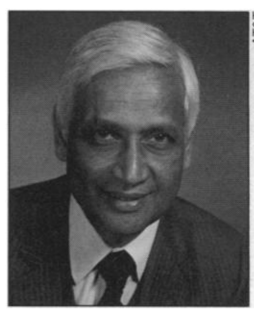
No More "Heat, Beat, and Hope"

A presidential initiative for materials research, announced last month, aims to fix the few weaknesses in what has become one of the hottest fields in science

A GENERATION AGO, MATERIALS RESEARCH was, as one old joke had it, mostly a matter of "heat, beat, and hope"—mix a few promising ingredients, stick them in an oven or over a burner, and see what developed. It was not a career that scientists recommended to their brightest or most promising students.

No more. Thanks to advances in basic science and applications like the ones detailed in this special issue of *Science*, the ugly duckling has developed into one of the glamour fields of the 1990s. Over the past few years, materials researchers have played starring roles in some of the really "hot" scientific work, from high-temperature superconductors and buckyballs to biomaterials and high-performance composites. One telling indicator of the new-found scientific appeal of the field is that membership in the Materials Research Society (MRS), founded in 1972, has more than doubled since 1987—at a time when many other scientific societies are struggling just to keep their memberships stable.

And it is not just scientists who have become enamored of the promise of materials research. Late last month, the White House, lured by the economic potential of the field, announced that it is launching a Presidential Initiative on Advanced Materials and Processing. That puts materials science on a par with such trendy fields as global-change research and high-performance computing, which have their own presidential initiatives. The initiative calls for a 10% increase in the \$1.66 billion federal budget for materials research—at a time when the overall discretionary budget must remain flat. But, perhaps more important for the long-term health of the field, it also offers a plan to correct two widely perceived deficiencies that exist in an otherwise robust U.S. materials program: a weak tradition of cross-disciplinary collaboration, and a lack of emphasis on the synthesis and processing that yield new materials.



Stressing synthesis. *AT&T's Kumar Patel.*

"What we have now is a three-legged stool where one of the legs is shorter than the other two," explains Kumar Patel, executive director of research for materials science and engineering at AT&T Bell Laboratories in Murray Hill, New Jersey. Two legs of the materials research stool—analysis of the structure and properties of materials, and the development of applications that take advantage of the materials' particular attributes—are in good shape, Patel says. The third—the synthesis and processing of materials—has been neglected, however, and much of the fault lies with the U.S. educational system: "We don't produce enough people who synthesize new materials." Indeed, materials researchers have been complaining for years that U.S. schools don't pay enough attention to solid-state chemistry, which lies at the heart of making new materials. European schools do better in this area, Patel says, and most of the best U.S. materials scientists have spent some time in Europe.

Praveen Chaudhari, former vice president of and now a research staff member at IBM's T.J. Watson Research Center in Yorktown Heights, New York, echoes Patel: "The U.S. educational system has relegated synthesis and processing to a second level. We've said, in effect, there's nothing intellectual about it." University departments, he says, have focused most of their attention on materials issues with obvious basic science components, such as the relationship between structure and properties, and have taken it for granted that industry could manufacture the materials. Yet, as high-temperature superconductors have demonstrated, synthesis and processing also offer hard and interesting questions: After the initial discovery of the superconductors between 1986 and 1988, much of the research on the materials has centered on how to craft them so that they fulfill their promise.

The chorus of complaints about this weakness has finally gotten through to Washington. Fully 40% of the \$162.8 million increase President Bush is proposing for materials science funding would go into research on synthesis and processing, with new or expanded programs in several dozen areas, from making nanometer-scale materials with greatly enhanced electronic, magnetic, or mechanical properties to developing artificial kidney membranes. The research is likely to pay off in more mundane arenas as well, yielding cheap new biodegradable plastic films and lightweight, high-strength ceramic replacements for much of the metal in engines and other automobile parts.

All that added money for research is bound to have a trickle-down effect on education, encouraging more students to enter materials science. But the initiative also takes a direct

A Special Section of *Science*

Frontiers in Materials Science

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.

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

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%

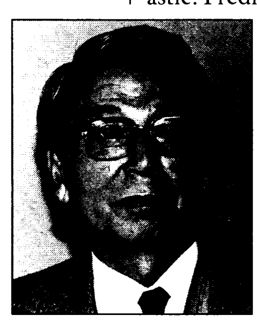
SOURCE: OMB

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.