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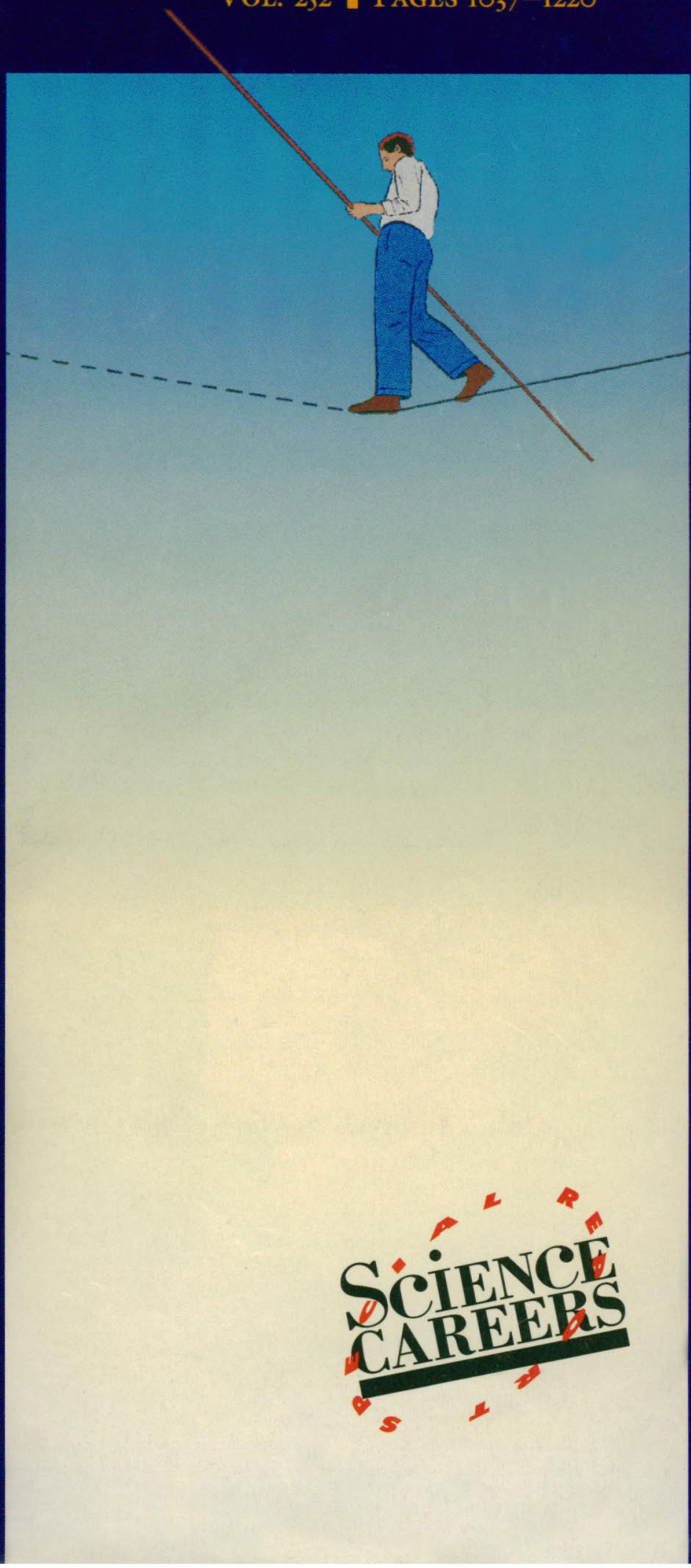

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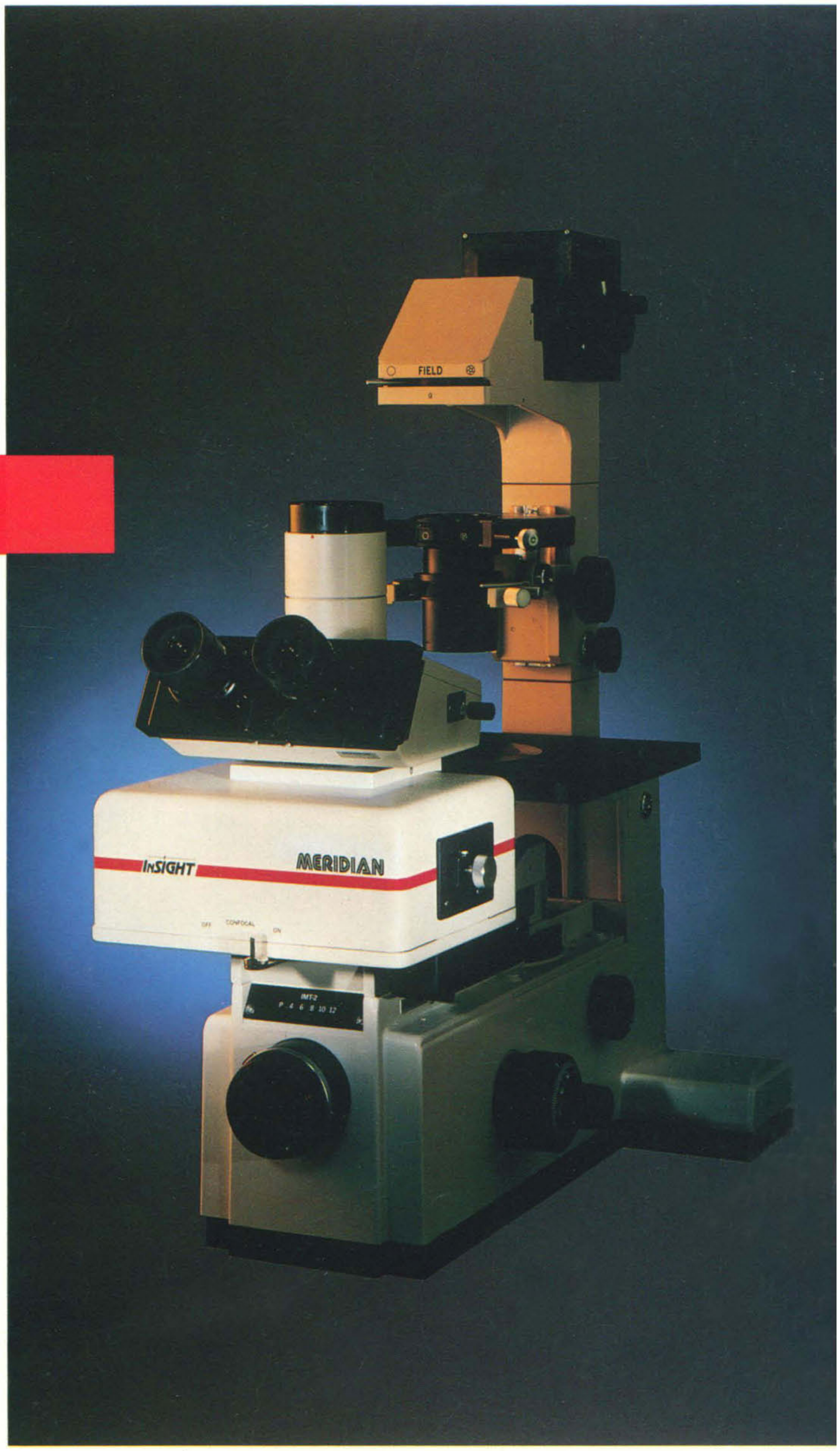

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*Brackenhoff, G.J. and Visscher, K. (July, 1990). *Novel Confocal Imaging and Visualization Techniques.* Paper presented at Micro 90, London, England.

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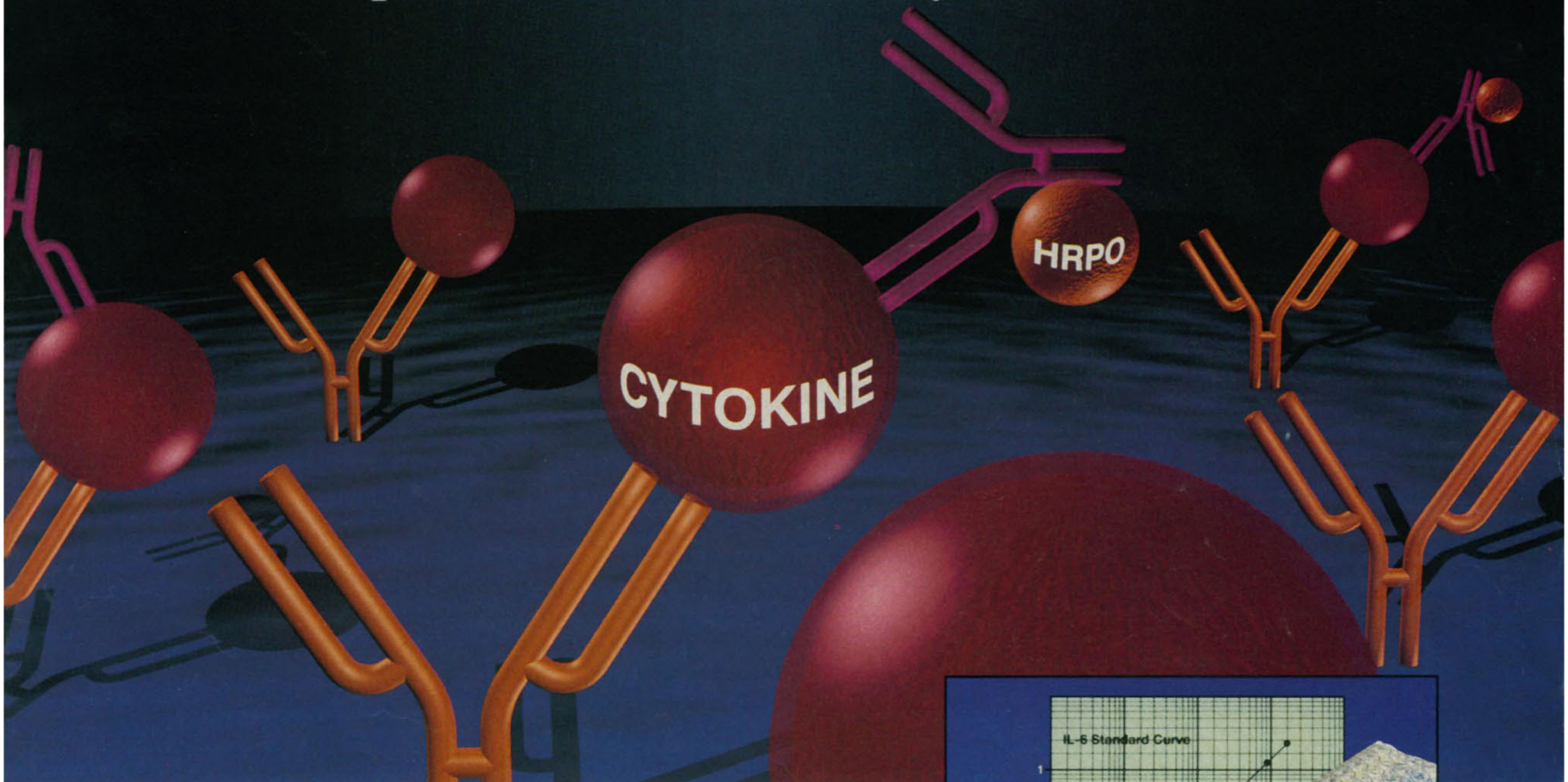

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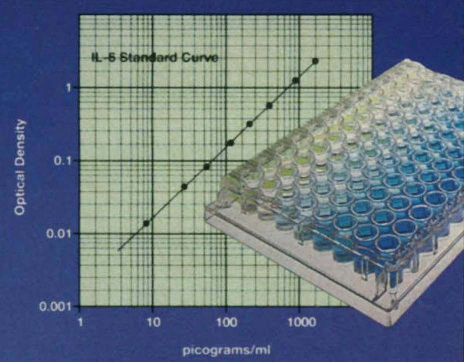

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■ The American Association for the Advancement of Science was founded in 1848 and incorporated in 1874. Its objectives are to further the work of scientists, to facilitate cooperation among them, to foster scientific freedom and responsibility, to improve the effectiveness of science in the promotion of human welfare, to advance education in science, and to increase public understanding and appreciation of the importance and promise of the methods of science in human progress.

COVER The career path of a scientist in the 1990s may seem a high-wire act with a dotted-line future. Today's successful scientist walks a tenuous line between seeking security in an uncertain funding environment and taking risks in an age of spectacular advances. He or she is asked to balance the competing tugs of business and academe, of applied and basic research, of authority based on narrow expertise and utility based on multidisciplinary experience. Our special pull-out report on careers, beginning on page 1107, is meant to help scientists navigate their individual high wires. [Image by Guy Billout]

Reports

Inside AAAS

Book Reviews

Products & Materials

This Week in SCIENCE

Scientific careers

THINKING about retooling or starting a career in science? This issue contains a special pull-out that includes an analysis of the current state of scientific careers, trends for the '90s, some personal perspectives, descriptions of hot tools and topics, and a request for reader comments (pages 1107 to 1150; editorial, page 1045).

Prescription drugs

PHARMACEUTICAL companies are in business for two major reasons: to develop and market new drugs and to make money (page 1080). Neither goal can be attained without the other. Estimates are that it costs about $231 million for each new drug to arrive at the marketplace (and only one in 10,000 compounds makes it); more difficult to assess are the savings (reduced health care costs, added time at work) that may be realized by an effective drug. What factors figure into efforts of drug manufacturers to balance profit-making with their obligation to serve the public? Vagelos describes how one major U.S. pharmaceutical company discovers, develops, prices, markets, and in one interesting case gives away prescription drugs.

Fragile X syndrome

FRAGILE X syndrome is a common heritable form of mental retardation with many cryptic features (see Hoffman's story on page 1070). Insertions, methylations, and amplifications all contribute to the production of abnormalities in an exceptionally unstable region of the X chromosome—region 27.3 of the q band of the X chromosome—a region that even changes size from generation to generation. Techniques described in two studies shed further light on the structure and inheritance of the unstable disease-associated segment of DNA and are expected to lead directly to reliable identifications of male and female carriers and to a better understanding of relations of genotypes with disease phenotypes (Oberlé *et al.*, page 1097; Yu *et al.*, page 1179).

Acid lakes and streams

ACID rain and snow are major but not exclusive causes of acidity in lakes and streams in the United States (page 1151). A survey of 1180 acid-sensitive lakes and 4670 streams across the country showed that acid deposition is responsible for acidity in 75% of acidified lakes and 47% of streams, mine drainage is responsible for acidity in 3% of lakes and 25% of streams, and organic anions cause acidity in 25% of each. The chemical analyses could be corroborated by paleolimnologic studies. Baker *et al.* point out that although pH values are lower than 5.5 in chronically acidified waters, dramatic biologic effects can be induced when values drop to 6.5 and below. Thus tallies of chronic acidity alone do not provide a full picture of how widely acid deposition effects may be felt.

Buckyballs

BUCKYBALL research is on a roll. Recently buckyballs were shown to have the properties of superconductors when they are doped with an electron-donating material such as potassium. Now Holczer *et al.* report that the composition of the only stable superconducting phase of the potassium-doped fullerene is K_3C_{60} (page 1154). Measures of shielding diamagnetism indicated that the yield of 19.3 K superconducting material was quite high. Superconductivity at 30 K was then found in a rubidium-doped form of C_{60}. Experiments by Fagan *et al.* show that buckyballs, which were thought originally to be chemically inert, can form covalent bonds with electron-rich organometallic platinum and ruthenium compounds (page 1160). The reactivity of the carbon-carbon bonds of the buckyballs resembled reactivity of bonds in electron-poor alkenes or arenes; other chemical properties of these classes of organics may thus be relevant to buckyball chemistry.

Bubble burst

SURFACE damage associated with the presence of vapor bubbles in liquids occurs when bubbles form, not when they burst (page 1157). This heretical conclusion comes from studies by Chen and Israelachvili in which the formation and collapse of gas bubbles were monitored with a surface force apparatus. A high viscosity liquid was placed between two curved surfaces. As the two surfaces were pushed together, they flattened. As they were pulled apart at high velocity, the liquid "cracked" open, the surfaces snapped back to their original curvatures, and vapor cavities formed. All of the surface damage occurred during recoil. This work is pertinent to "the bends" of divers and to vibration damage to ship propellers in water.

Arginine fork

SEVERAL RNA-binding proteins include a segment that is rich in the charged amino acid arginine. One such protein, Tat from the human immunodeficiency virus, binds to a bulged region of RNA, and the interaction is necessary for RNA transcription. The electrostatic charge rather than the specific sequence of amino acids in Tat's binding region appears to be important in binding and activation. To illustrate this sequence flexibility, Calnan *et al.* systematically replaced arginines with lysines in synthetic peptides fashioned after residues 49 to 57 of Tat (page 1167). Only one arginine (at position 53 or 52) is essential for binding and activation but it must be flanked on each side by three or four other charged amino acids. The protein-RNA interaction is probably stabilized by an "arginine fork" produced by hydrogen bonding between the arginine and adjacent phosphate groups in RNA.

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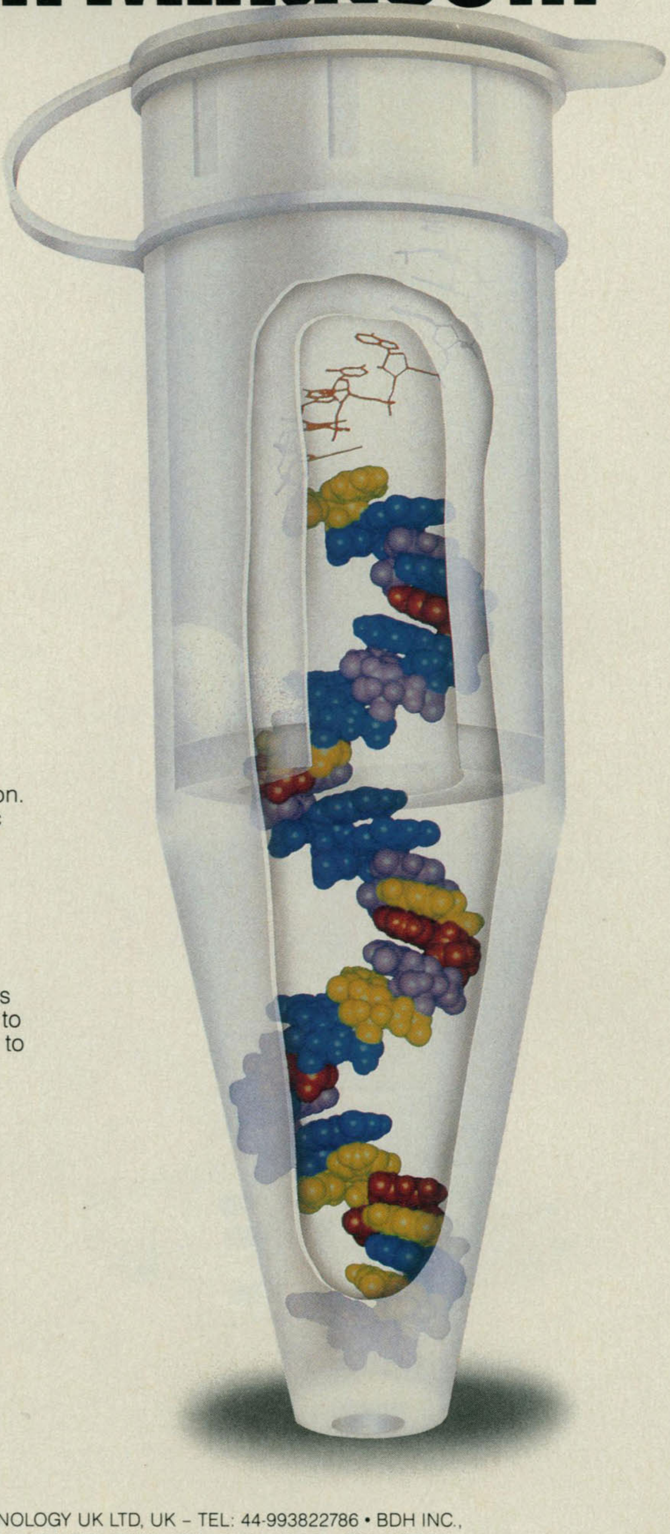

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*patent pending. *mRNA model courtesy of* BIOSYM

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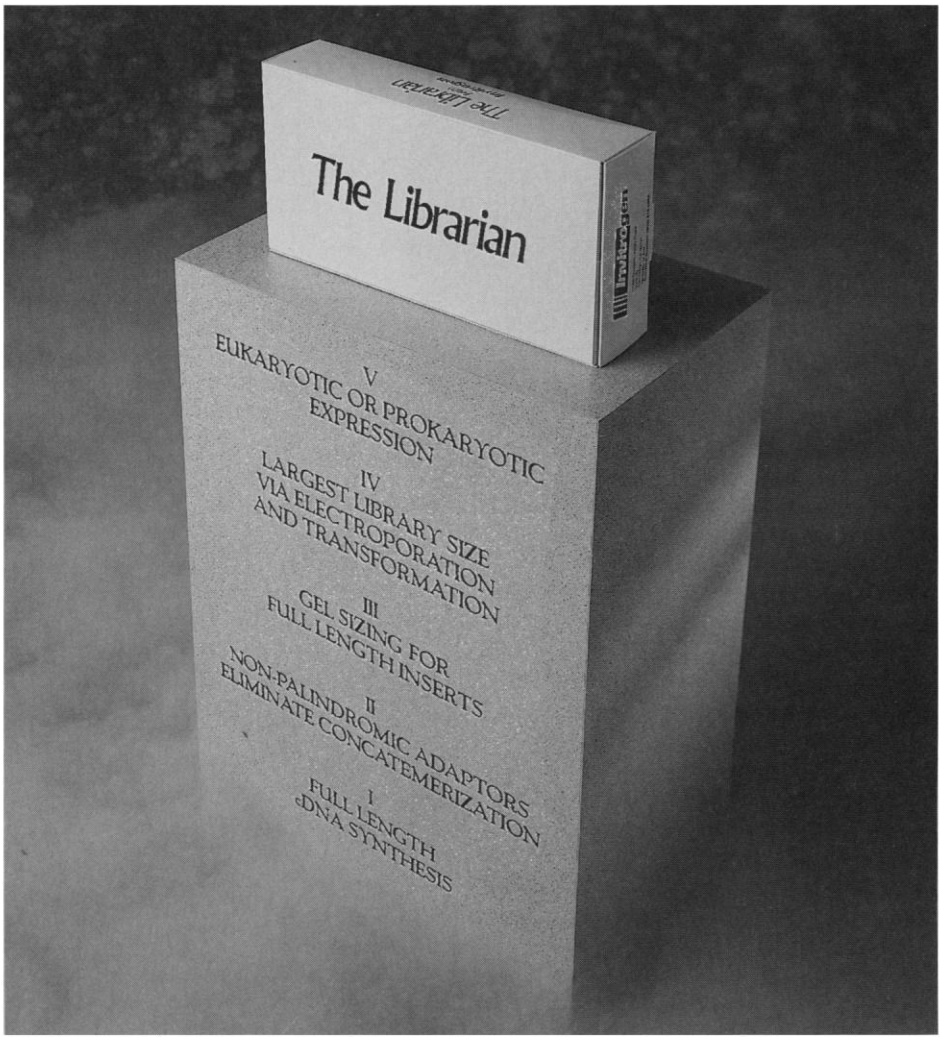

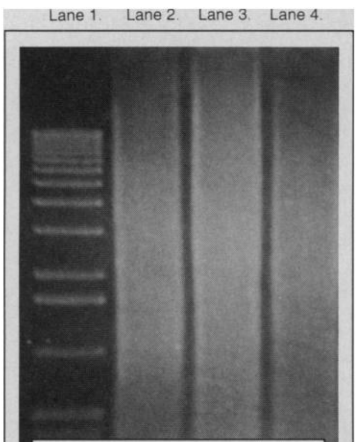

Lane 1: 1Kb markers (BRL). Lane 2-4: cDNA from fetal eye lens tissue, HI60 cells and umbilical cord endothelial cells, respectively.

