

Plessey announces research success

By Terry Dodsworth

PLESSEY, the UK electronics group, announced yesterday that it had made a successful entry into superconducting materials, regarded by many scientists as the most significant area of current research in the electrical and electronic industries.

Scientists at the group's Caswell laboratory in the Midlands last week demonstrated superconductivity, a process which allows electrical currents to travel down cables with no power loss, at temperatures that would be suitable for commercial applications.

The group expected to step up its investment in the programme, from a "generous six figure sum" this year to seven figures in 1988. Plessey was also seeking to step up the scale of its programme by collaborative ventures, including work with Warwick and Oxford universities, and a major overseas industrial partner.

The attraction of superconducting materials is that they set up no resistance to electrical currents, a property that could yield enormous gains in areas such as the transmission of electrical power, or in developing much faster switching systems. Superconducting materials, however, only work at very low temperatures, and the current research effort is aimed at finding ceramic material formulas that would allow them to operate at closer to room temperature.

Several large multi-national groups have recently announced big breakthroughs, claiming to have demonstrated super conductivity at temperatures as high as +17 degrees C.

CAPACITY ... CONTINUED

ple is greater than 5 million amp per sq cm.

The IBM measurements were made in a single-crystal thin film of yttrium-barium-copper oxide measuring about an inch in diameter and 1 μm in thickness. The film was made using electron beam vapor deposition, and the crystal itself was epitaxially grown on a strontium-titanate substrate. As the individual atoms of the film are deposited on the substrate, they align themselves so as to match the crystal structure of the substrate as closely as possible, thereby producing a single-crystal film.

That the IBM sample is a single crystal accounts for the great jump in its current-carrying capacity, the researchers believe. "The reason that people in the past have not been able to get such high values is that the measurements were being done in polycrystalline materials," Present says. "Essentially what was happening was that you had this collection of crystals that each independently could sustain very high currents, but they couldn't pass these high currents from one crystal to the next. Material scientists feel confident they can overcome that problem now knowing that the material is indeed capable of sustaining such currents."

That a single-crystal film conducts a current better than a polycrystalline one is just one more difference between the new superconductors and the ones currently in use, such as niobium-titanium and niobium-tin alloys, points out Gilbert Y. Chin, director of the materials research laboratory at Bell Labs. In conventional superconductors, he explains, "the idea usually is that the more grain boundaries you have—the more defects you put into the material—the higher is the current-carrying capacity."

Although for some applications, such as microcircuitry, single-crystal films may be a suitable form for superconducting materials, many potential applications will require polycrystalline materials. "You can't make a single crystal hundreds of miles long for use in a cable," Present says. "The next challenge is to see how you can make polycrystalline materials exhibit that kind of current density." The new materials also have problems with inherent strength and brittleness that will need to be overcome before they will be practical for many uses. □

Details have been agreed for an unprecedented co-operative effort, **Louise Kehoe** reports from Dallas

Bid to make US world leader in semiconductor technology

THE US semiconductor industry has agreed an unprecedented co-operative effort to re-establish the US as the world leader in semiconductor chip technology.

By pooling resources and talents, with government backing, the US chip makers aim to accelerate development of chip production technology and overtake Japanese competitors.

The project, called Sematech, has received the industry's official approval with the unanimous vote of the Board of Directors of the Semiconductor Industry Association, a trade group representing the US industry.

After months of debate over the size and scope of the project, Sematech will now move ahead in top gear.

"We will begin efforts immediately to raise funds, to find executives to run Sematech and to select a manufacturing site," said Mr Charles Sporck, president of National Semiconductor, who has spearheaded the project.

"We aim to have it up and running by this fall. Sematech plans to produce its first chips by the second half of 1988 and to achieve parity with Japanese manufacturing technology by 1990."

The project is an ambitious one, Mr Sporck acknowledges. It is, however, "absolutely essential that it is launched without delay to stop the erosion of America's semiconductor industry by subsidised foreign competitors.

"As an industry and a nation, we must make leadership in micro-electronics a national priority."

The cost of Sematech, $1.5bn (£937m) over six years, is too much for any one company or even the entire industry to bear, Mr Sporck went on. The chip makers are seeking half the funds for their project from the US Government. Member-companies will, however, be required to contribute 1 per cent of their semiconductor revenues to the effort.

Originally, Sematech was to have involved the large-scale manufacture of memory chips, a market sector in which US manufacturers have lost out to Japanese competitors.

The prospect of a co-operative manufacturing organisation supported by government funds was, however, too radical for some of the industry's Washington supporters.

It was also proposed by key industry participants, including IBM and Texas Instruments, both of which have major memory manufacturing operations.

The final plan "represents the collective thinking of the industry. As competitors, we battle for markets and sales, but in our desire to see this industry succeed, we stand united," Mr Sporck declared.

With this bold decision, the US semiconductor industry is telling the world we are united in our determination to lead the industry we invented."

'Sematech plans to produce its first chips by the second half of 1988, and to achieve parity with Japanese manufacturing technology by 1990,' Mr Charles Sporck, (right) who spearheaded the project says

As described by Mr Sporck and a group of industry executives in Dallas, Sematech will set out to develop next generation semiconductor production processes, materials, tools and test equipment.

Member-countries will contribute funds and lend engineers—"the best in their fields"—to the project.

Sematech will set up its own pilot production line on which new technology will be proved, but will not manufacture commercial products. The product "vehicle" for Sematech technology will, however, be memory-chips, industry executives said.

Once developed, Sematech technology will be made available to member-countries. The success of the projects will depend heavily on the effective transfer of technology to its members.

This transfer has proved to be a pitfall for other co-operative research efforts, but Sematech which will undertake development of commercially applicable processes and equipment, should face less problems, Mr Sporck believes.

CONTINUED BELOW

Sematech may licence non-members to use its technology, but the US industry group aims to provide American companies with an advantage over foreign competitors. Only US companies will be eligible to join Sematech.

Further restrictions on the the transfer of Sematech technology might be imposed by the US Government, if it provides funds for the project.

While Sematech supporters are confident they will win government backing, probably through the Department of Defence which is increasingly concerned about the health of an industry which supplies critical components for weapon systems, it remains to be seen what "strings" may be attached to government funds.

Already, semiconductor industry executives acknowledge that foreign nationals working in the US semiconductor industry may be precluded from working at Sematech. This represents a real limitation, since half of all electronic engineering doctorate graduates in the US are foreigners.

