early gift of PCR, making it possible to obtain rare DNA sequences in quantity. As a result, the labs at Berkeley were the first academic outfits to test the method, which has gone on to be of tremendous importance in research.

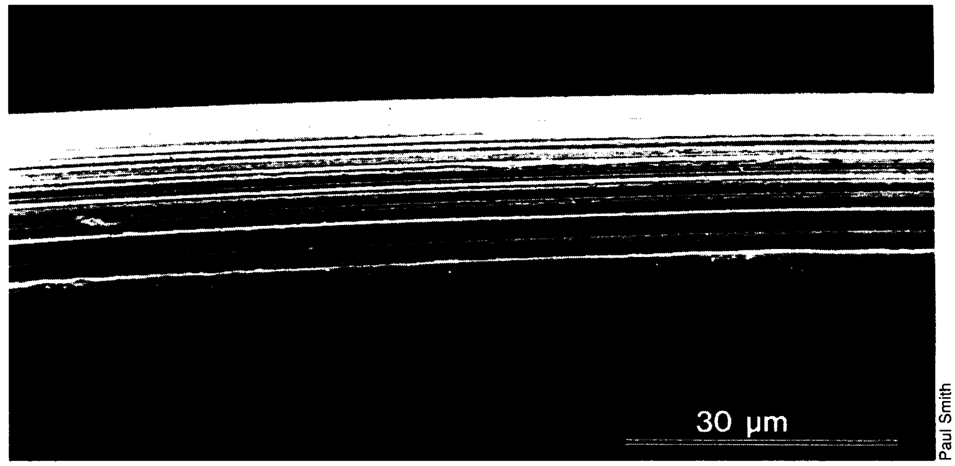
Indeed, PCR, which received its commercial release in 1987, has now convinced virtually all organismal biologists that using DNA could actually be a tremendous boon to them. "PCR means all of a sudden that all these dead rats in museums are genetic goldmines," says NSF's Yates. Svante Paabo, another pioneer, who has just left Wilson's lab to set up a new molecular lab at the University of Munich and at the Zoological Museum in Munich, enthuses: "I think it's kind of a renaissance for museums. You can obtain samples from extinct species, and you can look at populations over time, which is totally unique."

As a result of PCR (and other techniques), the tide is rapidly turning. "I think systematists like myself have settled down and are saying, hey, molecular data are really neat and need to be explored," says Michael Donoghue, a plant systematist who has been instrumental in convincing the University of Arizona to open a new $225,000 molecular systematics lab. "It's not going to reveal the truth in some sort of cosmic sense, but it's going to be extremely valuable to us and help us solve the sort of evolutionary questions we couldn't answer before."

Reflecting the trend, funding requests for molecular proposals are way up at the NSF. "We see a lot of people who 10 years ago were sending us proposals to work on a group of organisms; now...they need money to sequence the genes or to look for polymorphisms, as well," says Yates, whose agency funds about $13 million a year in systematics research (molecular and nonmolecular). "I find it interesting that curators were talking for years and years about how these things were valuable, but rarely convincing administrators. Now the same administrators are scrambling to get funds for molecular labs to re-examine these specimens."

Museum administrators also have another motivation to tool up: They are better positioned to recruit young scientists to replace their aging cohort of curators. Of 125 curators at the Smithsonian's Museum of Natural History, only about a dozen are under the age of 40. One of them is Graves, the 37-year-old ecologist who is a curator of birds at the Smithsonian. "People my age can't afford to be any other way," says Graves. "This is the future. I think 20 to 30 years from now the old style museum curator is going to be a thing of the past."

■ Ann Gibbons



Lining up. *Scanning electron micrograph of an ultra high molecular weight form of polyethylene made up of oriented polymers.*

Plastics Get Oriented—and Get New Properties

They can be stronger than steel and more conductive than copper. But producing them is no mean feat

"I HAVE JUST ONE WORD TO SAY TO YOU. JUST one word: plastics." More than 20 years ago an enterprising uncle uttered that bit of advice to Dustin Hoffman's character in *The Graduate*.

Looking back, it wasn't bad advice, but if the graduate had returned home in 1991, a forward-looking uncle might have added two more words: oriented polymers.

The uncle would point out that oriented polymers can make plastics stronger than steel and more conductive than copper, as well as resistant to heat, chemicals, moisture, and corrosion. Today, specially processed plastics give Oliver North's bullet-proof vest its stiffness and the ropes and sails on America's Cup yachts their strength. Still to come: plastic airplane parts, plastic wires, and plastic diodes and transistors.

Making plastics with oriented polymers takes elaborate and expensive tinkering. One chemist compares the process to "uncooking spaghetti" because scientists take the coiled, spaghetti-like polymers that make up plastics, straighten them out, and put them back together in a parallel fashion—something like the way spaghetti comes in the box.

