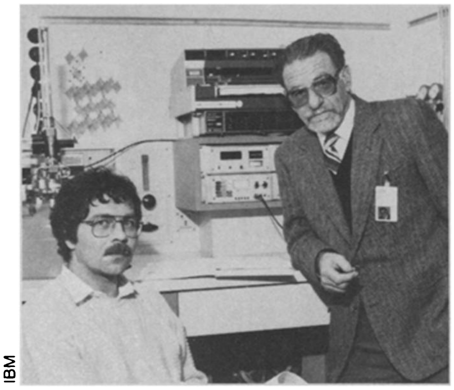
Superconductivity: A Physics Rush


IBM

Bednorz (left) and Mueller.

In science, "recent" usually means "in the last few years." In the search for high-temperature superconductivity it has come to mean "yesterday."

High-temperature superconductivity is the physicist's dream that now seems to be coming true – in a tremendous rush. The discovery of substances that lose all electrical resistance at manageable temperatures has been a goal of researchers for 75 years. The discovery last year of a new class of substances that become superconductors at around 30 kelvins, made by J. Georg Bednorz and K. Alex Mueller of the IBM Zurich Research Laboratory in Switzerland, triggered an avalanche that continues to intensify. The news has run to Japan, to China, to the United States, and the superconducting transition temperatures of new substances keep going up – 52.5 K, 94 K, 98 K (SN: 3/14/87, p.164).

Last week in New York City, one of the most extraordinary sessions of the American Physical Society ever held – it ran from 7:30 p.m. to 3:15 a.m. and played to an audience of thousands – addressed the latest progress in the field. This includes a claim to superconductivity at 125 K (still unconfirmed by others), from C. Politis of the University of Karlsruhe, West Germany, and a report of indications of superconductivity at 234 K by a group from the University of California at Berkeley and the Lawrence Berkeley Laboratory (Alex Zettl, Angelica Stacy and Marvin Cohen). The next day, at a press conference, Koichi Kitazawa of the University of Tokyo related that he had learned just in the last few days, from Japanese newspapaper reports, that a group at Kagoshima University had found room-temperature (300 K) superconductivity, or at least they seem to have found the Josephson effect – a superconducting phenomenon – at room temperature.

The meeting also displayed superconducting tapes and rings made of the new materials, a first step toward technological application.

The pace has been breathless, and it seems to be still accelerating. The first materials found by Bednorz and Mueller, whose superconducting transition temperatures around 30 K are 10 K higher than any previously known, are now called "low-temperature superconductors," *sic transit gloria mundi.* Announcements are dated by the hour: A summary put out by AT&T Bell Labs carried the overline "UPDATE – noon, 3/19/87."

Superconductivity, which was discovered in 1911 by Heike Kamerlingh Onnes of the University of Leiden, in the Netherlands, first appeared in solid mercury at a temperature of 4.2 K, which happens to be the liquefaction temperature of helium. Over the years, slow and painstaking work gradually pushed up the maximum temperature of superconductivity. The late Bernd Matthias, one of the great people in the field, used to show a graph of this progress. According to Robert Dynes of AT&T Bell Labs, if physicists had continued to proceed at the rate shown on that graph it should have taken until 2190 to reach the 94 K temperature that is the highest well-confirmed result as of today.

Refrigeration is one of the great hindrances to practical use of superconductors. Those in technological use now require liquid helium for refrigeration. Helium is rare, requires refrigeration to 4.2 K and is not a particularly effective coolant. Liquid nitrogen, essentially liquid air, is cheap, easy to obtain, a much better coolant than helium and needs cooling to only 77 K, a much easier refrigeration technology. Several of the new materials are superconducting at liquid nitrogen temperature, and neither experimenters nor theoreticians have been predicting any ceilings.

Some of the physicists seem to think it won't be too long before the appearance of superconductors that work at temperatures accessible to household refrigerators. The "unusual drops in resistance" – as Marvin Cohen of the University of California at Berkeley described what his group found in a compound of yttrium, barium, copper and oxygen at 234 K – occur at a temperature equal to −38°F. If that should prove to be superconductivity, a cold winter day in Bemidji or International Falls could give outdoor superconductivity. If that sounds like a joke, Paul Chu of the University of Houston notes that 80 K is already ambient temperature on the shadow sides of both natural and artificial objects in space. Some of these substances could work without refrigeration in those environments.

