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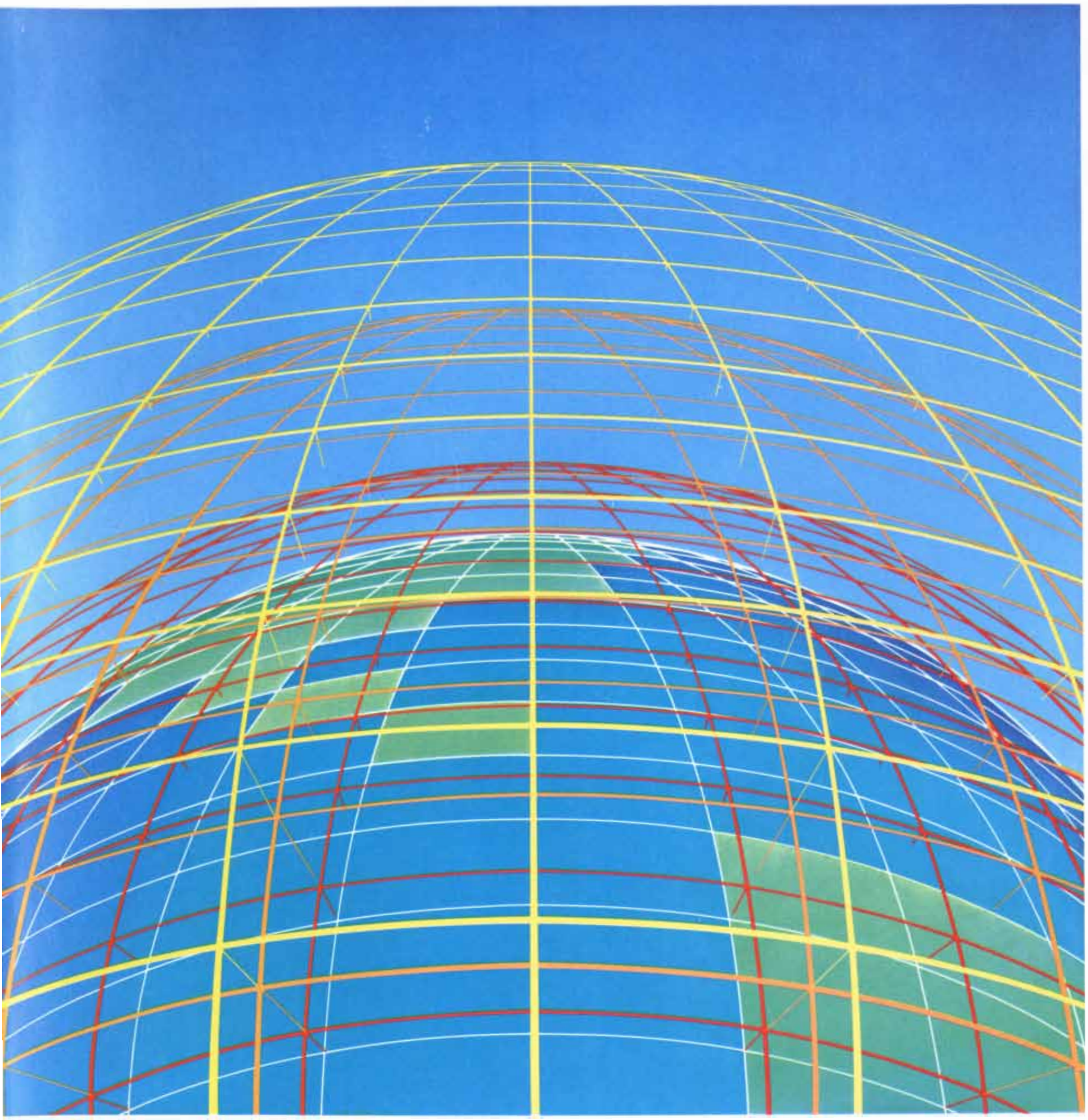

PREDICTING THE EARTH'S CLIMATE

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May 1987

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Someday, our children will be able to share information, anywhere, anytime and in any form as easily as we use the phone today. At Northern Telecom, we call this vision the Intelligent Universe,* and we're already building telecommunications products to make it a reality.

Recently, the global telecommunications industry established a set of standards called Integrated Services Digital Network, to help guide the future of telecommunications.

In concert with you our customer, we're fully committed to applying the principles of ISDN. After all, these principles are but another step on the way to our vision.

INTEGRATED—People in different parts of the world have different customs and speak different languages. That's because they were relatively isolated, and their cultures developed independently before the days of radio, television, telephones and fast, easy transportation. Sometimes, it's hard to communicate.

Similarly, computers and other equipment made by different manufacturers often find it hard to communicate, because they were developed independently and in isolation.

At Northern Telecom, we've been designing and building telecommunications products to help change this situation. The features and capabilities we have designed and the design information we make available to others let as many different kinds of products as possible connect and work together so they work better for you. We call a network which offers this kind of open interconnection an OPEN World.*

SERVICES—You don't need to understand what makes a telecommunications network tick to use it. For you, the network is just the communications services you need. And of course, the actual telephone or terminal you use is one means of accessing such services.

At Northern Telecom, we have defined and are building into the network a tremendous capability for the provision of services, and we have introduced a line of products to both access and realize this capability. We call it the Meridian† line of products. It's aimed at enhancing your communications effectiveness by offering you the services you need with the simplicity you demand.

Meridian by Northern Telecom.

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DIGITAL—Most people find that the best approach to solving a problem is the simplest approach. In telecommunications, the simplest way of carrying information is to convert it to a series of 1's and 0's—a digital bit stream.

A digital bit stream can mean anything—it can be your voice, a letter, a television picture, or the manufacturing diagrams for a new car.

At Northern Telecom, we've been designing and building telecommunications products based on the simple digital bit stream for two decades. We call a network that handles all information in digital form a Digital World.*

NETWORKS—In sports, a winning team starts with a good game plan, and adapts it in real time based on the changing flow of the game.

Up to now, telecommunications networks have followed a very static game plan. They were built mostly of separate elements to handle predictable changes in needs on a long-term basis. There was almost no way of controlling them in real time, so they provided little current information about overloads or breakdowns or anything.

At Northern Telecom, we have developed a new way of designing and controlling telecommunications networks. It's a game plan for public or private network architects who want to design and run their whole network like a winning team. It also lets networks carry different kinds of information more easily and economically and thereby provide the basis for supporting new services and capabilities for you.

We call it Dynamic Network Architecture.*

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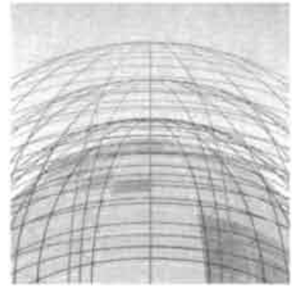

THE COVER

The cover depicts part of the three-dimensional "grid" employed by an advanced computer model of the earth's climate (see "Climate Modeling," by Stephen H. Schneider, page 72). Because it would take impossibly long to calculate temperature, humidity and other climate variables everywhere in the atmosphere, the computer makes calculations only at selected points: the intersections of the imaginary horizontal and vertical lines that make up the grid. The model "sees" geography at the same resolution, and so its world map is very crude; the view here is centered on Central America.

THE ILLUSTRATIONS

Cover illustration by Andrew Christie

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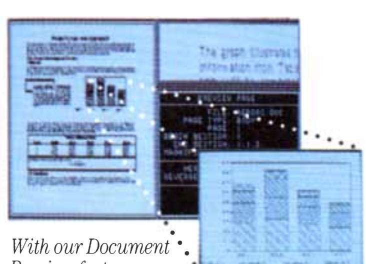

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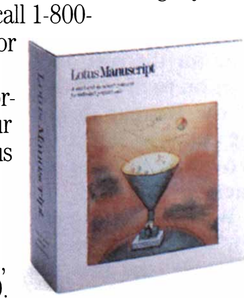

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LETTERS

To the Editors:

J. Larry Brown ["Hunger in the U.S.," SCIENTIFIC AMERICAN, February] implies that Federal cutbacks in welfare programs are associated with hunger and malnutrition and so with early death, diseases and developmental problems in infants and children.

The author totally disregards major social problems that exist to a much greater extent in the U.S. than anywhere else in the world and may well be associated with the health problems he describes. These social problems include single, often teen-age mothers, each of whom may have children by several men, extensive drug and alcohol use and cigarette smoking, particularly among teen-age mothers.

Unless a comprehensive review is made of the role of all these complex factors, singly and together (they may have synergistic adverse effects), the nation may be focusing attention on only one aspect of a very complex social problem. Any remedial effort concentrating on a single factor, such as Brown's article might inspire, will not suffice to solve the problem and thereby remove what we all take to be a national disgrace.

J. H. WILCOX

White Plains, N.Y.

To the Editors:

"Hunger in the U.S." is sadly lacking in scientific objectivity and method. In the concluding paragraph of the first section, for instance, Brown writes: "In 1985 the Physician Task Force calculated that hunger afflicts some 20 million Americans. Although more recent data are not available, later evidence suggests that the problem of hunger in America has grown worse." Either he is using the terms "evidence" and "data" in some private way or this statement is self-contradictory.

This remarkable assertion sets the tone for the rest of the article. Brown goes on to invoke the devil in the form of the Reagan Administration, alleging cutbacks in programs although not providing detailed data on these cutbacks or references for his sources.

Where he does provide data they do not seem to support his argument. For example, the two graphs on page 39 purport to show declining participation in the food-stamp program. Ruling a few lines across the upper graph appears to show that the population living below the Government-defined poverty level rose slightly and then declined during the period covered. The number of people taking part in the food-stamp program seems to have changed more or less in step with the number living in poverty.

The lower graph shows the ratio of those two figures. The ratio fluctuates through a range of about 8 percentage points over the period. The poverty level and the income qualification for food stamps, however, are both revised periodically. These revisions are carried out asynchronously by different organs of the Federal bureaucracy. The fact that the numerator and the denominator of the fraction being graphed are changed at different times by different organizations is sure to cause some volatility in the ratio. . . .

JAMES C. FINUCANE

Alliance, Ohio

To the Editors:

Wilcox is uncomfortable with the claim that there is an association between recent Federal policies and increased hunger. He urges that we look to the hungry themselves for causes, suggesting that we investigate marital status, sexual partnerships, drug use and alcohol consumption. That Wilcox is concerned about these problems is obvious, but there is no evidence that they cause hunger.

A few facts will show that the problems Wilcox describes are diminishing or bear no direct relation to hunger:

Teen-age pregnancy. Fewer teenagers are having babies, namely about 5 percent of the teen-age population per year, compared with 7 percent 15 years ago, according to *Statistical Abstracts of the United States.*

Abuse of drugs and alcohol. These problems are about as prevalent as they were 15 years ago, after significant declines from a high point in the late 1970's.

Paternity. No scientific or medical literature indicates conception by different men somehow produces hunger.

I share Wilcox' concern about these issues, but not as possible explanations for the rapid growth of domestic hunger. The farm families that are now hungry, like the families of former factory workers who supported themselves until industries closed down, are not drug-taking baby machines. Perhaps it is easier to ascribe negative traits to victims of problems than it is to examine the more complicated factors that create need among so many American citizens.

Some observers, for example, have ventured that poor people go hungry because they waste their money. They make that statement in spite of data from the Department of Agriculture showing that the poor, as a group, make wiser purchasing choices than other people in order to stretch their food dollars. The president himself recently suggested that people are hungry owing to ignorance, but he failed to explain why millions of citizens have suddenly become ignorant.

In sum, Wilcox' suggestion that personal maladjustment causes poverty and hunger, rather than the reverse, is not supported by fact or reason.

The criticisms Finucane advances are more technical in nature. Although he makes no distinction between the terms "evidence" and "data," scientists commonly do. "Evidence" is suggestive or indicative information, frequently based on observations or oral statements. "Data," on the other hand, usually take the form of numerical information, suitable for processing and analysis by computer. Hence my statement (that recent evidence suggests hunger has grown worse since we first calculated that it afflicted 20 million Americans in 1985) remains accurate.

Finucane then interprets the graph comparing poverty and food-stamp participation as indicating that they "changed more or less in step." He is dead wrong here. In 1980, 68 percent of the population living in poverty received food stamps; by 1985 that figure had fallen to 59 percent. If the percentage had remained steady instead of falling, three million more people would have received food stamps in 1985. This decline in food-stamp coverage is a major factor in the significant increase in hunger in the nation.

Finucane is also wrong in stating that the poverty level and the qualifying income for food stamps are revised "asynchronously by different organs of the Federal bureaucracy." The two income levels are tied to each other, based on the official poverty level established in 1965 and adjusted annually according to the cost-of-living index. The "volatility in the ratio" that Finucane observes is therefore due not to bureaucratic asynchronicity but to extant public policy.

Finally, Finucane maintains that I "invoke the devil in the form of the Reagan Administration." Science has made devils obsolete, I hope, and people who believe in objective analysis can reach conclusions without taking political persuasion into account. Although hunger has got much worse during the years of this administration, the problem is truly bipartisan. So, I hope, will be its resolution.

J. LARRY BROWN

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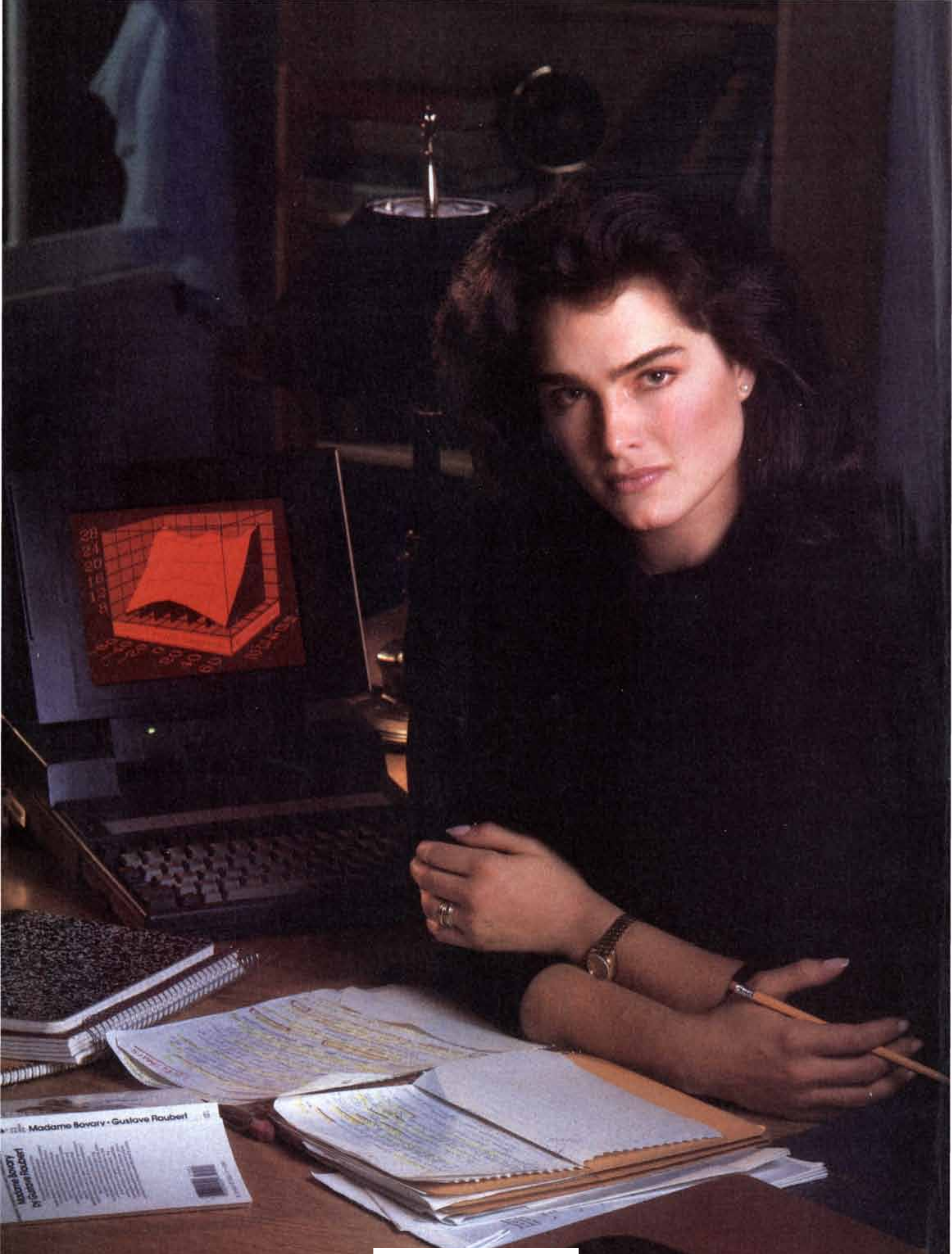

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50 AND 100 YEARS AGO

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MAY, 1937: "With almost startling suddenness, speculation as to when and how sealed, supercharged cabins would be used to transport air passengers at levels above the normal storm area has been translated into orders for airplanes provided with fuselages suitable for such supercharging. It is plainly evident that air transport is going 'up stairs.' This raises many questions of interest as to operating efficiency and passenger comfort."

"United Air Lines have now in service the world's first extra-fare planes. The company has recently purchased a fleet of 28 Douglas DC-3 twin-engined machines. Ten 'Skylounge Mainliners' have been put into non-stop service between New York and Chicago, with an extra fare of $2.05. The extra fare is no doubt fully justified because instead of seating 21 passengers, the extra-fare ships will provide accommodation for only 14, which makes a substantial difference in payload."

"The Golden Gate Bridge, which is due to open this month, as a definite project dates back to 1919, when the San Francisco Board of Supervisors authorized a survey to determine its feasibility. Preliminary plans were drawn up in 1924 and the Golden Gate Bridge and Highway District was formed in 1930. The bridge has been built as a self-liquidating project, being financed by a $35,000,000 bond issue, guaranteed by the taxable property of six Californian counties."

"Motor-truck manufacture is a half-billion-dollar industry. Add to this wholesale value of product the value of business done by companies and individuals engaged in truck transportation and you get a major industry centered around a product a little more than 30 years old. Today the motor truck moves 2 percent of the ton-miles and 5.5 percent of the nation's carload tonnage. Motor-truck transportation is still primarily a business of small operators, although concentration in fewer hands is proceeding rapidly."

"There are now 1,500,000 motor vehicles in the United States equipped with speed governors. It has been thought that governors increase operating costs and retard deliveries, but the experience of the General Electric Company has resulted in a favorable opinion of this method of curbing maximum trucking speeds."

