approach, calling for the development of new undergraduate courses in materials science.

Though it is by far the smallest component of the initiative in dollar terms, amounting to just $6 million, this education effort could play a role out of proportion to its funding if it addresses what many materials scientists point to as a second weakness in the field: a lack of communication among researchers with widely varying backgrounds and ways of looking at the world. Materials science is not a traditional discipline in the sense of physics or chemistry, but is rather what David Turnbull, an applied physicist at Harvard, has termed a "superdiscipline." Its boundaries are defined not by subject matter but by a particular goal—making materials with desirable properties—and so the field contains pieces of many different disciplines. For practitioners, that means learning how to collaborate across fields.

Such cooperation does not come naturally to most researchers. In school, Patel notes, budding materials scientists are generally shunted into one of the traditional fields—physics, chemistry, and so forth—and often have little contact with other departments, which tend to be both physically and psychologically separate. The problem is less acute at large corporate research laboratories and national laboratories, where organizational structure tends to reflect goals rather than subject matter. "We emphasize to young researchers [when they first come to Bell Labs] that they can work with others [outside their own fields]," Patel says. Still, it would help if universities would "do a better job of making people understand they can rely on others."

Scientists and educators disagree about the best way to do that, however, and the presidential initiative's call for new materials science courses doesn't meet with universal approval. "Your time in college is limited—you need to learn the basics of physics, math, and chemistry," says Stanford superconductivity researcher Ted Geballe, who recently won the MRS's highest honor, the Von Hippel Award. "I think there's a danger of becoming too generalized." His graduate students learn one subject in depth but also learn "to work with people who know other areas" by being exposed to problems they can't answer without going outside their group or even their department.

The Proposed Materials Initiative
(Dollar amounts in millions)

Program Component	1992 Enacted	1993 Proposed	Dollar Change: 1992 to 1993	Percent Change: 1992 to 1993
Synthesis and Processing	683	748	+65	+9%
Theory, Modeling, and Simulation	**224**	**253**	**+30**	**+13%**
Materials Characterization	474	603	+29	+6%
Education/Human Resources	**21**	**27**	**+6**	**+27%**
National User Facilities	257	291	+33	+13%

SOURCE: OMB

Merton Flemings of the Massachusetts Institute of Technology, who chaired a materials education workshop at the latest MRS annual meeting, argues that there is "no best way to educate students." The specialists will always play a major role in materials research, but even they need to learn to communicate with specialists in other areas, Flemings says. And there are many jobs, such as the processing of high-temperature superconductors, "that need a great deal of synthesis of different fields," for which a general education in materials science and engineering would be valuable. Thus universities need to keep turning out physicists, chemists, and engineers—and add a few synthetic chemists to the mix—while also making room for new integrated departments in materials science.

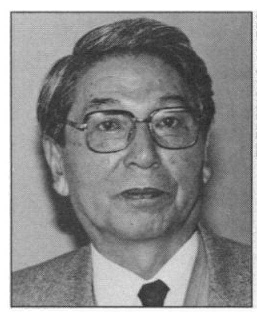
But those are disagreements about means, not ends. For Flemings and his colleagues, the common goal is to sustain the interplay among many independent disciplines that has taken materials science from the ugly duckling of "heat, beat, and hope" to a powerful and beautiful swan of a field. ■ ROBERT POOL

Superconductors in Japan

A sustained effort to apply the new superconductors has moved forward smartly in the past 2 years

Hiroshi Ohta's brainchild looks a bit like a large bucket, but it is prized for what it keeps out, not what it holds in. Ohta, an engineer at the Institute of Physical and Chemical Research (RIKEN), and co-workers from the Mitsui Mining and Smelting Co. have developed a superconducting magnetic shield that cuts extraneous magnetic fields from power lines, household appliances, elevators, and electric trains by a factor of half a million. The result is a zone of magnetic silence deep enough for researchers to listen in on the magnetic whispers of the human brain. The device, which is being eyed by companies trying to develop supersensitive brain magnetometers, is one of the first commercial products to emerge from Japan's effort—perhaps the most intensive in the world—to overcome built-in shortcomings of the current crop of high-temperature superconducting materials.

The magnetic shield and the smattering of other Japanese superconducting products on the market—a low-friction bearing and a handful of other devices—may seem a poor harvest from 6 years of research. But the effort has brought Japanese researchers within shouting distance of key goals of superconductor research: shaping the fragile materials into durable objects—especially long, flexible wires—and tailoring their internal structure so that they can remain superconducting in the presence of high magnetic fields. Heartened by recent reports of experimental high-field electromagnets and superconducting wires hundreds of meters long, researchers who only 2 years ago were adopting a wait-and-see attitude toward the materials are becoming enthusiastic. Predicts Genya Chiba, vice president of the Research Development Corp. of Japan (JRDC): "Within several years high-temperature superconductors will gradually take over many functions of the previous low-temperature superconductors while also finding new applications."


FREDERICK S. MYERS

Flux tamer. *Superconductivity researcher Shoji Tanaka.*

If any country was going to make a success of these recalcitrant ceramic materials, it had to be Japan. When news of high-temperature superconductivity broke from IBM's Zurich Research Laboratory in 1986, Japan was well positioned to plunge into research on the materials because it already had a strong foundation of expertise in ceramics.

As Chiba explains: "During the 1970s and 1980s we had a sort of ceramics madness. Things did not progress as fast as expected, but just when there was a threat that many of these ceramics guys were about to lose their jobs, the high-temperature superconductors were discovered, and thousands of ceramics experts could almost immediately turn their research to this field."

What's more, Japanese scientists and policy makers seized on high-temperature superconductivity as an arena in which Japan could prove itself as adept at basic research as the West. Even the popular press in Japan got into the act, talking about a coming revolution in transportation and energy based on high-temperature superconductors.

