Research News

Superconductivity: The FAX Factor

The pace of discoveries of superconductor research continues, and theorists are also beginning to develop models of mechanisms for the new age

In the ancient past of superconductivity research—which these days is about 2 years ago—international meetings drew an intimate group of dedicated specialists. But ever since the Nobel Prize–winning discovery at the IBM Zurich Research Laboratory of superconductivity in an unusual class of copper oxide compounds, everything has changed. For instance, almost 1200 physicists and chemists from 39 countries gathered recently in Interlaken, Switzerland, to discuss progress in materials and mechanisms.*

The pace of current research was reflected in part by the volume of new results on higher superconducting temperatures with known materials and by the announcement of novel superconducting materials. But the manner of the delivery of new data was even more telling, and gave new meaning to the term "last-minute results."

For instance, during a session on the thallium-containing superconductors, Paul Grant of IBM Almaden Research Laboratory reported that colleagues back in California had raised the transition temperature to 118 K, a result that had been confirmed just 1 hour earlier and transmitted to Interlaken by that latest addition to the arsenal of instrumentation vital to condensed-matter physics research: the FAX (facsimile) machine. In another session, K. V. Rao of the Royal Institute of Technology in Stockholm gave a rapid-fire, 5-minute, post-deadline talk unparalleled for its information density, that consisted of one FAX transparency after another.

One physicist ironically remarked that peer-reviewed journals and international conferences were now obsolete: the researchers should now simply get a bunch of FAX machines and call each other up and have a FAX conference.

The conference was marked by a large number of post-deadline presentations on the newly discovered bismuth and thallium superconductors. But although the identification of new superconducting materials continued to dominate the discussion, condensed matter theorists also made a strong showing at Interlaken. A welcome development, participants agreed. However, given that it required 46 years of sustained theoretical effort to arrive at the "BCS" theory of conventional superconductors, most theorists allowed that it might take a little longer than the 2 years that have elapsed before the copper oxide systems are understood.

Physicists now have a new class of compounds to explore for potential superconductivity effects.

Until January 1988, the highest temperature for superconductivity hovered in the vicinity of 95 K in the so-called "1-2-3" compound, $YBa_2Cu_3O_7$, discovered by Paul Chu and his colleagues at the University of Houston, together with a group led by Maw-Kuen Wu at the University of Alabama. Some of the most intriguing results at Interlaken, however, concerned new superconducting materials that, unlike the 1-2-3 compounds, do not contain rare earths.

For instance, a group of French scientists at the University of Caen had set the stage last year with the discovery of superconductivity in a bismuth–strontium–copper oxide system at around 22 K. A team at the National Metals Research Institute in Tsukuba, Japan, led by Hiroshi Maeda followed this up with the announcement of high-temperature superconductivity in a similar bismuth-based material at about 80 K. Although these zero-resistance temperatures are below that for the 1-2-3 compounds, the fact the new materials do not contain rare earths means that physicists now have a new class of compounds to explore for potential superconductivity effects.

In the week or so before the Interlaken meeting, the grapevine was buzzing with news of a compound that contained the element thallium, which was discovered by Zhengzhi Sheng and Allen Hermann at the University of Arkansas. Attendees at Interlaken were thus treated to the first results of many groups around the world who rushed to collect information on the physical properties and structural details of the bismuth and thallium materials.

Interest in the new bismuth-based compounds deepened as structural information came in from at research groups at E. I. Du Pont de Nemours & Company, Bell Communications Research, and IBM, among others. Most striking was the lack of copper-oxygen "chains," thought by some to hold the key to high-temperature superconductivity. The new high-temperature materials have additional copper-oxygen planes, which are features that give rise to an extensive multilayer sandwich. In the 1-2-3 compounds, long chains of CuO are positioned between the CuO_2 layers. The bismuth and thallium materials have only CuO_2 layers, but more of them.

This finding led several researchers to speculate about the correlation between the number of planes and the transition temperature: the more planes there are, the higher the transition temperature is likely to be (Research News, 8 April, page 146).

Incidentally, Grant's initial announcement of a 118 K transition temperature for the IBM Almaden Research Laboratory's thallium material was surpassed on the following day by the same group. More data zapped across the FAX line, and the figure now stood at 125 K, which, for the moment, is the record.

Even before the Interlaken meeting, many researchers had already agreed that the new superconductors will require some unconventional explanation, and the discussion at the meeting did not challenge that agreement. Conventional here means "BCS" (Bardeen-Cooper-Schrieffer) theory, the theory developed in 1957 with which physicists have been able to understand the microscopic behavior of current flow in almost all earlier superconducting materials.

Although the consensus was that no dramatic breakthroughs had been achieved in explaining the mechanism of high-temperature superconductivity in the copper oxides, some general lines of agreement among theorists did begin to emerge.

Conventional BCS theory has two fea-

*International Conference on High-Temperature Superconductors and Materials and Mechanisms of Superconductivity, 29 February to 4 March 1988, Interlaken, Switzerland.

tures, one that must be retained by a new theory, and one that must be abandoned, or at least supplemented by a new approach. The first is electron pairing, the so-called "Cooper pairs" of BCS theory. Several experiments have shown that the electrons are also paired in the copper oxides.

It is the second feature, the mechanism of pairing, the glue that holds the pairs together, that is puzzling to physicists. In BCS, the electrons are bound by their interaction with the lattice vibrations of the superconductor, which are known as "phonons." There is some evidence that the new materials do not appear to depend on electron-phonon interactions to achieve electron pairing, so theorists have been coming up with other interaction mechanisms. As Øystein Fischer of the University of Geneva expressed it: "We've got phonons, spinons, holons, magnons, and the and-so-ons. Take your pick."