Government overview of Sematech should be at arm's length, industry executives say. But they may be forced to accept much closer Defence Department involvement in the direction of the project.

Until the industry presents its Sematech plans in Washington, it is impossible to predict what the "price" of government funding will be.

The issue of government regulation of Sematech may be critical. Key participants in the project, including US semiconductor production equipment makers, are reluctant to accept close government involvement.

Critics of Sematech also say that the value of the project would be significantly reduced if it is directed towards military rather than commercial application.

Another hurdle still to be overcome by Sematech is to win the wholehearted support of the US semiconductor production equipment and materials industries.

Although it seems unlikely that these suppliers to the chipmakers would decline the business opportunities raised by Sematech, some of the biggest buyers of US equipment are Japanese, and the production equipment makers have been reluctant to take sides in the US-Japanese chip battle.

Sematech does, however, have some powerful supporters, including IBM, which has strongly allied itself with the project.

As both a major buyer of chips and a major producer, IBM has a strong interest in the future of both the semiconductor production equipment and the semiconductor industries in the US.

IBM's endorsement of Sematech, along with that of other major US computer and electronics companies, has helped persuade Washington law makers that what is at stake in the declining competitiveness of the US chip market, is much more than the future of the relatively small semiconductor industry.

"There is increasing recognition in Washington of the dependency of broad industry sectors on semiconductors," Mr Alan Wolff, the semiconductor industry's Washington Counsel, said.

Already Sematech has won broad support in Washington and appropriations for the project have been included in defence and trade bills.

With its approval of an operating plan, the industry will now begin an intense lobbying campaign to obtain full funding. Legislative actions may also be needed to clear anti-trust barriers.

To maintain the momentum behind Sematech, 13 of the leading US chip makers, who are represented on the board of the Semiconductor Industry Association, have agreed to provide start-up funds of a few million dollars.

Most if not all of the 13 companies are expected to become members of Sematech.

They include Intel, National Semiconductor, Advanced Micro Devices, Monolithic Memories, LSI Logic, Texas Instruments, and Motorola.

Also involved are Harris and Rockwell, IBM, Digital Equipment, Hewlett Packard and AT & T. Eventually, Sematech may have as many as 30 member-companies.

MILITARY SPACE
8 JUNE 1987 Pg. 8

Superconductors

Scientists at the Air Force's Rome Air Development Center are working to mate new electronic devices with new superconducting materials for SDI applications.

If successful, these superconducting devices would allow targets to been seen more easily and in greater detail. In certain applications such as space-based radars, this greater image resolution could discriminate the masses of missile warheads and decoys.

"The purpose of our program is to employ superconductive electronics in Defense Dept. systems operating in excess of 100 gigahertz," said Dallas Hayes of RADC's SDI Science and Technology Office. The Air Force's most advanced technology — monolithic microwave integrated circuits (MMIC) — operates in the range below 100 GHz.

Superconductors provide efficient speed-of-light electronic transmission without the accompanying heat loss found in conventional electronics.

Since superconductivity is such a new field, no systems have been built to prove the high frequency theory. But Hayes remains a believer. "We have the theoretical basis to make the claim that high frequencies would increase discrimination and make it easier to tell real warheads from dummies," he said.

Hayes and others at RADC currently are working on six SDI superconducting projects as part of its terahertz technology program. RADC is developing an electronic receiver, analog signal processor, and analog-to-digital converter out of superconducting materials.

Hayes' basic research uses a superconductor made of niobium nitride that operates at 10°Kelvin. Once the basic research is completed, the process will be transferred and different devices made from the recently discovered, higher temperature materials.

★★★

Interest in superconductors is not confined the Air Force. The Army Strategic Defense Command is exploring the new materials for use in highly efficient electrical power storage systems for ground-based free electron lasers. Meanwhile, **top Navy officials have hinted at their interest in basing superconductor sensors in deep space to detect and track Soviet submarines.**

NATURE
4 JUNE 1987 Pg. 356

Japanese poised to dominate in superconductors as well?

Tokyo

WHAT is happening in high-temperature superconductor research in Japan? Is Japan Incorporated ready to conquer the world? Not yet. Research is under way on a broad front but is largely uncoordinated, as government agencies and ministries manoeuvre to stake out territory and preserve their interests.

Since a group of researchers at Tokyo University confirmed superconductivity at about 30 K in a copper-oxide ceramic at the end of last year, research on the new materials in Japan has exploded. The April and May special issues of the *Japanese Journal of Applied Physics* contain nearly 200 papers on the new superconductors by several hundred scientists in about 80 laboratories throughout Japan. And barely a day goes by without the announcement of another 'breakthrough'.

Much of the effort, however, involves unnecessary duplication. On 4 March, the Science and Technology Agency's National Research Institute for Metals in Tsukuba announced that it had succeeded in making a high T_c ceramic, only to find that the same announcement had been made the day before by its Tokyo research institute. Researchers at the two laboratories were apparently unaware that they were making the same ceramics even though both had representatives on the agency's research committee on high-temperature superconductors. The committee, with representatives drawn from the universities, industry and the agency's laboratories, was formally set up in February but began informal meetings at the end of last year. The committee's principal job is to organize workshops and symposia; the first symposium was held on 1 May with I. Bednorz of IBM Zurich as guest speaker.

According to Koichi Kitazawa of Tokyo University, one of the committee members, the Science and Technology Agency has been very quick off the mark and has played an important role in disseminating news. The right 'atmosphere' to win financial support from the Ministry of Finance is being created. The new superconductors also provide a golden opportunity to boost the agency's National Research Institute for Metals whose fortunes have been declining along with those of the iron, steel and aluminium industries. On 28 May, the agency announced the establishment of a 50-man research centre at the Tsukuba site next spring to carry out basic and applied research on the new ceramics.

When it comes to funding research, though, the agency has been beaten off the mark by, surprisingly, the Ministry of Education. Casting aside its conservative image, the ministry has taken the extraordinary step of extending a major fixed-term grant, something that has only previously been done in the case of a natural disaster. A special research project to investigate new superconducting materials headed by Professor Nakajima of Tokai University (formerly of Tokyo University) is to be extended at a cost of Y180 million ($1.3 million). In addition, Professor Kazuo Fueki of the Tokyo University group has been awarded Y36 million by the ministry for this fiscal year (April 1987–March 1988). And Professor Shoji Tanaka, leader of the Tokyo University group, is a strong candidate for one of the ministry's special distinguished grants which are announced at the end of this month. Running from three to five years, the grants are usually worth Y100–200 million (about $1 million).