That technique can theoretically make plastic do many things metal can—only better, says Paul Smith of the University of California at Santa Barbara, a pioneer in the field. "Plastics have the potential for greater than ten times the strength and stiffness of steel." But for 2 decades scientists have been prevented from realizing that remarkable potential, because the materials that promised these properties proved impossible to make on a practical scale. "People can dream up all kinds of nice polymers but if you can't process them into useful materials, they have absolutely no interest," Smith says.

As long as processing problems separated scientists from their dream plastics, the quest for high-strength and conductive polymer materials waxed and waned. Scientists lost patience as the polymers promising the most strength and conductivity resisted the necessary first step of melting or dissolving.

But in the last 4 years, new discoveries have sparked excitement, offering the promise of breaking through the processing obstacles. Some areas of oriented polymer research are now so hot that competing industry scientists hesitate to divulge details of their latest work.

A major insight made 2 years ago further boosted the spirits of both scientists seeking conductivity and those after strength. Both groups of researchers realized they needed to achieve the same thing—alignment—says Alan Heeger, another pioneer who works with Smith at UC Santa Barbara. "In our experiments we put two types of polymers together and oriented both at the same time," he says. "We were excited to find that alignment improved both strength and conductivity."

Heeger says that scientists in the two pursuits, who traditionally followed separate paths, are now taking an interest in each other's ideas and examining materials combining strength and conductivity, as well as other properties—resistance to corrosion and heat, for example. Getting any of these properties from plastics is a matter of manipulating the material's chemical structure. Almost all plastics are made from simple organic chemicals, such as hycrocarbons and esters, bonded together in long chains like beads on a string. Plastics get their strength from the strong covalent bonds that link carbons down the backbones of these polymers. Their weakness: the flimsy forces that bind the polymers together.

Explains DuPont chemist Vlodek Gabara: "To get high strength you need to line up the polymers so the covalent bonds reinforce each other."

The few polymers that conduct electricity down their backbones also do so because of the alignment of the polmers, adds Smith. A disordered array hinders charges, making them jump from polymer to polymer, while a neat parallel arrangement gives charges a smoother channel of flow.

In traditional plastics, the polymers are arranged haphazardly. Some, known as the amorphous plastics, have no more order than a plate of cooked spaghetti; others come in a partly ordered "semi-crystalline" state, in which some polymers line up within loosely divided units or regions.

In the early 1970s, chemists and materials scientists at DuPont discovered they could get a whole new degree of alignment and in doing so, multiply the stiffness and strength of the material. This was an accidental discovery, made while the DuPont scientists were searching for something else—heat resistant plastics. But the discovery hardly solved all the problems in the field; in fact, it simply marked the start of a 20-year struggle to get the requisite degree of alignment cheaply enough for broad commercial applications.

The first fruit of the new discovery was a product known as Kevlar, made by DuPont. The Kevlar polymer is an aramid, a structure that resembles a stiff chain of connected carbon rings. When put together in an oriented structure, it is five times as strong as steel—but only in the direction of alignment, leaving it weak and crumbly in the perpendicular directions. As a result, it can't be used very effectively in solid form but is useful as a fiber that can be woven or used to reinforce other materials.

Scientists refer to the Kevlar polymers as "rigid rods," as opposed to the other main type, "flexible chains." Smith likens the rods to raw spaghetti and the flexible chains to the cooked variety. To get Kevlar from rigid rods, scientists must first dissolve or melt them and then squeeze the polymers into an ordered solution known as a "liquid crystal." With the flexible chains, on the other hand, researchers must stretch the coiled strands out as well as line them up, explains Smith. They do that by pulling on a sheet or fiber of the material.

But for years, the field of stretching was caught on a snag: No one could stretch flexible chains without tearing them, because the strands formed tangles that limited stretching to three to six times the original length. Then, in the early 1980s, Smith and others learned to disentangle polyethylene chains by diluting them. He explains that the chains stayed untangled when dried out, allowing the researchers to stretch them to 25 times their original length, yielding a material with twice the strength and stiffness of the best rigid rods.