The national enthusiasm quickly propelled government spending for superconductivity research to a level that in 1987 exceeded that of the United States (though Japan has since been overtaken). In short order, more than 100 people were doing basic research at the state-of-the-art Superconducting Research Laboratory (SRL), run by a government-supported consortium of private companies called the International Superconductivity Technology Center (ISTEC). Thousands more were at work in universities and industry.

But if Japan was expecting quick success, it was soon disappointed. Like researchers everywhere, Japanese investigators trying to turn the new materials into working technologies ran into some daunting problems. One was the vexing difficulty of making the brittle ceramic materials into flexible wires that could be wound into motor coils and electromagnets. Just 2 years ago, the best that the Japanese effort could boast was the work of Kenichi Sato of Sumitomo Electric Industries, who in 1990 announced that he had developed a bismuth-based superconductor that could be spun into a wire tens of meters long—well short of the kilometer lengths needed for practical devices.

And then there was the problem of sending the high currents needed for motors, power transmission, or electromagnets through such wires without destroying their superconducting properties. The problem arises because in high-temperature superconductors, the magnetic field that always accompanies a flow of current tends to shift around. This "flux creep" dissipates energy, thereby ending the resistance-free flow of electricity. Often, high-temperature superconductors could carry respectable amounts of current only at temperatures of a few degrees above absolute zero, where the magnetic field lines grow more sluggish. But that, of course, negated the key advantage of the materials over their low-temperature predecessors.

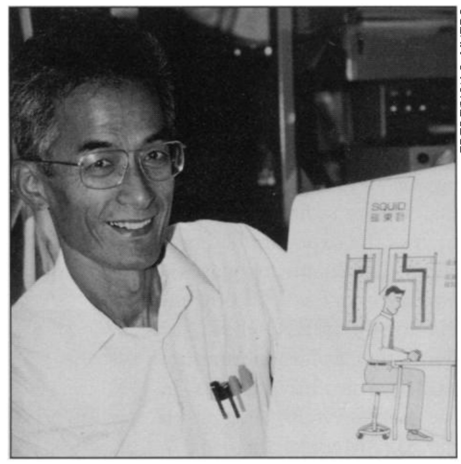
In the past 2 years, though, Japanese researchers have reported progress on both fronts. One measure of their success is the length of the wires now being produced by Sato's group at Sumitomo. "Our situation now is far beyond our anticipation a couple of years ago," he says. He and his colleagues have already made good-quality wires 100 meters long, and "in 1 or 2 years we expect to be making a wire that is nearly 1000 meters long." The basis of their optimism is the technique they have adopted for fabricating the wire, in which the bismuth-based superconducting compound is sheathed in a silver tube and rolled flat. In the resulting composite wire, the superconductor carries the current, while the silver coating protects the superconductor from degrading and gives it extra flexibility. Sato thinks the wire will soon be ready to be marketed as a cable for high-current power supplies or as winding for electromagnets.

Such wires are still plagued by flux creep, however. But investigators working with other superconductors have managed to lessen the problem by introducing "pinning centers" that lock magnetic field lines in place, preventing them from shifting and interfering with superconductivity. Shoji Tanaka, director of the SRL, reports that a new fabrication technique called melt-powder melt-growth (MPMG) can yield an yttrium-barium-copper-oxide superconductor peppered with nonsuperconducting impurity particles that efficiently trap the magnetic flux. That technique recently enabled SRL workers to increase the material's current carrying capacity several-fold, to more than 100,000 amps per square centimeter at 77 degrees K.—high enough for many practical applications.

The problem of flux creep is by no means solved; some researchers in the United States, for example, are taking a different, more theoretical tack in addressing it. They hope to find ways to freeze the flux lines in a so-called vortex glass (*Science*, 10 January, p. 158). Still, partial successes like SRL's are already opening the way to high-field electromagnets, such as a 1.15 tesla superconducting magnet recently announced by Toshiba.

Researchers at the SRL have also been exploring a new kind of magnetic levitation based on flux pinning. Traditionally, magnetic levitation has relied on the Meissner effect—the tendency of some superconductors to expel weak magnetic fields. Indeed, the Meissner effect lies behind the image that has become emblematic of high-temperature superconductivity: a small magnet floating over a slab of superconductor. But superconductors containing flux-pinning impurities exhibit a much stronger repulsive effect. Even though a strong magnetic field can still penetrate the material, it doesn't penetrate very far before the flux-pinning defects get in its way, levitating the source of the field.

And unlike levitation based on the Meissner effect, flux-pinning levitation has a flip side known as the fishing effect—an attractive force. The force results when the flux pinning traps an external magnet's force lines in the surface layers of a superconductor, suspending the magnet like a fish in a net. This attractive force has already been put to work in a superconducting magnetic bearing built by the SRL in collaboration with the NSDK bearing company. The bearing, in which a 2.4-kilogram rotor spins friction-free at 30,000 revolutions per minute, may see duty in gyroscopes for spacecraft.



FREDERICK S. MYERS

Listening to the brain. *Hiroshi Ohta and a sketch of a superconducting magnetic shield.*

Such early products, say Japanese superconductivity researchers, are giving their work new focus. Says Tanaka, "In 1991, the research situation changed from chaos to order. Now, most of the research laboratories and companies have fixed the direction of their own R&D. Each company has a target that meets the company strategy." Though government funding for research may be reduced this year, according to Kenichi Kondo, a materials scientist at the Tokyo Institute of Technology, researchers aren't panicking. Their field is over the hump, they say, and well on its way to realizing its potential. ■ FREDERICK S. MYERS

Frederick S. Myers is a science writer based in Tokyo.