Keeping Up with the Jonezawas

In the race to understand and develop high-temperature superconductors, "Made in Japan" has come to mean scientific research that is as good as any other in the world

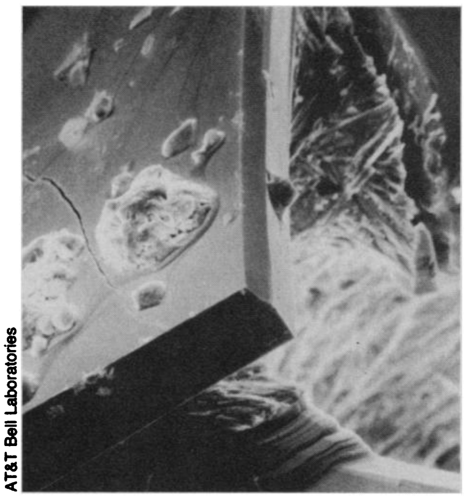
JAPANESE RESEARCHERS FEEL they have something to prove, and they have chosen high-temperature superconductivity as a place to do it. "They are very sensitive to the rap that they have been taking [other countries'] basic science and converting it to technology," says Robert Dynes of AT&T Bell Laboratories. "They're going to show that they can do basic science as well as the rest of us." The result: the United States will have to hurry to keep up.

Dynes and six other superconductivity experts were recruited by the Japanese Technology Evaluation Center, a program supported by the National Science Foundation, to spend 10 days touring Japanese superconductivity labs and to report back on their findings. In a workshop in Washington on 1 August, the panel contrasted the Japanese program in high-temperature superconductivity with the parallel effort in the United States.

Japanese researchers have been at the forefront of basic research in this field since late 1986, shortly after physicists Georg Bednorz and Alex Müller announced their Nobel Prize–winning discovery of the first high-temperature superconductor. A team from the University of Tokyo was the earliest to confirm that result, and since then, several of the breakthrough results on high-temperature superconductors, as well as many of the most thorough studies of their properties, have been made in Japan.

One area of superconductivity in which Japan does lag the United States is the theoretical side, the panel found. Although the top Japanese theorists are as good as their American counterparts, Dynes said, "they don't have the bench strength that we do." Further, the Japanese have no theoretical centers like the Institute for Theoretical Physics in Santa Barbara, nor, according to Dynes, do they interact the same way Americans do, even though many of the Japanese theorists were trained in the United States. "The Japanese don't seem to confront each other with the same brutality that we do," he said, "and as a result they don't have their results as well honed."

However, most superconductivity experts would argue that a theoretical understanding of high-temperature superconductors is


AT&T Bell Laboratories

Japanese growth area: *Crystals of high-temperature superconductors.*

not as important for applications as obtaining a good experimental knowledge of their properties, and in this area Japan matches up well with the United States. Both countries have about 500 scientists working on basic research, although the Japanese employ a much greater percentage in industrial labs. Japan's largest single effort is at Nippon Telephone & Telegraph (NTT), and half a dozen other companies have major superconductivity research groups.

In academia, the work of Japanese and U.S. researchers is of comparable quality, Dynes said, and although university laboratories in Japan have traditionally been poorly equipped, that is changing rapidly. The industrial labs and especially the government labs are already well equipped.

What really sets Japan's efforts apart from those in the United States is the heavy emphasis, both in industrial and government laboratories, on basic materials research, said Mildred Dresselhaus of the Massachusetts Institute of Technology, who chaired the panel. The Japanese are the best in the world at synthesizing the high-temperature superconductors and systematically characterizing their properties, the panel said. For instance, single crystals of the superconductors are vital in the measurement of the materials' properties, but making them is a tricky, tedious task. "Every night [during the tour] when we got back to our hotel I heard jealous cries from the guys at IBM and Bell Labs about how big the [Japanese] crystals were," she said. And Dynes agreed: "They are producing single crystals that make the rest of the world drool." The United States has few researchers with this skill, Dresselhaus said, in part because funding agencies have not encouraged it—in Japan it is considered basic research, but in this country it is thought of as technology.

Panel member Rod Quinn of Los Alamos National Laboratory said the Japanese excel in materials processing in part because they assemble large multidisciplinary teams. "In the United States, it is small teams that are developing the different processing techniques," he noted.

On the other hand, U.S. researchers were reported to have an advantage in how well they work together across institutional boundaries. In Japan, there is "a serious mismatch between academia and industry," Dynes said. "The people at NTT are not coupled to the University of Tokyo, for example." But the Japanese are aware of the problem and are working on it, he said.

In fact, they have made a good start with the International Superconductivity Technology Center, known as ISTEC. The center is sponsored by 111 Japanese companies who together account for half of Japan's gross national product. Of those, 46 are full-support members who each paid an $800,000 entry fee, pay $100,000 annual dues, and promise to provide two of their top superconductivity researchers to the center. ISTEC's total research budget is $17 million a year, excluding salaries for the 90 or so full-time researchers, which dwarfs anything the United States has put together.

One of the most striking differences between the Japanese and U.S. research efforts lies in which potential applications the countries are concentrating on. In the United States, the discovery of problems with the flux lattice in high-temperature superconductors has caused considerable pessimism about large-scale applications (see 26 May 1989, p. 914), but the Japanese are undaunted. They continue to focus mostly on large-scale products such as energy generation and magnetically levitated trains, Dresselhaus said. Here they have a built-in advantage because of their efforts on low-temperature superconductors in the same areas. The Japanese already have a working mag-lev train with conventional magnets and have been experimenting for 17 years with one that uses low-temperature superconducting magnets. They also have an ongoing program to develop an electric generator using low-temperature superconducting magnets, while the United States dropped its last such program in 1983.