But the biggest government backer of technology development, the Ministry of International Trade and Industry (MITI), has yet to show its cards. MITI has long been a strong supporter of superconductor research. Companies such as Toshiba and Hitachi, nurtured in MITI's magnetohydrodynamic project, and aided by Japan National Railway's bid to build a high-speed train levitated on superconducting magnets, have gone on to supply many of the magnets for US particle accelerators. Josephson junction research has also been supported within the national supercomputer project. Although US companies, including IBM, abandoned similar work, researchers at NEC, Hitachi and Fujitsu remain confident that a Josephson junction computer can be built by the twenty-first century.

MITI money is also being funnelled to private companies through the Electric Power Central Laboratory in Tokyo, thereby allowing eight companies all to continue production of conventional superconducting wire, despite the comparatively small size of the Japanese market. It was from them that the first reports of the manufacture of high-temperature superconducting wires emanated. First off the mark was Fujikura Densen with La-Sr-Cu oxide encasedin drawn-out tubes of copper and steel. Then on 2 April, Toshiba released pictures of wire

CONTINUED NEXT PAGE

DOMINATE...CONTINUED

fashioned from Y-Ba-Cu oxide. Although the current-carrying capacity of the wire was initially very low (a few amps per square centimetre), within a month Toshiba had reached 520 A cm^{-2} and now Hitachi claims the record at 4,000 A cm^{-2} for ceramic wire (0.8 mm diameter) encased in silver.

Despite these projects, however, MITI has yet to formulate a policy on the new superconductors. Some of the problems are internal. There are fears that a new project may siphon off funds from projects already established — to the Ministry of Finance, superconductors are all the same be they ceramic or otherwise.

After a hearing of the science and technology committee in the lower house of the Diet on 28 May, Professor Shoji Tanaka called for a national project to develop applications, such as a magnetically levitated train. Also present at the hearing was Yoshihiro Kyotani, head of Japan's linear motor car (MAGLEV) project. But ruling party politicians suggested that the project should be international and might even be proposed at the Venice summit next week.

Tanaka denies that he is suggesting that Japan set up a research association similar to the well-known VLSI (very large-scale integrated circuit) project of the late 1970s which drew together Japan's electronics giants with MITI support and helped power the conquest of world semiconductor memory markets. But it is no secret that Tanaka has close connections with Japanese industry, in particular Toshiba and Hitachi where several of his present and former students carry out research.

Other scientists who are on the government/industry university committee established by MITI to study the new superconductors doubt that the ministry will form a research association. Rather, they think that a medium-scale project under the category "basic research for future industries" may be possible. These projects which cover new materials, biotechnology and new molecular devices (including biochips) typically receive funding of a few thousand million yen (around $10 million) per year. But the earliest such a project could be set up would be 1988, and consensus would have to be reached in MITI within the next few months.

Meanwhile, research in industry is largely "free-style" with no particular coordination, government or otherwise, according to Dr Janshen Tsai, supervisor of the advanced device research laboratory at NEC. NEC has fewer than 10 researchers working full-time on the new superconductors but there are about 30 or 40 part-timers and many more are interested in joining the research, which covers primitive Josephson junction devices and thin films.

Researchers at Toshiba's Research and Development Centre in Kawasaki, on the other hand, seem to be interested primarily in wires and thin films, and they have no intention of pursuing Josephson junction research. Osamu Horigami, Toshiba's chief research scientist at the centre's energy science and technology laboratory, has 28 researchers working on superconductors and cryogenics and they are collaborating with scientists in the metals and ceramics laboratory of the same centre. Horigami says his laboratory began investigating superconducting ceramics about six years ago in collaboration with Professor Tanaka of Tokyo University — but they gave up when they reached a critical temperature of only 18 K.

How much money are these companies putting into the research effort? Company officials will quote only the percentage of total sales devoted to all research and development (8–7 per cent for Toshiba and 10 per cent for NEC). But Dr Ushio Kawabe of Hitachi says that in general they budget about Y10 million ($70,000) per researcher per year.

Patents are being sought apace. Sumitomo Electric Industries, a large wire and cable manufacturer, is reported to have applied for 800 patents on superconducting technology covering materials, processing and application. Many of the leading researchers in Japan have also taken out patents, although nobody knows who was first.

Tanaka fears that Japan may once again be criticized for failing to contribute to basic research. He and his colleagues have been publishing heavily to make the world aware of their efforts as students grind out ceramics in the laboratory (now up to processing 48 samples a day). And to drive home the point, 1,000 copies of the April special issue of the *Japanese Journal of Applied Physics*, weighing 0.7 tonnes, were airfreighted to the United States and distributed free of charge at the Material Research Society meeting in San Francisco. Mitsui Co Ltd agreed to cover the Y3 million ($20,000) air freight costs as a "contribution to basic science".

Other Japanese researchers are less concerned about such matters. "Our interest is how to get wire and devices using this material", says Horigami of Toshiba.

David Swinbanks

INSIGHT 25 MAY 1987 Pg. 14

Breakthroughs Turn Up Heat in Superconductor Research

SUMMARY: The low-temperature peculiarities of certain materials were discovered in 1911, but until last year they remained mostly curiosities for theorists exploring the surreal realm of atomic behavior in the absence of heat. Now, major research developments are leap-frogging other major developments, and all the theorizing seems to be about to give way to practical applications for superconductivity.

Imagine that you could accelerate to 55 mph on Interstate 80 out of New York City, then shift into neutral, kill the engine and coast all the way to the rising spires of the Rockies without slowing down. This may seem fantastic, but it would be even more fantastic to imagine an electric charge traveling the same distance in much the same way. Yet that is what superconductivity is, a phenomenon that exists in electric current at extremely low temperatures.

Under normal conditions, when current flows through a wire, resistance slows it and heats the wire, in much the same way that friction in the bearings and in the tires against the road slows a car and heats those surfaces.

In the real world, nothing ever gets from here to there without paying for fuel, or as scientists and economists are so fond of saying, there is no such thing as a free lunch. But close to absolute zero, the coldest temperature that scientists can imagine, resistance disappears. As a result, superconductivity is "about as close to perpetual motion as one is likely to get," in the words of physicist J. Robert Schrieffer of the University of California at Santa Barbara.

In the theoretical world of absolute zero, molecular motion would be so greatly reduced that thermal energy would vanish. Temperatures here are measured on the Kelvin scale, which has its zero at absolute zero (minus 459.67 degrees Fahrenheit) and degrees the same size as the Celsius degree. Thus 32 F, the freezing point of water, is 273.15 K; the boiling point of water is 373.15 K (212 F).