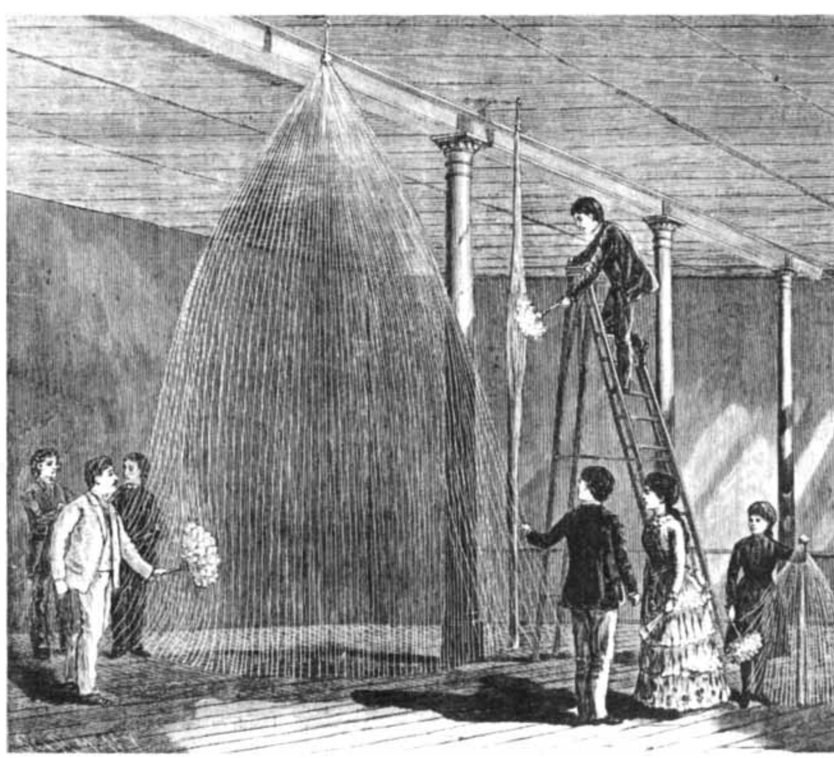
"As a test of glued-arch building construction, of which economy of cost and space are the outstanding merits, the United States Forest Products Laboratory at Madison, Wisconsin, has during the past year subjected one of the arches in a large service and storage building to a constant weight of 31,500 pounds from 315 sandbags on its roof. This weight, 50 percent in excess of that which would have to be borne by the arch were it blanketed with a drift of snow weighing 30 pounds per square foot, has deflected the roof peak, in all those months, the remarkably slight amount of only one and one-tenth inch."

SCIENTIFIC AMERICAN

MAY, 1887: "The prospects for a canal at Panama seem more illusive as time goes on, and not even the skill and perseverance of the French engineers has so far sufficed to lend to the scheme the air of practicability. Indeed, the tenacity with which these engineers adhere to the work must be regarded as remakable by those who know how formidable and disheartening have been the obstacles: the deadliness of the climate, the necessity for a monstrous dam at Gamboa, the great difference in level between the Atlantic and Pacific oceans and the disappointing character of the rock to be cut into in the mountain section."

"It is a good many years since the probable useful employment of balloons in warfare began to occupy the attention not alone of our own War Department but of that of nearly every country of Europe, as well as the countries of North and South America. In spite of all the endeavors made, very little seems to have been really accomplished. We have not progressed beyond the mere possibility of viewing an antagonistic position."

"An interesting example of the mutual repulsion of similarly electrified bodies is displayed in the annexed engraving. The elastic rubber strips employed in the experiment were suspended from the ceiling in one of the apartments of the SCIENTIFIC AMERICAN office and were electrified by simply brushing them with a feather duster. The threads became more and more divergent as the electrification proceeded, until it finally became impossible to approach the threads without becoming enveloped in them."



An electrical experiment

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THE AUTHORS

LESTER C. THUROW ("A Surge in Inequality") is professor of management and economics at the Massachusetts Institute of Technology, where in July he will become dean of the Sloan School of Management. Thurow did undergraduate work at Williams College, earned a master's degree at the University of Oxford and received his doctorate in economics from Harvard University in 1964. He spent two years on the President's Council of Economic Advisers and then joined the faculty at Harvard. His tenure at M.I.T. began in 1971. Among Thurow's books is *The Zero-Sum Solution: Building a World-Class American Economy.*

VICTOR E. VIOLA and GRANT J. MATHEWS ("The Cosmic Synthesis of Lithium, Beryllium and Boron") have collaborated for more than a decade in studies of elemental synthesis in the universe. Viola is professor of chemistry at Indiana University and director of the Indiana University Cyclotron Facility. He got a bachelor's degree at the University of Kansas and, in 1961, a Ph.D. from the University of California at Berkeley. Before accepting a professorship at Indiana, Viola taught at the University of Maryland at College Park, where he and Mathews first worked together. Mathews is a group leader for nuclear astrophysics research at the Lawrence Livermore National Laboratory. He has a bachelor's degree from Michigan State University and a Ph.D. from the University of Maryland, awarded in 1977 for research that included his first inquiry into the genesis of lithium, beryllium and boron.

TOMASO POGGIO and CHRISTOF KOCH ("Synapses That Compute Motion") study computation by machines and living things, Poggio as professor at the Artificial Intelligence Laboratory of the Massachusetts Institute of Technology and Koch as associate professor of computation and neural systems at the California Institute of Technology. Poggio got his doctorate in theoretical physics in 1970 from the University of Genoa and went on to study information processing in vision at the Max Planck Institute for Biological Cybernetics in Tübingen. He continues to pursue research on vision at the AI Laboratory; at the same time he serves as codirector of M.I.T.'s Center for Biological Information Processing, where he studies computation in the brain. Koch, who studied physics and philosophy at the University of Tübingen, earned a Ph.D. in 1982 from the Max Planck Institute for Biological Cybernetics for work done in part with Poggio. Later, as a research scientist at M.I.T.'s AI Laboratory and at CBIP, he investigated computer vision and information processing in single nerve cells. Koch moved to Caltech in 1986.

STEPHEN H. SCHNEIDER ("Climate Modeling") is deputy director of the advanced-study program at the National Center for Atmospheric Research (NCAR) in Boulder. He is a graduate of Columbia University, where he received a Ph.D. in mechanical engineering in 1971. He has pursued his interest in climate change, its natural and human causes and its impact on public policy in a variety of settings: at the Commission on Natural Resources of the National Academy of Sciences, at NASA's Goddard Institute for Space Studies and, since 1972, at NCAR. He has also served as a witness before Congress, as a member of the Defense Science Board Task Force on Atmospheric Obscuration and as a consultant to the Nixon and Carter administrations. Schneider is the editor of *Climatic Change,* a scientific journal, and the author of several popular books.

ANTHONY CERAMI, HELEN VLASSARA and MICHAEL BROWNLEE ("Glucose and Aging") are colleagues in the department of medical biochemistry at Rockefeller University who share an interest in diabetes and in the aging process. Cerami is R. Gwin Follis-Chevron professor as well as dean of graduate and postgraduate studies and head of the laboratory of medical biochemistry. He was educated at Rutgers University and at Rockefeller, where he was awarded his doctorate in 1967. Vlassara is assistant professor of medical biochemistry. She earned her medical degree at the University of Athens School of Medicine and then came to the U.S. for an internship and residency at the Columbia University College of Physicians and Surgeons. Brownlee, who is associate professor of medical biochemistry, holds an M.D. from the Duke University School of Medicine. He did his internship and residency at the Stanford University School of Medicine and in 1975 became a research fellow in biological chemistry at the Harvard Medical School. After a fellowship at the Joslin Diabetes Center and the New England Deaconess Hospital and a stint as an instructor at Harvard, he went to Rockefeller.

JAMES S. WALKER and CHESTER A. VAUSE ("Reappearing Phases") met and began their collaboration while they were postdoctoral researchers at the University of Pennsylvania. Walker, now associate professor of physics at Washington State University, received his Ph.D. in physics in 1978 from the University of Washington. He did postdoctoral work at Pennsylvania, the Massachusetts Institute of Technology and the University of California at San Diego. In 1983 he moved to his current position, where he relishes the outdoors and enlivens his course on mechanics with demonstrations. Walker writes that in one lecture "I add to the general increase of entropy by juggling a set of flaming torches." Vause is assistant professor of physics and astronomy at the University of Hawaii at Manoa. After earning his Ph.D. from Rutgers University in 1979, he went to the University of Pennsylvania, where from 1981 to 1983 he was a National Research Council associate. In 1983 he returned to Hawaii to take his present post.

WILLIAM C. DAVIS ("The Detonation of Explosives") is a fellow at the Los Alamos National Laboratory. He holds a bachelor's degree in engineering from Tufts University and a Ph.D. in physics from Johns Hopkins University, awarded in 1954. He then went to Los Alamos, where detonation physics has been his main interest. His approach has been both theoretical and experimental, making use of high-speed photography and flash X-ray systems.

JAMES J. CHILDRESS, HORST FELBECK and GEORGE N. SOMERO ("Symbiosis in the Deep Sea") have worked together for several years exploring the adaptations by which animals thrive in the unique environment of the deep-sea vents. Childress is professor of biology at the University of California at Santa Barbara. He received his Ph.D. in biology from Stanford University and joined the faculty at Santa Barbara in 1969. Felbeck is assistant professor of biology at the Scripps Institution of Oceanography. He earned his doctorate from the University of Münster's Institute for Zoology in 1979 and did research at Scripps before joining the faculty. Somero, professor of biology and chairman of the marine biology research division at Scripps, got his Ph.D. from Stanford in 1967 and did postdoctoral studies at the University of British Columbia. He went to Scripps in 1970.

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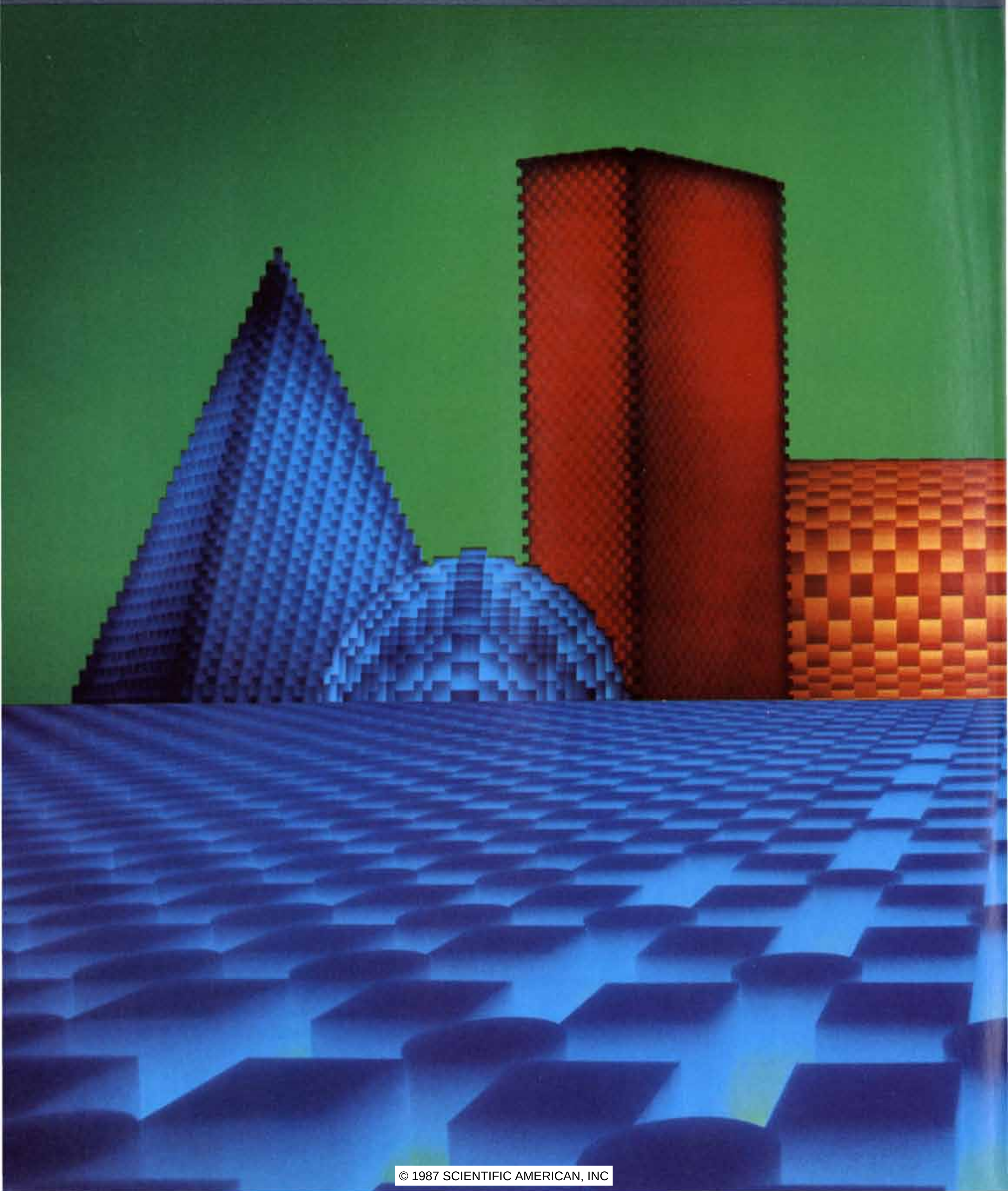

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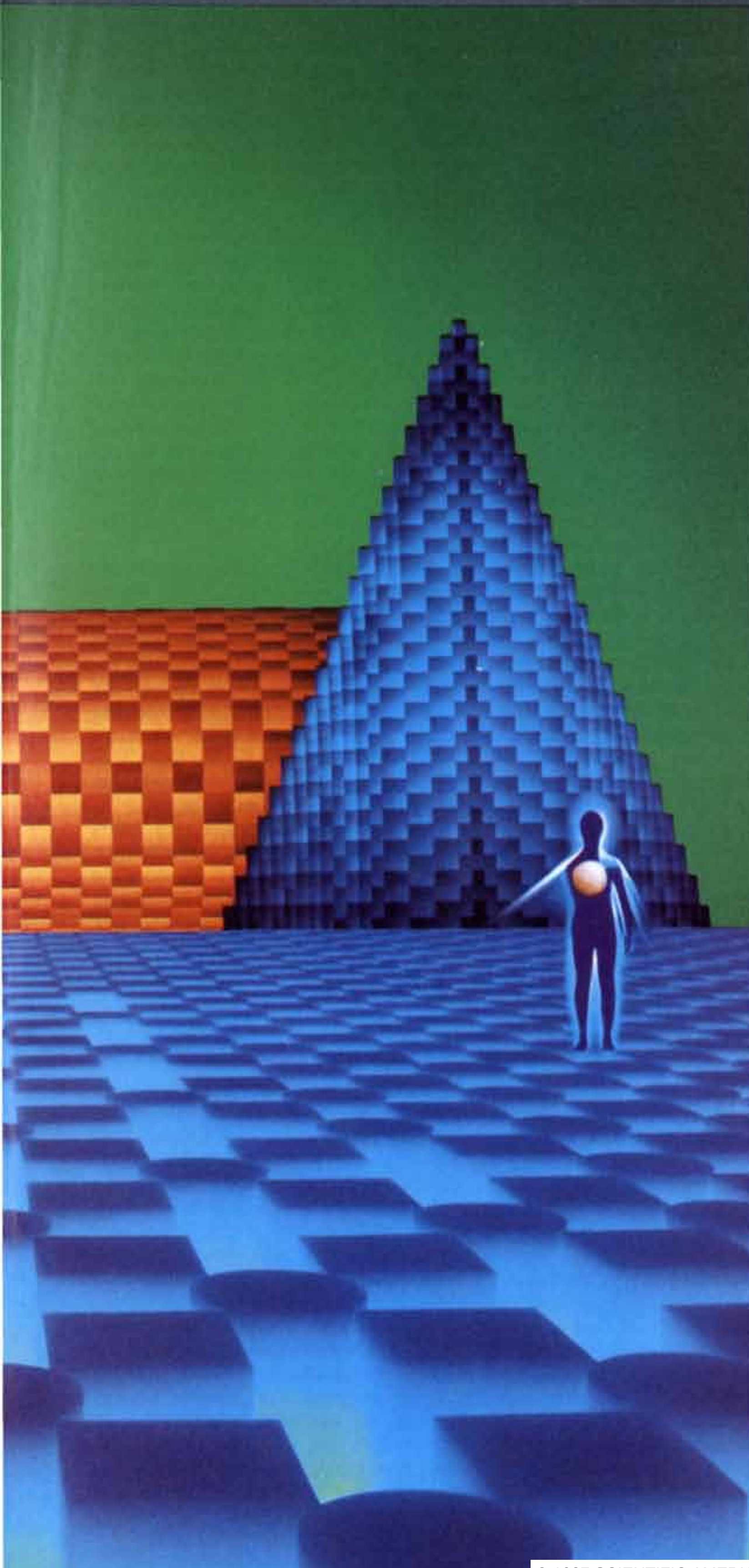

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COMPUTER RECREATIONS

Of bulls, bears and programs in the pit

by A. K. Dewdney

The trading floor of a traditional stock exchange is sometimes called the pit. Here one can see grown men and women shouting, gesturing and making rapid calculations on the back of envelopes. In this bedlam shares are bought and sold by cries and signs. Will the process ever be automated? Will computer programs someday silence the pit forever?

In the wider pit that includes the investor's home or office, automation is already under way. It is now possible for readers to buy (or write) programs that analyze technical or fundamental aspects of stocks. Closer to the exchange there are programs written by the so-called rocket scientists of Wall Street. Among the programs are certain ones that compute the outcome of complicated transactions involving large numbers of stocks hedged with stock futures. Transactions of this nature, known as program trading, were blamed by some people for the drastic one-day drop in the New York market last September. Closer still to some pits are programs that assist in the actual trading process, a subject worthy of mention at the end of this article. It may be that such programs can be extended to handle the actual trading—a tricky and contentious proposition.

First, a tour of the pit seems in order. A transaction there begins with the decision by an individual investor to buy, say, 100 shares of United Suspenders. The investor places the order with a broker, who (after extracting a commission) relays the order to the trading floor of a stock exchange where United Suspenders is traded. There a trader who specializes in United Suspenders fills the order from shares currently for sale. In due course payment is relayed from the investor through the brokerage firm to the seller of the 100 shares. At the same time ownership of the shares is transferred to the investor.

If the value of United Suspenders increases while the investor holds the stock, he or she may sell it again at a higher price and make a profit. If, on the other hand, United Suspenders drops, the investor may either hold on to the stock (in hope of an eventual rise) or sell it at a loss. In the first case the investor may feel optimistic. It is a bull market: the prices of many stocks seem to be increasing without limit, and a mood of cheery optimism pervades the investment community. Our investor feels like hanging on in the expectation that United Suspenders, along with its fellow stocks, will eventually rise. In the second case the investor feels pessimistic. It is a bear market: prices are generally falling, and the investment community grows fearful, even panicky. A severe bear market such as the one that hit Wall Street in 1929 is called a crash. The impact of a stock-market crash can be catastrophic, resulting in bank failures, plant bankruptcies and unemployment—in short, a depression.

Does our investor make a decision to buy or sell based purely on the prevailing emotional climate? The answer is surely "Sometimes." At other times the investor might take a more reasoned approach. Two traditional avenues are available: fundamental analysis and technical analysis. The fundamental avenue involves purchasing a stock on the basis of entrepreneurial or financial strengths of the issuing company. I shall have more to say about this approach later.

The technical approach offers much fascination for lovers of charts and numeric patterns. Believing that the past behavior of share prices has predictive value for future prices, the technical analyst employs a variety of means to make predictions. The simplest of these exploit apparent trends in price, upward or downward. Suppose, for example, that United Suspenders has traded for some time in the $10 range and has recently begun to go up in price. If the movement is smooth and linear, the class-C technical analyst (the tyro category) might examine a chart of recent prices [*see top of illustration on page 18*] and superpose on the price line a ruler-drawn line that matches it closely. If the current price is $15 and the trend indicates a rise of approximately $1 per day, the analyst might buy 100 shares in the expectation of harvesting $100 per day. Alas! On the day of purchase the stock begins to plummet.