U.S. researchers, on the other hand, generally believe it will be difficult, if not impossible, to develop applications dependent on very large magnetic fields. Instead, their research has been largely aimed at small-scale uses, such as superconducting electronics and microwave applications. The one exception, Dresselhaus said, is a superconducting energy storage system, and the push for this has come not from industry but from the Pentagon, which needs it for the Strategic Defense Initiative.

But even in the area of electronics, the Japanese may have a subtle advantage. Thin films of high-temperature superconductors, which will be needed to make electronic components, can be made in various ways. U.S. researchers are generally ahead of the Japanese in the laser ablation technique and electron beam evaporation, the panel said. But the Japanese are better at sputter deposition and chemical vapor deposition, and it is these two techniques that will probably be easiest to apply commercially.

The panel's most surprising discovery was the emphasis in Japan on organic superconductors. Japan has some 100 researchers studying these carbon-based materials, while a small group at Argonne National Laboratory provides the only major effort in the United States. Organic superconductors are scientifically interesting, but few U.S. researchers believe they will have significant commercial applications. However, the Japanese work has some of the panel members wondering if the Japanese know something they don't. "I was so worried about this," Dynes said, "that we now have a couple of researchers at Bell Labs working on it."

Dresselhaus said the fundamental advantage Japan has over the United States is a leadership that can assign projects and coordinate between different groups. In response, the panel recommended increasing the number of consortia and collaborations between industry, government, and university labs in the United States. It is particularly important, the panel added, that industry be included in the collaborations early because eventually industry must make the decision whether to commercialize a product. ■ ROBERT POOL

How the Grinch Stole Mathematics

Herb Wilf has been having fun making mathematics less fun for his colleagues. Wilf, who is a professor of mathematics at the University of Pennsylvania, and Doron Zeilberger at Drexel University, also in Philadelphia, have created an ingenious method for rendering ingenuity unnecessary in dealing with a class of (formerly fun) mathematical problems known as combinatorial identities. "I feel like the Grinch who stole Christmas," Wilf says gleefully.

Combinatorics, loosely speaking, is the art of counting complicated collections of objects, such as the number of ways a rowdy group of kids can choose up sides to play baseball or your chances of drawing to an inside straight. Beyond its recreational value, the subject has practical applications, especially in computer science. Algorithm designers, for example—the people who make computer programs work efficiently—frequently need to know the number of steps or amount of memory required by a potential algorithm. So they turn to combinatorial arguments, which, for mathematicians, means a line of reasoning, not a dispute between rival researchers.

Once it was an intellectual challenge to make a combinatorial argument. To do so you'd find a secluded spot and, with a pad and a sharp pencil, you'd prove a few combinatorial identities. An identity is an equation relating one combinatorial expression to another—equating a sum of binomial coefficients, for instance, to a power of 2. One side of the equation is usually rather complicated while the other side is relatively simple. The mathematician who could find and prove such an equation would succeed in simplifying an otherwise awkward calculation.

Now, here's where the fun used to come in. A standard proof of a combinatorial identity uses a series of cleverly chosen algebraic manipulations and rearrangements. The best proofs are a kind of mathematical poetry.

Wilf and Zeilberger's approach turns the poetry into a password. They use a computer algebra system to produce a "certificate of proof" from which an ordinary paper-and-pencil proof can readily be generated with no further insight needed. The certificate doesn't look like a proof at all. It looks like, and is, nothing more than an algebraic expression: a ratio of the two polynomials in two or more variables.

The secret? An algorithm developed in 1978 by William Gosper of Symbolics, Inc., in Palo Alto, California, and a clever idea added by Wilf and Zeilberger. Gosper's algorithm is incorporated as a single command in the computer algebra system Macsyma, and, like some kind of exquisitely trained hunting dog, it homes right in on the proof certificate.

Maybe you don't trust this techy, uninspired way of doing mathematics. Maybe you suspect these really aren't proofs, that the algorithm might accidentally certify an incorrect identity. But Grinch Wilf notes that even for anyone who doubts the certificate, there is an easy way to check it, in much the same way that a computer-generated factorization of a large number can be checked by simply multiplying the factors back together.

Gosper's algorithm occasionally meets an identity which it is unable to handle. But the Grinch's partner has the answer. For those identities Zeilberger has a general, more elaborate "machine" that is guaranteed to work in all cases (as long as the identity is in so-called "closed form"). Zeilberger actually developed the general method first. Wilf noticed that Zeilberger's proofs all "had much the same music to them," and helped find the simplified approach. "I had the advantage of not understanding his monster machine," Wilf explains.

One application of computer-generated proof certificates, Wilf notes, is to spare researchers the embarrassment of misstating identities or overlooking an obvious simplification. There are other spin-offs as well, which will likely provide deeper insights into the structure of combinatorial identities. In the process of proving one identity, the method actually proves a "companion" identity as well, and each of these has an associated "dual" identity. By repeatedly taking special cases, companions, and duals, Wilf and Zeilberger can grow an entire tree of identities out of a single proof certificate. They have already obtained several new identities this way.

So in trying to take the fun out of mathematics, the Grinch may have only put yet more presents under the tree. ■ BARRY A. CIPRA

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