Difficulty of fabrication is another hindrance to using superconductors. The ones in current use are all metals or metal alloys, and some of them are hard to work or have inconvenient mechanical properties. The new materials reported at the meeting are copper oxides containing rare-earth elements. P.M. Grant of the IBM Almaden Research Center in San Jose, Calif., whose group has deciphered the crystal structure of the yttrium-barium-copper oxygen compounds, reports that it is a perovskite – a crystal of a basically octahedral shape – that seems to be built of layers that are alternately conducting and insulating.

Theorists who spoke at the meeting seemed to agree that the presence of copper and oxygen and the chemical relationship between them is important for superconductivity, but whether the relationship involves planes of atoms or simply lines of them is not agreed. Again, the presence of rare earths seems important, and that is slightly paradoxical, as rare earths are magnetic, and magnetism and superconductivity have usually been incompatible.

Particularly striking is a compound discovered at Los Alamos (N.M.) National Laboratory (LANL) that includes gadolinium, a particularly magnetic rare earth. As James Smith of LANL pointed out, gadolinium is something physicists used to introduce into a superconducting material to see how much of it was necessary to destroy the superconductivity. Here gadolinium seems to enhance it.

Incidentally, rare earths are rare chemically but not geologically. As pointed out by Zhongxian Zhao of the Academica Sinica group in Beijing, which first found a 94 K superconductor, China has rich deposits of rare earths, and so technological development of these compounds would be good for the Chinese economy as well as a benefit for all humanity.

Most theorists who spoke at the meet-

Louis de Broglie, 1892-1987

Louis, Duc de Broglie, one of last survivors of the group of brilliant physicists who developed modern physics and quantum mechanics, died in Paris, March 19, at the age of 94. His first academic degree was in history, but then he turned to science and the philosophy of science, receiving a D.Sc. degree from the Sorbonne in 1924 for work in which he predicted the quantum mechanical wave-particle duality of matter. After experimental physics had confirmed his prediction, he received the 1929 Nobel Prize for physics for the work. De Broglie spent most of his life as a teacher at the Sorbonne and at the Institut Henri Poincaré, both in Paris. □

ing agreed that a new mechanism was necessary to explain these high-temperature superconductors. The one holdout was D.A. Papaconstantopoulos of the Naval Research Laboratory, who insisted that slight modifications of the traditional Bardeen-Cooper-Schrieffer (BCS) theory would work.

To get superconductivity, the conduction electrons in the material must form pairs. However, electrons normally repel each other, and some intermediary is required to induce them to pair. In the BCS theory the intermediary is a phonon, a vibration or ripple in the lattice of the crystal.

For the new superconductors, Philip W. Anderson of Princeton (N.J.) University reported a computer simulation of the crystal that suggests, rather than a phonon, a phenomenon called "resonating valence." In that case, valence electrons, the electrons that bind the atoms together in the crystal (which are not the same as the conduction electrons that form electric currents) jump from one atom to another, causing force distortions that bind the conduction electrons in pairs. Other theorists view interactions between the bound electrons known as excitons as the intermediaries in pairing.

These new materials are fairly easy for chemists to make, and so any two or three physicists and/or chemists can get together and get into the act. As Neil W. Ashcroft of Cornell University put it, this is "truly tabletop physics," a line that drew thunderous applause from the more than 1,100 people in the room. Many of these substances are ceramics, and technology has long experience in dealing with ceramics. In spite of their brittleness, they have already been fabricated into potentially useful forms. Mueller showed a film that is fully superconducting, as did R. J. Cava of AT&T Bell Labs. Groups at Stanford University led by Malcolm Beasley, chairman of the Applied Physics Department there, and at Energy Conversion Devices, Inc., of Troy, Mich., led by Stanford Ovshinsky, also claim production of superconducting films. Bertram Batlogg of AT&T Bell Labs showed a ring, the first step to a solenoid, a common shape for a magnet.

In spite of talk of superconducting electric transmission lines and other large-scale applications, observers, particularly Brian Schwartz of Brooklyn (N.Y.) College and Alex P. Malozemoff of the IBM Thomas J. Watson Research Center in Yorktown Heights, N.Y., think the first applications are likely to be in microcircuits, particularly in the interconnections between microcircuits, and possibly in memory elements. There, superconductivity could do a great deal for speed and miniaturization. The Stanford group claims already to have made thin film interconnects of this sort, but they refuse to tell how they did it, patent pending. — *D. E. Thomsen*

Amassing momentum for Mars

The idea of going back to Mars, where the last arrivals were the Viking spacecraft in 1976, has been much discussed in recent years, with issues ranging from keeping a planned U.S. Mars orbiter on track in NASA's budget to the possibility of joining with the Soviet Union for human exploration of the planet. But discussions and possibilities, to say nothing of recommendations by various panels and advisory groups, are a long way from making decisions to do something.