Scientists have run currents in circular wires at temperatures approaching 4 K (minus 452 F), and years have not diminished their flow. "These currents," says Schrieffer, "could flow for longer than the age of the universe."

Until last year, superconductivity was strictly a laboratory phenomenon because the required temperatures were impractical for everyday use. The only way to cool the wires to superconducting temperatures was to immerse them in liquid helium. "At $3 to $7 per liter, about the cost of cheap whiskey, that's much too expensive to use on power lines," says Paul C.W. Chu of the University of Houston, a leading superconductivity researcher.

Scientists had theorized that superconductivity would be impossible at temperatures that would make it economically feasible. So when Chu announced Jan. 29 that he had raised the maximum superconducting temperature (the "critical temperature") by 55 degrees, to 95 K (minus 288 degrees F), the shock waves hit the scientific community as deeply as when Chuck Yeager broke the sound barrier.

The industrial community was excited as well. Now liquid nitrogen — only 19 cents per liter — could replace liquid helium as the coolant. This could revolutionize the way we handle electricity. Electric motors and computers can shrink in size and grow in power. Levitating trains will go 300 mph. New kinds of batteries will store a lot more energy, in the form of superconducting current.

Chu thinks, but has not yet proved, that he has materials that will be superconducting at temperatures near zero degrees Fahrenheit (255 K), where household applications of superconductivity become possible.

High-temperature superconductivity is made possible by new materials, half-metal ceramics called superconducting oxides. These materials are like sandwiches piled high on top of one another. In the original oxide, each sandwich contained layers of copper and oxygen separated by layers of such elements as lanthanum, barium and oxygen. Finding superconductivity in these materials was quite surprising; they normally are poor conductors of electricity — "almost insulators," says physicist Brian Schwartz, education officer for the American Physical Society.

Intrigued by this apparent contradiction, scientists all over the world had been working with these sorts of materials since the accidental discovery of superconducting properties in closely related oxides, in 1973. But no real progress was made until January 1986, when J. Georg Bednorz and K. Alex Muller of the International Business Machines Corp. research laboratory in Zurich raised the maximum superconducting temperature to 30 K.

Word got out late last fall, sending scientists scrambling. Chu dropped his other research projects immediately to devote full time to superconductivity.

By pressurizing a superconducting oxide, he raised the critical temperature to 70 K. This suggested that compressing the layers together was raising the critical temperature. But this strategy was not going to commercialize superconductivity because pressurizing wires is impractical on an industrial scale.

Instead, Chu brought the layers closer together by replacing the barium with the similar element strontium, which has a smaller atom. This step raised the critical temperature from 30 K to 40 K without pressure. Then he replaced lanthanum with yttrium, which brought the layers still closer but also drastically rearranged their order and composition. The critical temperature shot up to 95 K, and a revolution was born.

Within three months, IBM had unveiled a superconducting device that measures faint magnetic fields. Other electronic applications may soon follow. Nonetheless, two serious technical obstacles remain before superconductivity can achieve wide use. The first problem is that the brittle, glasslike oxides can neither be molded into coils for electric motors nor laid out as power lines with any confidence that they will hold up. But researchers at AT&T Bell Laboratories are developing coils by filling thin-walled copper tubing with powdered superconducting materials.

Second, the new materials cannot support enough current to serve as power lines or coils. Conventional electric wires transport 100 times more current than superconducting oxides.

This problem is fundamental. A current is composed of electrons, the tiny particles that normally orbit within their parent atoms. Strong conductors such as lead and copper have very loosely bound outer electrons that can break free to flow as electric current. Conversely, insulating materials have no loosely bound electrons. Semiconductors have very few loose electrons, and this limits current-carrying capacity in the normally semiconducting oxides.

Some scientists are trying to mold better conductors into high-temperature superconductors. Others are trying to design