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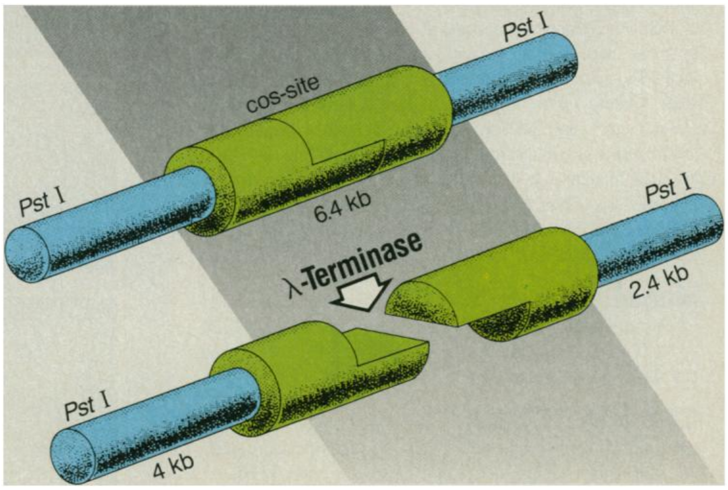

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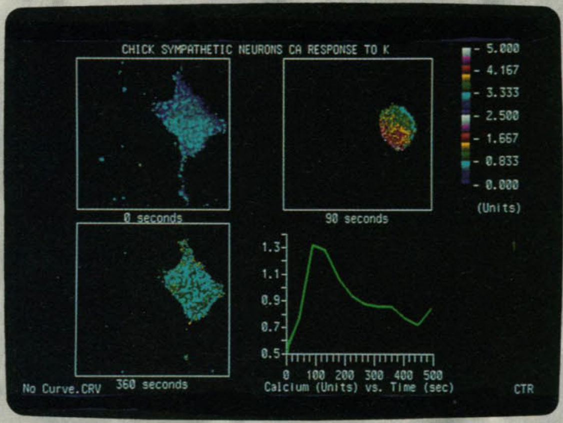
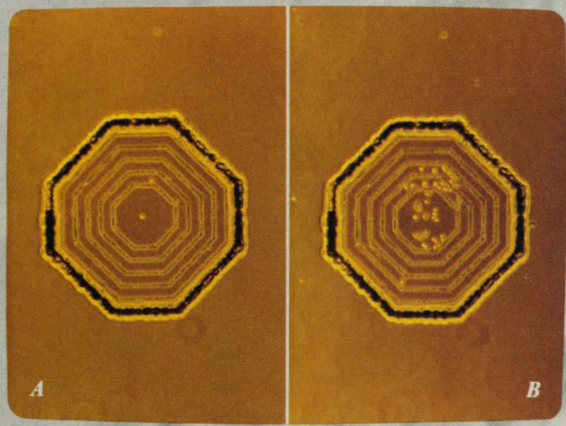
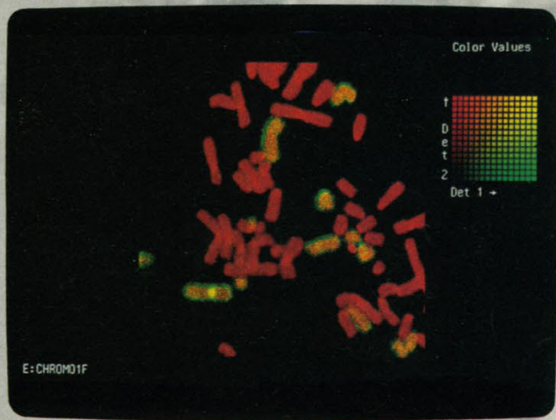


Confocal quantitation and localization of Ca^{2+} using the ACAS 570. *Ca^{2+} response to potassium is shown as a function of time in a 1μ confocal optical slice of an Indo-1 labeled chick sympathetic neuron. (Courtesy of Dr. Arun R. Wakade, Dept. of Pharmacology, Wayne State Univ.)*



Attached cell sorting using the ACAS "Cookie-Cutter"™ technique. *A) CHO cell isolated in culture. B) Cell out-growth after two days. (Courtesy of Dr. Margaret Wade, Meridian Instruments, Inc.)*



Detection of human chromosomes by* in situ *hybridization using the ACAS 570. *Mouse/human hybrid cell culture labeled with fluorescein-human DNA and propidium iodide. Displayed as a dual-label overlay image. (Courtesy of Dr. Roger A. Schultz, Molecular Genetics Laboratory, Univ. of Maryland.)*

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Latest LSC technology cuts sample and cocktail costs; increases throughput

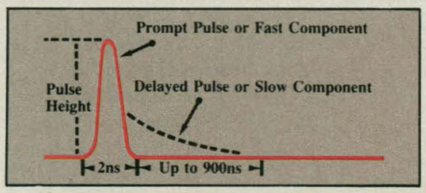
In the past, liquid scintillation counting used traditional technology to overcome background noise. Now, there's a new, more sensitive technology – TR-LSC or Time-Resolved Liquid Scintillation Counting – that reduces background noise by an additional 30%-40%, and more. This new patented technology is available only in Packard's Tri-Carb® liquid scintillation analyzers.

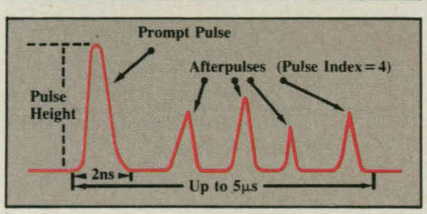
Originally developed for extremely low level counting, TR-LSC technology has now been applied to a broad range of applications. While these don't always require high sensitivity, additional benefits have been realized. By increasing sensitivity, TR-LSC reduces sample and cocktail consumption while shortening the time required for accurate counts. The benefits? Lower cocktail costs, lower disposal costs, and increased throughput.

How TR-LSC is superior to older technology

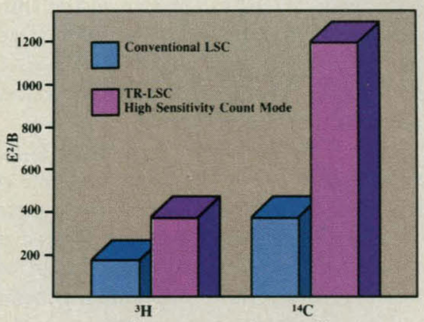
Traditional counters are based on two-dimensional pulse analysis: pulse height and pulse counts. They provide a level of sensitivity that's merely adequate for most applications.

Patented TR-LSC adds a third dimension to pulse analysis: a pulse index that measures over time the afterpulses associated with background. In doing so, TR-LSC clearly distinguishes between beta pulses and background pulses. By identifying, and reducing, background noise, TR-LSC provides a great level of sensitivity (see chart comparing E^2/B values) and more accurate counts.





The typical beta scintillation pulse (top) is very fast and may be followed by a delayed component. The typical background pulse is followed by a series of afterpulses. Patented TR-LSC distinguishes between the two.



Typical E^2/B values for ^3H and ^{14}C using traditional and TR-LSC counting.

Achieve accurate counts on samples as small as 25 μL

Traditional technology limits sensitivity. The improved sensitivity of TR-LSC, however, allows you to achieve accurate DPM results for single and dual label samples in volumes as small as 25 μL. That can add up to substantial savings in sample and cocktail costs.

Slash radioactive waste disposal costs

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Increase sample throughput by over 80%

Just as TR-LSC reduces the volume of sample and cocktail required for accurate counting, it also reduces the time required for an accurate count. By cutting background in half, high sensitivity TR-LSC lets you count nearly twice the number of vials of a 250-DPM sample, in the time it would take to count a single vial using conventional technology. For lower activity samples, the increase in throughput with TR-LSC is even greater.

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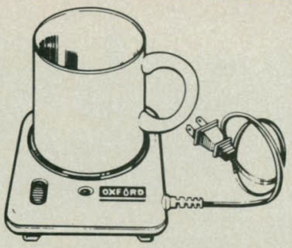

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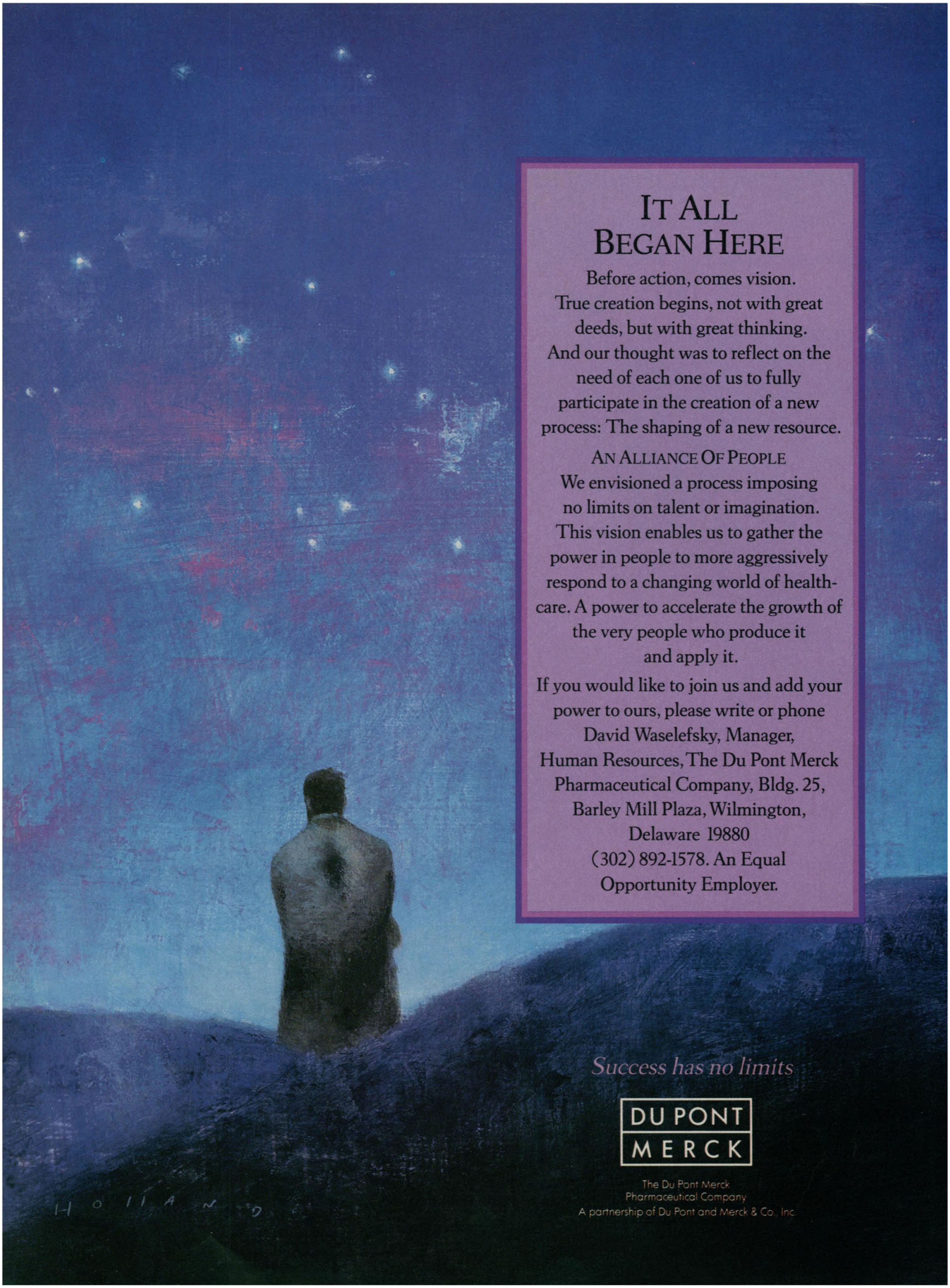
IT ALL BEGAN HERE
Before action, comes vision. True creation begins, not with great deeds, but with great thinking. And our thought was to reflect on the need of each one of us to fully participate in the creation of a new process: The shaping of a new resource.
AN ALLIANCE OF PEOPLE
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Science, 24 May 1991
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SCIENCE CAREERS

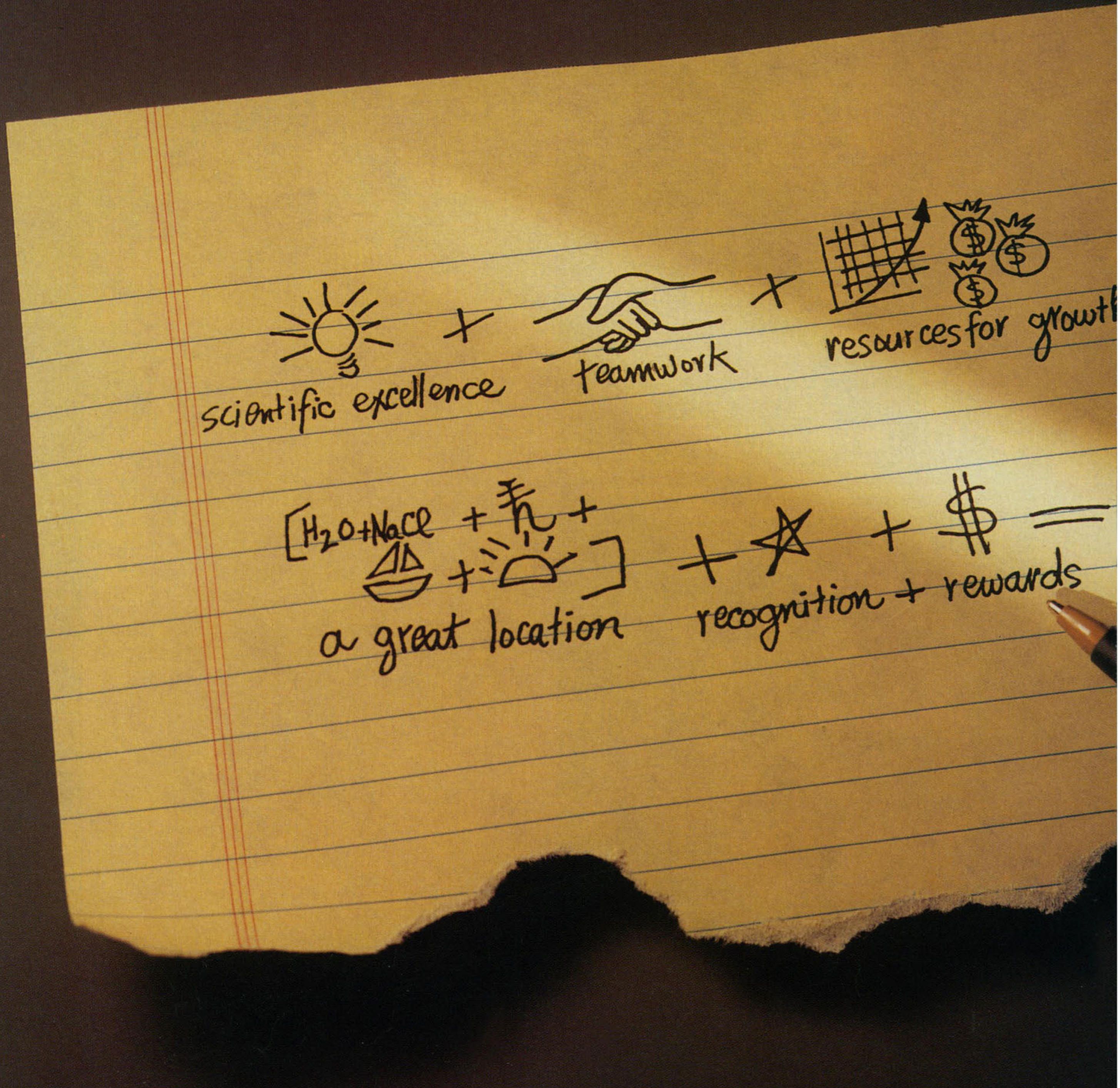
SPECIAL REPORT

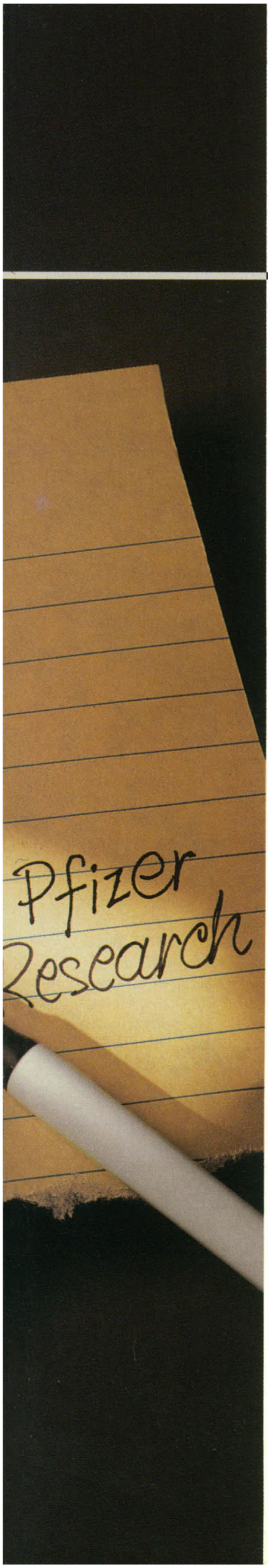
SPECIAL PULL-OUT SECTION

Edited by Constance Holden
Graphic design: Noah Dan
Cover illustration: Guy Billout

BS/MS Scientists

Solve the equation for success.





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Cellular Biochemistry—Identify and understand cellular processes involved in inflammatory response and develop drug therapies to modulate these processes.

Microbial Pathogenicity—Study virulence factors that determine colonization and host immune responses to a novel gastrointestinal pathogen. Biochemistry or Immunology background desirable.

Infectious Disease Modeling—Develop new models of disease to evaluate antiinfectives. Study bacterial pathogenesis employing microbiological, biochemical and molecular biology techniques.

Pulmonary Biology—Investigate airway disease and dysfunction. Relevant *in vivo* and *in vitro* laboratory experience highly desired.

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Central Research

The elements of success.

CAREER TRENDS FOR THE '90S

There ought to be a fin de siècle air of excitement for the newly fledged science postdoc these days: after all, he or she will hit the most productive years of scientific life not merely in a new century but in a new millennium. The horizons should seem limitless. Except...

By Constance Holden

...everywhere our young hopefuls look their scientific elder statesmen are grousing.

In academia, administrators and investigators alike are hounded by money shortages. In industry, vice presidents of R&D are bemoaning the sluggish economy, which they blame for holding down research budgets. Policy gurus in government are anguishing over where the next generation of scientists will come from. Lab heads are worrying about what new hoops the government science police will make them jump through. And nearly everyone connected to science fears for the morale and motivation of young investigators.

Confusing as all this is, there's yet more to confound the budding scientist. As Heraclitus might say, all is in flux. Traditional boundaries are dissolving. High-tech firms are bridging the gap between academic and industrial science; universities—and many academic labs—are looking more like businesses. Lines between basic and applied research are blurring. Disciplinary divisions are becoming irrelevant—even counterproductive—as many of the most striking research advances are occurring on the interface of multiple fields. Even geographical boundaries count for less as science becomes increasingly globalized. And all of these potentially exhilarating but disorienting trends are being accelerated by the emergence of incredible new tools—the computer being the most ubiquitous—that are altering and speeding up the process of science at a dizzying rate.

Thus, in what may be something of an understatement, one longtime observer of the scientific culture, Yale economist Eli Ginzburg, says: "It's increasingly difficult for a young scientist to have any sense of security."

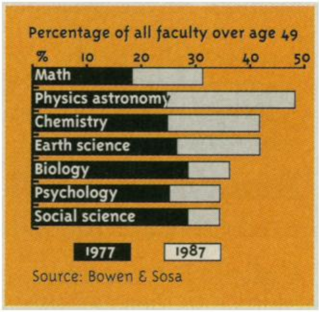
That's one reason why *Science* set out 6 months ago to assemble the combined wisdom of senior statesmen, younger practicing scientists, and close observers of the scientific community. Our hope: to arrive at a consensus about the trends most likely to affect science in the '90s and beyond, and to suggest some strategies to help early and mid-career scientists trim their sails to navigate the turbulent seas ahead. Following interviews with more than 100 scientists, we present this career guide—which, if you find it useful, will be the first of an annual effort.

What have we learned? As we proceeded, we concluded that there is in fact no clear consensus on where science is heading—much less agreement on the best strategies for career planning. Even such core questions as: Is there a looming manpower shortage? or Is there really a funding crisis? are up for grabs. So, instead, we present an overview of the most responsible, if often conflicting, notions. In the article that closes this section, we examine what life seems like to the individual young academic scientist and his or her adviser. In between, we offer data, tips, and the personal experiences of successful scientists.

One last note: Because we will expect to improve on this effort next year, we have included a questionnaire at the end. We hope you will respond to it so we may serve you better the second time around.