Enter the class-B (apprentice) analyst, who, watching the stock during subsequent days and weeks, notices a seesaw pattern of ups and downs in the price of United Suspenders. At the same time each new high is higher than the previous ones. The trusty ruler is again employed, this time to draw two lines [*see middle of illustration on page 18*]. One line bounds stock prices below and the other bounds them above. In between lies a "channel" in which the price of United Suspenders zigzags.

The class-B analyst may exploit the channel in a number of ways. He or she may buy the stock at whatever the current price may be with the intention of holding the stock long enough to exploit the broad, upward trend to the fullest. In the short term, however, the analyst might wait for the price of United Suspenders to hit the bottom of the channel. Here is one place to buy in the hope of turning a quick profit.

The top of the channel also offers an investment opportunity: the analyst may sell the stock short. This means borrowing, say, 100 shares of United Suspenders at $20, selling the shares immediately at that price and paying for the shares later when the price reaches $15. The borrowed shares are paid for at the new price and the investor subsequently pockets the $5-per-share difference.

In either case there are obvious dangers. For example, the class-B analyst may buy 100 shares of United Suspenders when it reaches the bottom of the channel. Convinced that the price will rebound like a tennis ball from a brick wall, the analyst watches in horror as the price continues to plunge. Aghast, the class-B analyst turns to a class-A (expert) friend for help.

"It's probably a new channel," says the friend, hardly looking up from his charts. Subsequent weeks bear him out, so to speak; the price of United Suspenders has now begun to jitter downward just as it originally seesawed upward. How did the class-A analyst know that a down channel had

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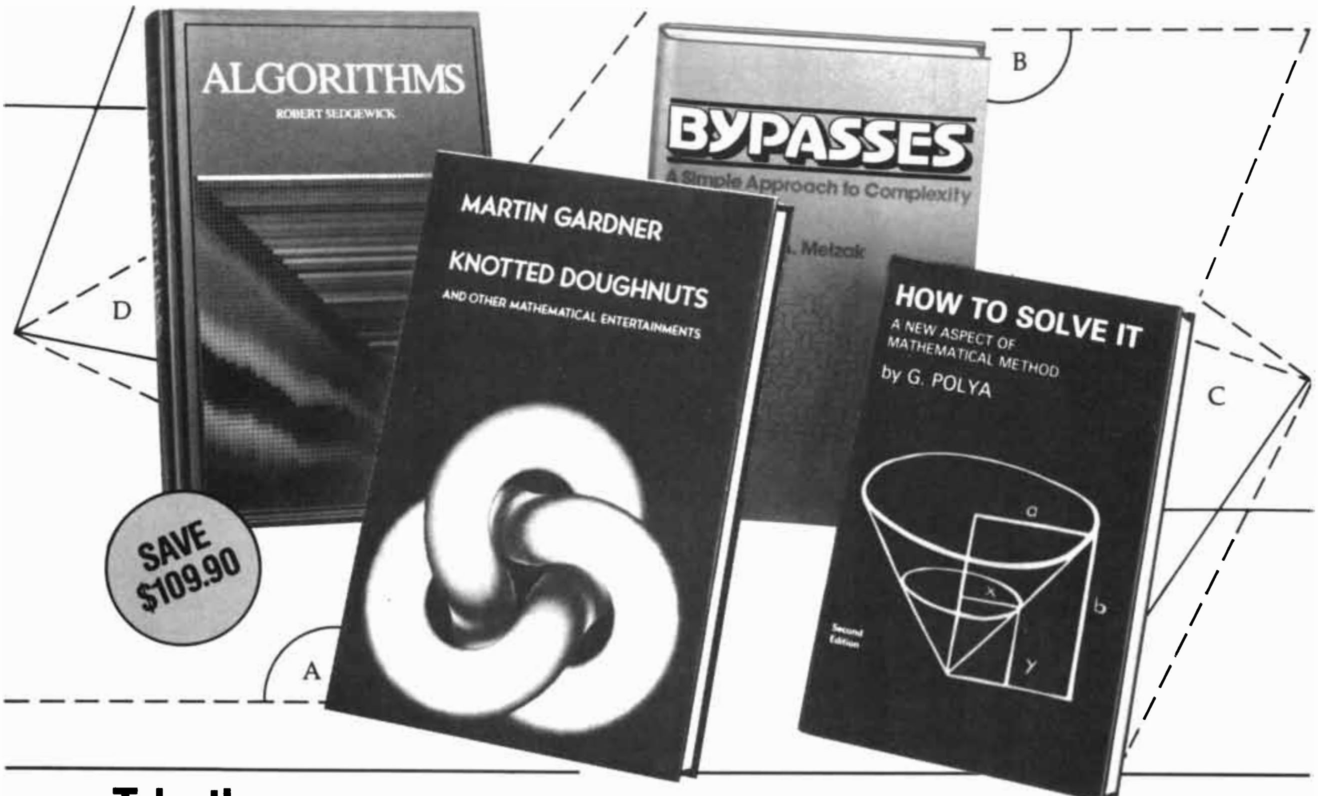

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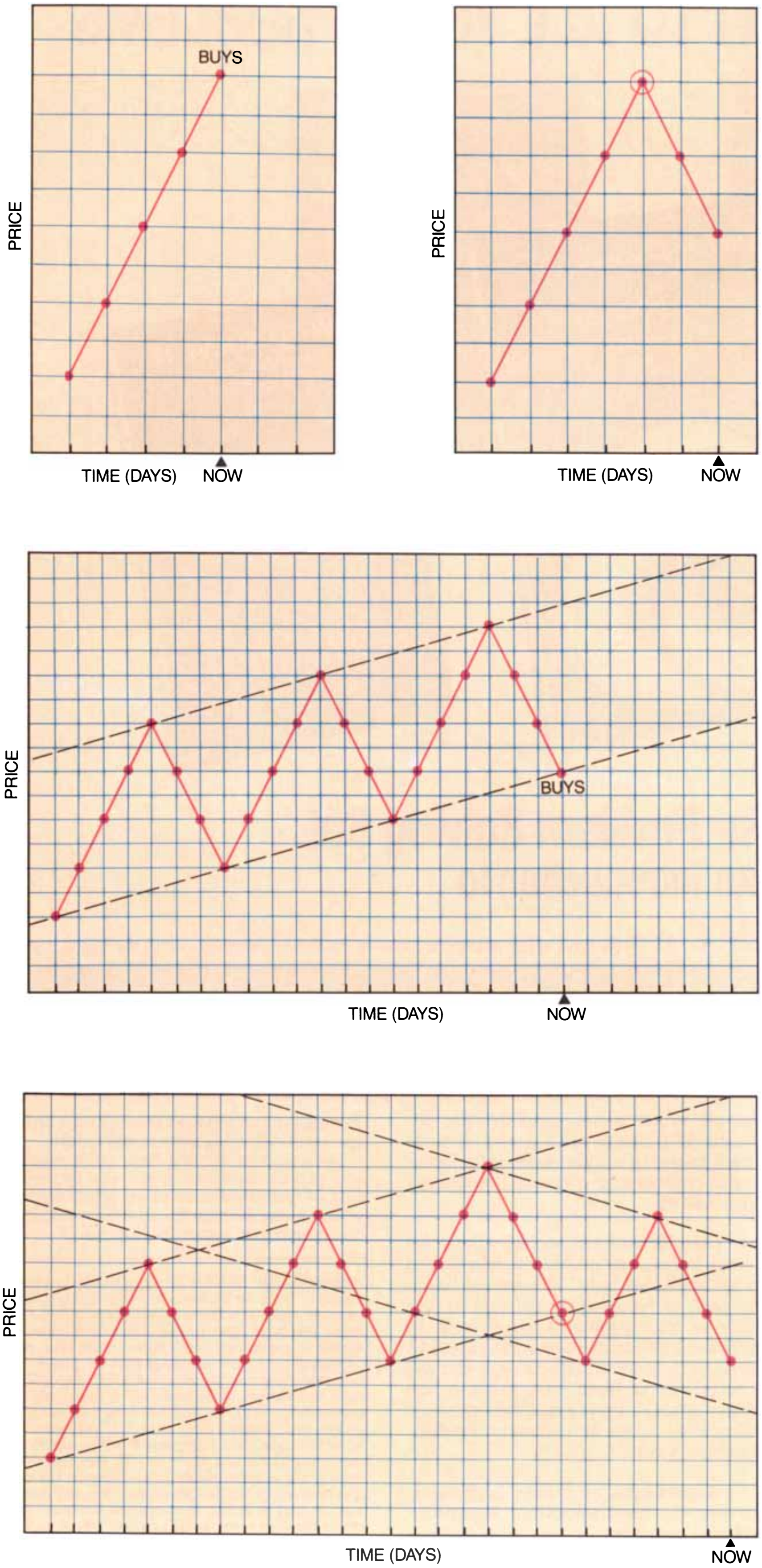

The dangers of technical trading in United Suspenders

begun? "History, my friend; it did the same thing last spring."

I have used the foregoing scenario—however unlikely it may be—to introduce the notions of trends and trading channels. There is much more than this to technical analysis. An examination of stock prices over a long period reveals price movements at nearly all levels of temporal magnification. Small movements are enclosed within larger ones, and so on ad infinitum. Stock prices have a near-fractal quality: similar structures exist at all scales of magnification.

Another tool of importance in the technician's kit is the moving average. If one plots not the day-by-day prices of a stock but a weekly or even monthly moving average, the short-term fluctuations are smoothed out [*see illustration on opposite page*]. As most readers can guess, the value of a moving average for a given day is computed by averaging the prices of a stock over the past *n* days, where *n* is the period of interest. The average has a built-in patience. If the stock bucks like a bronco about the same typical value, the average holds steady. If the stock rockets or plummets, the average moves more slowly, almost reluctantly, in the same direction. In returning to previous levels the price line may cross the moving average like a prodigal son coming home.

The moving average can be used to establish what technical analysts call a trading band. If the moving average is computed and then displaced upward and downward at the same time into two new curves, it may happen that the stock price vibrates for the most part within the curves. It is much easier to analyze the sedate curves that form the boundary of the band than it is to analyze the twitching prices within it. If a trend or a pattern is apparent in the band, the technical investor may feel compelled to exploit it. A trading band may also indicate when a stock is over- or underpriced; occasional excursions in the price of the stock above its band, for example, are taken by some as a sign that the stock is overbought: the price may soon drop.

The foregoing techniques and many others are described in a book called *The Dow Jones–Irwin Guide to Investment Software,* by Robert Schwabach. According to Schwabach, there are about 200 investment programs offered commercially to owners of microcomputers. The book describes the leading programs in both technical and fundamental analysis. It goes beyond these to describe programs for portfolio management, spreadsheets, even programs that in Schwabach's

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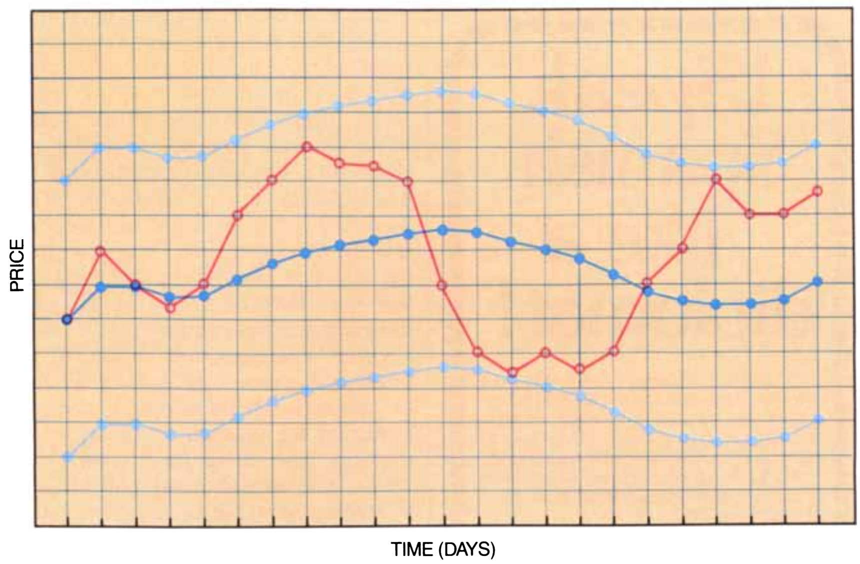
words allow one to "tap the motherlode": by means of a modem that connects the computer to a host machine, the analyst can acquire historical and even real-time, or current, stock-market data.

Without venturing to the brink of unheard-of riches or bankruptcy, the adventurous reader may write his or her own programs to taste technical analysis in its humbler flavors. First, however, one must acquire stock-price data to analyze. There are two sources of such data, one real and one imaginary. The inexpensive way to obtain real stock prices is to glean a record from daily stock quotations in the local newspaper. Ten stocks of interest can be recorded in 10 arrays that are part of a program I call TECHNIX. The arrays can be named after the stocks and should be dimensioned to a size that reflects the period over which one wishes to analyze them. For example, one might have arrays with names such as *ibm, itt, gm* and so on, all made large enough to hold 365 days' worth of data. A more expensive but quicker method involves subscribing to an information service that will make such data available if one dials in through a modem.

Artificial prices are both easy and inexpensive to generate. One can fill a 365-element array called *usp* (the stock symbol for United Suspenders) in seconds by invoking a certain fractal-pricing procedure. Readers may remember the "Computer Recreations" column about fractal mountains last December. The program I called MOUNTAIN draws the cross section of an imaginary mountain by repeatedly subdividing and displacing a single line segment. As a number of readers who tried the program were quick to point out, the program produces an entire range of mountains just as readily as it does a single one. Indeed, if the resulting outline is compressed laterally, the landscape takes on a decidedly financial character: it looks rather like the chart of an actively traded stock over the course of a year. There are ups, downs and occasional trends and channels.

If at least one array is loaded with real or artificial prices, TECHNIX will bring to bear a battery of simple tools for technical analysis. The simplest tool is the moving average. The following short algorithm will suffice:

```
input period
input day
for i = period to day
  sum ← 0
  for j = i − period to i
  sum ← sum + usp(j)
average ← sum/period
plot average
```



A 10-day rolling average defines a trading band

Here *period* refers to the number of consecutive days used in the averaging process and *day* refers to the current trading day given as the value of the index for the array *usp*.

The algorithm can be modified to plot trading bands by inserting a new variable called *band* into the program. *Band* must be given a value that reflects typical price movements of the stock being analyzed. If, for example, United Suspenders has fluctuated by no more than 4 percent of its value 90 percent of the time over the past few months, the user of TECHNIX will key in a value of 4 for *band* when the program is run. The algorithm given above is easily extended to plot the curves that make up the trading band. The upper curve is obtained by plotting the value $average + (band \cdot average) / 100$. The lower curve has the same formula with the plus sign replaced by a minus sign.

It is no more difficult to draw trading channels than it is to draw trading bands. If the analyst observes a linear trend in recent prices, he or she specifies a period of interest by entering values for *day*1 and *day*2 from the keyboard; *day*1 is the first day of the period and *day*2 is the last one. TECHNIX first establishes a trend line for the prices during the period of interest and then translates it up and down to find the trading channel.

A reasonable trend line may be found in a variety of ways. Perhaps the quickest and simplest method involves splitting the price data into two halves. Designate the number of the day halfway between *day*1 and *day*2 by *middle*. TECHNIX is written to compute two averages: the average share price from *day*1 to *middle* and the average price from *middle* to *day*2. Call the two averages *avp*1 and *avp*2. It remains only to find the numbers of the two days midway through their respective periods. These are obviously easy to compute. Call them *m*1 and *m*2. The trend line is defined as the line that passes through the points with coordinates (*m*1, *avp*1) and (*m*2, *avp*2). TECHNIX now increments the trend line until it lies on or above all prices in the segment of interest. The program decrements the trend line in an analogous way to find the lower boundary of the trading channel, often referred to—rather hopefully—as the line of support.

The y coordinate of the point on the trend line at the nth day of the period is given by the complicated-looking but essentially simple formula

$$y = (avp2 - avp1) \cdot (n - m1) / (m2 - m1) + avp1$$

The formula is simply the equation for a straight line, $y = m \cdot x + b$, where m (the slope) is equal to $(avp2 - avp1) / (m2 - m1)$, x is equal to $n - m1$ and b (the y intercept) is equal to $avp1$.

It would make an interesting experiment to evaluate the success of the technical approach in the context of the program TECHNIX. The process of detecting a trading channel could be automated, for example, by accepting any channel that has a thickness within some suitable fraction of its length, say one-fourth. Prices, whether from a fractal or a real source, would be fed to the experimental program one day

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at a time. As soon as a trading channel is detected the program would wait until the price touches or nearly touches one of the channel boundary lines. At the upper line the program would sell short and accumulate profits until the first change in direction of the price. At the lower line the program would buy stock and accumulate profit at the first downturn. Of course, having touched the boundary, the price line may keep on going. In that case the program loses money.

Other strategies can be employed, but they become increasingly difficult to quantify. If the simplest strategy, based on the essence of the technical method, fails to make a profit, why would one expect more complicated strategies to achieve anything but a slightly better result?

This raises the question of just how well technical methods work. According to Burton G. Malkiel, author of the popular book *A Random Walk Down Wall Street,* there is no way to predict stock-market prices that will consistently outperform the market index. In other words, one might do just as well as the average technical analyst by buying a wide portfolio of randomly selected stocks. If that is the case, the experiment described above ought to come out pretty much the same for fractal prices and real ones. I shall be grateful to readers who report such experiments for mention here.

Professor Malkiel looks somewhat more kindly on investors whose hearts are guided by fundamental concerns. How much debt, for instance, does United Suspenders have? How much does it earn per share? Is the price per share reasonable in relation to earnings? Is United Suspenders small with strong growth potential? *The Dow Jones–Irwin Guide* also has a section on commercially available programs that examine fundamentals and guide the investor through the rumblings of heavy financial machinery.

I am most fascinated by programs that might be implemented closest to the individual at the heart of the market: the stock specialist who determines the price of stocks under his supervision. The specialist is granted the potential of turning a profit in return for accepting the obligation of maintaining a fair and orderly market in the stocks for which he is responsible. The specialist has the opportunity of making money for his trading account by selling stock at a higher price (the asking price) than he buys it at (the bid price). He also makes money on occasion by buying the stock when he sees the price go up or shorting it when it goes down. The specialist stands to make a great deal of money and, in fairness, may also lose a lot.

In view of recent scandals involving insider trading, not to mention occasional grumbling over the specialist's role, it might be asked whether it is desirable to replace the specialist by a specially designed trading program. This immediately raises a second question: To what extent might a stock specialist be replaced by a program?

The answer is certainly "To some extent." At the Toronto Stock Exchange, for example, the world's most advanced computerized trading system is currently in operation. Known as CATS, short for Computer Assisted Trading System, it relieves some of the burden on the stock specialist by automatically filling smaller buy and sell orders entered at the current bid and asking prices. At the same time orders above and below these prices are also displayed. The latter represent buyers and sellers hoping for better prices in the direction they wish to trade. Using such information, any of the approved traders with access to one of the 300 CATS terminals across Canada can guess the direction that prices will take with some hope of success. The display of orders irked some of the Toronto specialists. Their order book, once private, was now half public.

How much of the stock specialist's role can be explicitly described and programmed? Not all of it, according to one former specialist with whom I recently spoke: "Sometimes you just have this hunch about which way the price will go." One wonders what degree of the specialist's knowledge is extractable by the form of interview surgery known as knowledge engineering. How much knowledge would be needed to write an expert system that trades quickly, reliably and fairly? Watch for the August issue, in which some expert opinions on this topic may be aired.