CONTINUED NEXT PAGE

INSERT

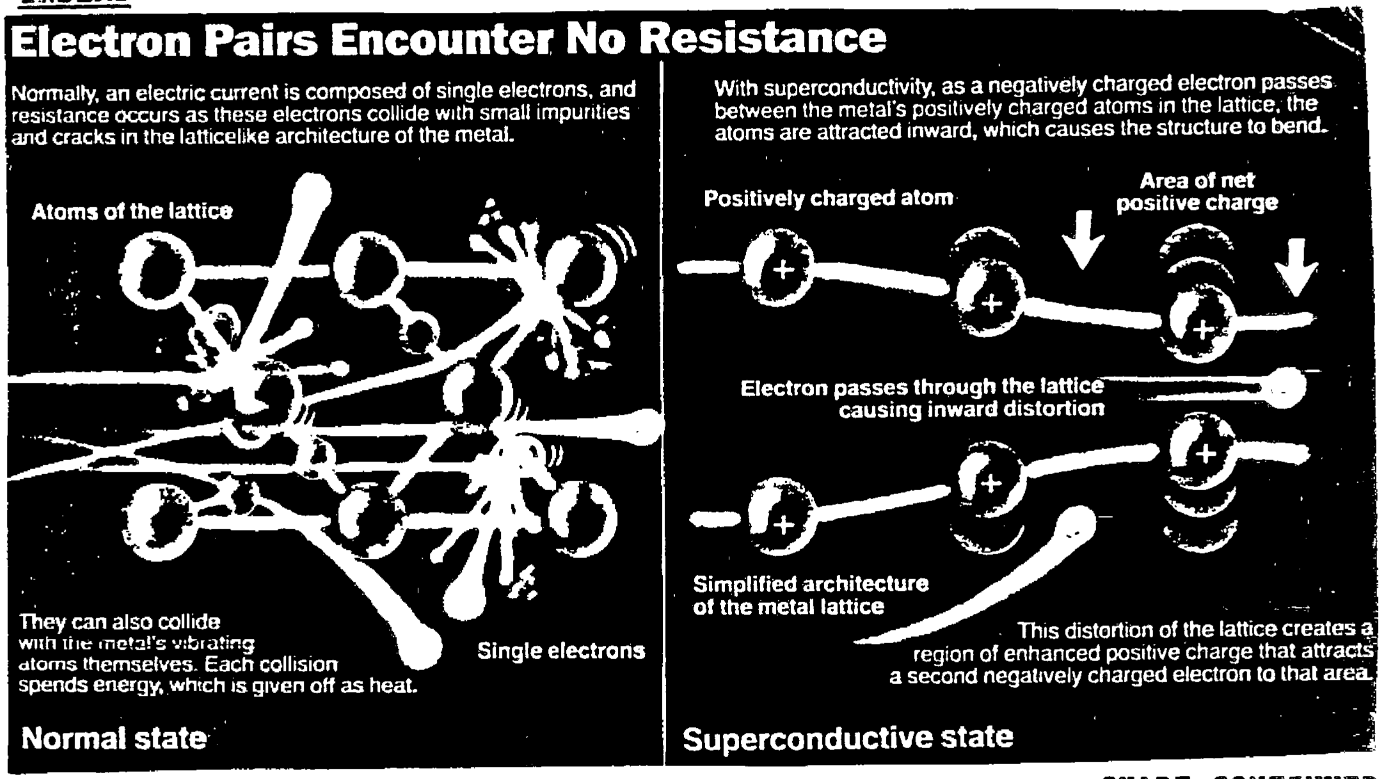
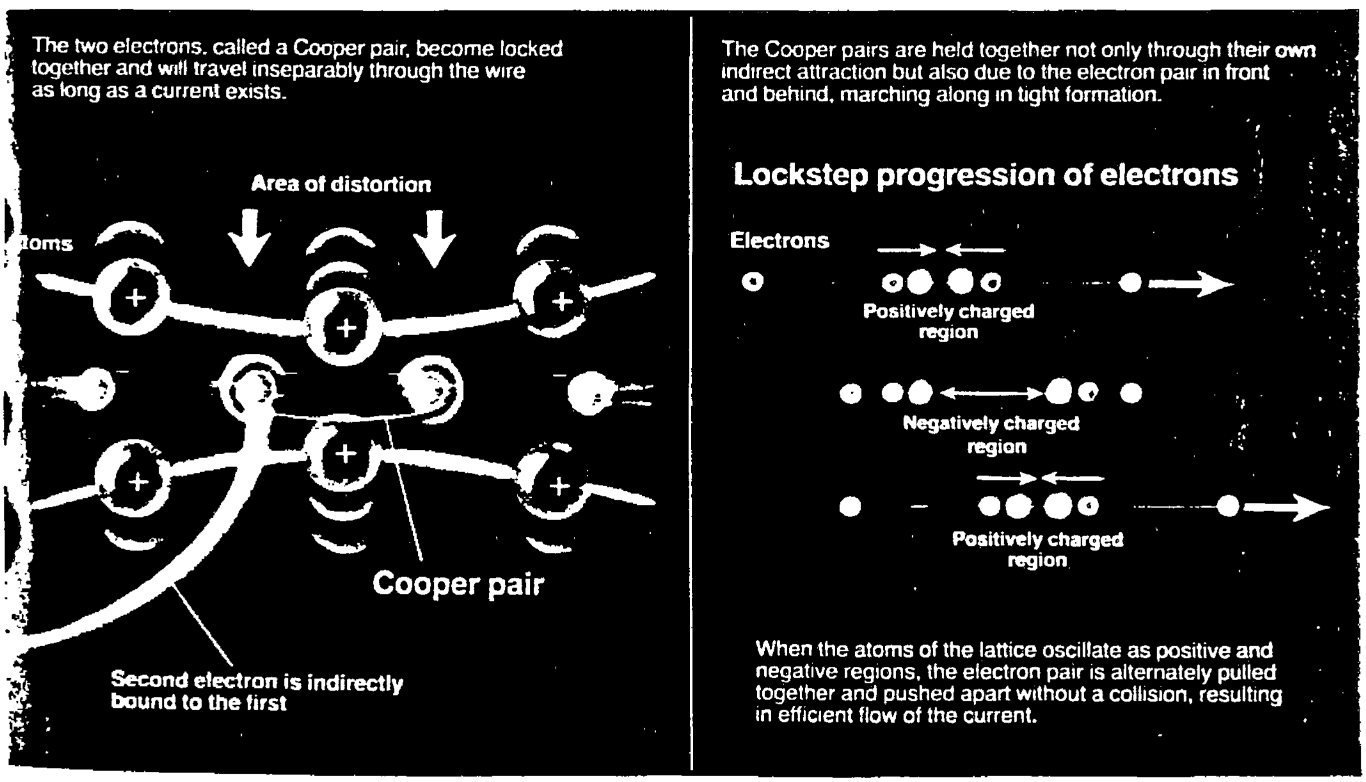


CHART CONTINUED BELOW



ARTICLE CONTINUED NEXT PAGE

BREAKTHROUGHS...CONTINUED

more powerfully conducting oxides. Researchers at IBM believe they may have solved the problem with the creation of a new ceramic that can handle as much current as standard copper wire, although their discovery has yet to be substantiated.

Extreme cold makes metals become superconductive. Heike Kamerlingh Onnes discovered superconductivity in 1911, in the course of experiments in which he had liquefied helium. Helium gave him a unique experimental tool with which to cool the wires; it liquefies at nearly absolute zero.

To understand what this means, imagine an explorer who could shrink to a fraction of the size of an atom. At this size, the adventurer could climb into different materials to find out how their atoms are held together. Climbing into a wire, which is a crystalline structure, he would feel as if he were climbing into a vast jungle gym, the bars holding the atoms in place at their junctions.

But these bars are unlike the bars of any ordinary jungle gym. They are force fields that bounce like springs, the atoms at either end always vibrating back and forth. Always, that is, except at absolute zero. The vibration is heat energy. As the temperature drops, the vibration diminishes, until at absolute zero, it ceases altogether. (Conversely, at the temperature at which a substance melts, the vibration becomes so intense that it weakens the bonds between atoms — the bars of the jungle gym stretch.)

Kamerlingh Onnes had theorized that as he obtained purer metals and colder temperatures, electricity would flow ever more freely, until at absolute zero there would be nothing to stop it. Observing the flow of a current, the subatomic explorer would see why this might be so:

Electrons flow suspended in the outer reaches of the force fields that hold atoms together. They would flow unimpeded if every atom in the crystal lattice remained in place and out of their way. But impurities — foreign atoms — create one set of obstacles by distorting the lattice and by sticking out themselves like cones on a highway. The vibration of atoms in and out of their proper positions creates another set of obstacles. Electrons collide with these misplaced atoms, making the lattice vibrate harder, heating the wires and slowing the flow of the current.