Trend 1: The Graying of Science

The U.S. population of scientists and engineers nearly doubled, to well over 4 million, in the 1980s. Despite this rapid growth, one of the chief worries these days is the widely touted "shortfall" of U.S. scientists and engineers expected this decade. That's the result of the rather remarkable demographic picture now shaping up: In the late '90s, the current decline in college enrollment will begin to reverse as the offspring of the Baby Boom generation reach college age, and many academics hired in the '50s and '60s will reach retirement age.



That means the demand for scientists in academia will rise sharply in the late '90s and early 2000s. Meanwhile the nation's annual output of American PhDs has remained flat for the past two decades, and there are no signs it will increase. These figures have led the National Science Foundation (NSF) to project a shortage of a half-million scientists and engineers by 2000.

Whether or not this disaster will actually materialize depends on how you define it. Analyses by the Bureau of Labor Statistics and the Office of Technology Assessment (OTA) among others, do not anticipate a supply/demand imbalance in the foreseeable future. But to people such as Nobel prize-winning physicist Leon Lederman, that's irrelevant: "There's a tremendous number of tasks science has to face—there are not nearly enough to do this," he says.

Scientists are justifiably perplexed. Although unemployment among scientists is much lower than in the general economy **[see manpower tables]**, the job market has been sagging in some fields such as math, theoretical computer science, and experimental physics. That's led to occasional reports of openings—such as one for a physicist at Union College—drawing several hundred applicants. But young scientists who can hang on through the next few years may find that what's bad news for science is good news for scientists as the demographics work their inexorable way.

Trend 2: The Vanishing "Natives"

While Europe and Japan are experiencing the same demographic shift relative to age, other aspects of the phenomenon seem to be especially troublesome in the United States: Science education is in sorry shape, and proportionally fewer members of the white middle class are opting for scientific careers. Women have made only modest gains, and their participation in engineering and the physical sciences seems stuck at low levels. And although Asian Americans have been conspicuously successful in science, progress has been dismal among Hispanics and blacks. Virtually no one believes that any significant change in minority participation can be effected in the next decade—former NSF director Erich Bloch himself has said it will take about 20 years.

Instead, what's happening is that foreign-born scientists are flooding the United States in unprecedented numbers. And last year's change in immigration laws could make the trend even more pronounced, allowing for about 20,000 more technically trained personnel a year to enter the country, according to tentative NSF estimates. A large proportion of these will be from the Soviet Union and Eastern Europe. At Harvard, says Nobel prize-winning physicist Sheldon Glashow, four foreigners—including two Russians—have simultaneously received tenure offers in the math department. Recent appointees to physics posts have been Iranian, Japanese, Polish, Russian, Indian, and Dutch. And in engineering, Americans have almost disappeared in some places—such as the University of Nebraska, where, says one scientist, "Poles are teaching the Indians now."

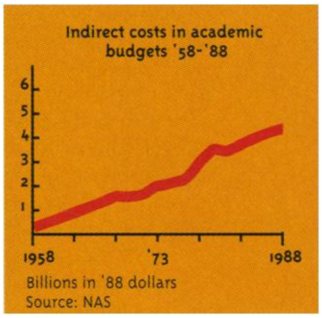
What are the implications for Americans? No one suggests foreigners are nudging out the natives; rather, says Glashow, "it's an indication that there's room at the top."

Trend 3: Limits to Growth

If there's room at the top, that's one of the few hopeful signs for academic scientists, who in the past couple of years have run head-on into some rude fiscal realities. Everyone seems to agree that discontent in academia is at an all-time high. Scientists always complain about not having enough money, said Lederman at recent congressional hearings. But, he said, "never before, in my experience," has the unhappiness "spilled over to the best young entrants and to the graduate students." Said MIT physicist Daniel Kleppner earlier this year: "I feel more and more uneasy about advising students to enter science."

PhD researchers increased by about 50% in the '80s—to 419,000 in 1988—and those doing research in academia increased by 65%. Among these, the proportion of those engaged primarily in R&D has increased to 25% from less than 20% a decade ago—partly because of the increase of those who, unable to get on the tenure track, are living on "soft" money. All this leads one industrial scientist, Peter Cannon, CEO of Conductus in California, to say: "I think academia has become rather overpopulated."

Not only have bodies multiplied faster than dollars, but costs of research have been going up much faster than inflation. With instrumentation, for example, cost-sharing with the government worked well with a $40,000 machine, but budgets are dwarfed by equipment requiring investments of 10 or 20 times that. Conformance with a proliferating welter of regulations exacerbates the problem. Federal rules covering worker safety and toxic emissions, "if applied fully in universities, could shut down many laboratories" in chemistry, materials science, and, in some cases, biology, says Harvard chemist George Whitesides. Last but hardly least, new animal welfare regulations (not to mention animal activism) are putting a severe crimp on research with animals.



The confluence of factors has caused rather sudden dislocations. At NIH, for example, although the research budget has increased by more than 50% since 1980, the annual number of grants has fallen by almost a third. At NSF, only 30% of those who apply for funds can hope to get them. There are no signs of any substantial increase in private sources of research support, either from foundations or from industry. And, as the Stanford University overhead costs fiasco has abundantly demonstrated, universities—and particularly, expensive private ones—have yet to figure out a way around the cost crunch.

Lederman raised a ruckus early this year by arguing that science funding must return to levels that characterized the "Golden Age" of the '60s. By his reckoning, that means the current level of funding for academic science should be doubled. But others find this completely unrealistic. As Bloch sees it, "the system has outgrown the capability to support it." Says Bloch: "We are going through tremendous changes"—by which he means, among other things, that scientists can no longer have their cake and eat it too. But, he adds pessimistically, "people are not fast learners."

What's the scientist to do? Physicist Bob Dynes of the University of California (San Diego) says the difficulties in getting funding make it "more clear than ever that an assistant professor has to have guidance from a senior professor"—someone to show him the ropes, pull the right strings, guide him to the best funding sources, get him on a project that will show payoff by tenure time. A "mentor" isn't enough, says Dynes. "You've got to have a godfather." [More on that in "Real Life"]

Trend 4: Erosion of the Ivory Tower

As competition tightens and boundaries dissolve, the Ivory Tower has eroded—science is no longer science's private business. The funding scramble, as well as the increasingly prescriptive nature of federal policies, has forced science into the political rough-and-tumble of the rest of the world. Washington is now crawling with science lobby groups—universities alone have opened some 80 offices, according to National Academy of Engineering president Robert White. The unhealthy trend toward pork-barrel set-asides as well as the increase in cases of alleged fraud and conflicts of interest all reflect the intensely competitive milieu in which scientists must now work.

NIH, for example, used to be seen as a model environment, combining scientific freedom with financial security. But recently that citadel of health research has seen many departures by eminent scientists who are dissatisfied not only with salary limitations but with professional ones inflicted by conflict-of-interest rules and restrictions on fetal research.

The collision of science and society is also seen in the tension be-

Continued on p. 1116

Scientists Are Grumbling

"High-energy physics is in a funk—most people don't want to work for big teams."

Physicist C.J. Martoff, Temple University

New federal regulations, "if applied fully in universities, could shut down many labs..."

Chemist George Whitesides, Harvard

"It's increasingly difficult for a young scientist to have any sense of security."

Eli Ginzburg, Yale University labor economist

"It's getting harder and harder to do both teaching and research."

T.K. Li, Indiana University biochemist

"I think the system has really pushed people into a no-risk approach."

Erich Bloch, former director, National Science Foundation

"I think we have had an enormous loss of imagination that has affected science in this country. The brightest people aren't being attracted to science. The feeling's not the same."

astronomer Margaret Geller, Harvard/Smithsonian Center for Astrophysics

Ivory Tower Under Siege

"Discontent among academic researchers is at an all-time high."

Roland Schmitt, president, Renssalaer Polytechnic Institute

"I think academia is in serious trouble. Only a very uninformed person would pursue a career in academia now."

Donald Shapero, NAS

"I think academia has become rather overpopulated."

Peter Cannon, CEO, Conductus, Calif.

"Academia is way overspecialized. They've got the bologna sliced so thin you can see through it."

Donald Frey, industrial engineer, Northwestern University

"The academic community...in my view is the segment of the national research community least important to the nation's well-being."

Rustum Roy, materials scientist, U. of Pennsylvania

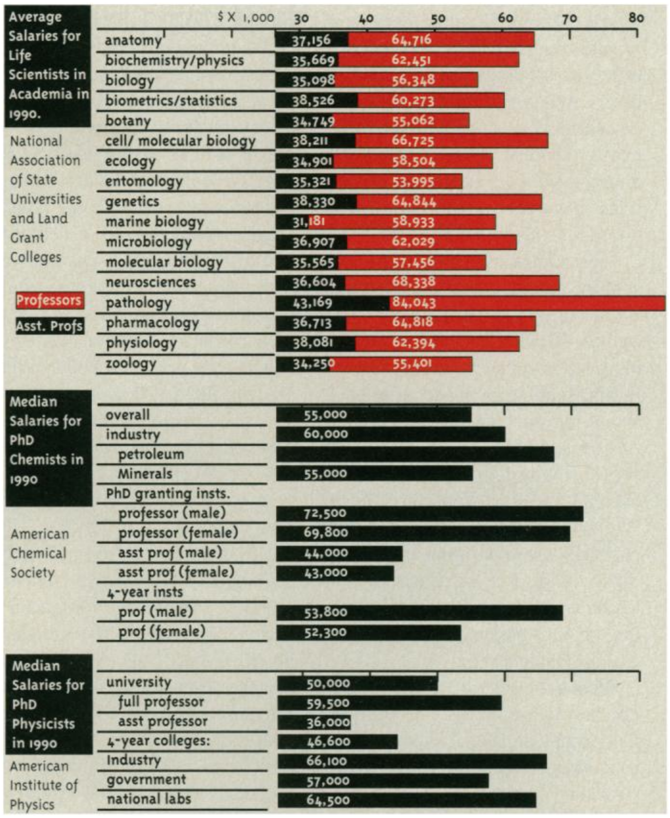
"Look for where to work other than in academe."

Robert White, President, National Academy of Engineering

"The stigma of going into industry right out of a PhD has been lessened."

David Jensen, Search Masters International, Sedona, Ariz.

DOLLARS & JOBS



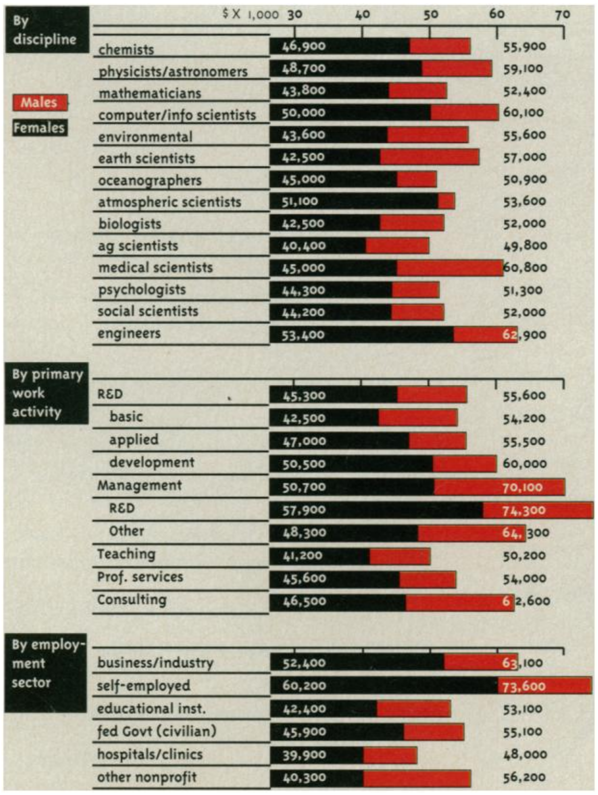
How much do you make?

Should pathology professors earn on average 25% more than neuroscience professors and 50% more than biologists, as reported in the 1990 survey by the National Association of State Universities and Land Grant Colleges? Do we believe it is socially equitable for assistant professors of marine biology to be making on average about $2,000 more than the average wage of American policemen, three quarters of whom have no degree, much less a doctorate? Why in the latter decade of the 20th century is the median salary of male medical scientists with PhDs one third greater than that of their female counterparts?

Equally fascinating questions will surely emerge from the job market statistics on the right-hand page. For the most part, this special careers section of *Science* is anecdotal in nature: a compilation of the advice and experience of scientists of all ages and disciplines about the profession as they see it. These two pages are our first annual effort to compile just a few hard numbers for our readers' delectation. One of our worries is the lack of comparability between surveys; another is the likelihood that we will have missed recent surveys of equally great or even greater interest than those we've published. If you know of some that you think we should include next year—or if you wish to vent your spleen at the surveyors sampled here—please turn to page 1148 and provide us some words of wisdom for next year's edition.

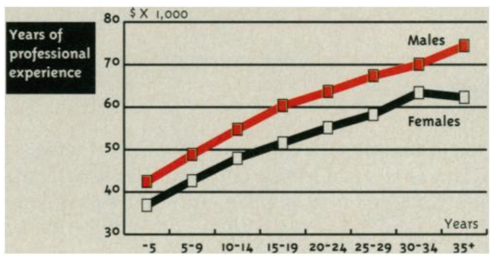
The Penalties of Being Female in Science.

Median annual salaries of employed PhD scientists and engineers, by gender, in 1989. (Source: NSF Biennial PhD Survey)

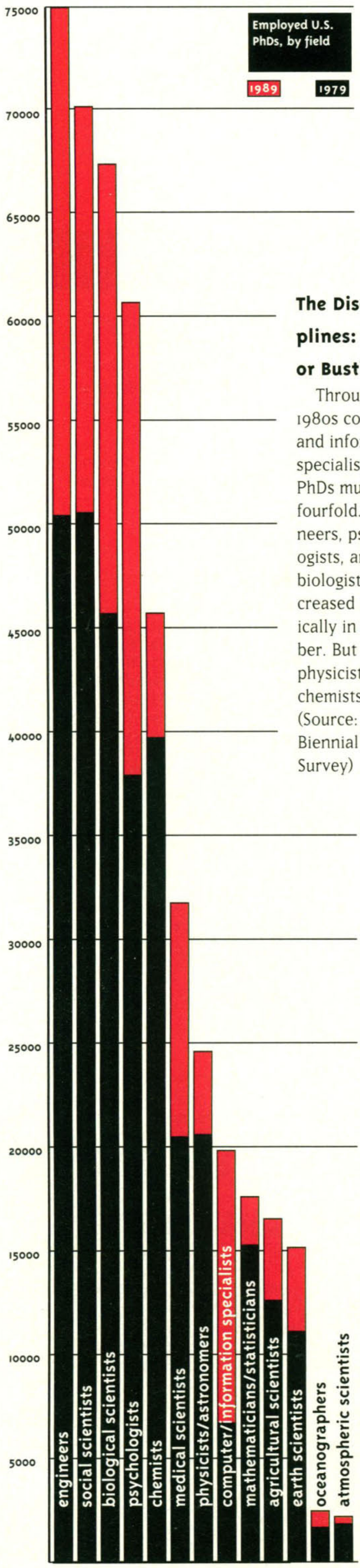


The Experience Gap

No matter how long the women are in science, the disparity between their pay levels and those of their male counterparts persists.



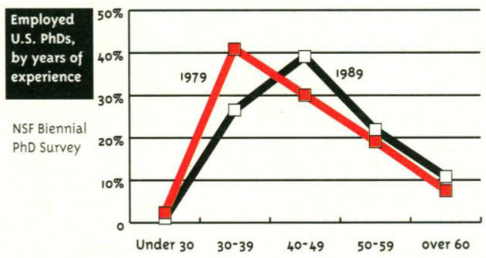
The Shifting Scientific Work Force



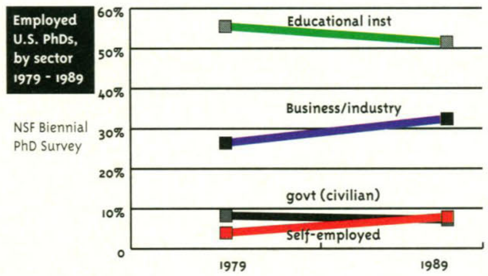
The Disciplines: Boom or Bust?

Through the 1980s computer and information specialists with PhDs multiplied fourfold. Engineers, psychologists, and, yes, biologists increased dramatically in number. But not so physicists and chemists. (Source: NSF Biennial PhD Survey)

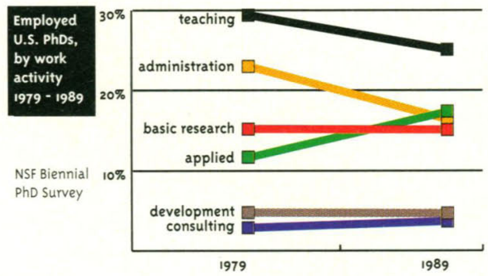
The Graying of America (in Science).

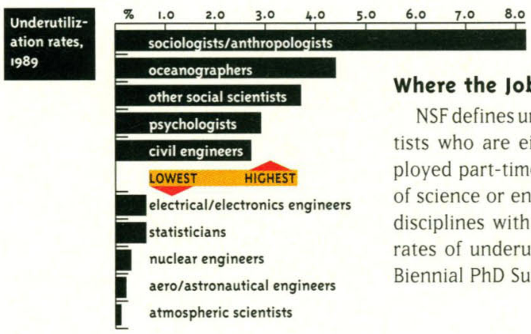


Getting Down to Business.



Out: Teaching. In: Applied Research.





Where the Jobs Are...and Aren't.

NSF defines underutilization as scientists who are either unemployed, employed part-time, or employed outside of science or engineering. Here are the disciplines with the greatest and least rates of underutilization. (Source: NSF Biennial PhD Survey)

Paltry Progress Toward a Scientific "Rainbow Coalition"

Results from NSF's latest survey of employed PhD scientists, ranked by percentage of whites in each discipline, show psychology to have the smallest percentage of minorities. But it has by far the greatest percentage of female members. Among the intriguing aspects of these numbers, notice how dramatically the percentage of Asians changes from field to field. One other point: percentages will not add up to 100 even excluding the females because most Hispanics are also identified as blacks or whites.

Field(s)	Total #	White %	Asian %	Hispanic %	Black %	Female %
psychology	60,596	95.4	1.5	2.1	2.2	36.0
agriculture	16,504	92.8	5.9	1.7	1.0	7.4
environment	19,787	91.8	5.8	1.6	1.2	8.4
social science	70,027	90.7	5.3	2.1	3.0	21.2
biology	67,250	89.8	8.4	1.7	1.2	23.4
physics/astron.	24,560	89.8	8.5	1.8	0.7	4.7
medical	32,079	88.9	8.2	1.6	2.0	29.1
math. science	17,611	88.7	9.3	1.8	1.1	8.7
chemistry	45,649	86.6	11.2	1.6	1.4	10.7
computer sci.	19,797	86.0	12.2	1.8	1.0	11.6
engineering	74,783	79.1	19.5	1.7	0.8	3.1

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Research Scientists – Molecular Biology

Papillomavirus Research

This individual will contribute to our ongoing program of study in the molecular biology and pathogenesis of human papillomavirus infection. Specific duties include conducting in-depth studies of the virus/host interactions that occur during human papillomavirus infection to define pathogenetic mechanisms and determine potential drug targets. Additionally, you will be involved in establishing cell culture and/or animal model systems. Position requires a PhD and/or MD with a minimum of 2 years' experience in one or more of the following: molecular biology of the skin; human or bovine papilloma virology; and analysis of human or animal skin biopsies. **Code: PR.**

Receptor Gene Cloning

This individual will conduct research within the beta interferon project team focusing on receptor gene cloning. This position requires a PhD or MD scientist with experience in the field of growth regulation and signal transduction. Candidates should have knowledge of cytokine receptors and experience with cell-based assays. Proficiency in vector design and construction using modern molecular biology techniques is required. **Code: RGC.**

Recombinant Antibody Engineering

This individual will be involved in the design and construction of recombinant antibodies. Candidates should have a broad knowledge of antibody structure and function as well as computer-aided molecular modeling skills. A PhD plus 2-4 years' postdoctoral experience required. Industry experience preferable. **Code: RAE.**

Research Scientists – Cell Biology

Immunologist

We currently have an opening for an immunologist with an emphasis on T lymphocyte biology. The principal focus of this work will be on T cell functions in inflammatory and autoimmune diseases, and in transplantation through investigations on the molecular mechanisms of T cell activation, tolerance, and immune regulation. This position requires a PhD or MD/Scientist with a minimum of 2 years' postdoctoral experience and demonstrated expertise in examining T cell functions in vitro and in vivo. **Code: I.**

Vascular Physiology/Pharmacology

This is an opportunity for a scientist with expertise in vascular physiology and pharmacology to address the needs of our Cardiovascular and Endothelial Cell Biology programs. Specifically, you will develop and apply small animal models of thrombosis and vascular injury/repair to the evaluation of exciting lead compounds and help identify novel points of intervention for cardiovascular and inflammatory diseases. A PhD or related degree is required. Experience with tissue histology desired. **Code: VP.**

Director of Toxicology and Preclinical Pharmacology

This key individual will be responsible for a wide range of duties to include: designing and implementing pharmacology, pharmacokinetic and toxicology studies for regulatory purposes; advising on the correlation of preclinical studies and clinical design; and developing the preclinical development/clinical support function. Additionally, you will review and present preclinical data as well as write preclinical summaries for INDs, NDA, investigational brochures, protocols and publications. Candidates must possess a PhD in Pharmacology or Toxicology and 10 or more years' experience of increasing responsibility, including pharmaceutical industry experience in directing preclinical programs. **Code: DT.**

Process Development

Protein Chemist

In a team setting, this individual will develop and optimize purification methods used in the manufacture of recombinantly derived proteins for use as parenteral therapeutics in human clinical trials. You will also create and execute validation studies to support applications to regulatory agencies. Knowledge of physical and biochemistry,specifically in protein chemistry and separations techniques a must. A PhD in Biochemistry, Chemistry, Immunology or related field, with hands-on experience in protein purification/characterization, and 2-5 years in related postdoctoral research are required. **Code: PC.**

Cell Biology

You will be responsible for research leading to the development and improvement of mammalian cell lines used for production of human therapeutic proteins. This position will also be an integral part of a team investigating methods for optimization of cell culture methods, including culture media development. The ideal candidate will have a PhD in Cellular Biology or Immunology or related field with 3+years' postdoctoral experience. **Code: CB.**

Research Associate/Associate Scientist

Protein Chemistry

We currently have an opening in our Protein Chemistry Department for an individual to prepare, characterize and release high purity protein products for reagent use. You must have a Bachelor's degree in Life Science and 4-6 years' experience in lab-scale production and purification of recombinant proteins. Familiarity with bioassay techniques preferred; Molecular Biology experience is a plus. **Code: RA.**

Our compensation and benefits package is one of the best in the industry, and is designed to attract and retain the finest talent available. Our Relocation Assistance is only one example of the benefits you can look forward to at Biogen.