As this department continues to generate special-interest groups, the monthly addendum increasingly plays the role of a bulletin board. The first couple of announcements this month are for Core War fans. Readers who have sent for the "Core War Standards" document from Mark Clarkson, director of the International Core Wars Society, will have to be patient: a fire in the Clarkson home in January has caused a long delay in filling requests. Competitors continue to line up, however, for the second international Core War tournament, to be held in Boston this fall. Watch for details later.

The main item on this month's bulletin board is the announcement by

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Carter Bays, impresario of three-dimensional Life, that he expects to launch a newsletter within a few months. The February column featured two three-dimensional cellular-automaton games recently discovered and explored by Bays. Instead of the squares that live and die in the original two-dimensional game discovered by mathematician John Horton Conway, cubes live and die in Bays's three-dimensional space. Because Bays has received approximately 500 letters, he thinks a newsletter may be warranted. He hopes to publish quarterly and to include all observations of interest, whether made by him or by subscribers. Everyone who orders the 40-page document "The Game of Three-dimensional Life" will automatically receive an announcement when and if the newsletter is born. The Life document can be obtained by sending $3 to Bays at the Department of Computer Science, University of South Carolina, Columbia, S.C. 29208.

Bays continues to be on the lookout for successful three-dimensional analogues to Conway's game. Bays has recently found two criteria that seem to work well in distinguishing winners from losers. His first criterion is that a primordial soup must not grow without limit. In other words, if one starts with a random assortment of living cells, it should not tend to expand forever. His second criterion is that from time to time the primordial soups must spawn gliders: cyclic configurations of living cubes that wriggle their way across the screen.

One analogue in three dimensions was pointed out by Kerry Pearson of Nanaimo, British Columbia, who wrote Bays to tell him about a book called *Ox,* by Piers Anthony. In the book Anthony mentions a candidate for three-dimensional Life, which, following Bays's lean lexicon, is called Life 6777. In this version a living cubic cell will die in the next generation if it has fewer than six or more than seven living neighbors in the present generation. If a cube is dead, it will spring to life if it is currently surrounded by exactly seven living neighbors. Bays reports that he had already investigated this version of three-dimensional Life. He found it violates the first criterion.

Currently Bays has isolated just two candidates as worthy successors to Conway's game. (Those candidates, many readers will remember, are Life 4555 and Life 5766.) The great quest, as far as Bays is concerned, is the search for a glider gun in either of the three-dimensional versions. A glider gun would endlessly spew out gliders in one or more fixed directions.

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BOOKS

Spies in the sky, the continent made of ice, stones from heaven, life on other planets

by Philip Morrison

DEEP BLACK: SPACE ESPIONAGE AND NATIONAL SECURITY, by William E. Burrows. Random House, Inc. ($19.95).

Not even a black hole can manage to remain entirely invisible. In this volume full of satisfying and documented detail a responsible and savvy journalist has fitted together patches and fragments of published information and informed opinion to depict the nature of overhead reconnaissance today. The portfolio of relevant images he offers is capped by a sunlit orbital photograph of the first large Soviet aircraft carrier, under construction on the Black Sea, made by the video imagers of the satellite *Keyhole-11* in the summer of 1984. The view at 500 oblique miles is sharp and informative: it is the look of a shipyard seen from a light plane passing a mile or so away. We owe the image to the London editors of *Jane's;* the American naval analyst who unofficially supplied it to them has since been convicted and is awaiting judgment on appeal. The technical manual for that satellite had been sold earlier by a Central Intelligence Agency employee to Soviet intelligence for $3,000, a bargain price (although it is notorious that early editions of such manuals are often badly written).

Suite 4C-956, part of an Air Force province in the Pentagon, houses the headquarters of the National Reconnaissance Office (NRO), "responsible," since its formation in August, 1960, "for the design, development, and procurement of all U.S. reconnaissance satellites and for their management once in orbit." Its input includes dollars—up to five billion of them during 1985—and policy guidance from a couple of boards; the director of the CIA is also a prominent influence. The U.S.A.F. and the CIA share this high task somewhat uneasily, troubled by memories of "all-out tribal warfare" in the distant past: targeting and analysis are no easy mirrorfellows, particularly when information confers more power than a handful of Cayman bankbooks.

The NRO is to be found again at the Big Blue Cube in Sunnyvale, Calif., from which all U.S. military satellites are controlled, and also in El Segundo, where not the Red Army but the contractors are monitored. The chief systems contractors to the NRO are Lockheed and TRW; they head a long parade of other high-technology firms.

The NRO is a little short of assets these days, "blind in one eye" after the *Challenger* disaster and two other launch failures. Its single deployed *Keyhole-11,* the sixth of its design, has been working overtime. Usually there have been a pair in low polar orbit overflying everywhere, one in the morning, one in the afternoon. This *KH-11* was launched in December of 1984; on the record such a craft serves for 1,000 or 1,200 days. Its two-meter mirror and infrared scanner feed a package of sensors, in particular a CCD (charge-coupled device) mosaic of high resolution, as well as an array of special-purpose detectors including a photomultiplier for night views. The satellite propagates its digitized data by relay satellites to Fort Belvoir, and there the downlink is completed.

The admirable images are seen in "real time." Within an hour of their capture they are available by courtesy in the Oval Office. Less honored images are interpreted in a variety of places; each user seems to prefer its own eyes, or programs. Nowadays the images are enhanced, transformed and even routinely monitored by computer. The machines can detect changes and report them. Stereo views are made and multiband analyses can be run. The National Photographic Interpretation Center, a windowless beige warehouse on M Street S.E. with plenty of air conditioning, was once the seat of the unified eagle-eyed watchers of Cuban-crisis days but now is probably a lending library of digital images pored over by cool, sedulous Crays.

KH-11, the fifth generation in its lineage, is formidable. Its resolution must be about two to four inches, not quite good enough to read license plates. Its datalink bandwidth matches the quality of the films so daringly dropped from orbit by *KH-4* in 1962.

What of *KH-12?* A Lockheed design, it was tightly integrated with the shuttle for launch and resupply. It is a heavy platform, 20 tons when full. It has plenty of its own fuel, hydrazine, for wide maneuverability. Four satellites are intended to serve at the same time, two for night and two for day. The sensors will be improved, as usual, and there is a grandiose plan to deliver real-time images to commanders in the field. Tactical imagery will flow along a chain of seven *Milstar* relay satellites, hardened, encrypted, jamproofed and highly maneuverable, not only to Washington but also "straight off the bird" to the theater staff. When costs rise, you broaden the market.

Soviet orbiters bring film back by returning to the earth; such craft are relatives of the manned *Soyuz.* The Soviets launch one such vehicle routinely every couple of weeks, and when events suggest it, one every few days. Their style is that of the assembly line: each device delivers relatively low performance, but each is simpler, less expensive, adaptable and quickly replaced. The impression is that since 1984 the craft have also been able to transmit digital images in real time. The most impressive Soviet satellites are aimed at the blue-water U.S. Navy. These include radar satellites powered by small nuclear reactors—one fell on Canada years ago—and paired passive trackers of radar and radio from the fleet. These are fitted with ion microthrusters to allow minute control of orbit altitude, so that a target's shifting position can be triangulated.

There are air breathers in plenty overhead. The stealthy "blackbirds" of Beale Air Force Base in California, Lockheed SR-71 aircraft, fly everywhere, staging in Okinawa and England. They are no strangers to Nicaraguan seaports at low altitude. In more developed regions of the world their cameras, side-looking radar and electronic monitors move at Mach 3+ 100,000 feet up. They are only first within a large and complex system. The narrative of overhead reconnaissance from aircraft is the topic of almost half of the text. The crises entrained by the downings of U-2's over Sverdlovsk and Cuba and the involvement of an RC-135 flying toward Sakhalin in the tragedy of a Korean Air Lines 747 are recounted. Those Tupolev four-engine Bears photographed seasonally off the East Coast bound for Cuba are the visible Soviet counterparts. The text treats undersea information gathering briefly but well.

This is an up-to-date, thoughtful,

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nontechnical, factual study of a topic that lies behind much of the news. Although the actions in this arena are hostile, even warlike, they continue by tacit consent. This state of affairs may even hold the promise of a world where armed forces can also be reliably reduced by consent. The new French commercial system, SPOT, offers pictures with a resolution of 10 meters in black and white, and multiband images as well. Their CCD's blur the boundary between civil and military observation from space; they may help to keep the NRO, SAC and the others "honest." A SPOT photograph reproduced here clearly shows the Semipalatinsk nuclear test site in the summer of 1986; it has lain fallow for almost two years, although tunnels are being readied. The world is open enough; we can see what we need to see. "To cast doubt on the process itself by falsely labeling national technical means of verification as inadequate is to subvert reason to the basest political posturing." In orbit, war and peace fly together. The carrying of physical conflict into space is a danger just ahead.

THE ICE: A JOURNEY TO ANTARCTICA, by Stephen J. Pyne. University of Iowa Press ($37.50).

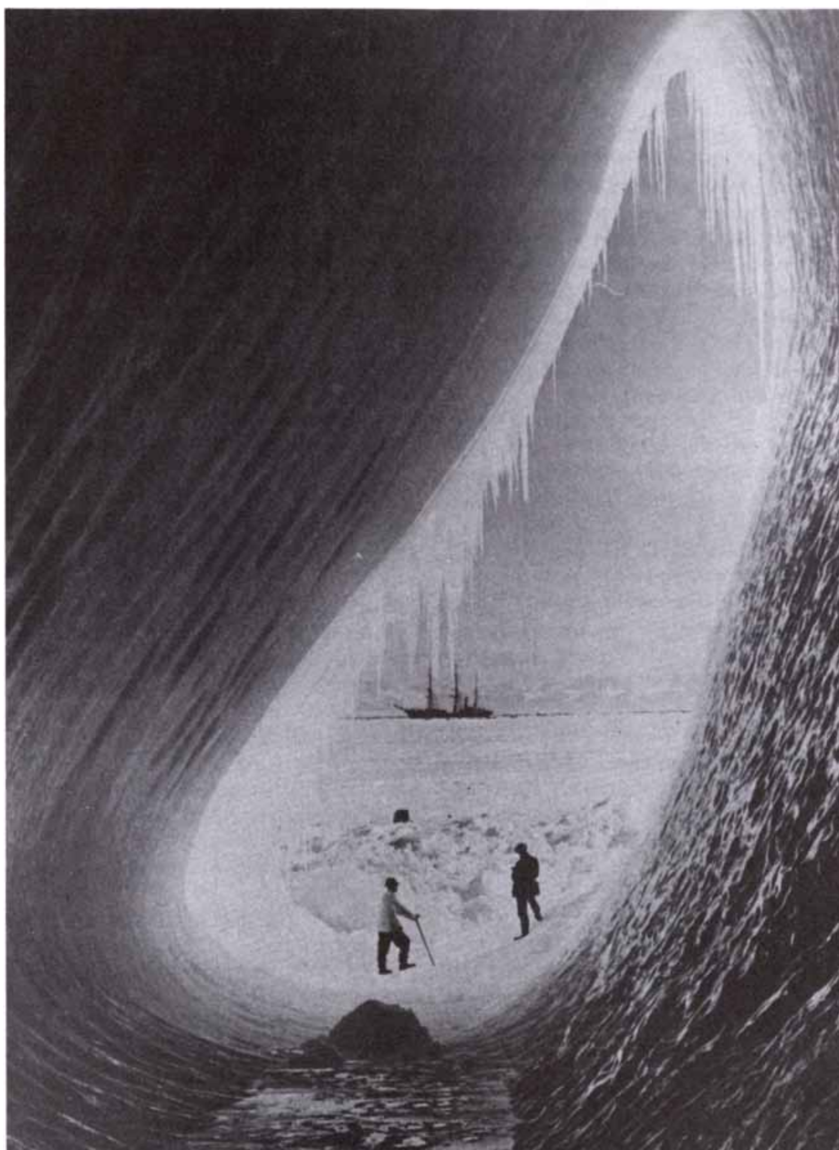
A Greenland audience watches a film of the Antarctic: "'What my audience...had seen...was as strange to them as the expression I had seen [in] their eyes.... They had seen only a cold desert, beautiful but barren.... no vegetation there; no gnats, mosquitoes, mice or hares; no musk-oxen, reindeer, caribou or polar bears. It was a weird world...desolate and pure—quite unlike their living, breathing, hunting territory.'"

The judgment of the hunters is expected, understandable and profound. This sophisticated book is an extended essay nucleated by the same chilling purity the Greenland hunters felt. Out of the simplicity of The Ice, out of its reductionism and its inertness, out of its minimalist aesthetics and its elemental geography, out of its political metastability and its high philosophical reflectivity, the author, a historian of ideas at Arizona State University–West, has constructed this most unusual book. It is an alloy of physics and metaphysics, of criticism and glaciology. Its tight focus on a diversity of interests and its charged, even lyrical prose make it both demanding and rewarding.

Stephen Pyne spent a season traveling widely on The Ice with the Antarctic Research Program of the National Science Foundation as a fellow of the National Endowment for the Humanities. What he experienced there informs the writing, and he has since made himself master of what we know about that ice as matter, form, process and goal. The chapters of the book are layered. Sustained, rather elevated pieces of exposition, without mathematics and with very few (although telling) maps and diagrams, they carefully describe the circumstances of the six terranes—regimes—of The Ice, from the icebergs that are its isolated and distant envoys to the trackless dome that is its central source. Between those accounts there are warmer chapters of narrative history and intellectual assessment that survey one by one the explorations, the literature, the art, the earth sciences and the politics of a continent that is simultaneously unearthly and central.

The chapter on icebergs is prelude, as at sea the tabular berg in the dust-jacket photograph was itself prelude to the continent from which it came. The mobile sea, filled with life, and the floating visitor from the land of ice are in powerful contrast. The story develops vividly, describing the pack itself, the collectivity of bergs in all their sizes, whose congealed boundary "marks the limits of life on Earth." Blue and green ice color the scene. Jade green ice is not well understood; there are yellowing proteins and the fabric may come from pure ice that is squeezed bubble-free in the shear zones of sliding glaciers. The full circumpolar ocean current has been unimpeded in flow for about the past 30 million years; its frontier has expanded northward since then, although the current has stayed stable in form.

The history of the exploration that



Scott's ship **Terra Nova,** *seen from an ice cave in a photograph made by Herbert Ponting*

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led to the discovery of The Ice invites periodization. The First Age of Discovery was the maritime legacy of the European Renaissance. The continents were rather in the way; the sea connected the maritime peoples of the world. The Europeans led by Columbus and Magellan were only the widest-ranging of voyagers. Captain Cook's gingerly circumnavigation at the edge of the pack was one of the final scenes of Act 1, performed in the style of the Enlightenment.

Act 2 was Romantic. Now it was interior lands that were visited in detail, their complex natural history the fascination, wide extension of both mind and rule the aim. No 15th-century explorer would have struggled for the North Pole; what they wanted was ice-free passage. Antarctic exploration was late and anomalous; it came out of the realization by the powers that all the other continents had been explored and divided.

The Third Age of Discovery began, Pyne believes, with the International Geophysical Year. That opened the epoch of global remote sensing, of voyages to the sea bottom and to space where no one has ever lived—the epoch of modernism: "a chance universe; the relativity of time, space, and perspective; the blurring of the observer with the observed; the delight in abstract, minimalist art.... Modernism and The Ice were perfect complements." The maps of Antarctica are white on white, like some modern paintings.

But the art that has come from there has not been modernist at all. The painters who went along with the explorers of the heroic decade of Scott and Shackleton were not yet moderns. Today "few artists ask to go." The photographers have mixed the old and the new. One important photographer brought perspectives into his images to force the scene into a more contrasty and representational tradition, selecting masts, instruments, vehicles and their tracks to deck the pure icescape. One exception (by Eliot Porter) is reproduced, a linear picture of "stunning emptiness"; another (by Emil Schulthess) is a remarkable fish-eye look down at the Pole itself, marked with signposts. It is aerial photographs and satellite images that have artlessly created true modernist landscapes. "No modernist or postmodernist could match The Ice for coolness." (Only a footnote tells us of recent plans to promote and exhibit modern works of art about Antarctica.)

The review of the history of the earth sciences adds quite fresh comment to a familiar narrative. Plate tectonics served to unite the strange continent with the world as a whole; in that sense it made the continent more normal. Yet meaning had to come into and not out of the ice. The Ice is a reflector of thought as much as it is of radiation. One theme of the book is that The Ice is mainly to be seen as a great distorted mirror. "Only a civilization rich in energy and intellectual activity can enter the site and emerge with a residue of information.... The properties of the mirror may be studied, but the outcome is ultimately a better understanding of the civilization that gazes into it."

The Ice is reductionist; there everything is simplified. The one substance is water; it is in one state, snow; its crystalline diversity is compacted by one force, gravity, into a lithosphere of one mineral, ice. The sciences are few. The most famous mineralogical finds of the continent (bar an important fossil and a lump or two of coal) are a few hundred meteorites. They are certainly extraterrestrial gifts of The Ice. It preserves the rather perishable chondrites a couple of hundred times longer than do other landscapes where they fall, and it obligingly concentrates them in conspicuous meteorite deposits for alert and lucky mountain prospectors. Even the politics is simple: a cold peace across a common territory, whose resources so far are mostly informational.

The last section about the central plateau, a vast dome shaped almost solely by the flow of ice, is brief but splendidly evocative. The precipitation of submillimeter ice crystals in clear air happens there, sometimes even by spontaneous nucleation at temperatures below −40 degrees Celsius. At Dome Summit it snows aggregated crystals of ice for only a month out of the year. Almost 90 percent of the annual deposition is of that strange "diamond dust." Diamond dust occurs widely in all cold regions of the world, a mere background of precipitation overwhelmed by other processes. On the high and dry dome "those higher-order processes have been eliminated. Diamond dust becomes prominent by virtue of the relentless reductionism—the erasure of alternative processes—that is the essence of The Ice."

COSMIC DEBRIS: METEORITES IN HISTORY, by John G. Burke. University of California Press ($45).

Thomas Jefferson was out of patience with New Englanders by the end of 1807; those contentious merchants were grumbling about secession and smuggled apace to get around his recent Embargo Act. And so he might well have said he would rather believe that two Yankee professors would lie than that stones should fall from heaven. But the famous remark is not verifiable; it was ascribed by a biographer to the president after his death, and no manuscript supports it. That he was skeptical in the Enlightenment fashion is clear, but his letters of the time suggest ambivalence about stones from heaven. Chondrites by the hundreds of pounds had indeed just fallen "in the County of Fairfield" near Weston, Conn. The first analysts were two Yale professors; the senior author at least, the savant Benjamin Silliman, was a true Yankee who was born and who died in the Nutmeg State.

Professor Burke is a veteran historian at the University of California at Los Angeles who has already written one careful study in the history of crystallography. He has turned his talents and training for some years now to the history of meteoritics, a science defined not by a discipline but by one many-sided problem: the nature and origins of those alien chunks of matter that fall toward the earth as shooting stars, fireballs and meteorites. The volume is lively and varied, as is the subject matter: folklore, archaeology, astronomy, chemistry, physics, the growth of a market for collectors and even the current concerns that small meteorites might have brought life and that large enough ones might end it. Every book on meteors includes a chapter on the history of how we came to know; an entire volume in this documented and cheerfully probing style is a pleasure.