But resistance did not diminish gradually as temperatures approached absolute zero and as purity increased. Instead, Kamerlingh Onnes found — using wires of mercury — that resistance disappeared altogether quite suddenly at 4 Kelvin degrees above absolute zero. Nor did impurities change the temperature at which the material became superconducting. "He fell out of his lab chair when he saw that," says Schwartz.

Nearly 50 years would pass before John Bardeen, Leon N. Cooper and Schrieffer would develop their Nobel Prize-winning theory on the resolution of this puzzle. They would find that the lattice vibrations make superconductivity happen.

In the 1930s, physicist Fritz London painted the first broad picture of how superconductivity might work. He theorized that electrons move as a unit, like the coupled cars of a train, rather than independently like cars on a highway. Bardeen, the senior scientist of the Nobel team, found this idea compelling because it seemed that it could prevent obstacles from deflecting individual atoms. "Imagine kicking a ball that rolls your way," says Schwartz. "It goes flying. Now imagine kicking a ball that is part of a line of balls all connected by springs. Your kick won't deflect it."

This idea presented several theoretical problems. First, electrons have negative charges, and the atoms of an electric conductor have positive charges. This means that they attract each other like the north and south poles of magnets, but the electrons all repel one another. It was difficult to imagine a force that could overcome that repulsion to make the electrons act as a unit.

But in the early 1950s, Herbert Frohlich and David Bohm figured out a way in which electrons might attract one another indirectly, a theory Bardeen subsequently refined. Vibrations in the lattice are the key to this attraction. As the negatively charged electron flows through the wire, it attracts the positively charged atoms of the lattice, pulling them together as it passes. This pinches the lattice. The pinch follows the path of the electron, traveling down the lattice in a wave like the wave that can be set up in a rope with a flick of the wrist.

The concentrated positive charge in the pinch attracts negatively charged electrons in the path of the first electron, much as the draft of a large truck can pull other vehicles along the highway. This reaction was thought somehow to unify the current.

Exactly how was the second problem. In the world of subatomic particles, the forces of nature operate very differently from the way they do in the world we experience. In fact, some of the laws of this subatomic world make no sense at all to our intuitions. One such law is that no two electrons in a current can have the same velocity. This is like saying that no two cars on a highway can travel at the same speed. Under this condition, it was hard to imagine how electrons could flow in a coordinated manner. (One theoretical result of this principle, says Schwartz, is that when the number of neutrons inside a neutron star becomes so great that they cannot retain different velocities, the star blows up.)

Cooper and Schrieffer provided a solution to this problem. It was a two-step process. First, Cooper figured out that the vibration of the lattice does not directly unify the entire current. Instead, it creates pairs of electrons (christened Cooper pairs) that act as if they were single particles.

Then Schrieffer discovered a corollary to the laws that govern the subatomic world, a corollary that allowed the pairs to travel in lockstep. As the laws require, each member of a pair has a different velocity from its partner, as well as from all the other electrons in the current. But every pair has the same collective velocity as every other pair. (To stick together, members of a pair constantly change their velocities, as if they were attached to one another by a spring.)

It is this militarylike formation that can keep a superconducting current flowing forever. Obstacles that send single electrons careening are powerless against the force these electrons attain when they condense into a superconducting current. "Imagine soldiers crossing a field," says Schwartz. "If they link arms in formation, one can step in a rut, the others will hold him up and everyone will keep going."

How high-temperature superconductivity works remains an enigma because above 33 K or so, the lattice cannot vibrate quickly enough to create Cooper pairs. "There are as many theories as you can make phone calls," says physicist Douglas Scalapino of the University of California at Santa Barbara. Most of these are derivatives of the Bardeen-Cooper-Schrieffer theory. Electrons still form Cooper pairs, which condense into a superconducting current. But something has to be vibrating much faster than a lattice in order to pull everything together.

One typical theory suggests that this vibration is electronic. Copper oxides, present in the new superconducting materials, have positively and negatively charged ends, the way magnets have poles. The passing electron is thought to shift this polarity, creating an area of strong positive charge in its wake. This charge, like the positive charge generated in superconducting metals by the pinching of the lattice, could set up Cooper pairs that could condense into a superconducting current. The theory, however, fails to explain several other observations about high-temperature superconductivity.

As scientists wrestle with inadequate current and brittle materials — the technological problems of bringing superconductivity to commercial fruition — they expect a better understanding of how high-temperature superconductivity works to help them find solutions. "We thought we were going to have to break physical laws to get from 41 [K] to 171 degrees," says Schwartz. "By comparison, bringing this new technology out of the lab and into everyday use should be relatively straightforward."

— *David Holzman*

NATURE 4 JUNE 1987 Pg. 357

Superconductivity at room temperature

New Delhi

SCIENTISTS at the National Physical Laboratory (NPL) in New Delhi are proudly claiming to have found the hottest ever superconducting oxide phase. It shows superconductivity all the way up to +26 °C (299 K), or room temperature.

The development was officially made public before publication in a scientific journal in an attempt to ensure its legitimate place in the race in superconductivity both in India and elsewhere. Indian scientists frequently complain that although they are keeping pace with the latest developments in Japan and the United States, their work is often dated by the time it is printed in international scientific journals.

The NPL discovery was made in multiphase samples of $Y(Ba,Sr)_2Cu_3O_x$ prepared by the direct oxide-mixing technique. The typical resistance-versus-termperature curves show a sharp drop in resistance above 230 K followed by a gradual metal-like decrease of resistance with temperature. A study of the inverse a.c. Josephson effect revealed the presence of a phase superconducting up to +26 °C. "It is the hottest superconducting phase observed so far", said Dr A.V. Narlikar, the leader of the NPL team.

Because the sample had many phases, the studies were repeated in several different samples. In each of them, superconductivity was found to persist up to temperatures of 15 to 26 °C, said Narlikar. Studies also showed that the 26 °C phase constituted the bulk of the sample. Narlikar said his team is now working on isolating this phase. "When we do that, we will really have a room-temperature superconductor", he said. K.S.Jayaraman

Just five years from superconductor cable

Washington

THE US Department of Energy (DoE) is showing unusual alacrity in pushing for research on the new superconductors. Motivated by constant but uncertain rumours of furious Japanese activity, DoE officials have taken some considerable steps towards an organized national effort in this new technology.

A series of conferences to promote collaboration between the national laboratories, universities and industry is already under way, but DoE has now gone beyond this cheerleading role and has given Argonne National Laboratory a specific brief to produce a practical superconducting wire, operating in liquid nitrogen, in five years. (Argonne researchers have already made 'wires' by embedding superconducting grains in a plastic base.) The aim of the programme, in which Brookhaven and Ames (Iowa) Laboratories will also participate, is to make a cable suitable for electric transmission lines.