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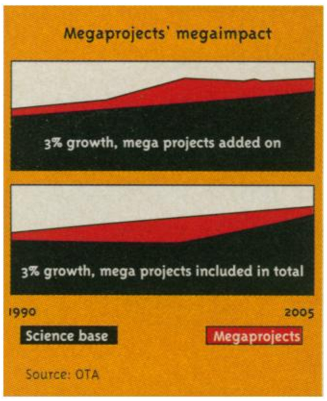
BIOGEN

continued from P.1111

tween elitism and democracy: In funding big projects, should the government focus solely on obtaining top-quality science, or weight decisions with geographic and other political considerations? That was one element behind the unpleasant fracas over the location of a new magnet lab desired by MIT, which legislators awarded to the University of Florida. On a smaller scale—despite the government's position that distributional equity will ultimately mean better science—efforts to provide special training and opportunities for minority and women scientists may cause conflicts where even the most promising new investigators are not getting adequate support.

Trend 5: Big vs. Little Science

The eternal tensions between Big and Little science have been brought into stark relief with the controversies over the Human Genome Project, the Superconducting Supercollider (SSC), and the space station. The OTA projects that if R&D budget increases stay constant at 3% a year, four mega-projects—the Human Genome Project, the SSC, the space station and NASA's Earth Observing System—will keep the rest of basic science funding flat for most of the decade. And that's assuming cost estimates don't increase. The SSC alone—whose cost is conservatively projected at $8 billion over the next decade—is skewing the high-energy physics budget, which is threatening a crisis at the national accelerator labs.



It's not just the money but also the quality of the science that concerns observers when it comes to NSF's engineering and science and technology centers. Although the agency says they make for more efficient use of research dollars, Princeton physicist and Nobel Prize-winner Philip Anderson says they represent the "collectivization" of research. Dynes agrees: "Individual investigators are where the real creativity comes from." The trend toward largeness is also evident within universities. Physicist John Hopfield of Caltech believes that "large, impersonal labs in biology and chemistry" may be discouraging students from entering these fields. "The typical organic chemist or molecular biologist runs a small business with students and postdocs, and never sets foot in the lab," he says.

Trend 6: Basic vs. Applied

The controversy over academic research funding is at root an old one over priorities. Whereas basic scientists like Lederman believe competitiveness depends primarily on a strong basic research base, engineers like Robert White believe additional resources should go, instead, for work on "critical technologies."

Who's right? The iconoclastic Rustum Roy, materials scientist at Pennsylvania State University, states one extreme position: "The academic community...in my view, is the segment of the national research community least important to the nation's well-being." White puts things more cautiously: Last year he suggested that there exists "a fundamental mismatch between what the nation needs from the research and development enterprise and what the science and engineering community wants." Others, such as Harvard's Whitesides, are more selective in their criticism. While defending universities as the locus for basic research, he points out that they haven't kept up with certain federal high-priority areas like education—including new teaching technology based on findings from cognitive science—and industrial competitiveness. Concern for national security, "a major determinant of the allocation of resources," has shifted from national defense to economic competitiveness, says Whitesides. But "one thing missing in universities is a focus on types of research that could be connected to manufacturing."

Dynes believes the basic vs. applied schism is aggravated by "a funny mentality where people think there is some nobility in saying they do only pure research. People in the '40s and '50s had the mentality of taking new concepts and thinking them through to application." That's the kind of thing that "is going to have to be done again," says Dynes. Indeed, that's just what Al Cho did when he came up with molecular beam epitaxy [see "Model Systems"].

Trend 7: Multidisciplinarity

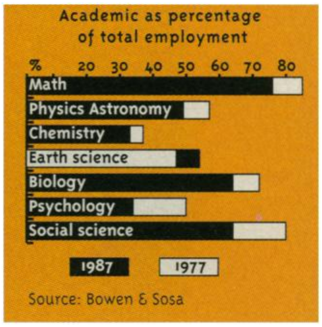
In the future, observes biologist Peter Raven, head of the Missouri Botanical Garden, "the ability to pursue interdisciplinary careers is going to be increasingly important." But although boundaries are dissolving everywhere, some observers believe universities add to their problems by clinging to antiquated disciplinary structures and failing to adapt to new developments. "Academia is back in the 12th century in terms of organization," says physicist Donald Shapero of the National Academy of Sciences. Says engineer Donald Frey of Northwestern University: "Academia is way overspecialized. They've got the bologna sliced so thin you can see through it." The setup is reinforced by funding agencies—for example, at NSF, deputy director John White recently wondered if "we are really doing science a service by the narrow disciplinary organization" at that agency.

Observers agree that scientists have to counter these pressures by distributing their eggs in more than one basket. Columbia University molecular biologist Alex Goldfarb says, for example, that his academia-bound students are putting particular emphasis on learning techniques that are relevant to industry needs. "Every graduate student has an eye on an industrial job as a fallback position," says Goldfarb.

Says Caltech's Hopfield: "Anyone who uses their postdoc to continue their thesis isn't making the right kind of investment. The market is not going to be for hiring people necessarily doing what they were actually trained to do." And that's for reasons both scientific and economic: "People with a calling for high-energy physics, for example, should pay some attention to providing themselves with another set of skills if the supercollider goes away," says Cannon.

Trend 8: A Shift to Industry

While it's by no means a rush, there is evidence that proportionally more PhDs have been heading for industry rather than academia. A long-term trend is illustrated by statistics from the American Institute of Physics: Of physicists who got their PhDs before 1969, fewer than 25% are employed in industry, but among those who got their degrees in 1987-89, the proportion is over 40%. Those employed at universities decline correspondingly from 47% to 28%. Indeed, the only field where academic employment increased as percentage of total employment was earth sciences—presumably a reflection of the drop in exploration accompanying low oil prices.



Words of Wisdom, Part I

"If you look around at a field and everyone there's over 50, stay away."
Charles Shank, Director, Lawrence Berkeley Laboratory

"What is growing today almost certainly won't be growing 15 years from now."
Peter Cannon

"To be trained in [only] one area any more is anathema."
Biologist Roger Beachey, Washington University

"The ability to pursue interdisciplinary careers is going to be increasingly important."
Peter Raven, director, Missouri Botanical Garden

"The market is not going to be for hiring people necessarily doing what they were actually trained to do."
Physicist John Hopfield, Caltech

"For good instrumentation, go to industry or the national labs."
Peter Cannon

One reason for the attraction of industry is obvious: salaries are better. And the anti-industry stigma traditionally held by academics has considerably lessened as industry-university ties have proliferated, particularly in the mushrooming biotechnology business.

However, industry labs aren't as much fun as some once were as companies are putting more of their resources into the rapid creation of marketable products. R&D budgets, on average, are not expected to do any more than keep pace with inflation, says Charles Larson of Industrial Research Institute. And static budgets mean, says Larson, that "industry is not increasing hiring very fast if much at all." He says that if manpower needs go up, they can be met regardless of any looming shortage: There is more substitutability between disciplines and between degree levels in industry, retraining is routine—and there are a lot of Russians out there. Besides, he says, some jobs currently done by PhDs will be performed by technicians as processes become increasingly automated.

Bob Dynes, formerly of Bell Labs, which used to be the Elysian Fields of industrial research, says: "There's going to be substantially less flexibility for younger people" in industry. "When I joined Bell Labs the only drive was to do good science and that was enough. That's no longer the case."

Trend 9: Globalization

It's a new—and global—ballgame out there. Scientists must recognize that "your sandbox is much bigger now," as engineer Deb Chatterji, of BOC Group in New Jersey, puts it. As industry consolidates and merges, it is also becoming increasingly globalized. The movement is both ways, as countries from Europe and Japan buy up U.S. corporations or set up industrial labs in the United States, and U.S. multinational corporations establish facilities in foreign countries.

"New PhDs are going to have to be much more world focused," says NSF's John White. Chatterji points out that this is true in many senses. First, scientists increasingly need "cross-cultural abilities" for dealing successfully not only with foreign-born scientists in the U.S. but with colleagues and business contacts abroad. Furthermore, he says, foreign employment is an "option that is increasingly arising" as U.S. companies set up R&D facilities or technology monitoring offices in the Far East and many parts of Europe. He believes the number of American scientists and engineers abroad, now numbering a couple of thousand, will at least double during the decade.

Research is also becoming much more international as global problems such as climate change, only dimly visible a generation ago, have become urgent priorities. International collaboration will be possible on a scale never before imagined as most of the world's scientific information becomes instantly available by computer. And the problems of developing nations make it inevitable that more U.S. scientists (like ecologist Christopher Uhl in Brazil—see "Model Systems") will be heading for opportunities in health, agriculture, conservation, and industrial development.

Trend 10: The New Scientist

The scientist today can no longer get away with just toiling away at the bench. He or she also has to be a politician, a savvy businessperson, a communications expert, a skilled grantsman, financially alert, computer-wise, and adept in human relations. Along with increasing reliance on computers is the need for sophisticated math skills. "Creative researchers of the future are much more than in the past going to have to be mathematically literate—everything is going to become more mathematized," says Cornell mathematician John Hubbard.

Breadth and resourcefulness count for more than narrow expertise as knowledge accumulates so rapidly that old fields die and new ones are born practically overnight. In biology, predicts Harvard biologist Walter Gilbert, experimentalism will die as the "reigning paradigm" and the primary activity of leading scientists by the early 2000s will be "thinking." Cutting-edge technologies like DNA sequencing, unheard of 15 years ago, will soon be so routine that scientists will be purchasing them from a supplier. By the end of the decade, says Gilbert, "all the genes will be known...and we can't go any further than DNA." Biology, like physics, will come to be dominated by theory. "The starting point of a biological investigation will be theoretical," he says, and experiments will be used only to test hypotheses. With the technical obstacles overcome, creative scientists will be free to concentrate on fundamental questions like: How does the brain work?

Scientists are also going to have to apply their creativity to shaping their careers. As our mini-profiles demonstrate, some shrewdly chose an unpopulated niche to make their own, while others headed for what looked like big areas of future growth. In any case, "if you look around at a field and everyone there's over 50," says Charles Shank, director of Lawrence Berkeley Laboratory, "stay away."

Scientists will need to become more flexible than ever as the funding environment becomes less so. And that includes being willing to deviate not only from conventional career patterns but—more difficult—from one's own expectations and preconceptions. For example, scientists will need to overcome some of their native reluctance to work on other peoples' teams. Not everyone starting out has to have his own lab—indeed, says Max Cowan of the Howard Hughes Medical Institute: "We're beginning to see for the first time some very bright people who don't plan their own labs." Peter Raven has an even more radical thought: "A lot of PhDs think they have to rigidly stick to research or they're a failure." But the need for scientific knowledge, which has infiltrated every major sector in society, means that a lot of opportunities outside research—such as in business, law, and economics—will be opening up.

But even if scientists are sticking to research, it won't hurt to be equipped with some special knowledge about business and industrial processes. That's happening now, says Raven: "More people in more fields are thinking about getting MBAs." Adds industrialist Cannon, "If a person getting a PhD wants to know where to work, he should learn about corporate and public finance. When you see disinvestment . . . head the other way."

If scientists want to know where their skills will be needed in the future, advises Cannon, "look at what the world will be like in 2005"—and at needs such as improved agricultural productivity and new energy sources. Whitesides points out that in chemistry, for example, the challenges posed by diseases of aging as well as by the threat of more global epidemics assure the future for such fields as molecular recognition and computerized drug design. Industrial competitiveness may provide the impetus for reviving lagging research on materials chemistry and on manufacturing technologies. And environmental concerns, ranging from global climate change to local waste management, call for increasing power in computational chemistry and in understanding of toxicology.

All rational career calculations notwithstanding, successful scientists always hark back to what they regard as the most pivotal consideration of all. As Shank puts it: "The really important thing for anybody is to pursue something that they are really wildly excited about."

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Remember, your comments on this overview are welcome—see page 1148.

Words of Wisdom, Part II

"If a person getting a PhD wants to know where to work, he or she should learn about corporate and public finance,"
Peter Cannon,

"More people in more fields are thinking about getting MBAs."
Peter Raven

"Today in science things get mined very quickly. You really have to be thinking where is the next thing that's going to yield important results."
Margaret Geller

"Traditional advice to a new PhD is try for big labs—ATT, GE, GM. But they should think of some place with fewer people, and a more focused purpose. It's socially acceptable now."
Peter Cannon

"Most of the conventional wisdom out there [about jobs and grants] is false."
Geneticist David Botstein, Stanford University

HOT FIELDS

by Elizabeth Culotta

So your offspring is college-bound, science-prone, and susceptible to parental guidance. What advice would you offer? Or maybe you're simply curious about which of your colleagues may be riding high during the next decade.

With the help of a variety of scientists known for their broad perspective, we present some answers here in the form of *Science's* first-ever list of "Tomorrow's Greatest Hits in Science." We do not pretend to be comprehensive, but all the fields mentioned combine high intellectual ferment with the promise of significant contributions to society. We're aware of the pitfalls fashion creates, but we've tried to avoid making this look like a beauty contest—while some fields are obviously extremely attractive, others, while important, may be risky investments.

You say your field is so hot that it sizzles to the touch—and we forgot to mention it? Hold your fire until you turn to page 1148, where we invite you to write a brief explanation of your picks.

Materials Science

"In a very real sense we have entered the era of tailored materials....New capabilities have made it possible to fabricate solids and surfaces with desirable properties that in the past were simply unattainable."— Presidential science adviser D. Allan Bromley

Nanostructured materials

"In the '60s, we dealt with bulk; in the '70s, it was surface phenomena; in the '80s, we got the scanning tunneling microscope. Now we can get down to nanometers," says John Weaver, professor of materials science and chemical engineering at the University of Minnesota, Minneapolis. "I can show you a single crystal that's just gotten big enough to know it's a crystal.... We couldn't do that 10 years ago." We will be able to produce things ranging from "artificially structured materials where we place atoms where we want them one by one, to steel in thin sheets at 30 meters per minute," says Merton Flemings of MIT.

Superconductive materials

The day when high temperature superconductors find roles in everything from power transmission lines to motors to magnetically levitated trains may still be far in the future, and some of the frenzied activity of a few years ago has simmered down. But research on high temperature superconductivity is still very much in the forefront of materials research. Small-scale applications are emerging, notably in the form of extremely sensitive magnetic field detectors known as SQUIDS (superconducting quantum interference devices).

Biomaterials

The term includes biocompatible, high-performance materials for medical uses such as implants and prostheses, and biomolecular materials based on nature's designs. We have a "beginning ability to design biologically fabricatable materials that nature never built," says John Hopfield of Caltech. Physicist Donald Shapero of the NAS says: "We can look forward to duplicating natural materials with the strength and toughness of a spider's dragline" as well as materials with the properties of bone, teeth, shell, the eye's crystal, or the sea urchin's spine.

Electronic, photonic materials

This class of potentially explosive research products will lead to more powerful computers, communications, and control technologies. Emphases are on increased miniaturization, the development of hybrid opto-electronic chips, and synthesizing thin films and tiny structures of new materials.

Structural materials

This category included composites for cars and planes; ceramics for hotter-running, more efficient engines, and new superalloys for jet engines and other aerospace vehicles.

Environmentally benign materials

This class involves low-polluting manufacturing processes, and the design of products for recyclability and, ultimately, easy disposal.

Computational Science

Modeling

Simulation—hailed by many as a "third form of science" in addition to theory and experimentation—allows scientists to explore problems and the consequences of their theories in ways far more complex than have ever been possible. And, at a time when costs are skyrocketing in every other area of research, the falling costs of computer use make simulation "a completely adequate and cheap substitute for experiment" in some areas, says Hopfield. According to Larry Smarr of the University of Illinois, "the fastest growing area right now is computational biology: neural networks, molecular dynamics, modeling cell membranes, modeling the entire circulatory system...the biosphere."

Neural networks

"There's a revolution in both sides—the cognitive neuroscience side and the computer side," says Stephen Grossberg of Boston University. "Neural networks are not just a more convenient way to package an old computational idea. These are major new breakthroughs in understanding how we see or talk." Neural networks are already helping engineers with pattern recognition and classification, noise filtering, robotic motor control, and even stock market predictions.

Computational fluid dynamics

With applications ranging from airplanes to instruments to bombs, this field is poised for explosive growth, thanks to faster computers. "They've never truly been able to simulate the fluid flow around an airplane with full equations. They've always made simplifying assumptions. One day—we think within this decade—that will be possible with parallel machines," says Ken Kennedy, professor of computer science at Rice University.

Molecular dynamics

This field offers biologists what computational fluid dynamics offers engineers, giving biologists the computational and theoretical support to explore molecular configurations. "It's now possible to carry out structural analyses more quickly and thoroughly," says Wayne Hendrickson, structural biologist at Columbia University.

Rational design

A computational approach that cuts across many fields, this involves the use of microdynamics and basic chemical knowledge as opposed to trial and error for designing drugs, catalysts, and materials.

Complex Systems

"Complex systems is a new interdisciplinary research endeavor that draws on the fields of dynamical systems, condensed matter physics, ecological modeling, learning algorithms, and economic modeling, among others," says University of Illinois physicist Norman Packard. It represents an attempt to build a theoretical framework that will explain such diverse phenomena as chaos, neural organization, prebiotic evolution, evolution of complexity, and dissipative structures.

Chaos is the simplest of complex systems. "Chaos isn't adaptive at all...it just sits there," says Packard. The real challenge is to "make connections between simple and higher forms of complexity." One route is through cellular automata, a theoretical model in which a problem is divided up into discrete "cells," which continuously update their value in response to changes in neighboring cells. Another approach is through developing models of adaptive systems such as the immune system. Packard says: "The key word here is emergence—how do more complex structures emerge from many interacting components?" How, for example, does a mind emerge from chemicals?

"Potentially, I think there are going to be some general principles about how complexity gets produced that will emerge, in flavor, similar to the laws of thermodynamics," opines Stephen Wolfram, computer scientist and physicist of Wolfram Research.

Optical Physics

"Where the electronics and computer industry is today, [optical technology] will be in 17 years," pronounces Harvard Nobel Prize-winning physicist Nicolaas Bloembergern. Optics, revitalized by the development of lasers and nonlinear optics, includes applications such as holography, femtosecond pulses, optical switching, and soliton pumping.

Photonics

The term denotes systems in which electrons are replaced by higher speed photons. "The growth for photonics will be in interconnections—replacing wires by light beams or fibers," says Bob Lucky of Bell Labs. Connections will range from long-distance ones between cities to microscopic ones between computer chips. "Photons are capable of transferring a great deal of information at a very high rate. We're used to a frequency of hundreds of megaherz for TV. But with light the frequencies are 10^{10} to 10^{15} herz," says Shapero. "It's a sea change—like switching coal for wood."

Molecular Biology

"I think the 21st century will be the century of biology in the way that the 20th century has been the century of physics and of chemistry," says Columbia's Hendrickson.

It's now crucial to understand the 3D structure of a molecule in order to understand how it works. "Fifteen years ago every biochemist had to be a cloner. Many biochemists now will become at some level structural biologists," says Hendrickson. "We can't yet predict function from structure, but we're moving that way," says John Burris, biologist on the NAS Life Sciences Board.

Where chemistry and immunology meet, chemists are borrowing the immune system's power to make molecules to order. "Chemists are taking advantage of the huge synthetic potential of nature, instructing nature to make novel molecules," says chemist Peter Schultz of the University of California, Berkeley. "Chemistry in the '90s is to do chemistry asymmetrically and catalytically." Catalytic antibodies look like the best bet for approaching the catalytic power of enzymes.

Genetics

"I used to think of genetics as a subspeciality of medicine. Now I think of medicine as a subspecialty of genetics." says Fred Bieber, Harvard Medical School pathologist.

Costing $3 billion, it's the largest project ever in biology: an effort to decipher the genetic blueprint of humans by determining the exact order of the 3 billion nucleotides stretched out along the 23 pairs of chromosomes. The map (expected to be completed in 5 years) and sequence (by the end of the century) will be a tool that will have early practical spinoffs like genetic tests for human diseases and new instruments for biotechnology. Ultimately, it will lay the foundation for molecular biology in the next century. As a result, says Max Cowan of the Howard Hughes Medical Institute, "the Human Genome Project will transform medical practice."

Thus far, diagnostic efforts have focused on relatively rare single-gene diseases such as cystic fibrosis and Huntington's disease. The next decade will see intense effort on the genetic components of more common—and complex—diseases such as atherosclerosis and Alzheimer's.

We used to treat diseases with chemicals, says Allison Tauton-Rigby, vice president for biotherapeutics at Genzyme—"now it's with proteins, using the body's own defenses. If you look at the significant new drugs that have recently been approved, most of them are biologicals." Some examples: colony stimulating factors to stimulate white blood cells and protein replacement therapies for diseases ranging from cystic fibrosis to dwarfism to emphysema. The next decade is likely to see the development of platelet stimulating factors and platelet inhibitors for cardiovascular diseases.

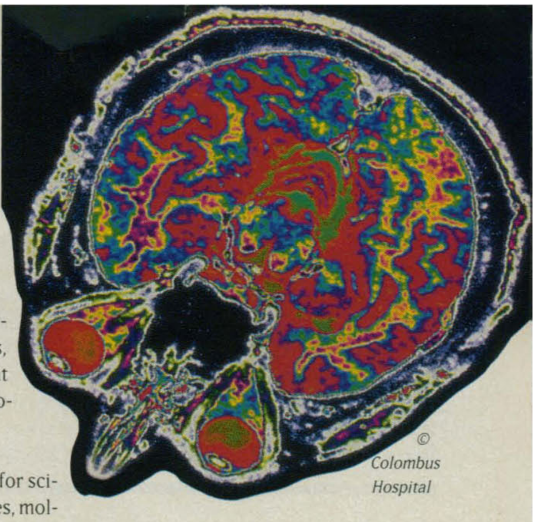
After genetically engineered drugs, the logical next step is using genes directly to correct deficiencies. "Gene therapy is perhaps the only way to treat a tendency for a disease, or the disease itself, at the source," says W. French Anderson, chief of the molecular hematology lab at the National Heart, Lung, and Blood Institute. "There are now a few hundred identified genes that could be used in therapy, but there are thousands and thousands out there" holding promise for new treatments in almost every area of medicine. "The next 10 years will establish the field," says Anderson. "By the following decade, gene therapy will revolutionize medicine."