The book is broadly chronological, starting with Aristotle and ending with iridium at the K/T (Cretaceous-Tertiary) boundary. A chapter on the myth, folklore and utility of meteors across time is included. In spite of interesting bits, the chapter becomes a patchwork of accounts and sources. That the holy relic, a polished black stone, in the wall of the Ka'ba is a meteor is now doubtful. Is it an agate or a piece of impactite glass from the desert crater at Wabar? Is it a very heavy stone? Perhaps it floats. Meteorites are found ceremonially wrapped and buried in quite a few North American sites, and meteoric iron has been included in many examples of royal and splendid blades and ornaments. The forgeability of meteoric iron is demonstrably variable; some are irons malleable when they are cold, others refractory even when they are hot.

A clear connection between folk observations of the fall of thunderbolts and Enlightenment skepticism delayed the recognition of meteors as E.T.'s until the end of the 18th century. If the bolt strikes in the fields, the farmhands or the shepherds who have seen it seek it out, often with M'sieu or

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Padrone. If they find something lying there that is new in their experience, it will be associated with the strike. Those authentic finds—but of what?—will induce other correlations with similar objects found but not seen to fall. Thus the European collectors and museums stored plenty of polished stone axes, bright pyrite crystals and fossil sea urchins, all held without any fraud as true thunderstones.

Michele Mercati, head of the botanical garden at the Vatican, a famous naturalist of the 17th century, is credited with the recognition that worked stone implements were made not by lightning but by human hands. When his posthumous work appeared in 1717, other questions grew, fed by hints from Edmund Halley himself. Still the Newtonian view prevailed that space had to be empty (only a suitably ineffable ether was acceptable) to avoid the damping of orbital motions.

Burke makes a fine case for the fact that the scientific acceptance of stones that fall from heaven, which came about in one decade, was much assisted by the chance that half a dozen falls in western Europe and one in India were well witnessed. Ernst F. F. Chladni's book of 1794, the first to take the present-day cosmic-origin view, was the beginning; he had a number of falls to cite. Jean-Baptiste Biot's famous study of the fall of thousands of fragments on a Normandy village gave the coup de grace to disbelievers in 1803. Easy cases make good law; noisy signals are full of error. Poor Chladni is an interesting figure; he never got tenure, but he made a living by lecturing throughout Europe on acoustics, his famous vibrating-plate patterns the hit of the performance, as were meteors later on.

It was nearly mid-century before the cosmic as distinct from celestial origin of meteorites was accepted. Maybe they came from lunar volcanoes, or were made somehow in the rarefied air, or dropped from fireballs that were earth-orbiting comets. There is a touch of truth in all those theories. Chladni had proposed measuring the orbits of shooting stars by triangulation. It was tried by students of Georg C. Lichtenberg at Göttingen; too hard. Another clarion signal came by chance from the incredible meteor shower of 1833 over eastern North America. Stars fell on Alabama and everywhere else between Kansas and the mid-Atlantic. They radiated like fireworks, a few each second, from a point "within the bend of the sickle" of Leo that moved over the hours with the stars; clearly, they were extraterrestrial. Another Yale professor, Denison Olmstead, made the study and drew the conclusion, somewhat confused by a triangulation that was too crude. Over the next decade periodic shooting stars were watched almost as "a sacred duty" even without the stimulus of a great shower. Their cosmic source was widely confirmed, and orbits were assigned.

The fireball was always a puzzle; good observers said the objects appeared to be as large as the moon and estimated their diameters in miles. How could such bodies be assimilated as intermediate cases between mere shooting stars and actual falls of small rocks? In 1848 James Joule himself showed that a six-inch cube of rock traveling at orbital speed would make a huge amount of heat and light if it entered the atmosphere. The physics was becoming plausible. Fireball sizes were merely an attribute of the eye: bright sources at night seem large. In 1854 J. Lawrence Smith of the Smithsonian experimented with carbon arcs and red-hot slivers of steel; the observers saw them all as big moon-size balls of fire at a quarter of a mile.

The discussion sounds two echoes. It was Kepler and his contemporaries who measured the size of the stars by eye, at almost a minute of arc; clearly a star could not be a sunlike luminary standing off at a proper Copernican distance. The telescope ended that difficulty. Fireballs do not wait for the right instruments. It was Karl Jansky who began radio astronomy by finding that the direction of his source of 15-meter static moved with the stars—and not the sun—in the course of a year. The source was the galactic center.

The maps of Meteor Crater and of the felling of trees in the Tunguska event are both shown, valuable period pieces. Today's meteoritic world is not slighted: there are good accounts of the struggle to determine the time of formation, the time in orbit and the time on the earth. The discriminating textural and chemical classification of our day is tabulated; it sorts 2,600 meteorites into some 30 classes—and a few puzzles. Craters are treated, although little is said of flight and fireball physics.

Clearly the entire domain is growing; it must consider matter from dust grains to asteroids—all moving in orbits, chaotic or stable, that range across our system from the sun out to big Jupiter. This vivid history is substantial enough to be a highroad into the subject for any serious general reader; it chronicles a paradigm of how we learn to unify rare experience.

To Utopia and Back: The Search for Life in the Solar System, by Norman H. Horowitz. W. H. Freeman and Company ($17.95; paperbound, $11.95).

A distinguished biochemical geneticist at Caltech and imaginative theorist of life's origin, Norman Horowitz was invited in 1958 to "assist in planning a search for life on the planet Mars." He writes: "You accept—who could resist?" Horowitz served as chief of the biosciences section at the Jet Propulsion Laboratory throughout the six missions J.P.L. spacecraft conducted on and around Mars between 1965 and 1976. Life was not found, and in that deeply felt sense the missions were a failure. In other equally important ways "they were a dazzling success." Horowitz lays out in his clear, hardheaded and nontechnical book what the search for unknown life entails, the early allure of Mars, the dominance of its dry, red desert, the wonderful instruments built for the search and the force of the findings.

The opening chapter approaches the problem of definition. What is life, that we may search for it? The genetic definition has won out: life must be self-replicating and mutable. Its replication makes possible the slow realizing of its potential for inordinate elaboration. The life we know is unitary in its chemical basis, both for the genetic code and for the enzymatic and mechanical structures of life. Carbon is its backbone, the four directed bonds supporting an entire architecture of compounds. Although unstable under the conditions of the earth (or Mars), the compounds are long-lasting.

Silicon is a four-valent rival, and it makes the mineral kingdom as carbon makes the kingdom of life. Silicon-silicon bonds are weak, silicon-oxygen bonds strong. There are no long silicon chains in rocks. The silanes, analogues to hydrocarbon chains, are unhappy on the earth; they ignite in air and decompose in water. "The first prerequisite for a chemist aspiring to synthesize higher silanes is said to be a great deal of courage." If chance is involved, abundance helps, and atoms such as vanadium or germanium seem hopeless. Once we have found many forms of carbon-based life it will be time to seek the rare exotics.

In the same crisp style the next two chapters examine the three long-proposed theories of origin: spontaneous generation from nonliving matter (adorned by a delightful long citation from old Francesco Redi); cosmic transmission, by chance or by design, from life elsewhere, and chemical evolution, in which the gap between the dead and the quick is bridged by a sequence of molecular stages. Complex carbon compounds abound in interstellar space and are even commoner

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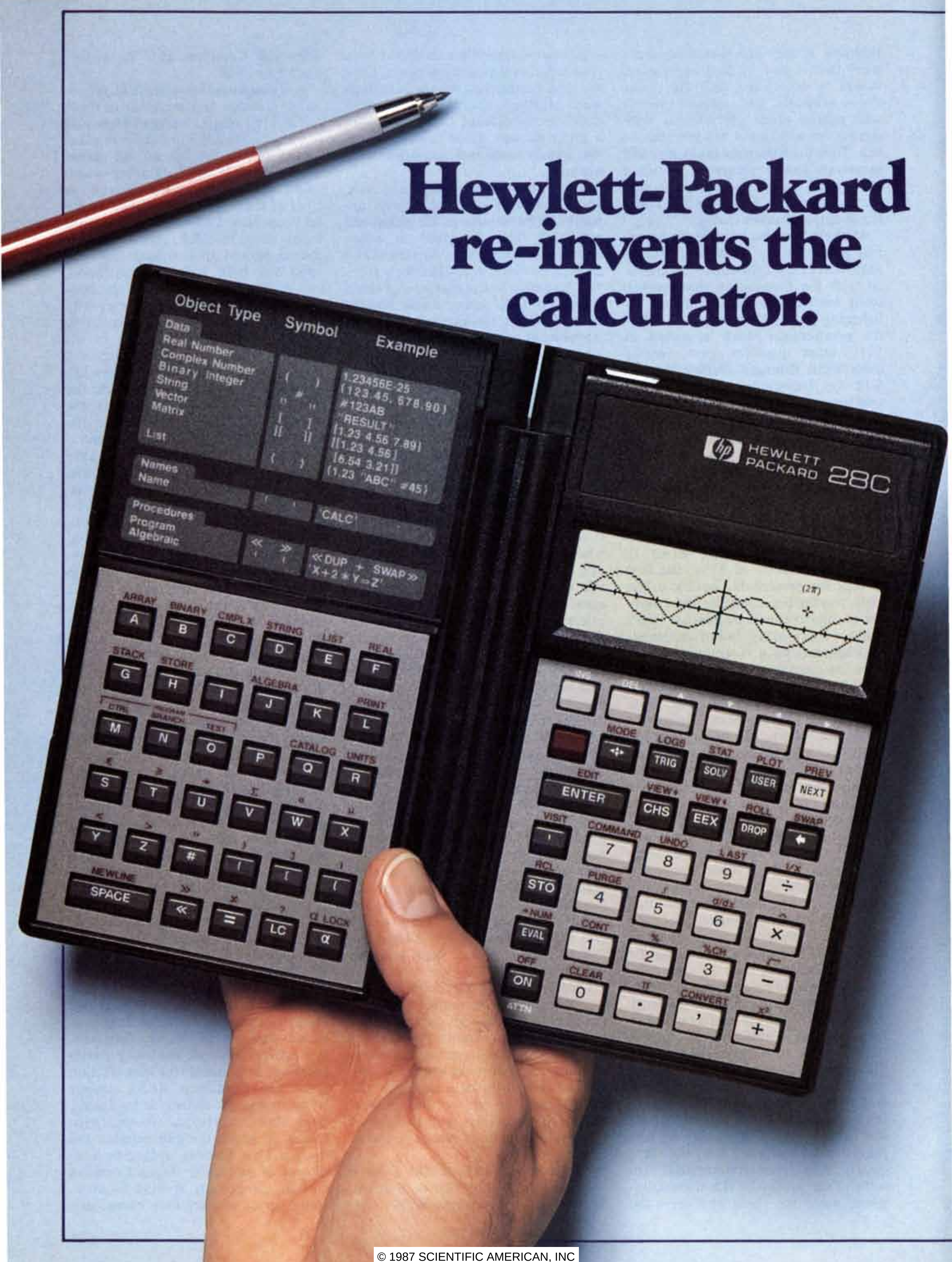

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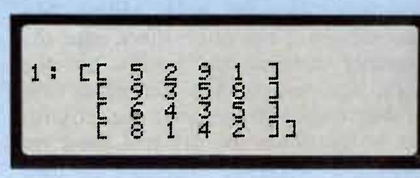

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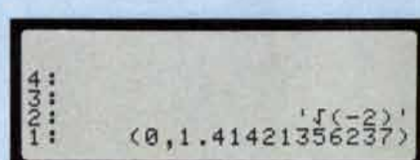

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on cool bodies of the solar system. Organics are of cosmic range. The biopolymers we need do not come so simply. Nucleic acid chains have been shown to be able to copy themselves, to replicate if supplied with monomers and a source of energy, not necessarily enzymatic. Very recently the nucleic acid RNA has been shown to be capable of catalysis, raising hopes that the two polymer classes of life, nucleic acid templates and protein tools, might be reduced to one for a start.

Where should we look? The life basis we know seems to have so few competitors that the outlandish is again hardly worth early pursuit. Therefore candidate worlds should offer abundant water (which is much more than a superb solvent for biochemistry), sunlight, a gaseous atmosphere and a temperature not too far from the range of liquidity of water. (Ammonia might do as a solvent-habitat but we do not know its biochemistry.)

Venus, enveloped in clouds of acid, is a high-pressure, waterless oven. The giant fluid planets do form organics, but those cannot endure for long, and the free-hydrogen excess is no help. Organics may abound on Titan in the dense carbonaceous smog, but it is so cold that life would have to arise slowly. If the process took half a billion years on the earth, Titan may have run out of time. The papers tell us that in ocean deeps life exists that is independent of sunlight, fed by the hot volcanic solutions that emerge from the rifts of the sea floor. The statement is not true; it rests on the neglect of oxygen, the indispensable co-fuel we think of as free. It is sun-fed photosynthesis on the surface that supplies the oxygen essential to the life of the rift. Volcanism furnishes only hydrogen sulfide and carbon dioxide.

Mars was the place. Percival Lowell had seen wonders there, and even those who doubted his canals and oases were impressed by the changing polar ice caps and the seasonal color variations of the planet. The pressure of the atmosphere was mismeasured several times; it seemed more earthlike than it is. Post-Lowell Mars began with new pressures determined in 1963. The Mariners did the rest; they disclosed Mars as a cratered and channeled landscape, without appreciable water, liquid or frozen, but with signs of erosion (perhaps underground) in the past.

Pindar wrote that "water is the best thing of all." Unfortunately Mars does not have it. A thin ground frost of water ice was seen by the Viking spacecraft. On the earth only the Antarctic rivals the drought of Mars, and the best-adapted desert beings we know, the lichens that can survive on water vapor, have not colonized all the ice-free dry valleys of Antarctica, where winds have blown dry the sparse snow and meltwater for millenniums. Microbial life is common there near the summer streams and ponds, but the high, dry regions are almost devoid of bacterial life; organic compounds are absent from the dry soil. And yet those localities are "very wet by Martian standards."

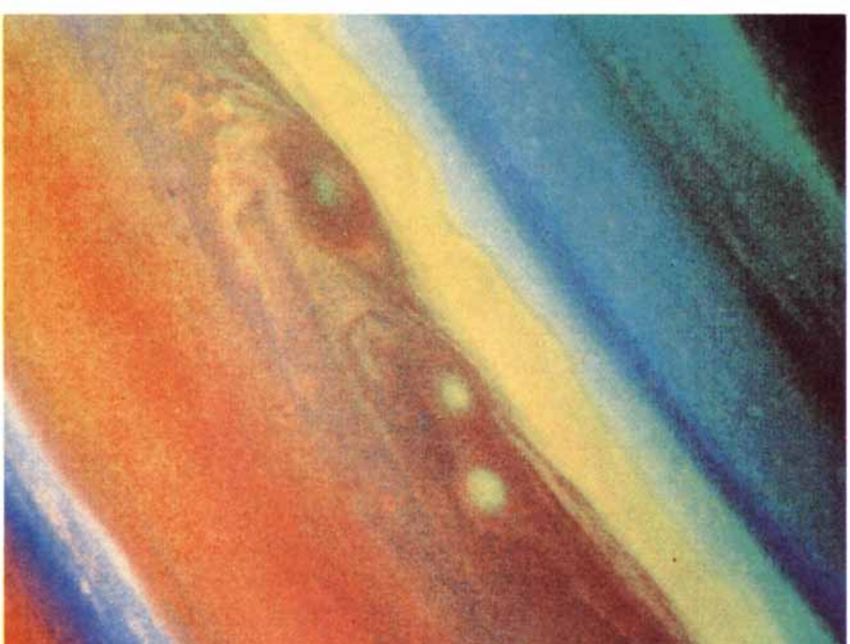
That was the daunting picture even before the Vikings: Mars was too cold, its air too thin, its soil too dry. But life is wonderfully adaptive; there was hope. Three distinct probes for microbial life went along in each spacecraft, in a costly boxful of intricacy and superb workmanship. They gave strange signals, but they were not designed for what was in fact found on Mars.

The cameras looked hard but saw no signs of macroscopic life. The most important biological experiment on the Vikings was not in fact a life-detecting device but an extremely sensitive gas chromatograph–mass spectrometer. It could detect complicated organics down to parts per billion in soil samples. It found nothing. Not only is Mars arid, cold and irradiated beyond any place on the earth but also its chemistry makes it self-sterilizing. The soil destroys organic compounds.

It took a few years, but by now the signals can all be rationalized. The two sites behaved alike; the atmosphere and wind-driven dust make the planet uniform. Solar ultraviolet radiation splits the sparse water vapor into reactive radicals, H and OH. It is OH that reddens Mars, by oxidizing the iron of the soil. It is OH that forms the peroxides on the soil grains to give just the varied chemical signals in the three probes that no life form easily explains. A little water is a dangerous thing.

Life on the earth is probably all the life that exists in the system of the sun. We have come back from Utopia (the formal old name of one Viking landing site). Thus our author forcefully argues. His arguments are tight and yet they rest on experience, so that they leave a little play. Perhaps Mars had a watery past; perhaps on the earth there was life before nucleic acid, its slower, sketchier replication consisting of patterns on a surface of clay.

I am something of a Utopian still, if admittedly a sobered and patient one. The flame and the crystal are not so remote in kind from replicating molecular life; the profound difference they show is quantitative, something like the relation between birdsong and speech. The modern genetic realization of life, based on one or two classes of thready biopolymers, may not be unique. The elegant apparatus of the ribosomes is today universal, but it hardly appears to have been a primitive invention of RNA. The far-flung stars may one day tell an unexpected tale by radio; the next voyage to Mars might seek not life in being but life long past, not metabolism but micropaleontology.



A **Voyager** *view of atmospheric storms on inhospitable Saturn*

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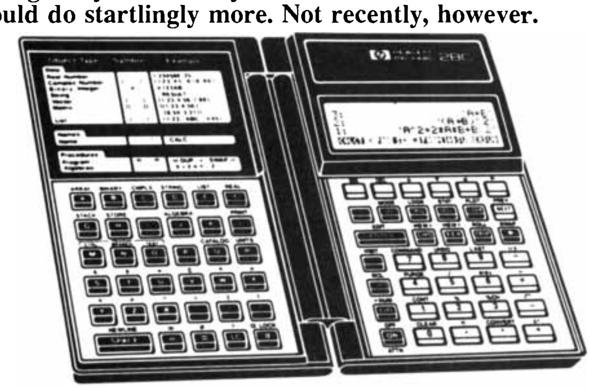
The UnExpected HP-28C— is this your next calculator?

HEWLETT PACKARD

A first report:

If you're at all like me, this is what you've been holding your breath for (in the calculator direction, of course). Just a few years back, calculators were exciting. Maybe once a year there was a new model that could do startlingly more. Not recently, however.



For a color picture, see HP ad in this issue, pgs. 26 & 27.

Now here's the next tantalizing toy and technical tool. I haven't got room here to do it justice, there are so many interesting features and specs for it. I'll sketch it for you, though . . .

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A Surge in Inequality

International competition and the feminization of poverty are distorting the distribution of income. The remedy may be an aggressive investment in education and technology

by Lester C. Thurow

Since the late 1970's a significant and disturbing shift has been taking place in the distribution of income and wealth in the U.S. The shares of total income going to different segments of the population have changed in such a way that the rich are getting richer, the poor are increasing in number and the middle class has trouble holding its own. The trend can be described as a surge toward inequality.