DoE also announced last week that it is setting up a computerized database to help US scientists to cope with the huge flow of results. Secretary of Energy John S. Herrington said that the normal channels of scientific communication are being overwhelmed, and that the DoE, by expanding its existing systems, could expedite the flow of information. The database will be accessible through electronic mail, and will be open to anyone who pays an entry fee.

The impetus for these initiatives is apparently coming from the top. At DoE headquarters, 'research applications' and 'Japan' are whispered in the same breath, and the current political climate is ideal for any venture which seeks to encourage US industry. David Lindley

SUPPLEMENTAL CLIPS DISTRIBUTION LIST

NEW LIST

JUNE 1, 1937

AIR FORCE AF/CC*
4E-925 (1)

AIR FORCE AF/CVAZ
5D-544 (1)

AIR FORCE AF/CVAE
SGT HAYNES
4E-949 (3)

AIR FORCE AF/DP
4E-211 (1)

AIR FORCE AF/DW-CC
BOLLING AFB (1)

AIR FORCE AF/IG
4E-1076 (1)

AIR FORCE AF/IN
4A-932 (1)

AIR FORCE AF/LE
4E-260 (1)

AIR FORCE AF/PR
4E-1020 (1)

AIR FORCE AF/RD
4E-334 (1)

AIR FORCE AF/RE
5E-916 (1)

AIR FORCE AF/SA
1E-388 (1)

AIR FORCE AF/SC
5B-482 (1)

AIR FORCE AF/XO
4E-1032 (1)

AIR FORCE SAF/AA*
4D-881 (3)

AIR FORCE SAF/ALR
4D-977 (1)

AIR FORCE SAF/FM
4E-990 (1)

AIR FORCE SAF/GC
4E-998 (1)

AIR FORCE SAF/LL
4D-923 (1)

AIR FORCE SAF/LLR
5D-934 (1)

AIR FORCE SAF/MI
4E-856 (1)

AIR FORCE SAF/OS
4E-874 (2)

AIR FORCE SAF/OSX*
5C-858 (1)

AIR FORCE SAF/PA*
4D-922 (4)

AIR FORCE SAF/RD&L
4E-964 (1)

AIR FORCE SAF/US*
4E-886 (1)

ARMY SA/PA*
2E-636 (10+15)

ARMY SA/US-D
3E-721 (1)

CIA*
(1)

DIA
DIC-RDIAC, C3757 (1)

DIA DIRECTOR
3E-258 (1)

DMA M/G R ROSENBERG
US NAVAL OBSERVATORY
BLDG 56 (58-1)

JCS ASST/CJCS*
2E-864 (4)

JCS SHAPE/LNO*
1A-711 (1)

MC/CMC*
2004 (1)

MC/PA*
1136 (1)

NAVY CHINFO*
2E-340 (7+25)

NGB-PA
2E-258 (2)

NSA/NCRDEF*
2A-256 (1)

OSD ASD/C (A)
3E-843 (1)

OSD ASD/C
3E-822 (1)

OSD ASD/C31
3E-172 (1)

OSD ASD/FM&P
3E-759 (1)

OSD ASD/HA
3E-346 (1)

OSD ASD/LA*
3E-966 (1)

OSD ASD/PA*
2E-800 (3+12)

OSD ASD/PA-NISI*
2E-800 (20)

OSD ASD/P&L
3E-808 (3)

OSD ASD/RA
3E-326 (1)

OSD DFOISR
2C-757 (1)

OSD HISTORIAN
5C-328 (2)

OSD OATSD/AE
3E-1069 (1)

OSD OD/PA&E
2E-313 (1)

OSD OD/PA&E
TAC AIR DIV (1)2C-281

OSD OIG/DOD*
1E-482 (1)

OSD SEC DEF*
3E-880 (17)

OSD USD/P
4D-825 (18)

OSD USD/A
3E-1006 (3)

OSD USD/RE/P&A
3D-373 (3)

RAND CORP*
(7)

SDIO*
(1)

VICE PRES*
WHITE HOUSE (1)

Science & Technology

Sci & Tech.

WASHINGTON POST
15 FEBRUARY 1987 Pg. C7

George F. Will

The Super Collider

After hearing scientific arguments for, and budgetary complaints about, the proposed $4.4 billion atom smasher, President Reagan swerved the discussion into an anecdote. He recalled Jack London's personal credo:

I would rather be ashes than dust,
I would rather my spark should burn out in a brilliant blaze,
Than it should be stifled in dry rot.
I would rather be a superb meteor,
With every atom of me in magnificent glow,
Than a sleepy and permanent planet.

Then Reagan said that London's credo was once read to Ken Stabler, the pro quarterback, who was asked what it meant. Stabler said: "Throw deep." Stabler was right. So was Reagan in endorsing the Superconducting Super Collider (SSC). Now the future of elementary particle physics is in the hands of Congress.

Congress willing, the SSC will be a tunnel in a circle with a 52-mile circumference. Atom smashers are, in effect, gigantic microscopes for peering into the heart of matter. In the SSC, counter-rotating beams of protons, each beam traveling at nearly the speed of light, will be steered by magnets into collisions. Only a few of these protons will collide, producing a shower of other subatomic particles. The characteristics of the resultant particles will be measured, often in intervals of billionths of seconds.

In order to probe into nature's smallest simplicities, progressively more gigantic and complex devices must employ progressively higher energy. The higher the energy, the finer the scale of investigation. In this century, we have progressed downward in scale, from atoms to nuclei to protons and neutrons and electrons, then to quarks and leptons, which seem—so far—to be the elemental constituents of matter.

The more energy is contained in the space where particles collide, the better the chance the energy will be transformed into new forms of matter. Fermilab, a particle accelerator in Batavia, Illinois, can create collisions yielding 2 trillion electron volts. The SSC will yield 40 trillion.

The collisions in the SSC should replicate energy and temperature conditions in the first fraction of a second at the creation of the universe. This should yield knowledge about the four known basic forces of nature: gravity, electromagnetism, the weak nuclear force responsible for certain radiation decays and the strong nuclear force that binds atomic nuclei. And perhaps the SSC will yield evidence about the Grand Unified Theory, the theory that the four forces form a single unified force.