Some of the differences in the way individuals respond to drugs are genetic, says David Housman of MIT. "Eventually we'll be identifying [via genetic testing] the people who should not get a certain drug, or those who would be particularly good responders."

Immunology

Now that the basic biology of the AIDS virus HIV has been determined, researchers are trying to figure out precisely how the viral proteins work together to infect cells. Some of the most exciting and confusing results have come from work on HIV's regulatory proteins, particularly *tat* and *nef*. But researchers are finding that the most intensely studied viruses—those cultured in the laboratory—may be significantly different from those removed from infected individuals. This will make it even more difficult to decide what viral strains to use when testing prospective vaccines.

"Lymphocytes are probably the best studied cell in the mammalian system," says Baruj Bennacerraf, president of the Dana-Farber Cancer Institute in Boston. Thus "immunology provides a model system to study...mechanisms of cell control and growth." The rules that generate functional T and B cell repertoires, long a puzzle to scientists, have been identified in the past few years, adds immunologist James Allison of the University of California, Berkeley. "We're understanding mechanistically what's important in generating [functioning] T cells, and in eliminating those that can have problems in autoimmunity."



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It took several decades for scientists to identify the "genes, molecules, and cells that are important in the development of the [immune] system," says Bennacerraf. The stage is finally set, he says, for the development of new therapeutic approaches. The marriage of immunotherapy and gene therapy—by inserting genes to produce more tumor-fighting cells, for example—is just one of many promising avenues.

Cellular Differentiation and Development

We know DNA sets the blueprint for an organism. But how are genes expressed? What turns them on and off? "With new molecular techniques the whole field is being revisited—areas that used to be called embryology are now being revisited at the cellular level, and offering new understanding of one of the great biological questions," says John Burris of the NAS Life Sciences Board.

Neuroscience

"Most of us regard the brain as one of the last frontiers of the medical sciences. I think this is one of the most exciting areas in all of biological sciences...[and] an area of most explosive growth," says J. William Langston of California's Parkinson's Foundation. "Neurobiology will represent an enormous source of opportunities for three or four decades," says Peter Raven, director of the Missouri Botanical Garden. "With the application of molecular biology to neurobiology, many of the classical problems that have been shelved are being approached in new and wonderful ways."

Thanks to advances in areas such as noninvasive imaging techniques, genetics, and the discovery of new neurotransmitters, "it's a very exciting time at almost any level—from the total organism, to connections between regions....down to ion channels," according to Stephen Paul, intramural research director of the National Institute of Mental Health (NIMH).

The application of neuroscience research to serious mental illness is receiving enhanced focus through work sponsored by NIMH and 21 other government agencies. Paul says there is "very exciting work" on neurodegenerative disorders such as Alzheimer's disease, and the interaction of genetic predisposition with environmental influences. Also, in the past 5 or 6 years, there has been "documentation that schizophrenia—the cancer of the psychiatric disorders—is fundamentally a brain disease."

Work on the biological bases of addictions is also proceeding at a feverish pace. Although identification of genes predisposing people to addiction continues to elude researchers, specific receptors are being identified for a variety of drugs, and new models of animal self-administration are casting light on addictive behavior.

NIMH's Paul says that by 2000 we may be able to identify "the brain regions subserving a whole host of cognitive functions." Furthermore, "genes important to brain function are being cloned and identified....By the end of the century I think we will have a much better understanding of those genes that are expressed uniquely in the brain to subserve important behavioral phenomena such as arousal, fear, and response to stress." Among the most intellectually interesting questions, says Caltech's Hopfield, is "what is intelligence, and how is it embedded in the nervous system?"—a search that combines computational neurobiology, psychology, psychophysics, and linguistics.

Molecular systematics will continue to offer new solutions to problems of evolutionary relationships. "Biodiversity is a really big, burning issue. And molecules give you a whole new set of data," says Wesley Brown, biologist at the University of Michigan.

Earth Systems Science

Biogeochemical cycles

"I consider this the real science behind global change," says William Schlesinger, biogeochemist at Duke University. "If we understand the chemical changes going on in the earth, then we'll have more of a handle on what level of climate change is possible."

Seismology

"Understanding the physics [behind earthquakes] and gathering better data will be very active areas in the next few years," says geophysicist William Ellsworth of the U.S. Geological Survey in Menlo Park, California. Advances in paleoseismology and nonlinear dynamics, coupled with a vast increase in data processing capacity, will lead to "a wealth of new scientific possibilities," and ultimately to better earthquake forecasting.

The interaction of seismology and engineering will lead to understanding of how seismic waves become amplified, and why materials break down under quake stress. "The outcome of the entire process is that within a decade the industrial world will be quake proof," says Allan Lindh, seismologist with the U.S. Geological Survey in Menlo Park.

Climate modeling

Like so many fields, this one will be greatly aided by leaps in computer power, allowing researchers to describe clouds better, keep track of gases like ozone and water vapor, and for the first time model detailed biological and chemical interactions between the atmosphere, oceans, and land.

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With reporting by Ivan Amato, Michelle Hoffman, and Robert Langreth.

Special thanks to George Whitesides of Harvard, John Hopfield of Caltech, and John Burris, Norman Metzger, Douglas Raber, Donald Shapero, and James Taveres of the NAS.

BIOTECH

For young biologists looking for excitement and money, one alternative to a bench in a hot university laboratory has been an even hotter bench in a startup biotechnology company. But in the past few years a bit of the bloom has faded from the rose. The young scientist who dreams about bolting academe may be well-advised no to take the plunge unless he or she is prepared to become a renaissance researcher.

In biotechnology as in many other fields, having a dual expertise is going to come in handy—"multidisciplinary types are absolutely imperative," says Richard Herrett of ICI Americas. Indeed, "one of the benefits of biotech is it's going to force a more multidisciplinary approach to problem-solving." And scientists with a head for business are going to be increasingly in demand as the sector reaches maturity.

The industry as a whole—now employing about 40,000 people—is in a state of transition. Growth has slowed recently as sources of venture capital have shrunk. And most companies are operating at a loss because new products aren't being approved at anticipated rates. That means many firms are retrenching, and even profit-making outfits like Genentech are merging with large drug companies.

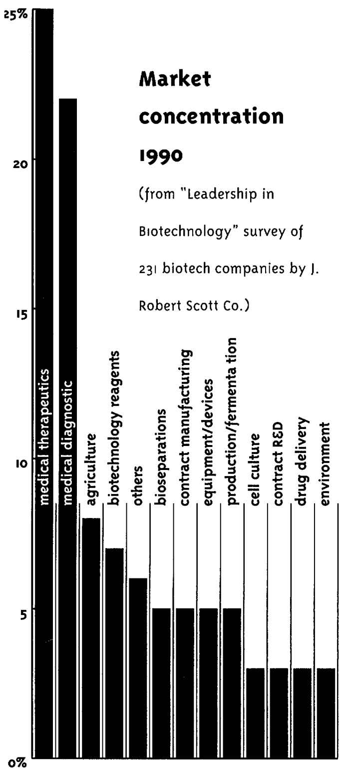
This is dramatically changing companies' personnel needs. Biotech is no longer the exclusive domain of molecular biologists. "The nature of biotech," Herrett points out, "is the application of nontraditional solutions to traditional problems." And that almost always requires problem-solving that crosses traditional disciplinary boundaries. As the variety of products continues to mushroom, firms are seeking more chemists, physicists, engineers, and bioprocessors—even biologists in older fields, such as classical pharmacology involving animal models and microbial physiology.

Stanford University geneticist David Botstein adds that medicine is another important field—drug makers need more people with clinical knowledge of diseases. "It used to be in biotechnology the problem was making the stuff, now it's showing that it's any good," he says.

Furthermore, biotech firms are directing more of their strained resources into getting products to the market. That means scientists who also have expertise in patent law, business, marketing, manufacturing, or regulatory affairs will have an edge over pure researchers. So if you want to switch careers, you ought to be sure you're holding some extra cards.

Nonetheless, biotech is increasingly attractive in some respects. The growth of the industry—and especially the academic atmosphere of smaller companies—has done much to lessen the stigma against industry work held by many academic researchers. And heading for industry immediately on completing one's PhD may become more common: One of the biggest changes in the past couple of years, according to David Jensen of Searchmaster International of Sedona, Arizona, is that there are now far more postdoc opportunities in industry. They pay better—$30,000, about $10,000 more than an academic postdoc—and offer two years of stability on a particular project. Large pharmaceutical companies like Merck and Dupont are big on postdocs, but smaller companies are starting to get into it too, says Jensen.

Ready to take the plunge? While new drugs and medical diagnostics still constitute about half the biotech sector, the mix is likely to get more balanced in the future. The environmental sector, now among the smallest in biotechnology, "is going to jump dramatically," in Jensen's opinion. "The market is absolutely ready," he says, for things like diagnostic kits for environmental toxins, biodegradable plastics, and products for bioremediation. And agricultural biotech may hold the greatest economic promise of all once its potential is unleashed. Currently, says James Taveres of the NAS board on agriculture, small companies are cutting back both because they lack the "economic push" to generate the necessary knowledge for new breakthroughs, and because regulatory obstacles are particularly severe in agricultural biotech. But the high priority the Administration has placed on biotech may smooth the road, and the economic picture may change when oil prices rise.



Market concentration 1990

(from "Leadership in Biotechnology" survey of 231 biotech companies by J. Robert Scott Co.)

With regard to medical applications, Anderson names four areas that he thinks will be growing the fastest in the coming years:

Neurobiology is taking off, with about 20 startups in the past few years. Driven in large part by the aging of the population, companies are capitalizing on genetic findings to develop new drugs for Alzheimer's and Parkinson's diseases in particular, as well as for schizophrenia.

Human gene therapy is moving beyond the first phase of genetically engineered drugs: Eight or nine companies have been recently formed to produce virus particles that can be inserted in blood cells to correct immune deficiencies and other diseases.

Anti-sense therapy involves DNA or RNA molecules with complementary sequences that combine with defective genes to knock them out. A dozen new companies are working on anti-sense genes.

Transgenics, the injection of genetic material into germ cells, has applications for both agriculture and human health through the creation of more productive or disease-resistant animals, and animal models with genetic susceptibilities to human diseases. ∞

That Maverick Moment

Stanford University geneticist David Botstein, 48, is best known as a developer of RFLP technology.

Stanford University geneticist **David Botstein** says all the key choices in his career had a negative motivator: "phobia of the herd."

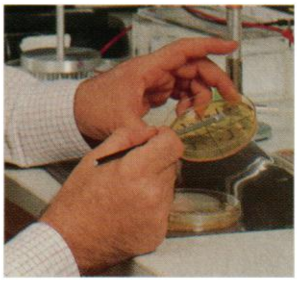
One of America's foremost geneticists, Botstein is best known as a developer of Restriction Fragment Length Polymorphism, or RFLP, technology. He has been a yeast man for two decades, having helped establish yeast as a model genetic system for the study of biological problems.

What's brought him such success? Some might point to his uncanny ability to sense where future events would be taking the life sciences. But Botstein, 48, says his "contrarian impulses" dictated his first critical choice back in the '60s: "not going to medical school when everyone else was." That, he says, "was a major choice for many biologists of my generation," but instead he resolved to do pure science. His next push against the mainstream was to go into genetics rather than biochemistry, which was the prevailing fashion.

After attending graduate school at MIT, Botstein took a more daring turn: halfway through his program he moved the University of Michigan (where his future wife had been admitted to medical school). Conventional reasoning was "I was throwing away my career," says Botstein.

In the late '80s, after spending most of his career at MIT, Botstein once again defied convention by jumping into the world of biotechnology at Genentech. Joining industry is still infra dig in some circles: "I'm still getting attacked for 'selling out.' But I still think it was the best thing I could have done for my education—I learned more in 3 years there than in many previous years."

Botstein, who came to Stanford last year, keeps his feet in both camps by doing consulting for Genentech. Although very much in the mainstream, he still manages to raise eyebrows with his version of how he keeps up with the literature: "I avoid all papers with certain key words like 'oncogene' or 'transcription factor'—all the hot topics. People are really shocked by this. But I say in hot fields like these, each change is incremental; if it's important I'll hear about it."



Botstein's advice to postdocs: "Look at how good the students are where you're going. They're the ones who will be doing the work." But don't build up a big lab, he says, because, as principal scientist, "you need to have time to think. Money is less important than the quality of the work." He also tells his students "teaching is good for them." "Teaching and research," he observes, "have become completely dissociated. And teaching tends to be worse the more famous the institution."

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by Constance

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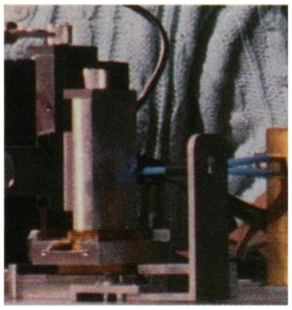


Adaptability has been a crucial factor in the career of chemist **Marye Anne Fox**, who learned a valuable lesson early on: When confronted with two desirable but apparently conflicting courses—try doing them both.

There was Fox, in the middle of graduate school, and suddenly she's pregnant. "I had to decide at that point whether to continue" in school or put a hold on the scientific career. She continued and found that "everything else fell into place"—she ended up having three sons *and* a PhD. Now Fox feels she has the best of both worlds: a family plus a separate life doing research on organic photoelectric chemistry at the University of Texas. And this year her achievements were recognized when she was appointed to the National Science Board of the National Science Foundation.

While many scientists wring their hands over the hurdles faced by science-minded girls, Fox, 44, says she personally never suffered doubts because of her gender. To the contrary, she says, "times were different [when she was in high school]. In those days people who were reasonably bright were interested in science." Why chemistry? Fox considered the field an obvious choice because it enabled her to steer clear of the "messy" aspects of biology as well as the "extreme emphasis on math" in physics.

In other respects though, Fox hardly made things easy on herself. Unlike many ambitious women, she not only got married promptly after graduating from Notre Dame—she married a medical student. He was in Ohio, so she went for a master's degree at Cleveland State, where she could get the degree in a year and "still support him." She pulled this off by teaching in the Cleveland public schools.

Fox pursued her professional development despite years deferring to her husband's career. For example, when her husband got a residency in Hanover, New Hampshire, she embarked on a PhD at Dartmouth. In her second year at Dartmouth, she became pregnant, yet completed her doctorate in organic photochemistry in 3 years. When her husband got drafted and had to go to Washington, D.C., Fox became a postdoc at the University of Maryland. When he set up his practice in Austin, Texas, she got a faculty research appointment at that university.

Everything hasn't been Mary Tyler Mooreish, of course. Fox and her husband eventually divorced. But today, she is happily remarried and now has a total of five sons. If anything, she thinks family demands have helped her career—"I am probably more organized than I would be." But most important, "It was very useful to come to the realization as a second year graduate student that [family vs. career] needn't be an either/or decision."

Marye Anne Fox, 44, does research on photoelectric chemistry at the University of Texas in Austin.

Having It All

Steve Be Nimble

Microbiologist Steven Geary, 38, of the University Connecticut, specializes in mycoplasmas.

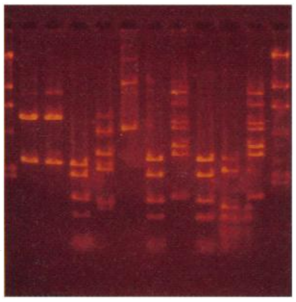
It's very rare for mid-level scientists to move to academia once they've established an industry career not only because industry salaries are usually better, but because academics "view industry people as profit-oriented and not so much interested in science for science's sake." So says microbiologist **Steven Geary** of the University of Connecticut, who has pulled off the switch by "keeping my options open."

Geary, who specializes in mycoplasmas—he discovered a receptor for Mycoplasma pneumoniae and its corresponding binding protein—got his doctorate from Connecticut in 1980, where he received the usual advice from professors who tend to encourage graduate students—particularly the better ones—to go into academia. But after finishing his postdoc at the University of Missouri Medical Center, Geary was recruited by Schering Animal Health in Omaha, a division of Schering-Plough Corp. He took the job because the salary and benefits were excellent (he has a wife and two children) and he was given freedom and plenty of money to set up his own lab.

But one side of working for industry—the concern for protecting proprietary information—began to get to him. Company people were inflexible about letting him go to meetings and present papers, even on nonproprietary research. If he couldn't be free to advance his career by gaining some public recognition, he says, "I felt that in a few years I would have no option but to stay" in industry. He was also troubled by the potential instability: If profits start falling in industrial labs, there are administrative shakeups and a scientist can find his project canceled overnight.

So when a friend started a new biotech company in Lake Placid, New York, Geary bolted. There, as director of R&D on developing diagnostic tests for mycoplasma contamination in cell lines, he found near-ideal conditions: an academic atmosphere where publishing was encouraged, plus the "fun and excitement" of working on applications for profit.

But after 4 years the research section was dissolved in the wake of a financial crisis. "For stability's sake" he applied for an opening at Connecticut, which welcomed him back. Geary believes the anti-industry stigma at universities is lessening, but he also points out that he took care to maintain his scientific visibility—even at Schering, where he kept his options open by having an adjunct position at Nebraska's Creighton University Medical School. Observers have noted that scientists who switch between the public and private sectors often get a severe case of "culture shock." But, says Geary, "I know both sides of the fence now."



Restriction digest map of Mycoplasma Gallisepticum cloned DNA fragment designated pMg6.

DEL

Holden

TEMS

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Like so many professions in contemporary America, science is prone to what might be called hyperactive careerism: the view that success comes from the singleminded devotion to a calling from early on and decades of 80-hour weeks. But like all myths, this one can be demolished by examples from the real world. Take tropical ecologist **Christopher Uhl**.

In college, Uhl majored in Japanese studies and "merely endured" his introductory biology course. He later spent a year in Japan and returned to the United States to teach at a Virginia reform school. One day in 1974, Uhl awoke, at age 25, to an apotheosis of sorts. "I was 'fishing' around, guessing that it would be worthwhile to go back to school," when "I walked into an ecology class." Says Uhl: "Halfway through the lecture, I knew I had hit paydirt. I walked home thrilled, sensing that I had found, in a twinkling, a life's work."

From then on, everything seems to have fallen together. Uhl swept through a PhD at the University of Michigan and a postdoc at the University of Georgia: "I especially like ecosystem science because it puts numbers on how the world works and features humans as key actors." By 1984, he was deep in Amazonia, studying the effects of human activities on the environment.

Today he lives with his family in a mud-walled, tin-roof house on the banks of the Rio Negro, Brazil. He is one of only a handful of serious researchers in Amazonia, where he has been evaluating the ecological impacts of ranching, agriculture, and logging in one of the areas of most intense deforestation in the Northern Amazon. An associate biology professor at Penn State University, he was recently awarded a Guggenheim grant to write a book on his research and to develop a battery of techniques that local citizens can use to inventory and make best use of their natural resources. He also plans to train some of the new cadre of Brazilian environmental scholars—on whom "the ultimate fate of Amazonia will, to a large extent, depend."

Forty-two year old ecologist Christopher Uhl studies the impact of human activities on the Amazon.

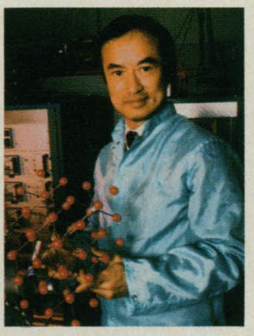
A tall order for a single pioneering researcher. But, biologist Peter Raven says that if anyone can do it, it's Uhl, who is not only an "impressive experimental researcher," but who "has been willing to put himself right on the line" with social action.

Uhl advises those who want to follow in his footsteps not to "worry about saving the world. Do what you do well and that will be enough." On a practical level, he says that environmental scientists seeking to do work in the Third World should use postdocs to broaden themselves as much as possible—including training in information processing, resource economics, writing, even history and law. Then Uhl adds his rather special perspective: "Don't rush the job search—enjoy your situation, enjoy the fact that you are unknown with few obligations."

Jungle Pioneer

Beaming Up

Electronics engineer **Alfred Cho** of Bell Labs wanted to be a painter or calligrapher as a youth in Shanghai and Hong Kong—"My first love is art." But he hearkened to the advice of his father, a Columbia-educated economics professor, who suggested "I probably should study something in which I can earn a living." So when Cho came to the United States for college, he studied electrical engineering, thereby starting a career that has been both creative and remunerative. He now has about 40 patents in molecular beam epitaxy, a technique for growing uncommonly pure crystal thin films, which is contributing to the development of a new generation of optical and electronic devices. Indeed, many would call Cho the father of molecular beam epitaxy.



Cho, 53, is an example of a researcher whose work has focused on the same basic phenomenon—molecular beams—over 30 years, while the implications and applications of the work have changed dramatically. His success has been related to his ability to adapt lessons from fields of former expertise to new areas—part of the "cross-fertilization" he believes is the key to creative science.

After getting a master's degree at the University of Michigan, Cho wanted to see the rest of the country and find out about life in industry. That was during the Kennedy years, when everyone was enamored of space travel. He ended up at TRW in Redondo Beach, California, where he spent 3 years working with physical electronics engineer Haywood Shelton on high-intensity ion beams, in cryogenically cooled vacuum systems simulating outer space, for the development interstellar of propulsion systems.

So absorbed was he in the work that he forgot about Michigan until the university told him that if wanted to come back for his PhD he'd better get cracking. Although returning to academia after more than 4 years was a wrench, he maintained continuity, doing his doctoral thesis on aspects of TRW's ion beam experiment. Cho, as it turned out, was riding a historical wave: the shift from vacuum tubes to solid state. Thus, although he had not changed fields, propulsion systems were behind him—he was now at the frontier of electronics. That meant that in 1968, when a job at Bell Labs was the ultimate dream of many a researcher, Bell was falling all over itself courting Cho.

At Bell, he worked with John Arthur, whose interest was in using molecular beams to grow thin films. But while Arthur's focus was on the basic physics and chemistry of atomic interactions with solid surfaces, Cho wanted to carry the work through to practical application. For precise control of films less than 100 atoms deep, he needed a technique to grow thin film crystals in a totally uncontaminated environment. So he summoned up his TRW experience, and became the first scientist to use ultra high vacuum, surrounded by a liquid nitrogen "shroud," to grow high-purity crystals. "It was the use of a technique developed for a totally different field," he notes. Thus was born molecular beam epitaxy.