According to the U.S. Bureau of the Census, the share of total income that went to the top 20 percent of all families was 43.5 percent in 1985, the highest level recorded since the data were first collected in 1947. (In earlier periods the income share of this group had moved narrowly between 40.5 and 41.5 percent of total income.) Conversely, the income share of the bottom 60 percent of the population in 1985 was 32.4 percent, the lowest level ever recorded. (This group's share was slightly less than 36 percent in the late 1960's.)

If one looks at the data of the Federal Reserve board on income distribution, the movement toward inequality is seen to be even more pronounced. The board's set of data includes items not counted in the Census Bureau's definitions of income; among them are returns on wealth such as capital gains and retained earnings. Between 1969 and 1982 the people in the top 10 percent of the population raised their income share according to this set of data from 29 to 33 percent of total income, those between the 60th and 90th percentiles held even at 39 percent and the bottom 60 percent saw their share fall from 32 to 28 percent.

Federal Reserve board figures also show that wealth is much more unequally distributed than income. The top 2 percent of the population receive 14 percent of total income and have 28 percent of total net worth. Similarly, the top 10 percent's share of income (33 percent) almost doubles to a 57 percent share of net worth. In contrast, the bottom 50 percent of the population have 4.5 percent of total net worth. About half of the country's top wealth holders got there by inheriting their holdings and half through their own efforts. In the top wealth group 98 percent are white.

Wherever one looks—industries, occupations, age groups—the surge toward inequality is evident. From 1976 through 1985 the number of middle-income male jobs (defined here as those paying from 75 to 125 percent of median male earnings, or from $13,334 to $22,224 in 1985) declined from 23.4 to 20.3 percent of the male work force. The decline was even larger (from 38 to 32.6 percent) for males who worked full time all year. In a period when total male employment was growing by 7.4 million jobs, 400,000 middle-income male jobs were disappearing; there were small gains in jobs in the upper segments and large gains in the lower segments of the earnings distribution.

The forces underlying the distribution of income and wealth can be understood best if they are arranged in sequence. The sequence starts with the growth in output per hour of work. Productivity and hours of work, taken together, determine how much extra output is available to be divided among the economically active members of the population. This output is then divided into two separate income flows: earnings (returns on work effort and skills) and capital income (returns on the ownership of physical plant and equipment). The separate income flows are then further divided among individual earners and individual capitalists. Government takes off a share in the form of payroll taxes and corporate income taxes.

Since the same person can be both an earner and a capitalist, earnings and capital income must then be recombined to determine total individual incomes. Those incomes must be further combined into household units to determine the distribution of the ability to buy goods and services. Government takes a share of household income in the form of personal income taxes but returns part of its total tax collections to those same households in the form of social-welfare benefits such as Social Security checks. What remains is the disposable income that can be used to buy consumer goods or to augment one's wealth.

One can follow this sequential chain along its length to see exactly where greater inequality is entering the sequence. The pressures toward inequality begin with the growth of output. The rate of growth of the country's gross national product has essentially halved in the past two decades, from 3.8 percent per year in the decade 1960 through 1969 to 2 percent per year in 1979–85. With output growing much more slowly and the economy operating with much more excess capacity, competition for the smaller additions to output was bound to intensify. For

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ECONOMIC SHIFT from well-paid manufacturing jobs to service jobs that usually pay less is caused to a major extent by two factors. The first is the closing of heavy-industry facilities such as the U.S. Steel Corporation's National Works at McKeesport, Pa. (*top*), because of intense international competition. The second factor is the rapid growth of service businesses such as those that occupy the Lenox Square Shopping Center in Atlanta (*bottom*). The move to low-wage jobs tends to shift distribution of income.

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example, some people who had been fully employed at good jobs would be pushed out of the labor market or squeezed down into more marginal economic positions. Indeed, unemployment has averaged 8.1 percent in the 1980's compared with 4.8 percent in the 1960's.

When one looks to see exactly who has been squeezed, the result is somewhat surprising. From 1976 through 1985 male incomes (after correcting for inflation) have fallen 8.4 percent and female incomes have risen 6.9 percent. Male incomes are still far above female incomes (median earnings of $24,999 versus $16,252 for full-time, year-round workers). Faster income gains by women are not what is closing the gap, however; in fact, their rate of increase is actually slower than it has been in the past. Instead the reason for the closing of the gap is reductions in male incomes. The most entrenched workers have lost the most.

The proximate cause of the slowdown in the growth of output is easy to find: the rate of growth of productivity declined by a factor of three, from 2.7 percent per year between 1960 and 1970 to .9 percent between 1979 and 1985. The ultimate causes of this slowdown in productivity are harder to find, somewhat mysterious and a subject of controversy among economists. What is clear is that the slowdown cannot simply be traced to a diminution in the quantity or quality of the inputs (capital, labor and technology) to the economy. Moreover, whatever is happening here is not happening to America's major international industrial competitors. The growth of productivity in countries such as West Germany and Japan is from three to five times the U.S. rate. Whatever the reason, a much slowed rate of growth of per capita income is a central reality from which an analysis of the distribution of income and wealth must start.

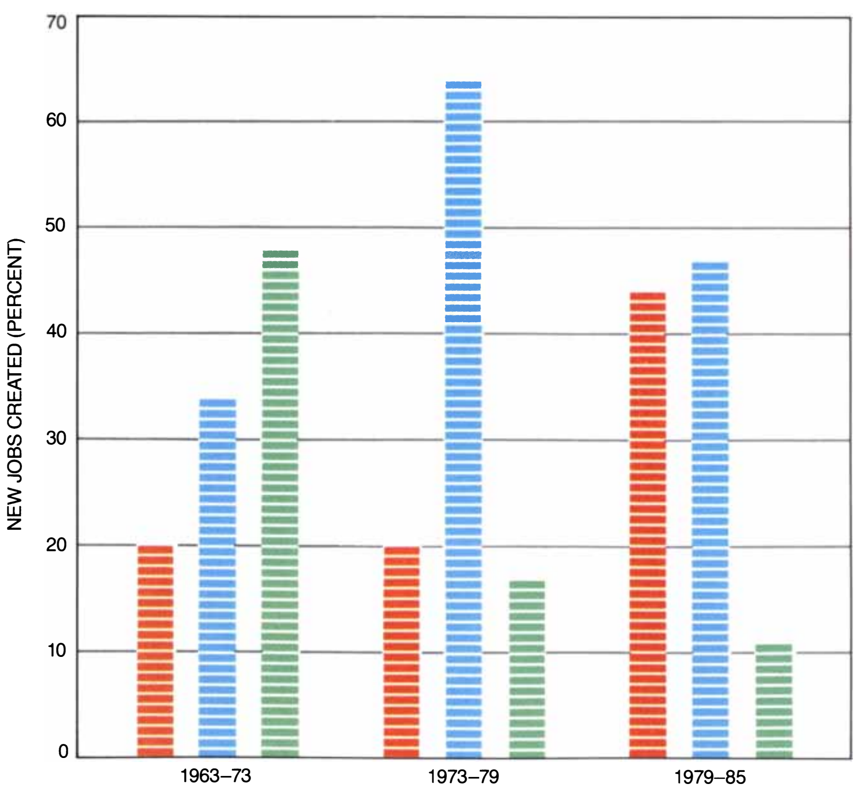
In what at first glance seems paradoxical, a low growth of productivity leads to a high growth of employment, and vice versa. Europe and Japan have had good growth of productivity but little creation of jobs. European employment is no higher now than it was in the early 1970's. The U.S. has had a bad productivity performance but has created 28.4 million jobs since 1970.

In reality there is no paradox. With low productivity growth it just takes more people to produce a given volume of extra output. If output and productivity are both growing at 3 percent, no new jobs are generated, but if output is growing at 3 percent and productivity at 1 percent, employment must grow by 2 percent. The new jobs, however, will not be associated with the wage gains that would have gone with them if productivity were growing more rapidly and output were expanding at an even faster pace.

Just such an effect can be seen in the wage gains associated with the millions of new jobs. After correcting for inflation, the compensation to labor per hour of work rose 2.7 percent per year from 1960 through 1969 but fell .4 percent between 1979 and 1985. Moreover, the new jobs were associated with a much more unequal distribution of earnings. Of the 10.7 million new earners added to the economy between 1979 and 1985, 48.6 percent were paid less than $10,000 (in 1985 dollars), 30.5 percent were paid from $10,000 to $25,000 (37.6 percent of the work force was in that range in 1979) and only 20.9 percent were paid more than $25,000 (compared with 23.2 percent in 1979). Right across the earnings distribution the new jobs were inferior to those the economy had been generating before 1979.

The distribution of output into two shares—one for labor and one for capital—affects the final distribution of personal income since capital income is much more unequally distributed than labor income. If one leaves aside homes and real estate, the top 2 percent of all families are found to own 54 percent of all net financial assets (stocks, bonds, pension funds and so on), the top 10 percent to own 86 percent and the bottom 55 percent to have zero or negative financial assets. This means that if the share of total output going to capital rises, the distribution of total income will automatically become more unequal because the most unequal component (capital income) is growing at the expense of the more equal one (labor income). The data in fact show a slight shift in the functional distribution of income: labor's share of the G.N.P. fell from 60.3 to 59.5 percent between 1979 and 1985.

Sometimes the Reagan Administration's tax and social-welfare policies are given the chief responsibility for the growing inequality, but this ignores the fact that the movement toward inequality began before the president was elected. The Administration's social-welfare cutbacks have in fact turned out to be fairly modest, adding at most probably only a few hundred thousand people to the poverty roll. Most of the four million people who have been added to that roll



CHANGE IN PAY for newly created jobs is charted for three periods. The chart shows the percentage of new jobs at the low-wage (*red*), mid-wage (*blue*) and high-wage (*green*) levels. The wage levels are defined respectively as less than $7,400 per year, between $7,400 and $29,600 and more than $29,600. The figures are in constant 1986 dollars.

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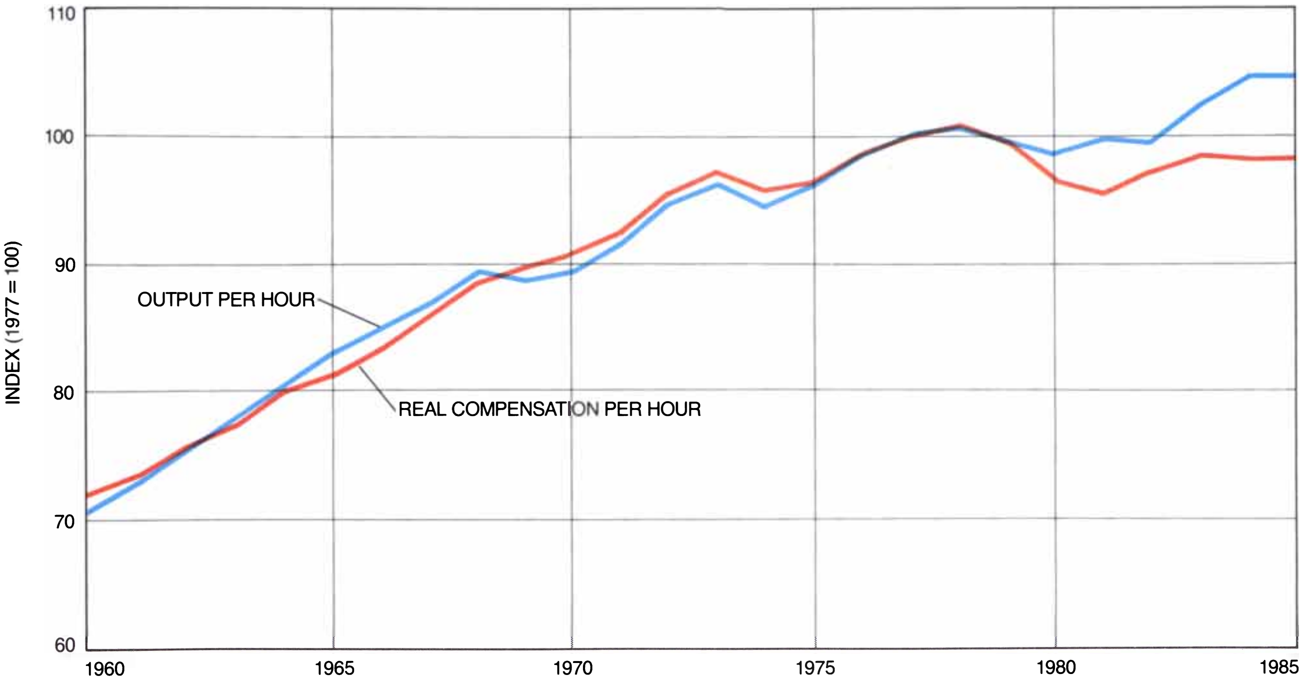

OUTPUT AND COMPENSATION have been diverging since 1980 in the nonfarm business sector. The data are presented on an index for which 100 represents the situation in 1977. The source of the figures is *The Economic Report of the President, 1986.*

since 1979 were not forced into poverty by the Administration's social-welfare policies; they were added by much more fundamental economic forces.

Similarly, changes in taxes have had little impact. Federal and state income taxes are progressive, meaning that the proportion of one's income paid in these taxes goes up as one's income goes up. Payroll taxes, state sales taxes and local property taxes are regressive, meaning that the proportion of one's income paid in these taxes goes down as one's income goes up. The net result is a tax system that is basically proportional. The percentage of income paid in taxes does not differ significantly from one income class to the next. The tax changes in 1981 were slightly regressive, but the changes enacted last year were slightly progressive, leaving the tax system about where it was when President Reagan took office.

Those who want a comforting explanation of inequality often point to demography. More young, unskilled and inexperienced baby boomers have entered the nation's labor force, and one should expect them to be paid less, the argument goes; when they become middle-aged and more skilled, the distribution of income will automatically reverse its current surge toward inequality. Therefore the surge need not concern policy makers; it will take care of itself eventually.

Neither part of this argument holds up under close inspection. If one keeps the age distribution of the work force constant at 1967 levels and calculates what the 1982 distribution of earnings would have been for that spectrum of ages rather than for the actual age distributions in 1982, the increase in inequality turns out to be just as large as the one actually observed. Today's inequality is being produced not by a more unequal age distribution of the population but by growing inequality in the earnings of each age group.

Nor does it automatically follow that relative incomes will rise simply because workers grow older. If the income of today's young baby-boom worker is lower than it has been in the past because of population pressures, those pressures will still exist when the baby-boom age cohort becomes middle-aged, because the cohort will still be crowded. Its members will still have lower earnings than they would have if they faced fewer contemporaries.

What, then, is the cause of the rising inequality in the distribution of earnings? There are two major forces: (1) intense international competitive pressures, coupled with high unemployment, and (2) a rising proportion of female workers.

The nation's huge balance-of-trade deficit (about $170 billion last year) is merely the most visible symbol of a much more competitive international economy. Numbers such as $170 billion are so large as to be meaningless to most people, but perhaps they can be made meaningful if one understands that it takes one million full-time, year-round employees in U.S. manufacturing to produce $42 billion worth of goods. Hence the trade deficit of some four times that amount has squeezed more than four million workers out of manufacturing and forced them to take other jobs. Because manufacturing is fairly highly paid and tends to have a more egalitarian distribution of earnings than other sectors such as services do, noncompetitiveness in manufacturing leads directly to more inequality in the distribution of earnings.

The U.S. is much more heavily involved in world trade than it used to be, but the rest of the industrial world is also much more competitive technologically than it used to be. In the past Americans did not have to compete much to export enough to pay for the small proportion of products that the nation wished to import. When the U.S. did compete, it did so on the basis of superior technology rather than lower production costs. Today's competition is among technological equals whose competition is based on which nation has the lowest production costs rather than which has the most superior technology.

With input-output techniques it is possible to isolate the earnings distributions of the industries that either export or compete with imports. This calculation reveals that both industry groups pay higher wages than the economy as a whole. In 1983 the median wage in exporting industries was $18,637 and in industries that compete with imports it was $19,583; for

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the entire economy the median was $16,168.

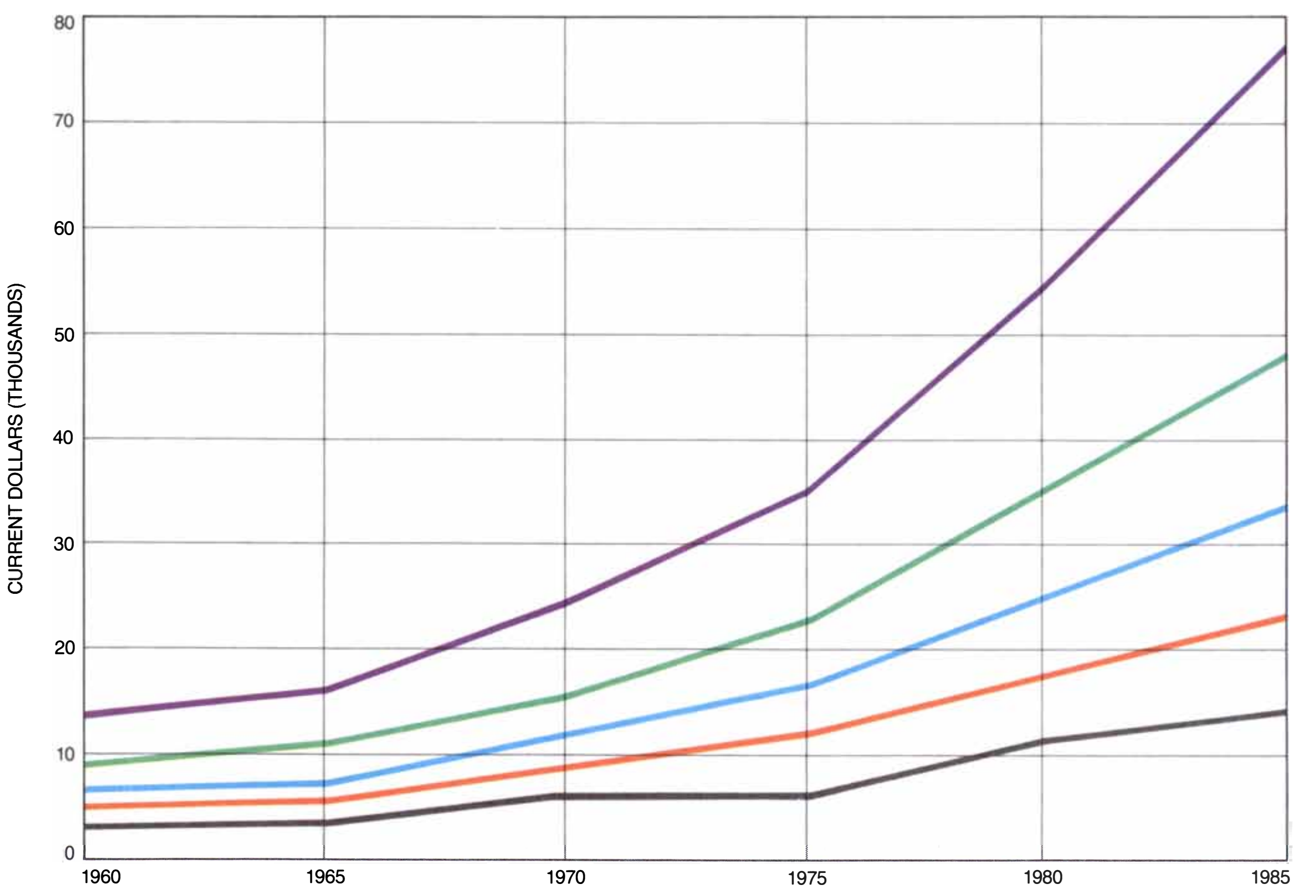
In addition to paying higher wages the exporting and import-competing industries generated a more equal distribution of earnings. In 1983, 41 percent of the entire work force worked at jobs that paid less than $12,500 per year, whereas only 31 percent of the workers in exporting industries and 30 percent of those in industries competing with imports held such jobs. Furthermore, whereas 56 percent of the total work force earned from $12,500 to $50,000 per year, 66 percent of the workers in exporting industries and 67 percent of those in the industries competing with imports were at that level. Yet at the very top of the income distribution the percentages were essentially equal: 2.6 percent of the export work force, 2.7 of the import-competing work force and 2.7 percent of the entire work force earned more than $50,000 per year.