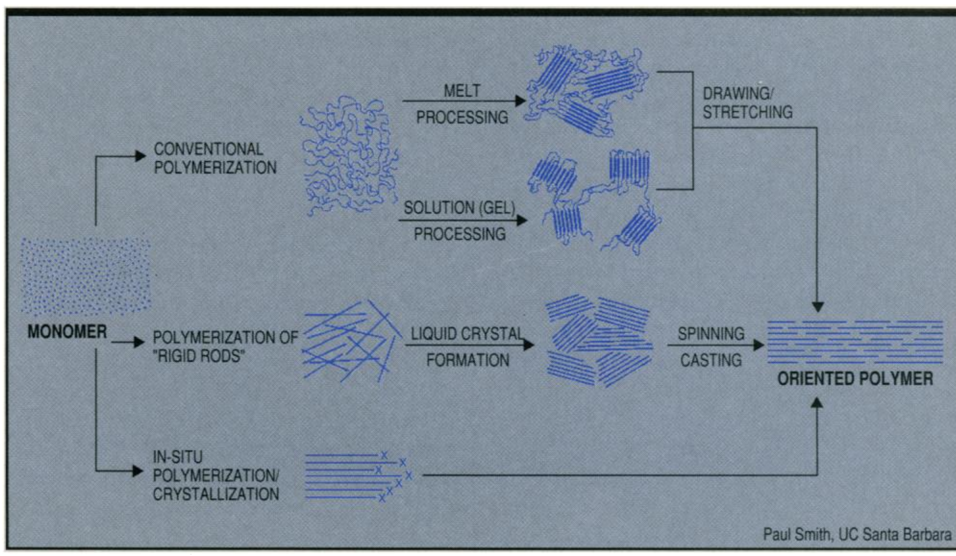
Flexible chains make up one major commercial product—Allied-Signal's "Spectra." Unfortunately for Allied-Signal, Spectra isn't the ultimate oriented polymer product, because it melts at temperatures of only 130°F; the temperature of an engine turns it to goo.

Stretching also works for conductive polymers, but researchers on that side of the problem are just catching on to the trick of disentangling the chains by dilution. Recently, University of California at Santa Barbara's Heeger mixed the conductive polymer polyacetylene in a solution with polyethylene and stretched both together, creating an alloy with conductivity 100 times higher than that achieved by "brute force" stretching. "The product gave us high strength as a bonus," he says.

Generally, scientists working with conductive polymers have had to jump through more hoops than those looking for strength alone. The structure of alternating double and single bonds that makes these polymers conduct electricity also renders them exasperatingly difficult to process, because they are difficult to dissolve—and they won't melt either.

In the last several years, scientists breathed new life into the field with tactics designed to trick conductive polymers into solution. Some workers are dissolving a soluble precursor and allowing it to react to form the desired conductive polymer in a dissolved state. Other researchers devise modifications to make the polymers soluble without destroying their conductive ability. Robert Grubbs and his group at the California Institute of Technology make their modification to the monomers before linking them up to build conductive polyacetylene. The modification renders the finished polymer soluble and easy to deposit in thin films, useful for possible silicon-polymer hybrid electronics.

Yet some of those who are working on these problems think it would be nice to sidestep the whole ordeal of dissolving and orienting. That is just what Roger Porter of the University of Massachusetts is trying to do, as are Smith and his colleagues. The idea, Porter says, is to build up polymers in an ordered structure directly from their monomer building blocks. By setting the conditions just right, Porter says, he is trying to get monomers to link up in an oriented solid.



Uncooking spaghetti. *Researchers are trying several different routes to making plastics with oriented polymers.*

"This field will really take off," he predicts. "It will be big."

Smith also predicts the technique, known as "in situ" polymerization, will mark a milestone, allowing scientists to align many kinds of polymers easily and cheaply. Smith and Porter hesitate to explain the details of their in situ work. Both hold contracts with companies developing the technique. Industry scientists familiar with the process also say they aren't allowed to say much about it.

But in situ polymerization isn't the only brand new, experimental route to oriented polymers. Flonnie Dowel, a chemist from Los Alamos National Laboratory in New Mexico, is trying a new path to high strength.

She designed theoretical "super strong" polymers that are supposed to hold their alignment with side chains that "interdigitate" like teeth of a zipper. She predicts her super strongs will give twice the tensile strength and 25 times the compressive strength of the best available oriented polymers.

Other researchers consider her vision a long shot. Indeed, most doubt anyone will be able to synthesize the stuff. But the proof is still in the polymer rather than in the speculation—and Jack Preston of Research Triangle Institute is now attempting to synthesize a version of Dowel's super strong oriented polymers.

"Part of the problem is no one really understands all the math in Dowel's theories and computer models," says Preston. "But even if the theory is all wet, these materials will show some interesting properties," he adds.

For the companies that want to make the new polymers for a market, processing isn't the only problem; cost is another key factor. The high price of producing materials sometimes outweighs the advantages conferred by their material properties. And, as a result, even the strongest oriented polymers are now largely confined to specialized applications—sporting goods, protective armor, cut-resistant surgeon's gloves, kite strings, and fishing nets—because of the cost of making them.

But oriented plastics are now on the verge of breaking into higher volume markets, particularly in the aerospace industry. Don MacLemore, a lab director at Dow Chemical, expects plastics to make a splash in the aerospace market as ingredients in molecular composites. In this new class of materials, individual rods of super-rigid polymers intersperse through a matrix to bolster its strength—much as glass and carbon fibers do in traditional composites, but with more strength and less weight. MacLemore and his Dow colleagues are exploring a rigid polymer known as polybenzobisoxazole (PBO) to fill the role. "This is one of our biggest projects," he says.