Cho also had the benefit of a sustained commitment from Bell—"If Bell labs hadn't supported me for long-term research, today you would not have MBE." Resisting offers to go into management, he stuck to MBE for 16 years, bringing it to full maturity, where applications include the creation of high speed laser-driven circuits for optical fiber communications networks.

"That's the value of cross-fertilization," says Cho, who believes his career makes a good case for interactions not only between disciplines but between academia and industry, and between basic and applied research. So did Bell Labs: Last year, the nation's premier industrial lab made Cho director of semiconductor research.

Thinking Big

Margaret Geller, astrophysicist and MacArthur Foundation "genius," is the quintessential basic investigator. "I always wanted to do MY thing," she says, and her main thing is tackling the "big questions." As a physical cosmologist studying the structure and origins of the universe, she's got the biggest ones of all.

How does she explain her renown? She cites three keys: as an undergraduate studying math at Berkeley, she took a course with solid state physicist Charles Kittel who gave her some "wonderful advice:" to "look for a field that would be very exciting 10 years after I got my PhD because that's when I would be mature as a scientist." Kittel named two fields he thought were opening up: astrophysics and biophysics.

A second key, after Geller got her doctorate from Princeton in astrophysics, also came from a memorable comment. While doing her postdoc at the Harvard-Smithsonian Center for Astrophysics, physicist Alistair G. W. Cameron noticed she was "flailing around" with routine problems. He asked her: "Do you do problems because you can, or because they're interesting?" Geller realized she was doing the former, and changed course. Now she and colleague John Huchra lead the group doing the center's Red Shift Survey, the first group to discover large coherent patterns in the distribution of the galaxies.

Geller has an appetite for challenges—"I like to

Freewheeling in Industry

There's a bon mot that has been making the rounds of some university labs, to the effect that "freedom is becoming academic."

Indeed, while funding shortages and bureaucratic demands have been making heavy inroads on the independence traditionally enjoyed by academic researchers, some industry scientists—like Dupont chemist **Edel Wasserman**—find that an industry job can offer considerable lattitude and variety, at least within the context of corporate needs. Wasserman's career has spanned three different industrial labs and covered both basic research and administration in a central research environment. On occasion he has been immersed in new fields almost overnight.

Now 58, Wasserman went to Bell Labs—after getting a Harvard doctorate in chemistry—where he did basic research until 1976. For 9 years he straddled two worlds, also being professor at Rutgers University. Then he got an offer to try yet a third type of job—as director of the Chemical Research Center at Allied Chemical (now Allied Signal). He took it, attracted to the prospect of trying out new ideas and "dealing with a substantial group of talented people."

"Administration gives you a larger view of where opportunities may be," says Wasserman. Nevertheless, trying to implement new ideas takes a lot of time. So, when Dupont offered him a chance in 1981 to pursue some of his own technical interests—such as in oscillating reactions—he took advantage of it. Now, as Associate Director of Chemical Science, he is involved in technical activities as well as administering exploratory programs for new materials and chemical reactions.

Wasserman thus has considerable perspective on life in science. How to prepare oneself? "The most important thing, particularly in industry," he says, "is to be able to train yourself, continuously updating your capabilities." He adds: "Previously you could become an expert in a certain area and expect to continue as a productive individual for decades." But now, "technology is changing more rapidly than ever." Research projects tend to be shorter term with the current industry push toward rapid development of applications—"we want things to happen over 5 years rather than 15." But while that's not for the individual who wants to spend a lifetime in a single field, it also means a fast-paced environment and a lot of opportunities to learn.

"There can be major changes in the subject you are dealing with on a much shorter time scale," says Wasserman. For example, a few years ago "high temperature superconductivity exploded in a period of weeks." Dupont promptly set up a major effort. "All sorts of new skills became necessary."

put myself in the way of something that's happening." In fact, nowadays she is getting increasingly involved in an ancillary career making science films. She also thinks she has been extremely lucky, particularly in having Huchra as her collaborator. The two have enjoyed an unusually close and productive relationship, in which Huchra does the observations and Geller the theorizing, that has lasted 15 years. It has "given us the courage to do big longterm risky projects that neither of us would have embarked on alone," she says.

Geller, who spends a lot of time advising graduate students, remembers Kittell's counsel to her: "I tell them you should be thinking ahead to problems on the distant (early) universe" with new telescopes that can now search billions of light years away. "Today in science, things get mined very quickly," says Geller. "You really have to be thinking where is the next thing that's going to yield important results."

Jack of All Trades

John Hopfield lives up to his name. Trained in theoretical physics, "I now wander between fields." Currently situated between the physics and biology departments at Caltech, he's doing research on how the nervous system works from the standpoint of computer science and electrical engineering.

Hopfield has also hopped sectors, having spent the first few years of his career at Bell Labs, where he still does consulting. "That's how I keep in touch with the real world."

Hopfield, 57, says his key career moves have been deciding "to get out of something and into something different. Changing fields has made my life more different from other peoples' and made me a more interesting, if shallow, scientist—a dilettante rather than a narrow scholar." Hopfield believes physics has supplied an excellent base camp for his forays from condensed matter theory to biological molecules to neural networks. "I still tend to regard broad education in physics as the best possible education in doing science."

Not surprisingly, Hopfield thinks universities suffer from being "locked into departmental structures." So new PhDs should look to broadening their expertise: "Anyone who uses their postdoc to continue their thesis isn't making the right kind of investment." The job market of the '90s, he adds, "is not going to be for hiring people necessarily doing what they were actually trained to do."

Hopfield believes people starting out should aim for "the best possible institution you can be at." But in the longer term, one should be ready to hop into the unknown to find one's niche. He mentions, for example, a young scientist who grimly accepted what he thought would be a job in exile at the University of Oregon. There, "He found he was the only liberal in town...he organized the town's first ACLU chapter. He found a whole new world."

Late Bloomer

Not all happy, successful scientists emerge full-blown from academia's hothouse. **Roger N. Beachey**, 46, founder of the two-year old Center for Plant Science and Biotechnology at Washington University in St. Louis, has triumphed despite early mediocrity and frustration. The lesson he cheerfully embodies: not every successful scientific career began with great grades, single-mindedness, and unerring career choices. At Goshen College in Indiana, Beachey's interest in having a good time held him to a lackluster B- average despite his long-time interest in plant viruses. Then the Viet Nam war came along. Beachey didn't know what he wanted to do, but he knew one thing: he didn't want to fight in that war.

He became a conscientious objector, recalling today that the choice "forced me to make a decision" about future plans. High school teaching—the course some of his teachers advised—didn't appeal. Instead, when offered a chance to work at a plant pathology lab at Michigan State University, he jumped at it. This led directly to a PhD in plant pathology and virology.

Under normal circumstances, Beachey probably would have gone on to a position at a land grant university doing classical plant pathology. But after doing his postdoc at Cornell, Beachey discovered that "nobody wanted a molecular virologist. I couldn't find a job in virology anyplace in the country." So he took his second significant gamble: he went back for another postdoc—this time on gene regulation in soybeans—to broaden his expertise.

The timing was fortuitous: he completed his work just as just as some big breakthroughs were occurring in plant genetic engineering. Washington University, attracted by the scope of his training, hired him in 1978. Soon afterwards, Monsanto decided to establish a biotechnology unit, and looked to the university for collaboration. They gave Beachey lots of money and freedom, and "from that led everything I had dreamed about putting genes into plants." His group went on to develop virus-resistant tobacco and tomatoes, becoming the first in the country to develop transgenic disease-resistant plants. And that success allowed him, in 1988, to set up the center, which does research on mechanisms of disease resistance in tropical food crops.

Despite the urgent need for agricultural breakthroughs, funding is still meager for plant science, says Beachey. And people who want to get into plant pathology now more than ever need to have the kind of flexibility he has demonstrated. In fact, Beachey says "As a department chairman, I wouldn't hire anyone who had done the same thing [throughout his or her training]." And that generalization doesn't just apply within plant science. "To be trained in one area any more is anathema."

Fast turnarounds may be easier for industrial scientists, who usually have a wealth of sources—including courses— available to them, and time to learn whatever they need to do their jobs better. Wasserman says industry people are also able to focus on research without other time-consuming duties, which allows them to seek collaborations with others both inside the company or with academic and government laboratories. "You can pretty much walk into anyone's lab or office to kick around an idea, and more formal collaborations can result....That's really a part of our job," says Wasserman. What's more, "our immediate worlds can be very much under our control—one can sometimes take off a few days or even a few months to pursue an interesting lead."

In short, says Wasserman, "if there's a good match between the company's and your own interests, industry can be a fine place to work."

In on the Ground Floor

"I have always wanted to be a scientist from the time I could read," says **Warren Washington**, now one of the nation's top global climate modelers.

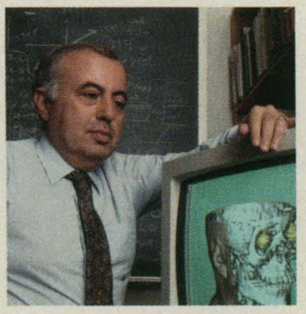
After getting his doctorate from Pennsylvania State University, a willingness to take risks installed Washington on the ground floor of what turned into a superhot field: at a meeting in Canada in 1962, he had beers with a group of atmospheric scientists who advised him to go to the newly established National Center for Atmospheric Research in Boulder, Colorado.

He ended up having to chose between a Navy job for $12,000 a year, and NCAR for $9,000. "It was a complete unknown," but he jumped for NCAR. Little did he suspect that 27 years later he would be visiting the White House to tutor chief of staff John Sununu on greenhouse warming models.

Money's not everything, says Washington, 57. "Go where you will be stimulated. Be on the cutting edge of research."

One Thing Leads to Another

Harvey Cline's plan, after he got his PhD from MIT in physics in 1965, was eventually to become a university professor. But he decided to get some industry experience first—"I didn't want to be an apprentice"—and besides, the atmosphere, at least at MIT, seemed too competitive. "I thought industry would be more relaxing."



This year, after 25 years of "relaxation" at GE, Cline has been awarded his 125th patent, making him the third most prolific inventor in the 99-year history of the company. It seems that after a few years in the company he got "basically hooked" on a variety of research projects.

The secret of Cline's extraordinary success, at GE's Research and Development Center in Schenectady, New York, may be his willingness to move to new challenges. Cline's original interest was superconductivity, the subject of his PhD thesis, and his first 15 years at the company—during which he racked up 16 patents—was devoted to the development of high temperature metal alloys.

Then, in 1970, he switched to the blossoming field of electronics, where he collaborated on the invention of a technique called thermomigration that greatly reduces the fabrication time for certain microchips. This resulted in a veritable blizzard of patents—50 in all.

Next, Cline moved on to laser processing and the development of interferometry techniques for the industrial inspection of surfaces. And the 3D inspection of objects led him, in 1983, to yet another field—3D medical imaging via computerized tomography and magnetic resonance imaging. The latest of 10 patents covers a system for the rapid conversion of millions of computer calculations into 3D images.

"Many people work on the same subject for 20 years," says Cline, 50. But because he has been willing to move from subject to subject, he says, "my colleagues and I had a steady rate of invention....I was fortunate to select interesting problems that are not only soluble but also are of commercial interest."

"There's a downside to changing fields" though, Cline points out. "There's a learning period where you feel uncomfortable, and there's a chance that a new area may not be productive." Also, management can be sticky about letting people cross organizational boundaries. Says Cline: "I've often thought of moving [to employment elsewhere] when I am in a period of transition and frustration." But in the end, "I have always been able to find something that was interesting here."

Walking the Cutting Edge

Jim Hawkins, 37, is an optimist and a "builder" who's always been attracted to the cutting edge in biology. For Hawkins, that's turned out to be the ideal formula for being a successful biotech entrepreneur. His new company, Synthecell of Gaithersburg, Md., is one of a tiny handful in the struggling world of small biotech companies that is currently turning a profit.

Hawkins has had an eye on the scientific fast track since he followed the advice of his undergraduate adviser, who pushed him to go to Baylor University. It's "a rising star," his adviser told him: "You want to get into a new field." Hawkins entered the PhD program in cell biology at Baylor College of Medicine "at a time when [some scientists were] wondering whether the genes of the human organism would ever be understood....My thesis 5 years later was on the isolation of human genes."

Hawkins got his degree in 1982, just when "molecular biology was going from a curiosity to the foundation of a new science." He got some handsome offers—a job at Genentech, and postdocs at Harvard and NIH—and chose NIH, he explains, because it offered an exclusive focus on research as well as an excellent view of its applications. "NIH is probably the most horizontal association of scientists that can exist," says Hawkins, who worked at the Eye Institute at a lab run by Joram Piatagorsky.

But Hawkins had entrepreneurial instincts, which were crystallized at his next job: a year as assistant professor at the Uniformed Services University of the Health Sciences in Bethesda. There he encountered pediatrics researcher Ken Hunter, founder of two biotech firms, who was a "significant influence" in getting him more interested in the applications of biotechnology, particularly the new generation of synthetic biomolecules. He also got to know Jeffrey Graham, a Washington lawyer with a keen interest in the biotech field (Graham now runs the Toronto Biotechnology Initiative in Canada).

One day Graham said to Hawkins: "You are at a rare moment where you can made a decision to go anywhere you want. Why don't you start a company? It's really very simple." The rest is history. With Graham's help, Hawkins and Robert Somers, also of the Eye Institute, incorporated in December 1986 and promptly started operations. By the end of 1989 they were putting out their first product line. The company sells synthetic DNA and is the first commercial purveyor of anti-sense DNA. And now the firm is getting into synthetic peptides.

Last year Synthecell turned its first profit and hired its first professional manager. What's more, in January the company started a journal, Anti-Sense R&D, which Hawkins edits. And it has launched a subsidiary, Genetic Medicine, for longterm research on such products as anti-sense applications for viral diseases. Synthecell now has 20 employees and plans to expand to about 100 in the next 5 years.

What's Hawkins' secret? First of all, he thinks "the kind of people that pioneer things are a very particular kind of people. They look at things differently—they see more possibilities in everything." They're also optimists and risk-takers. "You have to develop an attitude. More than an evolution, it's a kind of flip of the switch in the brain. You have to want to enjoy risk, and seek out those who do...people who like to build things."

Hawkins advises that starting a company "requires more than an elegant scientific idea and technical expertise." It also takes solid business sense—in his case, that meant turning down offers from venture capitalists and instead aiming to become self-supporting as rapidly as possible. But, he adds, "it is a very humbling experience to have to build a company and to pay your way. Starting something is actually pretty easy. The bigger risk is that it will succeed."

Smarrty Pants

If it weren't for supercomputer superwhiz **Larry Smarr**, who heads the supercomputing center at the University of Illinois at Urbana-Champaign, scientists would probably still be trying to cadge time on Energy Department supercomputers. Smarr's the one who got the NSF interested in setting up a national network.

Smarr, 42, has always been a high roller. In the early '70s, after the death of his Stanford adviser, physicist Leonard Schiff, he was confronted with the choice of switching fields or going somewhere else to study his passion: general relativity. So he went to Texas to work with Bryce DeWitt.

"That was really a shot in the dark," says Smarr. He wanted to solve the Einstein equation for nonlinear spacetime, a problem impossible to tackle with pencil and paper, on computers. "It was pretty insane for a graduate student to do," says Smarr. I was warned it was a swamp into which I was going to sink and never be heard from again." But he did it, thereby founding the field of numerical relativity.

After getting his doctorate, Smarr wanted to continue research in mathematical/theoretical astrophysics, but he didn't want to leave the university community although that meant only 1 or 2 months a year access to a government supercomputer. So, in 1983 Smarr made another bold move: he sent a $43 million unsolicited proposal to NSF telling it it ought to set up a network. "When I sent in that proposal I was like Don Quixote." NSF had no money or division for the purpose. Two years later Congress put it in the NSF budget.

"That's America," says Smarr. "A person that has a clear vision and a lot of guts will prevail. I do what I think is the right thing to do regardless of how absurd it may look." Adds Smarr: "The way to get famous when you are young is to look into an area that is just becoming possible because of a new technology. Look where a new technology will enable you to ask questions that no one's been able to ask before."

This Frenzied Life

by robert w. lucky

There's a greater entropy in the air today, as if somewhere the heat of life were being turned steadily higher. Perhaps we are obeying the second law of thermodynamics: We spin ever faster into a stream of chaos filled with airplanes, paperwork, fax machines, computers, committees, fruitless proposals, and burgeoning information.

One morning, heading to my office, I overheard a fragment of conversation between two strangers standing in front of me in the elevator. They were talking about some young person who had just been promoted to something or other. "They say he's the new Bob Lucky," one of them was saying.

It's odd enough hearing your own name spoken by strangers—your ears redirect themselves like an adaptive array. Even more disquieting is the experience of discovering you've been relegated to the scrapheap of legends in your own lifetime...

As I got out of the elevator, I looked back at the pair. "Once *I* was the new Bob Lucky," I said. The doors closed on two puzzled expressions.

Heading down the corridor, I couldn't shake the feeling of being superseded and useless. I wasn't always just another graying manager, I thought. Once I had worked at trying to be the new Claude Shannon. Those were the days when I couldn't wait to get up in the morning and get into the laboratory, when my greatest thrill was a new equation or a confirming trace on an oscilloscope. Back then money seemed to descend from science heaven without human intervention, and the chief management strategy was that of benign neglect. My phone seldom rang and my mailbox stayed empty. After all, no one knew my name, much less described anybody as the new me.

Robert W. Lucky is executive director of research at AT&T Bell Laboratories.

Sinking into a pool of nostalgia, I remembered what a pleasure it had been to work in the lab into the wee hours, yet have my weekends gloriously free for the family and the lawn. It was a time when people did real science, I told myself—and science for the sake of science, I added pompously. We didn't spend all our time frantically dashing hither and yon playing diplomat and fighting the octopus-like scientific bureaucracy.

How times have changed, I reflected. This new Bob Lucky was a beleaguered, stressed-out creature who would have been scorned and pitied by his namesake.

I rounded the corner and spotted my secretary's cheery face, but my thoughts remained with that pair on the elevator. Would they be as bored with me as I was with the old-timers of a couple of decades ago? They used to drive me mad with their nostalgic babble. Forever pining for the years during the Second World War, they would remember no bureaucracy, no budget squeezes, everything for the great cause. They would reminisce about developing atomic energy and the digital computer, about perfecting radar and proximity fuses, about conceiving information theory, pulse code modulation, and cryptographic techniques...and then they would sigh and lament the tight budgets, the managers who insisted on managing, and the inexorable erosion of good science and great satisfaction after the war ended. How tiresome all these stories had seemed at the time!

But then Old Bob Lucky—the one I had become—tried to defend himself: The environment for young scientists today is simply not the same as it was a generation ago, I insisted. There's a greater entropy in the air today, as if somewhere the heat of life were being turned steadily higher. Perhaps we are obeying the second law of thermodynamics: We spin ever faster into a stream of chaos filled with airplanes, paperwork, fax machines, computers, committees, fruitless proposals, and burgeoning information.

Yes, I thought, science is not what it used to be, and an image came to me from a short story I had read almost 25 years before. The main character was a scientist who seemed to be on the verge of a great discovery—if only he could get the time to finish his work. But he kept finding himself on dozens of boards and committees. Rushing sleeplessly from airplane to airplane, he kept encountering the same set of scientists, who themselves seemed always on the verge of great discoveries, if only they could stop rushing from plane to plane. The protagonist—scientist that he was—decided this was a phenomenon that had to be studied. Perhaps he could regain control of his life by investigating the sources of all those prestigious invitations he kept receiving.

I forget the details of his investigation, but in the end it turned out that the whole scientific committee structure was being controlled secretly by aliens. They were a resourceful lot: They had figured out that they could keep Earth a relatively backward place by making sure that, whenever someone threatened to make a scientific breakthrough, he or she would be invited to join a blue ribbon panel.

That story seems more believable today than when it was written, I thought, as I put my briefcase down on my desk and hurriedly scanned my daily schedule of travel arrangements and meetings. The printed words on my log blurred together, just as all the meetings they represented seem to do. I had my recurrent feeling of being only a package that gets delivered wherever the instructions dictate. I think of it as the "if it's Tuesday, it must be Stanford" syndrome.

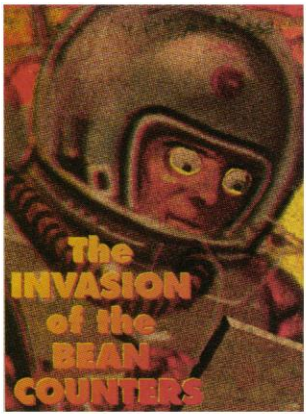
You've probably read the experts' explanations of this new busyness to "science": Research is becoming globalized; interdisciplinarity is "in"; funding agencies are getting pushier; research costs are going through the roof. And everywhere the footprint of the computer—like some new race of Bigfoot, trampling over traditional experimental technique, creating a new methodology of research...and generally making life much more complicated.

I thought of how tiring it was to be swimming constantly against a swelling tide of conferences, meetings, and publications. Whatever happened to the old friendly telephone call? Gloomily, I considered how the abundance of answering machines, computer mail, cellular phones, fax, Federal Express, and bulletin boards had rendered the friendly old telephone call obsolete. For one thing, there's hardly anyone home anymore. Indeed, the mean position of scientists may be rising steadily—but not in society, in altitude: Everyone's on a plane!

I cast an uneasy glance at my own telephone, poised like an alarm clock. This morning it had already delivered a stream of voice mail messages, and I could see over on my terminal that 17 unread messages were stacked up in my E-mail. That got me to ruminating over all the scientists swarming about in my life. Once upon a time, you didn't have to know more than, say, five: a pair of eager postdocs, your lab assistant, your boss, and your principal competitor. Now there were thousands whose names I was supposed to know and who would try to contact me every week or who would pop up at the end of one of my talks and act like we'd E-mailed for years. I love it when the academicians start bemoaning the coming manpower shortage in science. They keep telling us about how high school students are shunning scientific careers, but if that's so, I'd cite the reason Yogi Berra gave for the unpopularity of a certain restaurant: "Nobody goes there anymore; it's too crowded."

These days there are hordes of fren-

It looks innocent, but that is the hallmark of the best of the horror genre. Before long these accounting professors have unleashed upon the unsuspecting world a sect of apostles whose only religion lies in numbers.



zied scientists trying to beat me out for funding. They're lined up like hogs at a trough, but the trough just isn't long enough. Everyone jostles everyone else, and the little piglets are jammed out. And just about the time we all seem to have our proper places, a giant rhinoceros carrying a banner that says "big science" or "super something-or-other" appears and sucks up half the feed.