The meaning of these statistics is that when exports fall and imports rise to create a trade deficit, the distribution of earnings moves toward inequality. Jobs are lost in both exporting and import-competing industries and are replaced by jobs with lower, more unequal earnings in the rest of the economy. This factor is the principal reason for the observed decline in earnings of males. The industries that have been hit hardest by international competition—automobiles, steel and machine tools—are precisely the ones that have provided a large number of upper-middle-income male jobs. For women a service job does not mean a lower wage, but for men it does.

If one looks at earnings by industry or occupation, it is evident that the major effect of foreign competitive pressure has been to increase the variation in earnings within each occupation or industry and to push workers down the earnings ladder. Some of this effect might have been offset if unemployment had been low and the sectors of the economy not involved in international trade had been forced to raise productivity and wages in order to attract good workers. Instead high unemployment meant a plentiful labor supply, and wages could if anything be reduced and made more unequally distributed in those sectors that were not affected by international trade.

Another part of the surge in inequality can be traced to women, or more accurately to society's economic treatment of women. Since women are paid much less than men and are much more likely to be part-time workers, a rising proportion of female workers automatically leads to a more unequal distribution of earnings. The average female worker makes 52 percent of what the average male makes, and the average full-time, year-round female worker makes just 65 percent of what her male counterpart makes.

This phenomenon, together with an increasing proportion of households headed by females (up from 28 to 31 percent of all households in the few years between 1979 and 1985), has led to a low-income population that is increasingly dependent on the earnings of women: the feminization of poverty. Women and children account for 77 percent of those in poverty, and half of the poverty population live in



FAMILY INCOME has been changing in distribution quite signifiicantly over the past decade. The four lower curves show the maximum income in the 20 percent of the population with the lowest income (*gray*), the 20 percent with the second-lowest income (*red*), the middle-income group (*blue*) and the next-to-highest group (*green*). The purple curve represents families that are in the top 5 percent of income groupings. The data, encompassing 63.5 million families in 1985, are from the Bureau of the Census.

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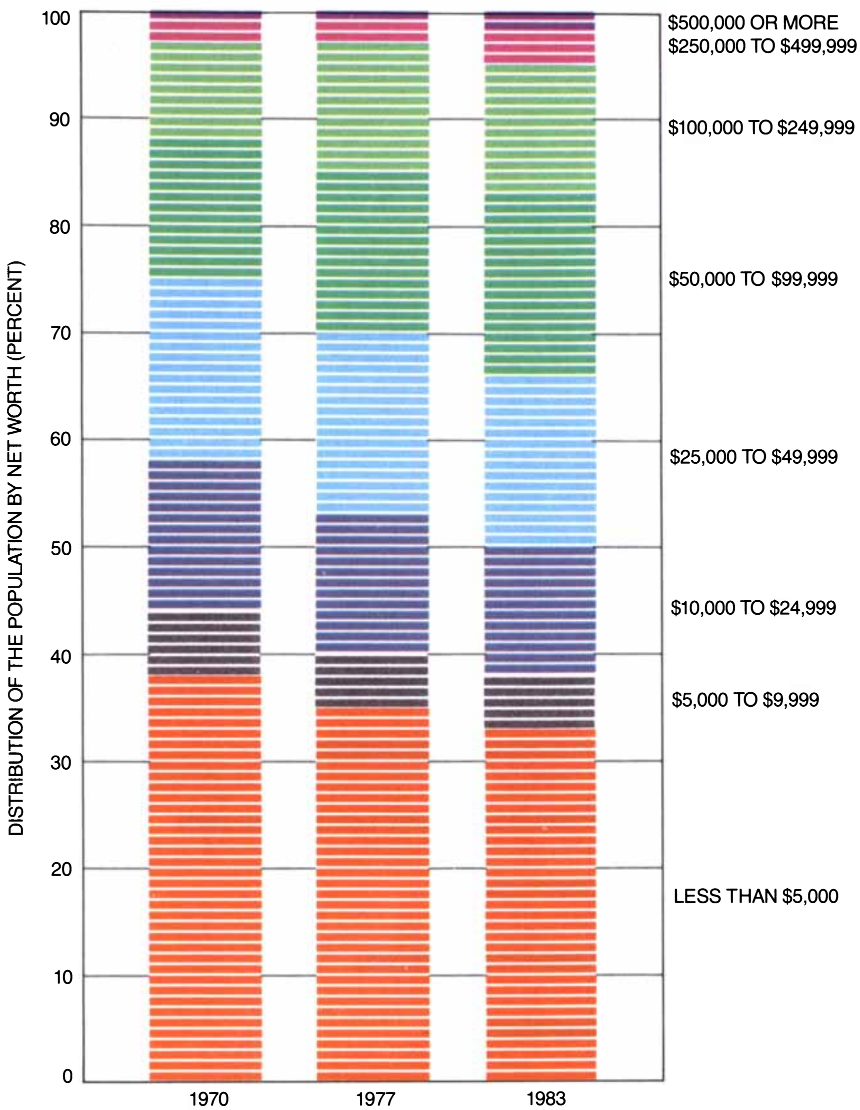
families headed by females with no husband present. The average female worker earns barely enough to keep a family of four above the poverty line. To do more than just escape from poverty a female must have a job substantially above the average.

The work situation of women does not merely affect the lower end of the income distribution. Women are increasingly influencing what a family must do if it wishes to have a middle-class standard of living. In 1984 the U.S. had 87 million households. Some 50 million of them were traditional husband-wife families, 40 million of which had earnings (most of the others consisted of retired couples). Of the 40 million, 28 million (70 percent) reported earnings by both husband and wife. These families had a median income of $31,000–$22,000 earned by the husband, $9,000 by the wife.

Among working men only 22 percent will earn $31,000 or more on their own, among working women only 3 percent. As a result few families can afford the $31,000 middle-class life unless both husband and wife have jobs. And although the dominant pattern today is a full-time male worker and a part-time female worker, the pattern is rapidly shifting toward a way of life in which both husband and wife work full time. In 1984, 11 million families had two full-time workers, and those families had a median income of $39,000–$24,000 earned by the husband and $15,000 by the wife. As an increasing number of families have two full-time workers, the households that do not will fall farther and farther behind economically.

Rising female participation in the labor market is also one of the factors leading the incomes of the highest-earning families to grow much faster than those of average families. If high-income males marry high-income females and low-income males marry low-income females (tendencies that are borne out by the available statistics), the net result is wider income gaps as potentially high-income women married to already high-income males enter the labor force.



NET WORTH of families has been changing in distribution since 1970. Each narrow colored bar represents 1 percent of the families in the U.S. In 1970 some 38 percent of families had a net worth of less than $5,000, in 1983 some 33 percent. At the top levels (from $50,000 to more than $500,000) the percentages have been rising. Data are in constant 1983 dollars and exclude such durable items as automobiles and home furnishings.

To describe the trend toward inequality as a surge might imply a high rate of change. Such is not the case; like a glacier, this kind of economic trend in reality moves quite slowly. A national economy can easily adjust to a shift in the distribution of purchasing power. It simply produces more low-income products, more high-income products and fewer middle-income products. The discount (K-Mart) and upscale (Bloomingdale's) department stores thrive while the stores in the middle (Gimbels) go out of business.

The Great Society programs of the 1960's to alter the distribution of income grew out of the political unrest of the civil-rights movement. Black and Hispanic households still have incomes far below those of whites (respectively 59 and 70 percent of white incomes), but the majority no longer seem to care and the minorities, even if they are not happy, do not seem to be aggressively complaining.

The distribution of income in Japan is about half as unequal as that in the U.S. In West Germany, before taxes and transfers, 28 percent of the population have less than half the median income; in the U.S. the figure is 27 percent. After taxes and transfers, however, West Germany is left with only 6 percent of its population in that predicament, whereas the U.S. is left with 17 percent. But to say that the Japanese and the Germans have or want less inequality is not to say that Americans want less inequality.

At the beginning of the Reagan Administration, David A. Stockman, the director of the Office of Management and Budget, declared that the distribution of income was not an appropriate subject for public remediation. The Administration was overwhelmingly reelected and is still popular in the public-opinion polls. Such polls also find that most of the public are in general satisfied with their economic circumstances.

One answer may be that no one

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cares. If that is so, Americans have changed. The past 100 years of American economic history show government deliberately adopting policies to prevent the growing inequalities that all too often seemed to be arising. In the last half of the 19th century the Interstate Commerce Commission was established and the antitrust laws were enacted to stop a growing concentration of wealth and to prevent that wealth from being used exploitatively. The railroads were not to be allowed to exploit their economic advantage over farmers and the oil trust was not to be allowed to exploit the urban consumer. Compulsory education for all was established to create an egalitarian distribution of human capital and more marketable skills in order to prevent large inequalities in earnings.

In the 20th century inheritance taxes and progressive income taxes were adopted to lessen inequalities. The rising inequalities of the Great Depression brought Social Security, unemployment insurance and eventually medical insurance for the elderly and the poor to prevent people from falling out of the middle class when confronting unemployment, illness, old age and other harsh facts of life.

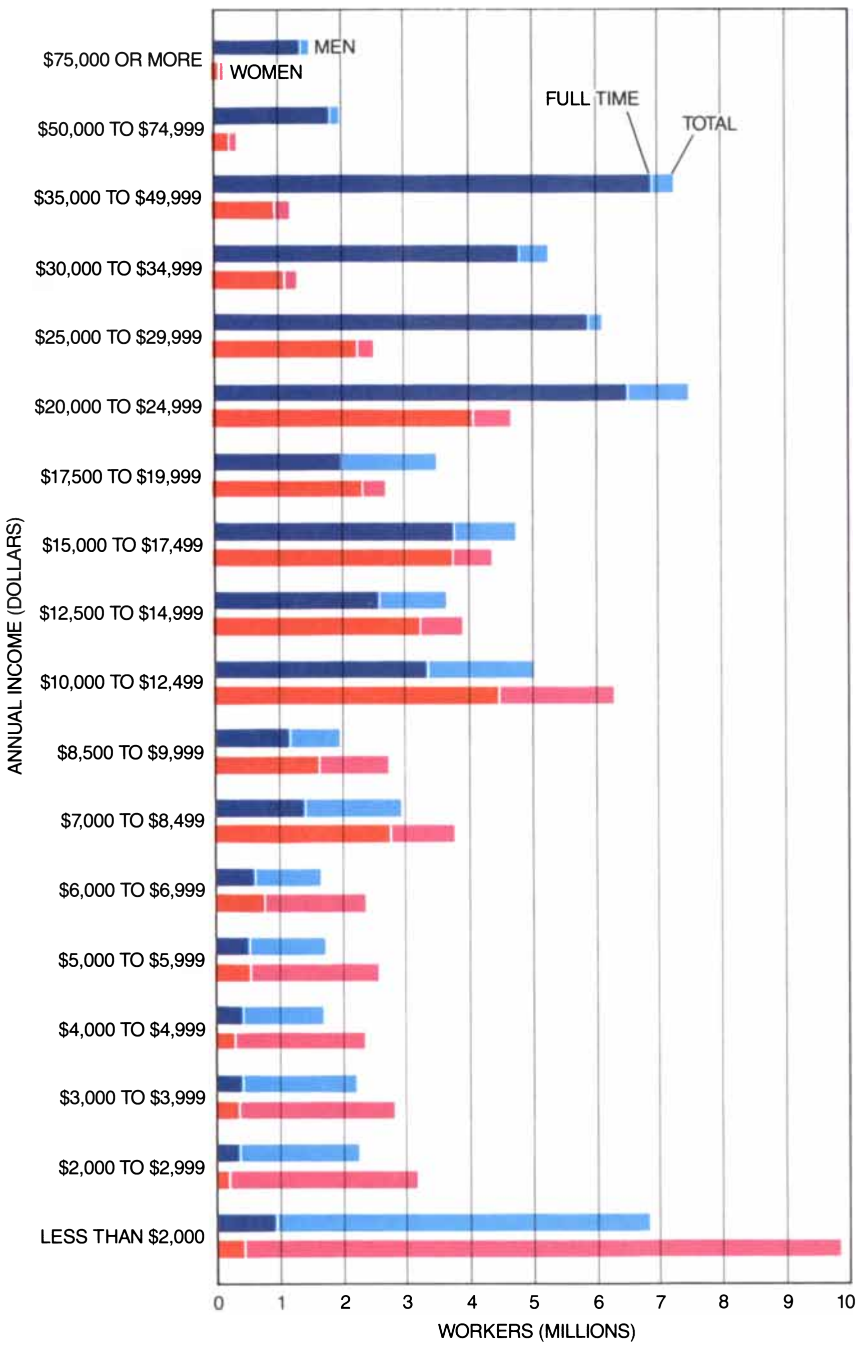
Whether one calls the increase in inequality modest or large depends on one's perspective. The bottom 20 percent of all families, who have seen their share of income decline by 18 percent since 1969, would no doubt call it large. However it is described, the surge is still under way, and no one can predict when it will stop.

Once the income-distribution problem has become so acute that it actually creates social or political unrest, it will be very difficult to solve. Politically it is a lot easier to prevent an increase in the income share of a dominant group than it is to adopt policies designed to take income away from that group. In economic health care as in medical health care, prevention is always better than remediation but—it must be admitted—is just as seldom undertaken.

Prevention or remediation, whichever, will require a return to the structural policies of the 19th century rather than to the tax and transfer policies of the 20th century. Regardless of what one thinks about the role of taxes and transfers in limiting inequality, they are clearly not the appropriate means for counteracting the current surge in inequality.

The heart of the solution will have to be found in a higher rate of growth of productivity and enhanced international competitiveness. Here the solution is not simply to lower the value of the dollar in order to regain a balance between exports and imports, although a dollar of lower value will have to be part of the cure until productivity growth can be enhanced. A lowered dollar is simply a way to have a national "giveback" and lower everyone's wages and capital incomes in relation to those in the rest of the industrial world. The wisest policy would aim not to lower the U.S. standard of living but to raise productivity so that the nation can compete in world markets while its private sector pays good wages and receives acceptable profits.

Economically what has to be done is as clear as the politics of doing it are murky. To compete in industries that pay high wages and make goods of high value a country must ensure that its labor force is as well educated and skilled as any in the world, must keep up with or ahead of competitors in investment in capital equipment and must make sure that the technologies being employed are the most effective. Comparisons with either Japan or Eu-



HIGHER-PAYING JOBS are mainly held by men; women predominate in jobs at low levels of pay and also in part-time work at the lower pay scales. The data are for 1985.

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rope reveal that the U.S. is not world class in any of those areas. The problem is not that the U.S. is doing worse than it used to but that the rest of the world is doing much better.

Judged by educational attainments and working skills, the U.S. lags far behind. How could one expect American children to learn in a 180-day school year what Japanese children learn in a 240-day school year? Yet the political difficulties of extending the school year are formidable. Both West Germany, with elaborate apprenticeship programs, and Japan, with extensive company training programs, have well-developed systems for teaching technical skills to people who are not bound for college. Such people are the forgotten majority when it comes to training in the U.S. Yet the Administration gutted the training programs of the Department of Labor.

American companies invest only half as much as the Japanese and two-thirds as much as the Europeans. To invest more the American family must save more than 4 percent of its income. Eliminating consumer credit would go a long way toward raising the personal-savings rate, but what politician wants to advocate that?

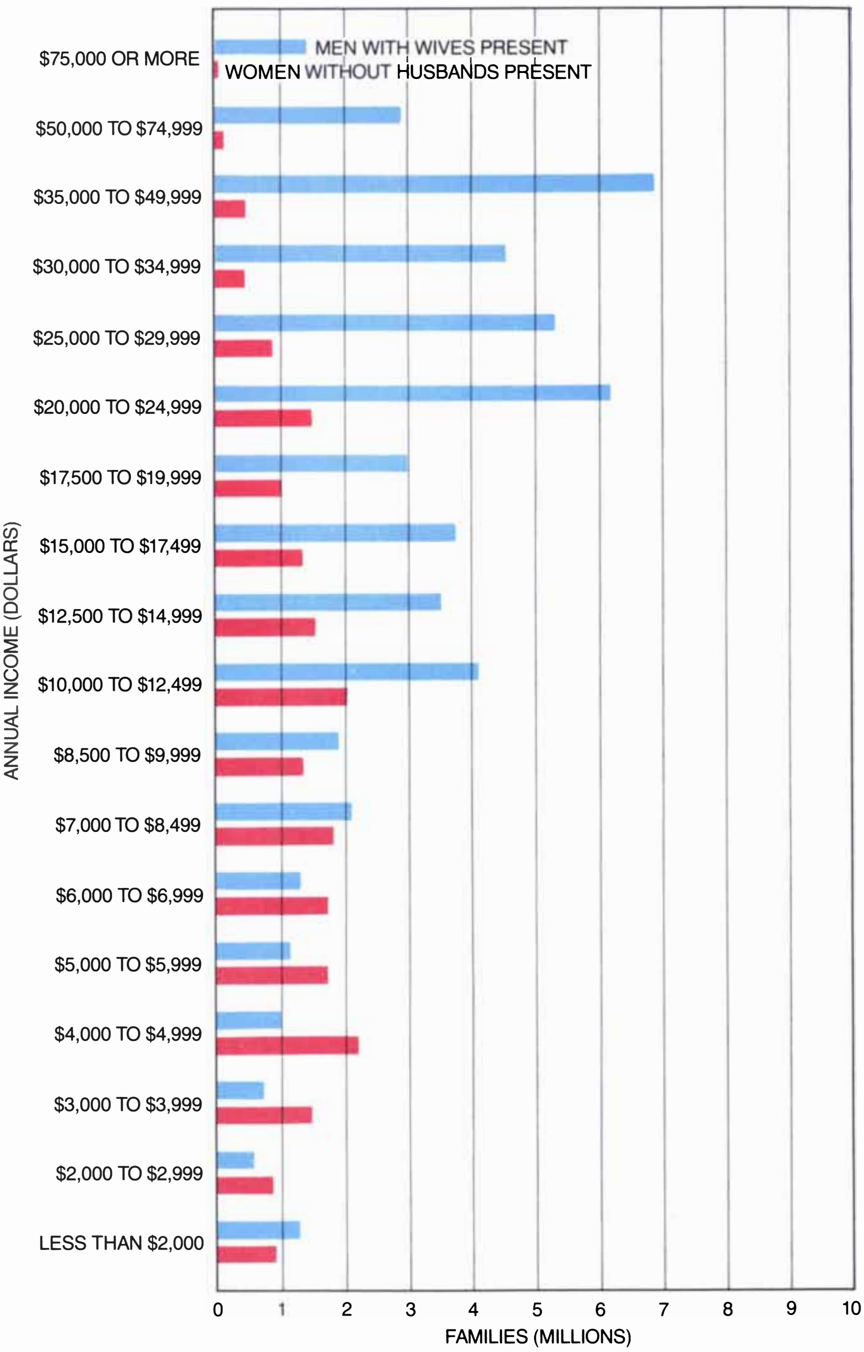
Civilian spending on research and development as a fraction of the gross national product now lags behind that of Japan, West Germany and France. One way or another, however, governments pay for almost all R&D spending in every country. To spend more on R&D means higher government spending and more taxes. No one in the U.S. wants to pay more taxes. That is why the Federal deficit is more than $200 billion.