According to J. Robert Schrieffer—the "S" in BCS theory—the newly emerging mechanisms can be put into three categories. First, there are those theories that preserve some aspects of phonon coupling by invoking strong "anharmonic" effects. The idea is that if normal, harmonic vibrating lattice ions do not quite do the job, perhaps vibrations that deviate substantially from harmonicity can cause electrons to interact with greater attraction. In effect, if the lattice is not as "stiff," the increased distortion due to the presence of an electron causes a stronger net positive charge, and hence a stronger attraction on other electrons.

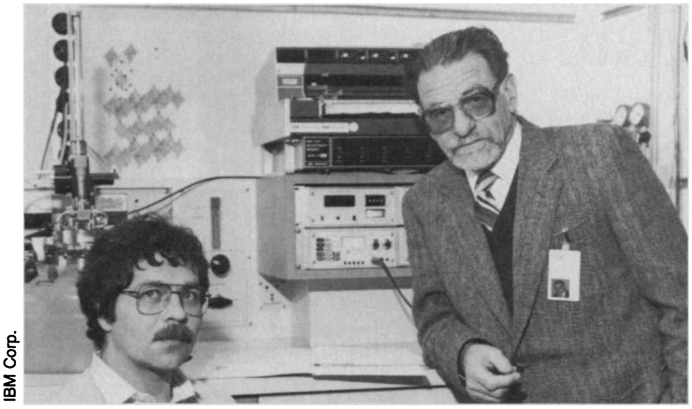
The second class of mechanisms involves electric charge fluctuations. In essence, where phonons are ionic lattice vibrations, charge fluctuations are the vibrations of the electrons themselves. If the charge fluctuations can mimic phonons, namely if they can be exchanged back and forth by electrons, then a net attractive force might result. The earliest of these theories was actually proposed not long after the development of the BCS theory, the latter having provided physicists with a means to calculate the limits of electron-phonon coupling.

Since electronic interactions can occur at a much higher energy than phonon interactions, the pairs remain bound at higher temperatures. Several theorists presented calculations to support a variety of such electronic mechanisms.

The third category is that of spin-mediated and magnetic interactions. Electrons not only possess electric charge, but also have "spin" and can act like tiny permanent magnets. A large collection of such spins can experience spin fluctuations and these fluctuations can act as quantized particles that give and take energy from electrons. If conditions are right, electrons can interact through these fluctuations and attract one another.

Pioneers

J. Georg Bednorz and K. Alex Mueller, of IBM Zurich, initiated the current burst of superconductivity research activity with discoveries that earned them the 1987 Nobel Prize in physics.


IBM Corp.

Schrieffer weighed in with his own model, which he calls "spin bags." Other spin mechanisms were the subject of much discussion, and some, particularly Philip W. Anderson's resonating valence bond theory, seemed to have generated a large number of follow-on papers that take the original ideas in new directions.

This last group of theories has the advantage of meeting head on the problems posed by the very unusual magnetic properties of the new copper oxide superconductors. Early in research with conventional superconductors it became clear that small amounts of a magnetic impurity such as gadolinium completely destroyed the superconductivity. The new materials exhibit no such sensitivity to magnetic dopants; on the contrary, they seem to show a host of interesting properties like antiferromagnetism and spin glass behavior.

Still in their infancy, none of these mechanisms stands out as the obvious explanation, but each has ardent and vocal supporters. In any event, cautions Schrieffer, not only do the theorists need carefully obtained data, they also need the right data from the right experiments. Echoing this plea, many hoped that the competitive rush for ever higher temperatures might subside to leave time for thorough studies of the physical properties of the new compounds.

Lost, perhaps, in the excitement surrounding the high-temperature copper oxide superconductors were developments in organic superconductors and "heavy" electron materials. Even as reports of 125 K superconductivity were drawing applause from the participants, Kokichi Oshima and his colleagues at the University of Tokyo reported superconductivity in a deuterated organic salt at 10.4 K, the highest for an organic system.

The significance of such results lies not so much in the temperature or possible applications as in the unusual mechanism likely to be involved. So too with the "heavy" electron superconductors. These materials have been found to have thermodynamic properties—specific heat, and so forth—that would be expected only in substances where the electrons have effective masses thousands of times greater than their normal mass ("heavy" electrons). Representative of these are a class of uranium compounds, including UPt_3 and UBe_{13}.

Like the organic superconductors, the heavy electron systems do not appear to be conventional BCS materials. Instead, unusual magnetic properties seem to coexist with superconductivity. A complete understanding of these compounds might therefore go hand in hand with a satisfactory theory of the high-temperature superconducting copper oxides.

The opening remarks at international conferences are typically given by the conference organizers and one or two government officials who welcome the distinguished scientists to their country. At Interlaken, however, some of the most interesting remarks from the dais were delivered at the conclusion of the conference by the Swiss minister for internal affairs, Flavio Cotti.

In what some considered to be a not very subtle reference to the high-profile superconductivity conference organized last July by the Reagan Administration, from which non-American participants were pointedly excluded, Cotti emphasized that Switzerland viewed its future being dependent upon technological advances and was committed to completely open and free flow of information. Under no circumstances would his country permit restrictions on travel or conference attendance.

Furthermore, he indicated, the Swiss government had just approved increases in basic physics funding of 8%. This was bitter news indeed to the participants from American universities who learned just before the conference of cutbacks in the equivalent National Science Foundation programs. ■

DAVID F. VOSS

David Voss is an editor at Science.