My secretary, standing at the door with an apprehensive expression, interrupted my fantasy. For an instant, I had the scare that I was supposed to be somewhere else. What meeting had I missed? But she was waving one of those illegible faxes that run my life—an overdue request (read "demand") from somewhere mystically high in the bureaucracy for yet another inventory of research expenditures. This inventory would undoubtedly be compared unfavorably against the latest inventory of research results.

Who needs aliens, I wondered, when we have our own dreaded bean counters? Surely they constitute one of the truly malevolent aspects of the change in our lives in science. Their incredible, inexplicable rise to power! In my overworked imagination, I could just picture the neon marquee announcing science's latest horror film: "The Invasion of the Bean Counters." In the opening frames of my movie, MBA-toting, red-suspendered professors are piling out of their latest-model 1970s Oldsmobiles, hustling to their classrooms where they are turning bean counting into something they call a science. It looks innocent, but that is the hallmark of the best of the horror genre. Before long these accounting professors have unleashed upon the unsuspecting world a sect of apostles whose only religion lies in numbers. In the movie's Orwellian conclusion, vision and leadership have been replaced by the ever more exact accounting of beans. The viewers straggle out into the light, reassuring themselves that it was only a movie. But was it?

Eventually, I find, the worst depressions pass, as even the most creative minds run dry of apocalyptic visions. At this point, Old Bob Lucky's mind sometimes ALT-F10's to another window where my favorite escape fantasies reside. It was over coffee at around 10 that morning that I devised the perfect job in this seething world of big league science. This Bob Lucky, I thought, would stun Boss Arno with the ultimate E-mail message: I would be leaving to take a Papal chair at the University of Shangri-La. The immensity of the grant they'd promised me, I would explain, would leave me completely free to do whatever research I wished. The vision carried an extraordinary piquancy—like when Tom Sawyer came back secretly to watch his own funeral. There I would be at U. S-L, but magically able to see my friends back in the Labs speaking of me in hushed tones, voices cracking with emotion, eyes misting over: Do you think we'll ever hear from Old Bob again? I am the stuff of legends, I muse; no one comes back from the great scientific beyond to tell us what lies outside our own frenetic sphere.

Sated with self-pity at last, my thoughts finally turned outward: Could the scientific community really be spiraling toward a heat death? If so, what might be done about it? That was when I came upon a modest proposal. Someone once suggested to me that each graduating scientist might be given ten chits constituting permissions to author papers. When these were used up, you would have no choice but to join the mute ranks of those who only stand and wait. Obviously you would use your chits carefully; very few minor papers would be published. At one stroke we would condense and upgrade the literature. Nonproductive scientists could trade their chits with excessive producers in exchange for perks—such as a tenure vote or relief from committee duties. Information pollution would be contained. We would have time for the wife and kids again.

Then I realized there was no need to make chits only applicable to papers. The true genius of the notion was that you could apply the same technique to membership on committees, invited talks, proposals, and so on. Upon graduation you would get a whole package of multicolored chits like a Disney World admission booklet. This would give new meaning to the concept of career planning. For example, you are invited to join the visiting committee at Podunk University. Suddenly you hesitate. Not that you mention this out loud, but what if you were chitless when the National Research Board calls?

I was undecided as to whether there should be an open market for chits. Perhaps you should be allowed to negotiate trades. For example, out of desperation you might be forced to trade two invited talks and three committees for a proposal chit. *Science* could list bids and ask quotes for various permissions. There might even be a market for futures. The free market forces would dictate exchange rates across nations and disciplines, and somewhere there would be a worldwide Chit Board (blue chit required for membership, of course) that regulated the printing and commerce of scientific chits.

The chit system would give us control of the environmental temperature. The more chits issued, the greater the entropy in our profession. Occasionally the Chit Board would make headlines by deciding to devalue chits or whatever. Unfortunately this uncertainty in itself would be a source of added entropy that would have to be factored into decisions.

The chit system may sound extreme, but, that day, after my trauma in the elevator and considering the forces that seemed allied against me, I figured that the most draconian measures were in order. And today, thinking about it during an intermeeting respite (otherwise known as a plane trip), as I reformat my overdue report on my laptop, I still think the idea has merit.

But maybe you have a better proposal. Please don't be shy about it. (See feedback p. 1148.) After all, anything would be better than having our lives controlled by those aliens that run things now. By the way, a piece of advice: I'd be sure to examine your next prestigious invitation very closely. I just received one to speak at a Meet-the-Faculty dinner at U. S-L. It was signed "The New Bob Lucky." ∞

Sated with self-pity at last, my thoughts finally turned outward: Could the scientific community really be spiraling toward a heat death? If so, what might be done about it? That was when I came upon a modest proposal...

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Hot Tools

These newest laboratory additions are changing the kinds of questions we ask in science, and many are impudently crossing traditional disciplinary boundaries. Some of these tools are already standard equipment in most labs; others are now employed only by a few forward-looking groups. But contacts with scores of scientists suggest that researchers expect these tools to grow in popularity, as prices fall and applications bloom.

By
Elizabeth Culotta

Seeing–and Moving–Atoms

Scanning tunneling microscope (STM)

Not quite a decade old and still finding new applications, this scope's probing tip can scan a sample, atom by atom. "It's a unique combination of high spatial resolution and spectroscopic information. It will be a standard, like the scanning electron microscope," says physicist Urs Staufer of IBM's Thomas J. Watson Research Center in Yorktown Heights, New York. The STM can also move atoms around, one by one. "From that you can start building your own molecules. And when you're in that position you have almost infinite possibilities," Staufer says.

Atomic force microscopy

This successor to the STM can scan insulators as well as conductors at high resolution, an important capability in the integrated circuit and magnetic disc industries. For research, force microscopy "offers a very broad range of possibilities of measurement. For example, you can measure electric and magnetic fields, and magnetic domains. We're already learning about friction at the atomic scale from the force microscope," says Stanford electrical engineer Gordon Kino.

Preparing Nanostructures

"The ability to engineer materials from atomic precursors is a dramatic change in the way we've even thought about making materials. It will revolutionize the field," says Richard Siegel, nanostructuralist at Argonne National Laboratory.

X-ray and electron beam microlithography

X-rays and E-beams are being used to etch tiny lines and help create micromachines. Applications include the next generation of computer chips and high-speed switching devices. "The inherent limitations of x-ray lithography are so small we're not even sure yet what they are," says John Wiley, dean of the graduate school and electrical engineer at the University of Wisconsin-Madison. Right now x-rays can etch features of 100 nanometers, smaller than the wavelengths of visible light.

Vapor-solid epitaxy

Using vapor condensation to lay a very thin film onto a planar substrate, atom by atom, isn't new, but its applications keep growing. "So much of what we deal with is in the form of a film—from the antireflection coatings on your sunglasses to fancy microelectronic devices. Epitaxy gets at all those lovely, complex issues related to nucleation and growth. You can also look at ion deposition, or cluster deposition or organometallic deposition," says John Weaver, professor of materials science and chemical engineering at the University of Minnesota, Minneapolis.

Manipulating Genes

Scientists, armed with an arsenal of new or improved tools, are finding the sky's the limit for analyzing and manipulating genes. The coming years will see new refinements in separation and sequencing techniques, thanks to a marriage between analytical chemistry and biology. According to Barry Kargger, director of Northeastern University's Barnett Institute of Chemical Analysis and Materials Science, some techniques will be able, within the coming decade, to resolve differences in length of as little as a single nucleotide base in segments of DNA that exceed 1000 base pairs.

Polymerase Chain Reaction

What's to say? Already the hottest tool in biology, this copying machine for DNA still has new tricks to offer. Expect both modest improvements and new sets of applications to emerge, from the Human Genome Project to forensics.

Micro-protein sequencing

This technology uses as its base an Edmund degradation, where amino acids are sequentially chewed off a polypeptide to yield a full protein sequence. The products of the chemical reaction are analyzed by liquid chromatography to obtain sequences for microquantities of protein. Currently, says Karger, micro-protein sequencing is accurate in the picomolar range, but eventually, with mass spectrometry, it will go down to the femtomolar ranges—where components from a single cell can be resolved and sequenced.

Capillary electrophoresis

This is "more quantitative, more precise, more sensitive, and more efficient than some of the existing techniques," says Karger. Proteins, nucleic acids, or even carbohydrates can be separated according to molecular weight by being run through a gel or buffer within a capillary tube. Capillary electrophoresis can be as much as 10,000 times more sensitive than traditional electrophoresis, detecting material at concentrations in the picomolar range.

Pulsed electrophoresis

This is designed to separate large stretches of DNA, possibly even chromosome-sized segments. Large molecules are separated according to size by applying electrical fields across a matrix containing the target material. This facilitates the assignment of genes on particular chromosomes. The technique can be especially powerful in combination with restriction enzymes for identifying DNA regions likely to contain the switches that turn on genes.

Laser-based detection devices

Karger notes that laser-based detection is sensitive to concentrations of material in the attomole (10^{18}) range and has the potential to detect concentrations as low as the zeptomolar range (10^{21}). "Indeed, single-molecule detection has already been achieved."

RNA scissors

The future may see the advent of the cell biologist as cellular surgeon, reaching into the cell to alter its contents. Thomas Cech of the University of Colorado at Boulder is developing catalytic RNA molecules designed to cut other RNA molecules. Currently the use of these enzymes is limited to research scientists specifically interested in RNA, but Cech predicts a big future for industrial applications. He says RNA enzymes, or ribozymes, "can be tuned to have any specific activity or specificity. This allows you to inhibit gene expression at the level of RNA which may be particularly useful in developing antiviral and anticancer agents."

Optical tweezers

Another technique for subcellular manipulations, the tweezers allow scientists to "grab microscopic objects with an invisible beacon of radiation and move them around," says Steven Block of Harvard and the Rowland Institute in Cambridge, Massachusetts. He is currently using them to measure mechanical forces of motor molecules like myosin, kinesin, and dynein. But, Block says, tweezers may have medical applications as well, such as bringing immotile sperm to an egg.

Footprinting

This technique can see where a drug or recognition element binds on DNA or RNA by applying the element to the genetic material, then treating the material with an agent that clips everything that's not covered. It's part of genetic analysis—seeing "where things bind," says Harvard's Whitesides.

Homologous recombination

This may be the crucial technique for success in interpreting data from transgenic organisms (see Biological Models Systems). Existing genes are knocked out and replaced with a modified gene.

Probing Molecules and Cells

2,3D Nuclear Magnetic Resonance

The workhorse of chemistry, NMR now offers molecular biologists the chance to analyze the structure of larger and larger molecules, and make "exquisitely fine images," says Columbia's Wayne Hendrickson. Some groups are already using 3D NMR, and a few are exploring 4D.

Injection of fluorescent dyes and markers

It's low tech but crucial. Dyes can tag everything from antibodies to neuronal connections and DNA hybridization probes. New markers—fluorescent, radioactive—add power. "The growth of the field is literally exploding at this time," says biologist Alan Waggoner of Carnegie- Mellon University. "The real power of these techniques is in not only learning the anatomy of the nervous system but combining that with physiology and pharmacology. It's smearing the boundaries between the subdisciplines," says Nell Cant of Duke University.

Patch-clamping

By isolating a patch of cell membrane, this technique allows neuroscientists to record the activity of a single ionic channel in the membrane.

Confocal microscopy

This scope slices samples into optical sections, allowing scientists to peer beneath surfaces without destroying the tissue. "It's as though you were to look at a wall, and see the surface of the wall dissolve as though it wasn't there, and you could see the wiring behind it," says ophthalmologist Dwight Cavanagh of Georgetown University, who uses confocal microscopes to study the living eye.

Biosensors

A growing array of sensors is being developed that detect, measure, and monitor physical, chemical, and biological phenomena. "There's no doubt about the fact that biosensors have really taken off in the last decade, and particularly in the last three or four years," says Gary Rechnitz, director of the Biosensor Lab at the University of Hawaii. Doctors can now monitor blood pressure inside the heart with a tiny sensor at the end of a catheter. Custom-made biosensors and chemical sensors—which are getting ever smaller and "smarter"—track everything from neurotransmitters in living brains to airborne organic chemicals to the composition of food.

Biological Model Systems

From worms to fish to humans, organisms turn out to be more alike than biologists once dared hope. "Each model plays off against the other. You can isolate genes in worms and flies, and get the homologous gene sequence from the fish. One model will facilitate progress in the others," says biologist James Weston of the University of Oregon, Eugene.

Zebra fish

These little fish hold a lot of future promise as a model for vertebrates. Good study subjects for both genetics and embryology, they breed faster than mice, and a scientist can watch the embryos develop. But the genetics remain to be explored, and only a small group of people have worked on them so far.

Nematodes

"For a biological problem concerned with the behavior of a single cell within a whole organism, there's no better model than C. elegans," says biologist Cynthia Kenyon of UC San Francisco.

Arabidopsis

This fruit fly of the plant world can be used to identify genes for use as probes for comparable genes in crop plants, as well as to understand the genetic basis of plant growth.

SCID mice

"Not only can we infect human lymph nodes with HIV and see it spread as it does in humans, we can see the human drugs work in that mouse model as they do in humans," says Irving Weissman, who with colleagues at Stanford University was the first to create this mouse model of human AIDS. "This is the first chance we've had to study normal human physiology or pathology in an ethical experimental model." It also can be used for the study of human malignancies and related genetic problems.

Transgenic organisms

Animal models for human diseases have already been created by the implantation of foreign genes. In the coming decade, says geneticist Philip Leder of Harvard Medical School, transgenic animals will enable scientists to explore the fundamental actions of particular genes, as well as to understand the causes and progression of diseases including autoimmune disorders, cancer, and diabetes. Transgenic organisms will also play a big role in animal and plant husbandry—but currently the technology is limited because scientists cannot direct where in the host's genome the transplanted gene will integrate.

"That's how science marches forward: when we get new eyes and ears. And we continue to extend our power over broader regions of time and space.... We've entered the relativistic world where time and space are linked, the universe Einstein only dreamed about."

Don Shapero, physicist, NAS Board on Physics and Astronomy

Intense Photon Sources

Free-electron lasers

With the aid of an electron beam, this new brand of laser produces a coherent light beam that can be tuned to different frequencies. It has a long list of current or potential applications in medicine, microelectronics, physics, chemistry, and engineering.

Ultrafast lasers

Operating in femtoseconds, (10^{10} to 10^{15} seconds), these lasers "allow us for the first time to directly resolve molecular vibrations and ultrafast chemical reactions," says Charles Shank, director of the Lawrence Berkeley Laboratory. "Physics, chemistry, biology—all will be impacted by this. Ultimately I think these machines will go into people's labs—like an oscilloscope."

Synchrotrons

These sources of coherent x-rays have applications in multiple fields as well as physics. They offer molecular biologists a more powerful tool for x-ray diffractions, let engineers build micromachines, and allow materials scientists to do photochemistry and x-ray plating. Says Shank: "The ability to do crystallography on very small samples will be greatly enhanced with the new bright sources" soon to come—the Advanced Light Source at Berkeley, and the Advanced Photon Source at Argonne.

Microdevices

Made with x-rays and electron beam lithography, tiny motors microns in diameter are expected to have applications in medicine, industry, and research. John Wiley, dean of the graduate school at University of Wisconsin-Madison, says: "In this field we're limited only by our imaginations. Anything you can do with a drill press or lathe you can do with x-ray lithography [and micromachines] if you're clever enough."

Computer Modeling and Analysis

Applied math

"As computational science grows, applied mathematics has got to become more important" says mathematician John Dennis of Rice University in Houston. At present, says Ken Kennedy, director of Rice's Center for Research on Parallel Computation, "scientists are using algorithms that went out of date 10 years ago because they're not talking to the mathematicians."

Metaanalysis

Using statistics to sum up the results of several similar but separate experiments, metaanalysis "is going to revolutionize the way the sciences, especially medicine, handle data," says Thomas Chalmers of the Harvard School of Public Health. "And it's going to be the way many arguments will be ended."

Wavelets

"The problem for the next 10 or 20 years is what to do with digital data. Computers can't handle it," says Yale mathematician Ronald Coifman. Wavelets, the successors to Fourier transforms, offer a better way to take a large dataset and represent it with fewer numbers.

Finite element analysis and finite lattice models

"Finite element analysis will certainly be used to solve all kinds of engineering problems...in bridges, dams, cars, spacecraft," says mathematician Hans Schwarz of the University of Zurich. Finite lattice models is a technique in both mechanical analysis and fluid dynamics as well as global climate modeling. With it, says Whitesides, scientists can model a complex system, such as airplane vibrations, by breaking up the individual pieces, calculating the strain on each piece, and seeing how this propagates through the lattice.

Ultra-smart chips

RISC (Reduced Instruction Set Computer) chips reduce the number of instructions issued per task, so a single chip can offer more computing power than was offered once by supercomputers.

Ultra-fast architectures

Almost synonymous with high-performance computing, this means stringing together thousands of ultra-smart chips in a massively parallel system to create an ultra-fast computer.

Analog computation

Instead of representing variables by a string of digits, analog computers will represent them by a continuously changing physical quantity—say, the voltage at a certain point in a circuit. Potential applications include designing chips that simulate eyes and ears, signal processing, and optimization.

Measuring Earth

Geographic information systems

This elegant computer system to integrate diverse geographic information is already simplifying earth science. Says biogeochemist William Schlesinger of Duke University: "Used to be you'd produce a weather map and a vegetation map and a soil map, and spread them all out on your desk. Now you can produce a single map showing exactly the variables you want."

Global Positioning System

GPS is expected to revolutionize surveying and has many applications in seismology and oceanography. It allows ground observers to position themselves on the earth to within a centimeter with the aid of satellites. "Old-style geodesy needed mountaintops and lasers. This is just like being at sea and being able to see multiple lighthouses and fix your position," says seismologist Allan Lindh of the U.S. Geological Survey in Menlo Park.

Earthquake sensors

"Until recently we've only been able to study narrow ranges of the amplitude or frequency band of earthquakes," says U.S. Geological Survey geophysicist William Ellsworth. "A new generation of sensors will allow us to get a complete recording of the whole earthquake process." These include satellites for charting minute movements in the earth's crust, buried seismic instruments, and portable instruments that make very detailed images of the Earth's crust.

Stable isotope tracers

Using a mass spectroscope to analyze stable isotopes offers earth scientists a way to track key elements from atmosphere to ocean. "I have a strong feeling that some of our quickest answers to the question of the missing carbon [in the global carbon dioxide budget] will come from mass spectroscopy of CO^2 in the atmosphere and in the ocean," says Schlesinger.

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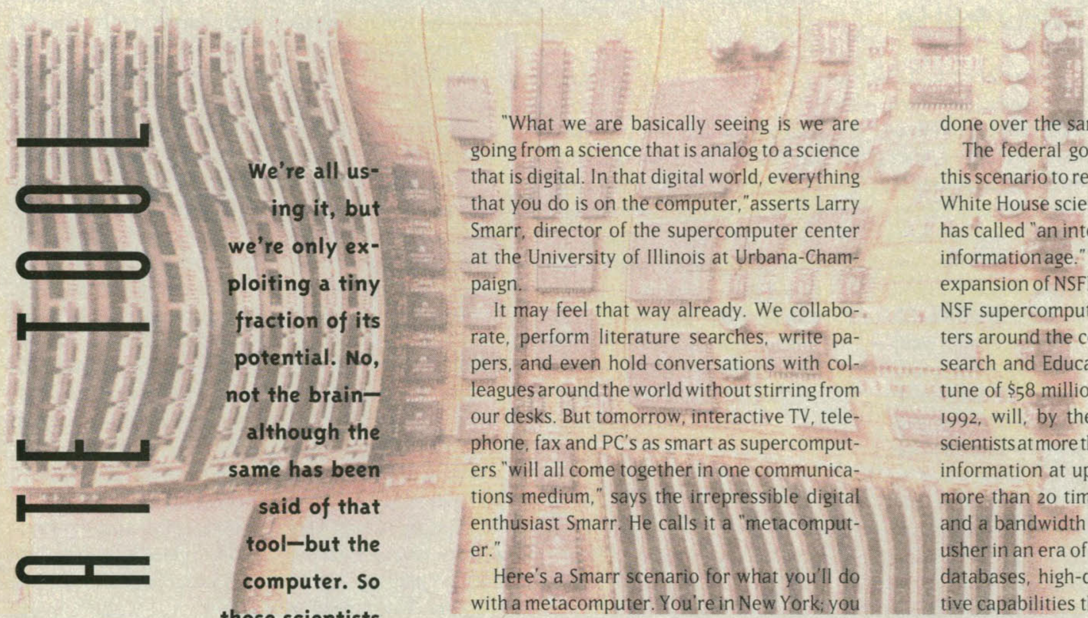
Remember, your comments are welcome—see page 1148.

With reporting by Ivan Amato, Michelle Hoffman, and Robert Langreth.

Special thanks to George Whitesides of Harvard, John Hopfield of Caltech, and John Burris, Norman Metzger, Douglas Raber, Donald Shapero, and James Taveres of the National Academy of Sciences.



THE ULTIMATE TOOL

We're all using it, but we're only exploiting a tiny fraction of its potential. No, not the brain—although the same has been said of that tool—but the computer. So those scientists who are still resisting the electronic mail system had better shape up.

"What we are basically seeing is we are going from a science that is analog to a science that is digital. In that digital world, everything that you do is on the computer," asserts Larry Smarr, director of the supercomputer center at the University of Illinois at Urbana-Champaign.

It may feel that way already. We collaborate, perform literature searches, write papers, and even hold conversations with colleagues around the world without stirring from our desks. But tomorrow, interactive TV, telephone, fax and PC's as smart as supercomputers "will all come together in one communications medium," says the irrepressible digital enthusiast Smarr. He calls it a "metacomputer."

Here's a Smarr scenario for what you'll do with a metacomputer. You're in New York; you have a theoretical model of a chemistry experiment, and you want to look at a visualization of the experiment and compare it with the theory. So you reach out across the network to California where there's a special lab instrument gathering relevant data and ask it to run the experiment. The computer in the instrument transmits the data to you. Then you shoot it over to a supercomputer in Illinois to run a simulation. Now, at your graphics workstation in New York, you can pull up a visualization of the California data on one quadrant of your screen, and on another quadrant, you produce a visualization of simulation from Illinois. On a third quadrant, you reach out to a digital library and summon a *Science* article on the topic. Finally, in the last quadrant, you set up a video teleconference with a colleague in Boston—who pulls up the same images on the screen that you have on yours—to talk it all over. That's "telescience," with televisualization, telecomputing, and teleconferencing all done over the same fiberoptic network.