Last week, a Soviet researcher told scientists attending the annual Lunar and Planetary Science Conference in Houston about tentatively approved plans for three Soviet Mars missions (and a possible fourth) to begin next year. Together, they include orbiters, landers, "hoppers," balloons, surface-roving vehicles and a round-trip mission to bring Martian samples back to earth. The day after the Soviet presentation, NASA officials described the status of U.S. efforts: that the one approved NASA mission, an orbiting craft called the Mars Observer, appeared to be locked to a 1992 launching by the space shuttle, despite pressure to arrange a 1990 launch aboard a conventional rocket, and that subsequent possibilities are beginning a new round of studies.

The first visit to Mars since Viking is to be a Soviet mission called Phobos, named for the larger of the two little Martian moons and due to be launched in July of 1988. The mission involves a pair of orbiters, each placed in paths whose greatest distances from the planet will be about 6,000 kilometers, approximately the distance of the moon Phobos. Each is designed to deploy a landing craft to Phobos's surface, as well as a "hopper" that will be set loose by a spring-like device in a series of jumps across the terrain. The orbiters, meanwhile, are to be stationed as little as 50 meters away, equipped with instruments such as a laser mass spectrometer that can zap the surface with a laser beam and analyze the resulting vapor to study its composition. Finally, if the first Phobos craft achieves its scientific objectives, the second may be diverted to try the same thing at Deimos, the other Martian moon.

Next on the road to Mars could be the U.S. Mars Observer, which could be launched as early as 1990 if in the next few weeks Congress comes up with enough additional money for NASA to buy a rocket to do the job. It is an unlikely possibility, however — NASA has yet to ask officially for *any* extra funding for such "expendable launch vehicles," despite the urgings of numerous groups and individuals — and the space agency is still planning for a shuttle launch in 1992.

The second Soviet mission is planned for that same year, having been moved up two years from 1994. It will be a large orbiter, with a scientific payload weighing 200 to 250 kilograms, according to Valeriy Barsukov, director of the Vernadsky Institute of Geochemistry and Analytical Chemistry in Moscow. The craft is also to carry a pair of "penetrators," spear-like probes that will be sent down from orbit (at about 200 meters per second) to stick in the Martian surface, carrying a variety of instruments to conduct studies from their implanted positions. In addition, the orbiter is to deploy a French-designed balloon to move up and down through the atmosphere, possibly traveling as much as 5,000 km over the landscape, covering about 500 km per day in the Martian winds. Yet another possibility, still under study, is the addition of a small surface-rover, though that option, says Barsukov, would depend on the availability of a rocket more powerful than the present Proton launcher to deliver the whole package from earth.

Also awaiting approval is another rover to be launched in 1994, which would include a pair of sampling devices called "moles," to gather material for analysis from as deep as 25 to 30 meters. Among its other tasks, the rover would be instrumented for what one of Barsukov's viewgraphs lists as "biological or paleobiological" studies. Heretofore, the only instruments so far sent to another planet to look for signs of life have been the "biology packages" that went to Mars aboard the Viking landing craft. Their data were inconclusive.

Questions of biology, however, are far from the only items of interest about the planet. One wide-ranging goal is a Soviet mission to bring pieces of Mars back to earth. It is scheduled for launch in 1996, though Barsukov notes that the mission's complexity is likely to make 1998 a more realistic date. Carried out in cooperation with France and the European Space Agency, the mission's list of proposed sensors includes a synthetic-aperture radar for detailed mapping of the surface from orbit. A similar device was used to radar-map the northern hemisphere of Venus from the Soviet Venera 15 and 16 spacecraft (as well as the U.S. Pioneer Venus orbiter), which also deployed wind-tracking balloons into the atmosphere.

As for U.S. plans for a Martian sample-return mission, some NASA officials envision that such a project could begin in the agency's 1993 budget for launching in 1998, with samples due back on earth in the year 2001. — *J. Eberhart*