Fundamental science such as high-energy physics inevitably has large economic and, more important, cultural effects, including effects on mankind's moral sensibility. And the SSC, the largest and costliest experimental device ever, will have a profound effect on science.

When Congress comes to consider approval of the SSC, it should bear in mind that many of America's foremost scientists were born elsewhere and came here to be on the moving frontiers of science. The sociology of scientific enterprise is complex, but this is clear:

CONTINUED BELOW

the momentum generated by synergism among scientists, spanning generations, can be quickly dissipated. It can be forfeited by government negligence and philistine parsimony in scientific investment.

The first cyclotron was at Berkeley in 1930. It was five inches in diameter. Until recently, America clearly led the world in high-energy physics research. In this decade, Europe has secured the lead, with the Soviet Union rising rapidly. The SSC will make America's particle physicists preeminent in the competition to understand the ultimate constituents of matter and the forces that bind those constituents to form the universe.

Roy Schwitters, Harvard physicist, says: "High-energy physics is the ultimate extension of man's curiosity about what things are made of and how they work." Such physics is increasingly interwoven with cosmology because of the "big bang" theory of the origin of the universe.

Approximately 15 billion years ago, when the universe was a nanosecond old, hitherto unapproachably high temperatures decomposed matter into its most primitive constituents. As the universe cooled, matter resulted. Understanding the nature of these constituents and processes is essential to understanding the history of the universe since creation.

Given the grandeur of this intellectual undertaking, it is demeaning to justify the SSC in terms of economic benefits. Suffice it to say there will be benefits and we cannot now know what they will be.

Who in the 1860s thought the synthesis of electricity and magnetism, and discovery of the laws of electromagnetic waves, would produce today's communication technologies? Who in the 1920s could imagine that quantum mechanics would produce the semiconductor industry? Applications of the two intellectual revolutions of the 20th century—quantum theory and relativity—account for a significant portion of today's gross national product.

When Reagan ended the meeting by saying, "Throw deep," thereby signaling his support for the SSC, James Miller, head of the Office of Management and Budget, said: "You're going to make a lot of physicists ecstatic." Reagan replied, "That's probably fair, because I made two physics teachers in high school very miserable." Reagan likes to say, "You ain't seen nothing yet." The human race has never seen a project of any sort as ambitious as the SSC. But, then, the human race is designed to "throw deep."

J

PHILADELPHIA INQUIRER 15 FEBRUARY 1987 Pg.24

For Japan, a new era in defense

By Tom Ashbrook
Boston Globe

TOKYO — Under cover of American jet fighter support, Japanese tank fire boomed over a windswept valley on Hokkaido in November, in mock battle with tanks simulating a Soviet invasion of Japan's northernmost island.

The late autumn maneuvers marked the first integration of U.S. air and naval forces into joint U.S.-Japanese military exercises. In Japanese mess halls, American troops grappled with chopsticks and lotus root at lunch. At sea, Japanese destroyers dogged American ships in mock combat.

On Dec. 30, Prime Minister Yasuhiro Nakasone's cabinet scrapped the 10-year-old defense-spending ceiling, 1 percent of the gross national product, which had come to symbolize Japan's resolve to maintain a strictly limited military capability.

Japan's defense minister dismissed the old ceiling — once considered politically inviolable — as "very unnatural." Nakasone coolly remarked that he was sure Japan's Asian neighbors would understand his country's change in policy.

Four decades after defeat in World War II left Japan in ruins and millions of Japanese bitterly disillusioned with an era of unbridled militarism, Asia's economic superpower is stepping cautiously back toward significance in the world military equation.

Loosening constraints

A combination of pressure from Washington, growing Soviet military power in Asia and a streak of Japanese nationalism, say Western diplomats, has gradually loosened postwar constraints on military development in a country where, only a decade ago, public discussion of bombs, buildups and combat strategies was all but taboo.

Although the strength of discussions on defense issues remains sharply limited, the change in tenor under Nakasone has encouraged military planners in Japan to envision the nation as less of a dependent ward and more of a contributing partner of the United States in the defense of the northern Pacific.

Japanese strategists are talking more openly than ever about participation in an array of defense strategies and technologies, from the "Star Wars" missile defense program — which Japan agreed last year to join — to sophisticated intelligence gathering, laser defense systems and domestic jet fighter production.

"A growing number of people think now that Japan will have a larger military role to play than they thought five or 10 years ago," says Masashi Nishihara, professor of international relations at Japan's National Defense Academy. "We should first say what we have to do to defend ourselves — and then see how much this will cost."

Japan is not now a major military power, and at its present steady but slow rate of defense buildup, say analysts, it is not on course to become one. The country's low-profile armed forces are geared exclusively toward limited self-defense and would be highly dependent on the aid of the 50,000 U.S. troops stationed in Japan plus reinforcements from the U.S. mainland in any actual fighting.

Japan's postwar "peace constitution" renounces war and the right of belligerency, its laws forbid arms exports, and its self-imposed "non-nuclear principles" forbid the possession, manufacturing and entry into Japan of nuclear arms.

But even before the defense-spending ceiling was broken in December, U.S. Ambassador Mike Mansfield told reporters at a year-end briefing that Japan ranked sixth among the nations of the world in defense spending, putting $22 billion a year into defense.

According to analysts at the Institute for Strategic Studies in London, Japan's naval force is now the world's fourth largest by tonnage, its fleet of 14 submarines is the world's fifth largest, and its air force is ranked eighth.

"The 1 percent ceiling has hidden the fact that Japan has the second-largest GNP in the world," said the institute's Reinhard Drifte. "You cannot compare percentages in Germany or France with percentages in Japan."

Pressure from U.S.

U.S. defense officials have pushed Japan to develop its capacity to control key straits that the Soviet Pacific fleet must sail through to reach the Pacific Ocean from its base at Vladivostok, on the Sea of Japan. They also have called on Tokyo to develop a more credible defense for strategically vulnerable Hokkaido and to fulfill a 1981 promise by former Prime Minister Zenko Suzuki to extend Japanese patrols over its sea lanes for 1,000 miles.

At present, Japan can fulfill none of those goals. Mansfield said recently that he hoped the 1,000-mile sea lane defense commitment would be met "before the end of the century."

Nakasone's willingness to bite the political bullet at home and break the 1 percent spending limit, say U.S. military officials, has raised hopes for further funding in future years. It also has eased Pentagon fears that a Congress on the warpath over unending trade deficits with Japan might cut U.S. military spending on operations in that country to force Japan to shoulder more of its defense burden.