The federal government is moving to bring this scenario to reality with the creation of what White House science policy analyst Paul Huray has called "an interstate highway system of the information age." That's the recently announced expansion of NSFNET, the system that connects NSF supercomputer centers and regional centers around the country. The new National Research and Education Network, funded to the tune of $58 million this year and $92 million in 1992, will, by the end of the decade, enable scientists at more than 1000 institutions to transmit information at up to a billion bits per second, more than 20 times today's maximum speeds, and a bandwidth 1000 times today's. That will usher in an era of instantaneous access to huge databases, high-quality graphics, and interactive capabilities that will permit collaborations on a scale never before possible.

The fiberoptics are already in the ground, having been laid during the '80s. And the first phase of the system, the national gigabit testbed, will be operational within a year. "The whole system will be working in research environments within 5 years," predicts Smarr.

And what about scientists? Are they ready?

Not to worry, says Smarr, who contends that the roughest days are already behind us. "The rate of the diffusion of computer literacy into the preexisting scientific community will accelerate," he says. "In this new world, once you're MacIntosh literate, the rest of the computer world just sits inside your Mac." Instead of having to learn complicated commands, all you'll need to do is "point and push" to run complex programs. "We're learning how to package computational science in the way word processors have been packaged. It'll be just another software package on your desktop."

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Real Life

Entering Academia in the '90s

By Marcia Barinaga

Three and a half years ago, when Karen Gleason finished graduate school in chemical engineering and took an academic position at the Massachusetts Institute of Technology, she knew it would be less secure and include "more hassles" than would a career in industry. But she decided it was worth it for the chance to work in the academic environment she loved. Then came reality.

"I wrote an enormous number of grants—more than 20—with a very low rate of success," she recalls. "It was very difficult and frustrating."

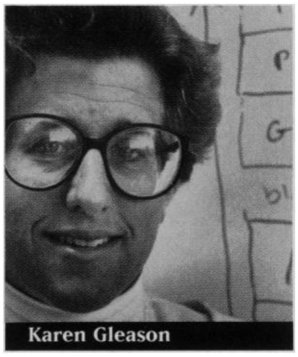
Happily for Gleason, that bitter taste of the real world was to be shortlived. For some inexplicable reason, things turned around. "Last year," says Gleason, "I got 8 [grants] out of 9." In fact, the only one she didn't get was her part of MIT's unsuccessful National Magnet Lab proposal. What caused the turnabout? Gleason is perplexed. "The topics were not any different. I was doing nothing different in the proposals...it leads me to believe there is a tremendous component of chance."

Chance has perhaps never been more important than now, when funding is something of a roulette game for senior scientists as well as neophytes. But the unpredictability is particularly hard on young scientists who may lack the resourcefulness that experience can bring, and who must simultaneously cope with all the other stresses of getting their careers off the ground. After the initial challenge of choosing and landing a job, they are uprooted from a world where all they have had to worry about was their own research. Suddenly, they are plunged into the role of assistant professor, where they must juggle fundraising, department responsibilities, teaching, and managing a lab. Furthermore, they need to hurry to make their mark in their field, as productivity in those first few pressure-cooker years has the potential to make or break an entire career.

How are young scientists rising to the multiple challenges and surviving these troublesome times? After conversations with young researchers in various disciplines and academic settings, *Science* has uncovered the following common denominators: a bit of savvy and a bit of luck.

Luck is a big part of the picture, because the scientists we talked to virtually unanimously confessed to following their hearts rather than their heads—moving in research directions that excited them, rather than those they judged to be lucrative. "I chose what was interesting to me," says Gleason. That her area of research—thin films—is of crucial importance to the electronics industry, was good fortune, she says, not design. In fact, when she chose chemical engineering as an undergraduate major, Gleason admits, "I didn't have any concept of what a chemical engineer did."

And as they pursue the science they love, these young scientists enter a morass of professorial responsibilities that demand abilities—such as grantsmanship, management skills and the ability to teach and be a mentor—for which grad school and postdoc provide little training. "You get no background at all on management of people or resources until suddenly you're thrown into it as a professor," says James LaBelle, an assistant professor in physics and astronomy at Dartmouth. "It would make some sense to have some managerial-type courses" in graduate school, he adds. It's a matter of sink or swim as learning comes on the job, agrees David Julius, an assistant professor in pharmacology at the University of California, San Francisco: "There's a lot to handle in the beginning. You deal with things as they come up." Indeed, most of the investigators interviewed by *Science* said many of their most valuable lessons were learned through hindsight, by analyzing what worked and what didn't. And it is their Monday morning quarterbacking that we bring to you here on the theory that it contains some useful advice for young researchers—and their advisors—as they deal with common problems.



Ivan Masser

Karen Gleason

Experience with grants "leads me to believe there is a tremendous component of chance."

Guaranteeing a niche

It would be foolish to suggest that just because no one is getting much training in careersmanship, careers are taking shape with no planning at all. Despite the unknowns, young scientists are still doing their best to shape their fate. Julius, for example, was drawn to life in the scientific fast lane, and put together a pedigree designed to get him there. After graduate school at UC Berkeley, where he studied the molecular biology of yeast,

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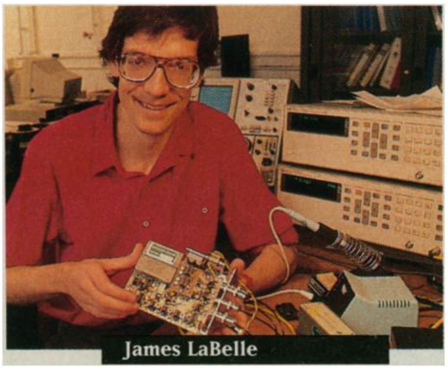

James LaBelle

"...one resume made me look a lot like an electrical engineer, and another made me look like a physicist"

he decided he wanted to focus on molecular neurobiology, so he looked for a mainstream lab to help him make the transition.

"You should pick your postdoc carefully," advises Stanford molecular neurobiologist Richard Scheller, "because it's going to determine what you base your own lab on." And that's what Julius did. He settled on Richard Axel's lab at Columbia, he says, because it was one of the few high-profile labs doing molecular neurobiology. Indeed, that move proved successful: during his postdoc Julius cloned the receptor for the neurotransmitter serotonin, an important piece of work that made him a shoo-in at UCSF.

While Julius chose molecular neurobiology because his interests lay there, the decision was also a strategically sound one. Says Scheller, "There are molecular neuroscience jobs in huge numbers. Whole new departments are being formed." Scheller has another reason for appreciating the benefits of doing a postdoc in a hot lab like Axel's: he made the same choice to work with Axel 10 years ago, a move that helped land him his job at Stanford.

When it takes two to tango

Of course, not everyone can count on one postdoc as an adequate springboard. Jim LaBelle recognized early that his love—experimental space physics—could be problematic when it came to landing a job. "My field straddles two disciplines, electrical engineering and physics," he says. "There is a feeling among physicists that space physicists are electrical engineers, and among engineers that they are physicists. There are few schools where they hire faculty in space physics."

Undaunted, LaBelle decided to build himself the best possible resume in both areas. He did that with two postdocs—the first at the Max Planck Institut in Munich, where there was a first-rate space-physics team, and where LaBelle had the chance to analyze huge amounts of data and be involved in many publications. Then, once he had both his data-analyzing experience and his CV beefed up, he went to Utah State University, and got engineering training in constructing the instruments that he would need to gather data on the radio-waves he studies. "I could basically prepare two resumes," says LaBelle, "one of which made me look alot like an electrical engineer, and another of which made me look like a physicist." His strategy worked: he landed the first job he applied for, at Dartmouth.

Research in a liberal-arts world

Jennifer Cruise set her sights early and didn't waver. Her goal: to teach and do research at a small liberal arts college, where she could re-create for her students the exciting glimpse into research that she had gotten as an undergrad at St. Lawrence University in upstate New York.

Cruise had faith in her ability to teach. But she knew that what she would need to pull off her plan was experience in managing a research program, and a research project with which to set up her own lab. By the time she received her PhD at Duke University she knew she had found both. She enjoyed her graduate work on liver regeneration so much that she decided to stay on in the same lab as a postdoc and serve as co-investigator on a grant to continue the work, which she would eventually carry on at her new job.

After her postdoc, Cruise accepted a job at the College of St. Thomas, in St. Paul, Minnesota, because new faculty there are being encouraged to carry on research, which the college supports at a low level. Cruise says that support is one of the advantages of the career path she has chosen. "My job doesn't depend on my maintaining external funding," she says. "It was important to me not to have to depend on federal grant funding in order to hold my position."

Nevertheless, Cruise has been successful in her first round of grant-writing. She received an Academic Research Enhancement Award grant from the National Institutes of Health, and a Presidential Young Investigator award from the National Science Foundation. The grant money has enabled her to hire a research associate.

But even with grants and research personnel, Cruise says, conducting research at an undergraduate college is quite different from at a large, research-oriented university, because most of the work is being done by undergraduates who are in the lab part time for a year or two at best. "You can't do the same kind of things you can do at a major research university...you have to break everything down into tiny little [student-sized] pieces."

Hitting the ground running

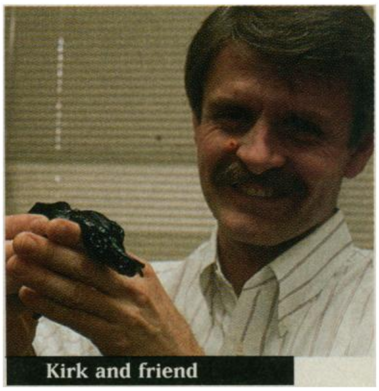
Whatever the path one has chosen, the day arrives when one suddenly has to take on the role of assistant professor. For many, that change—with all its new responsibilities—is an eye-opener. "I expected it would be like making the transition from one postdoc to another, or from grad school to postdoc," Jim LaBelle recalls. "But it really was a very different step from either of those."

Chuck Gasser agrees: "Running a lab is a very different thing from doing research." His recommendation for getting a leg up: do a stint in industry. When Gasser finished his PhD at Stanford, he applied for a postdoc at Monsanto. That's not terribly unusual in his field of plant research, he says. But the company gave him an opportunity that was a bit more unusual. Instead of the postdoc he had applied for, they offered him a permanent position. Gasser says he wavered a bit because he was "a little worried about getting back into academia," his eventual goal. He gambled, took the job, and stayed 5 years. Reflecting back from his current position as an assistant professor at UC Davis, he says going to Monsanto was the right move. "I wouldn't recommend against it to anybody," he enthuses, "as long as it's a company that publishes. I got to go to meetings, I got to present talks, I got to publish my work. If you can't do that, it might be much more difficult to re-enter the academic community."

Gasser says he realizes now that Monsanto was an ideal training ground for professorship: "I've had to make up budgets for the last 5 years...I've had to divide my time between research and administrative stuff, and I've borne the responsibility for educating the people that worked for me." Because of his industry experience, he thinks he's "more comfortable with this position than I think some other people might be."

Another strategy that paid off for Mark Kirk, a neurophysiologist and assistant professor at the University of Missouri, was to write his grant and order his equipment for his new lab before he left his postdoc. Staying put, he says, allowed him to work at maximum efficiency and continue experiments, while he got funding and equipment for his own lab lined up. As a result, "When I arrived, my equipment was sitting in the lab ready to put together. We were doing experiments in no time."

Rob Hill U. Missouri


Kirk and friend

"when it comes tenure time, even here at a public university, more emphasis is put on the research."

Getting funded

Despite the gloomy funding statistics that haunt the nightmares of today's grant seekers (see main story), Kirk was lucky; he got the first grant he applied for—an NIH award tailored for first-time grant applicants—for his work on the neurophysiology of the marine snail Aplysia. But others learn the hard way that there are do's and don'ts of grant writing.

"Getting grants is pretty tough, I'll tell you," says Chuck Gasser, who has some wisdom to offer based on his first unsuccessful effort. His biggest mistake? "I put all my good ideas into [the grant]. And they don't grade you

Continued on p. 1147

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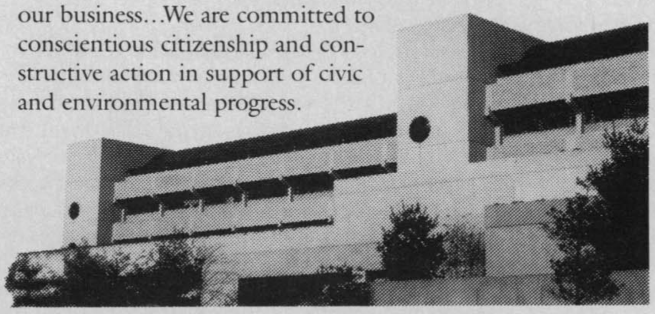

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Continued from p. 1145

on how many good ideas you have; they have to find something to criticize. The more ideas you put into your grant, the more likely there will be one they pick out to criticize." This time, Gasser says, he wrote a more focused grant, and expects it to do better.

LaBelle has a related ploy that has worked for him: "I tend to keep [grant proposals] fairly small. I have a definite sense that small proposals have a better chance of getting funded. The disadvantage of that is that you have to write a lot of proposals, and...each grant has a different aspect that you have to satisfy and write papers for." LaBelle currently has 5 grants, for an average of $40,000 annually each. The diversity acts as a bit of a safety net, he says: "If any one fails, it's not a disaster," but the short terms, generally 2 years, mean "the renewals are on you before you know it."

Lectern lessons

Prepared or not, most new faculty find teaching to be difficult and time consuming at first. "Teaching was a total shock to me," admits MIT's Gleason. "I had been a teaching assistant when I was doing my PhD, but that was primarily grading problem sets, not lecturing. You forget what people know at given stages. It also takes a certain personality." Lecturing to an auditorium and working in a lab, says Gleason, "are diametrically opposed [activities]."

Gleason says she got some support from fellow faculty, but she also got the feeling that teaching takes second place to research. "Even though people talk about rewards for teaching and rewards for research in an academic career, you don't get the impression that those two are weighted equally," she says. "So as long as you are not abysmal, it is OK." Similarly, Kirk thinks that although he's been "an above average teacher, I know I could be doing a lot more if it were a more important part of my job. But when it comes tenure time, even here at a public university, more emphasis is put on the research." Kirk advises getting a head start on teaching experience—he picked up some during his postdoc at Stanford by volunteering to give guest lectures in courses, and got some experience as a mentor by taking on the training of graduate students in the labs where he worked.

Despite the nearly universal priority placed on research productivity, faculty at schools with a heavy emphasis on undergraduate teaching have to accept that teaching will always take a substantial amount of their time, says Dartmouth's LaBelle. "The students...expect a lot, and I feel that. I feel compelled to do a really good job, and it takes more than 40 hours a week." LaBelle says he expects teaching—which he does for three quarters per year, will always occupy more than half of his time during those quarters.

Managing a lab

Whether they are facing an auditorium of undergrads from behind a lectern, or facing a single graduate student from behind their office desk, many new faculty feel suddenly lonely—separated from the world of postdocs and students they used to be immersed in. "When you're a student, the relationships you develop with your peers are helpful for relieving stress, says chemist Banita Brown, of the University of North Carolina at Chapel Hill. "When you're the manager, you're the one who's in charge. If I wanted to gain the respect of my students, I couldn't go around acting like them."

Physicist Monica Olvera de la Cruz, of the University of Chicago, learned that lesson the hard way. "I got very close to my first students. We were almost the same age—I'm 32 now, and five years ago when I started, I had students of 24 and 25. I was not used to keeping the distance that is necessary for being an adviser." Although the friendship with her students was a comfort, she says, it was an invitation to trouble: "Even if you are very close friends, you will have to act like an authority at some point, and that will be resented by the student. So it's not fair to them. I tell all my new [professor] friends to be careful."

Establishing authority is not the only step in learning successful management, young faculty find. After years of doing the experiments yourself, it can be hard to sit back and let students find their own way. "A large part of your responsibility is not only to get science done, but also to provide an adequate training environment," says UCSF's Julius. "Within the boundaries of good science, you have to let people learn what they need to learn." Kirk agrees. "You have to let the students do the experiments, but that can be agonizing," because they can be so slow.

But Kirk has found that training time can be converted into a direct research payoff. He has trained a series of undergrads who have stayed on to work as technicians for a year or two before going on to graduate school. "They make great technicians," he says. "They are soaking up everything, and are really eager to learn. And they provide a young, fresh perspective on what you're doing."

Being a good citizen

To a new professor in the midst of adjusting to all the demands of academic life, administrative and committee responsibilities may seem like the last straw. At the small college where Jennifer Cruise works, she found she was practically a one-person administrative show. "I'm the radiation safety officer at my college. In order to be able to work with radioactivity here, I had to rewrite our license. And I'm the chairman of the institutional animal care and use committee." Having to be a committee pioneer, observes Cruise, "is not a solution that a lot of people would find acceptable."

Even those who don't have Cruise's burden can find themselves taking on a hefty share of committee responsibilities. Mark Kirk has watched his schedule fill up with meetings of committees for everything from symposium-organizing to student discipline. "It's important to be a good citizen," he says, but it's equally important to avoid overcommitment. "I know people that frustrate the hell out of you because they say they're going to do something and they never do it." MIT's Gleason agrees that there is a fine line between being a good citizen and being overextended. She manages a department seminar program, and serves on the graduate admissions committee. She says she keeps her time commitment to these things small, by being organized. "The word 'no' is also helpful," she adds.

Kirk says he got valuable insights into what to expect from committee work by volunteering to be the student member on faculty committees back when he was a graduate student at Rice University. There were other bonuses as well: "I was on a search committee one time—that was a great experience. It shows you so many different aspects of what it takes to get a job."

When you add up all the difficulties of launching an academic career, it's clear that it must be a labor of love. "Academic careers do require an incredible amount of devotion," says Dartmouth's LaBelle. "For a certain number of years of your life, you have to totally work hard, and give up a lot of extra activities. There are times when this job is very rewarding, and there are other times when I wonder why I'm doing it. But I'm definitely going to be sticking with it."

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A few words of warning

"Junior faculty need protected time to develop. Look for a job where the boss is willing to give protected time for 3 years with as little teaching as possible."
biochemist T.K. Li, Indiana University

"Committees [particularly if you're female or minority] are a big distraction. There are so many distractions that a lot of people never really make this transition [from postdoc to assistant professor]"
Max Cowan, Howard Hughes Medical Institute

"There is little or nothing about the ordinary PhD training that qualifies anybody to manage anything."
Peter Raven, Missouri Botanical Garden

Getting an academic job is a "hard life—you have really got to be passionate about it to stand it because the demands are really excessive."
Sylvia Ceyer, MIT chemist

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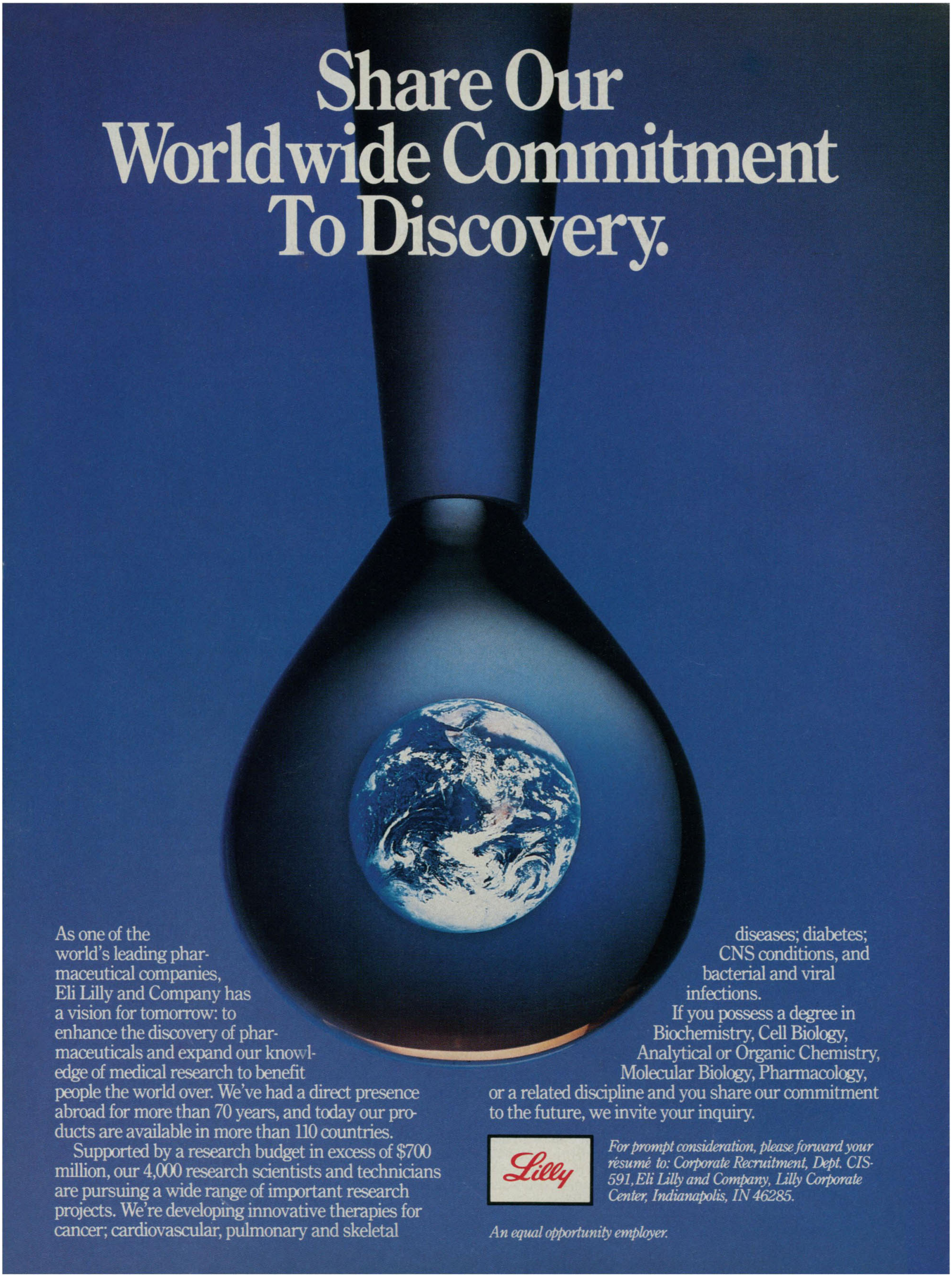
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