PBO is stiffer than existing rigid rods, and prototype materials made from PBO boast twice the stiffness and equal strength of its nearest competitor, says MacLemore. "It's tough as nails."

Because of the significance of molecular composites for aircraft, U.S. Air Force scientists are eagerly collaborating on producing them. Thaddeus Helminiak of Patterson Air Force Base explains that molecular composites escape some of the weakness that comes from the interfaces between different materials in traditional composites. He is now helping work out remaining kinks, such as the tendency of PBO rods to clump together. "In the Air Force the important words are higher, faster, farther, cheaper, and invisible," he says, adding that PBO composites promise to fill those goals.

Most aircraft applications so far have centered on strength, but those who are working on conductive polymers also hope that the aircraft industry will provide an outlet. Some see conductive polymers in shields that would protect equipment from static electricity or make planes invisible to radar. Others envision lightweight coatings that would protect planes from lightning and save ships from corrosion.

The first commercial conductive polymer, however, didn't appear in the aircraft market, but in a much humbler product: rechargeable batteries. These have had some commercial success, although industrial researchers have much more powerful successors already on the drawing board.

Other applications for the conductive properties of oriented polymers are even more intriguing, because they are less closely tied to existing products such as batteries or aircraft. Scientists hope to exploit the sensitivity of conductive polymers, which react to small changes in temperature, chemistry, or radiation by switching from the conductive to a nonconductive state and often changing color. These polymers may someday go into the detectors used to measure environmental pollutants.

In addition, Mercouri Kanatzidis of Michigan State University and others are trying to harness the same switching ability to make conductive polymers into "smart" windows that let in just enough sunlight on hot days and insulate rooms on cold nights. To do that requires a polymer that can alter its opacity, by changing from colored to transparent and back. A transparent conductive polymer could also convert sunlight to electricity in solar energy collectors without blocking any of the light. "Transparency is sort of a holy grail in our field," says Kanatzidis.

Kanatzidis and others in the field get excited about the variety of possibilities new polymer materials open up. "We will see major commercialization within the next few years," predicts Heeger. "The really exciting thing is we are seeing a full range of applications—things from low-cost commodities to high-priced, high-technology products," he adds. Kanatzidis compares the prospects for today's new polymer materials to the bright future of ordinary plastics around the time Dustin Hoffman's graduate came home from college. "Our work has the potential to start a revolution like the first one," agrees Heeger. "We just have to see how far it will go."

■ FAYE FLAM

Faye Flam is the Washington correspondent for Chemical Week.

Mutation Identified

In the annals of medical research, few ideas have seen such rapid ups and downs as the notion that mutations in the gene encoding a protein called amyloid precursor protein (APP) might cause the hereditary form of Alzheimer's disease. In 1987, when the gene was first isolated, researchers thought it might be *the* Alzheimer's gene. Barely a year later, new studies seemed to rule out the possibility that a defect in the gene could be the primary cause of the brain disease. Now comes yet another study—and the APP gene's stock is shooting up again.

In work described in the 21 February issue of *Nature*, a team of nineteen researchers, led by neurogeneticist John Hardy of St. Mary's Hospital Medical School in London, reports that it has discovered a mutation in the APP gene that may cause some—but definitely not all—cases of hereditary Alzheimer's disease. If that is the case—and Hardy emphasizes that this is still a big if—it would be the first time that researchers have been able to pin down a biochemical event leading to the brain degeneration that characterizes Alzheimer's.

And that would certainly be reason for celebration. Any clue that could result in a better understanding of the biochemical basis of Alzheimer's pathology is sorely wanted by researchers who have been studying the baffling and devastating disease. Such an understanding might help researchers devise effective therapies for Alzheimer's—which is currently incurable. Moreover, if the disease should turn out to be caused by one or more mutations that can be picked up by genetic screening, then early detection of the condition should be possible.

What Hardy and his colleagues have done in the current study is determine the nucleotide sequence of one segment of the APP gene in members of a family with hereditary Alzheimer's disease, which is characterized by early onset of symptoms, usually when the patients are in their forties or fifties. (There is also a late-developing form of the disease, which generally comes on after 70 years of age, that may not be of genetic origin.) The researchers chose the family they did, Hardy says, because earlier genetic analysis had indicated that the gene causing Alzheimer's in its members is on chromosome 21, the same chromosome that carries the APP gene.

When the researchers sequenced the APP gene segment, they found that all the family members with Alzheimer's had a specific mutation not seen in unaffected members. The result: amino acid 717 in the 770-amino