In short, the solutions to the problem of competitiveness are visible and at hand. To say that the nation knows how to solve its problems with competitiveness, however, is not to say that it will solve them.

Working women are a fact of life. If the U.S. wants to avoid increasing inequality and the feminization of the lower reaches of the income distribution, it will have to do something to raise the earning capacity of women. One can argue about whether the issue is one of comparable worth (female occupations that are simply paid less than male occupations because of habit, history and exploitation) or the relative skills of female workers. Probably both factors contribute to creating the problem. In any case, the society must do something to improve the earnings of women if current trends toward inequality are not to continue.

Families headed by women raise a variety of sociological, religious and ethical issues; they certainly create an economic problem. They are unlikely ever to be able to attain an economic standard of living anywhere near that enjoyed by intact two-earner families. Their problems can be lessened, however, by adopting efficient social policies that make fathers pay to support their children even if they do not live with them. Nature may make mothers but society can make financial fathers. There is an easy solution: if a court orders child-support payments, the Federal Government automatically sends the mother a monthly support check for that amount and collects the money from the father through the Internal Revenue Service—with the state guaranteeing a minimum level of support whatever the amount collected from the father may be.

If history is any guide, the current surge in inequality will sooner or later be met with a political countersurge to contain it. The nature of that countersurge, however, remains buried deep below the political ice.



FEMINIZATION OF POVERTY is evident in this depiction of the incomes of families in data for March, 1986. Families headed by women predominate at the lower levels.

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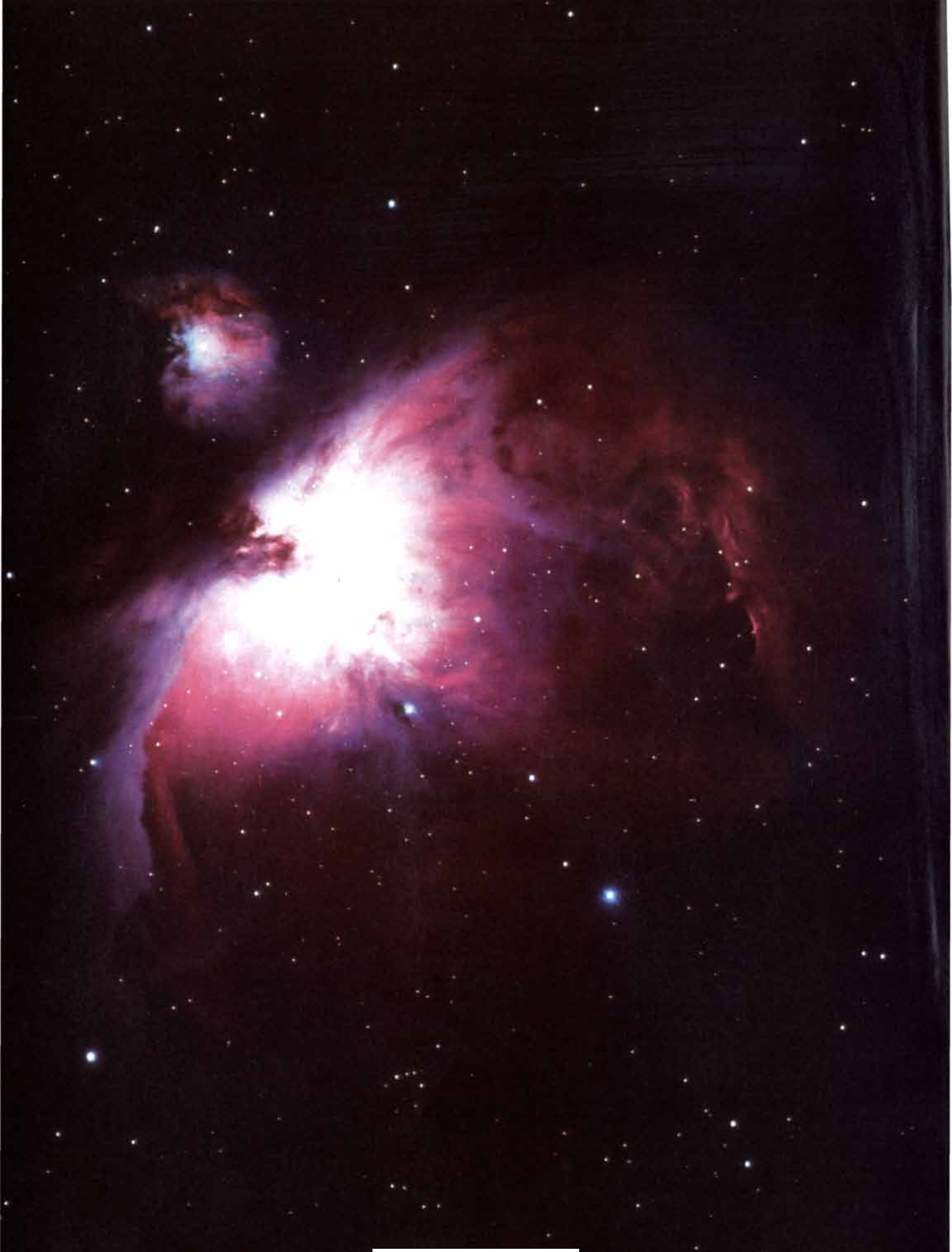

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The Cosmic Synthesis of Lithium, Beryllium and Boron

The three light elements, which cannot withstand the violent stellar environment where most elements were born, are created as cosmic rays collide with low-density clouds of gas and dust permeating the galaxy

by Victor E. Viola and Grant J. Mathews

Most of the elements that make up the solar system were forged during the course of stellar evolution. The process began billions of years ago when clouds of primeval matter condensed to form young stars. Within these stellar furnaces hydrogen and other light elements were fused together to form heavier nuclei. The heavy elements were then spewed out into space during either the cataclysm of a supernova (the explosion of a massive star) or the death of a red giant, the kind of star the sun will become in about five billion years. The cycle then began anew with the birth of a second-generation star that was richer in its composition of elements.

As successful as the theory is, however, it cannot explain the existence of three light elements, lithium, beryllium and boron. The nuclei of these elements, which contain three, four and five protons respectively, are extremely fragile and would rapidly disintegrate in the hot, dense and violent interior of most stars. In fact, any lithium, beryllium and boron initially present in the core of a newly formed star would actually be destroyed as the star contracts and heats up. How, then, were the three elements formed? The question has long proved baffling.

Recently a merging of theoretical astrophysics and experimental low- to medium-energy nuclear physics has begun to yield an answer. Work by collaborators in the two fields shows that lithium, beryllium and boron were probably synthesized outside stellar interiors in the immense clouds of low-density gas and dust that permeate the interstellar space in our galaxy. Taken together, the clouds constitute the so-called interstellar medium. As cosmic rays, which consist primarily of high-energy protons, have passed through the interstellar medium in the course of the past 10 to 15 billion years, they have initiated nuclear reactions that produce the three light elements. A large fraction of one of the elements, lithium, also appears to have been produced in the nuclear genesis associated with the first few moments of cosmic expansion during the big bang: the primordial explosion some 15 billion years ago from which the birth of the universe is traced.

The relative scarcity of lithium, beryllium and boron—each is less than one billionth as abundant as the most prevalent element in nature, hydrogen, and many orders of magnitude less abundant than helium, carbon, nitrogen and oxygen—belies their importance. The unique origin of the three elements has made them fascinating expositors of the history of the universe. As more information from laboratory experiments simulating their production in nature has accumulated, the models for the cosmic synthesis of these elements are becoming precise enough to provide important clues even about the final fate of the universe. The data may help to answer the question of whether the universe will expand forever or ultimately collapse again into another hot, dense fireball of fundamental particles.

The interaction of cosmic rays with the interstellar medium has emerged as the most plausible of several candidates to account for the cosmic synthesis of lithium, beryllium and boron. Nearly 30 years ago E. Margaret Burbidge, Geoffrey Burbidge, William A. Fowler and Fred Hoyle, all then at the California Institute of Technology, pointed out that the fragile nature of the three elements means they must have been synthesized in a low-density medium, where temperatures are low enough to keep the nuclei from fragmenting after formation. The collaborators postulated a loosely defined "x process" as the source of the three elements. They hypothesized that the elements might have been formed in nuclear reactions involving the fragmentation of heavy nuclei by collisions with energetic light nuclei within an appropriate low-density environment.

One such environment, for instance, might have been the surface of the newly formed sun or the surface of other young stars during an early epoch of intense flare activity. Another possible site could have been the outer envelope of gas and condensed matter surrounding the sun when the solar system was beginning to form, as Fowler, Jesse L. Greenstein, Donald S. Burnett and Hoyle proposed in a series of papers from 1962 to 1965. The surrounding envelope would then have contained an abundance of carbon, nitrogen and oxygen. During early periods of energetic flare activity, protons and alpha particles (helium-4 nuclei, which consist of two protons and two neutrons) could have been accelerated to high enough energies so that they would have fragmented the heavier nuclei in the outer envelope and produced lithium, beryllium and boron. Because the stellar surface and outer envelope are much cooler than the interior of the sun, the reaction products

GREAT NEBULA in the constellation Orion may be an example of a site where lithium, beryllium and boron are synthesized. Here an interstellar cloud is illuminated by newly formed stars behind it. As energetic cosmic rays pass through gas and dust clouds in the galaxy, they are thought to undergo nuclear reactions that produce the three elements.

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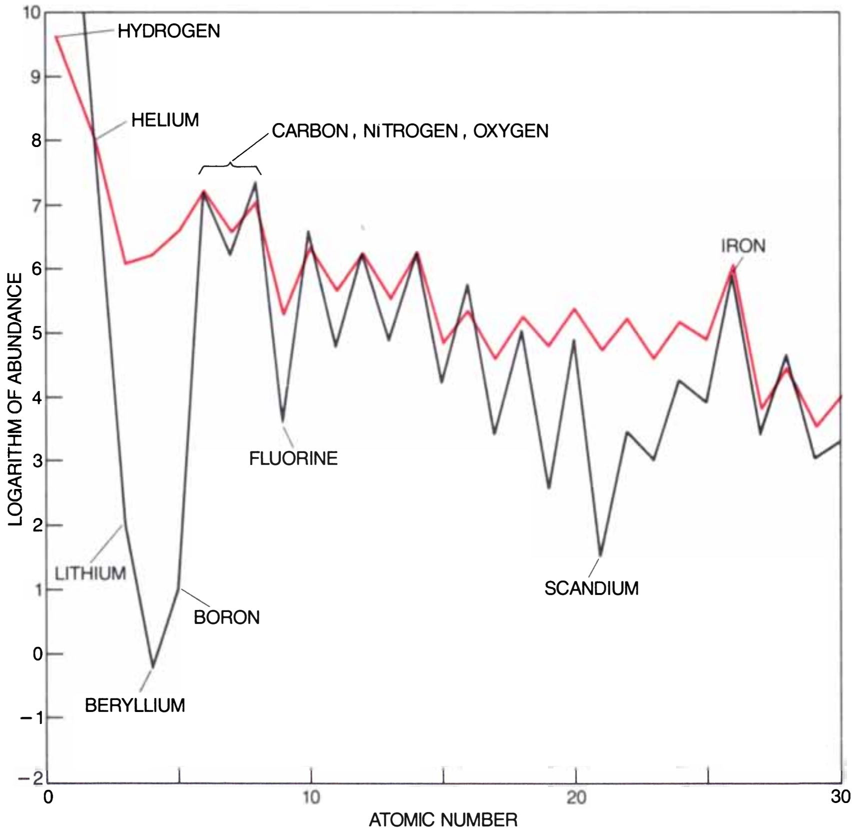
would have survived and been incorporated into the solar system.

At the time it was put forward the model appeared quite plausible from the standpoint of the relative abundances of elements and the probabilities of particular nuclear reactions. Unfortunately the model suffered from the requirement that it would have taken a significant fraction of the sun's total gravitational energy to accelerate protons and alpha particles to speeds high enough to create even the small amount of lithium, beryllium and boron present in nature today.

Recognizing the difficulties of the model, in the 1970's Hubert Reeves of the Institut d'Astrophysique in Paris, Fowler and Hoyle suggested the cosmic-ray mechanism. A number of considerations made the proposal attractive from the start. First, the abundances of lithium, beryllium and boron in the spectrum of galactic cosmic rays are enhanced by as much as a million times in relation to the normal interstellar-medium abundances. The cosmic-ray abundances have been known since the late 1950's, when Phyllis S. Freier, Cecil J. Waddington and their colleagues at the University of Minnesota and the University of Bristol succeeded in measuring them with equipment mounted on balloons flown at high altitudes. Second, as Sam M. Austin of Michigan State University pointed out, given the known energies and intensities of galactic cosmic rays and the present-day composition and density of the interstellar medium, the production of lithium, beryllium and boron is inevitable. Furthermore, if the interaction of cosmic rays with the interstellar medium has proceeded continuously over the lifetime of the galaxy (some 10 billion years), there has been ample time to synthesize the three elements.

In spite of the appeal of the cosmic-ray mechanism, other theories have continued to be put forward. Lithium, beryllium and boron might have been produced during a supernova, according to a model first proposed by Stirling A. Colgate of the Los Alamos National Laboratory. During a supernova the inner parts of a massive star implode to form a dense neutron star and the outer parts explode to generate a surrounding nebula, or cloud of gas and dust [see "How a Supernova Explodes," by Hans A. Bethe and Gerald Brown; SCIENTIFIC AMERICAN, May, 1985]. As the shock wave from the implosion passes through the outer layers of the star, lithium, beryllium and boron might have been created. Thomas A. Weaver and George F. Chapline, Jr., of the Lawrence Livermore National Laboratory have shown, however, that this scenario is unlikely because the temperature behind the shock wave is probably too low to produce the energetic particles necessary to synthesize the three elements. Other sites of formation could also be proposed, including regions surrounding newly formed pulsars, dense regions of active galactic nuclei and areas near quasars: galaxies that spew jets of high-energy particles into space.



ABUNDANCES of the elements are shown for both the solar system (*black*) and high-energy cosmic rays (*red*). Lithium, beryllium and boron are more abundant in cosmic rays.

To determine the validity of the various proposed mechanisms for the nucleosynthesis of lithium, beryllium and boron, one might think that all possible nuclear collisions producing the three nuclei in a particular astrophysical environment would have to be examined. Given the some 100 elements in the periodic table, that would be a monumental task. Fortunately one need consider only the most abundant elements and the probabilities that those elements will interact to produce the light elements. As a consequence the problem can quickly be reduced to a relatively small network of nuclear reactions. Analysis shows that reactions of cosmic-ray protons and alpha particles with other alpha particles and the nuclei of carbon 12, nitrogen 14 and oxygen 16 dominate the production of lithium, beryllium and boron in all the proposed synthesis models. (The number following each element gives the total number of protons and neutrons in the nucleus; elements that have the same number of protons but a different number of neutrons are called isotopes. Carbon 12 and carbon 14 are isotopes, for instance; carbon 14 has two more neutrons than carbon 12.)

Although the relative abundances of the elements have been fairly well known for many years, knowledge of the nuclear-reaction probabilities necessary to test the various models has been only fragmentary until rather recently. This is in large part owing to the difficulty of measuring the reaction products of interest and to the lack of nuclear particle accelerators needed to span the range of bombarding energies appropriate to the various production mechanisms.

In the past 15 years major experimental efforts at several laboratories have succeeded in determining all the salient reaction probabilities relevant to the problem. In the 1970's Austin and his colleagues at Michigan State and David D. Bodansky and William W. Jacobs of the University of Washington independently carried out im-

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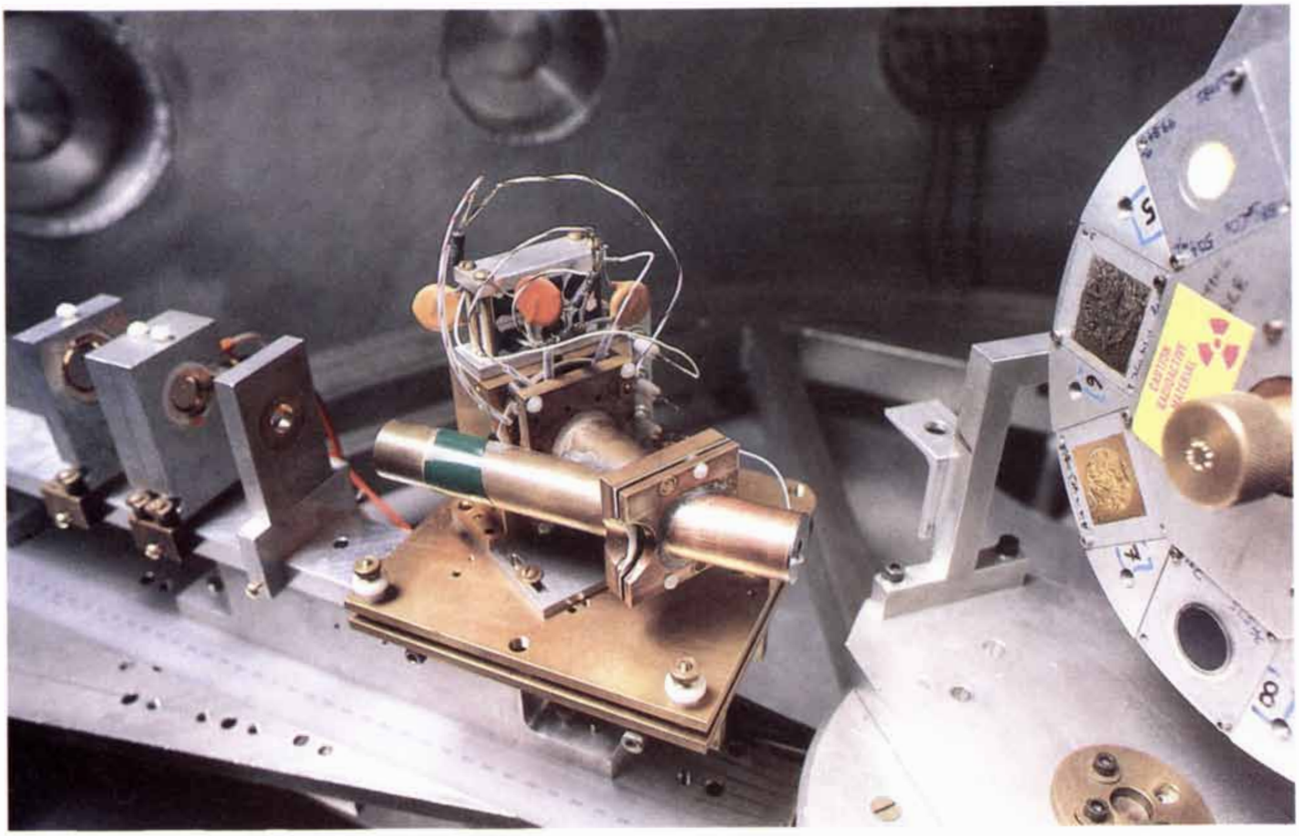

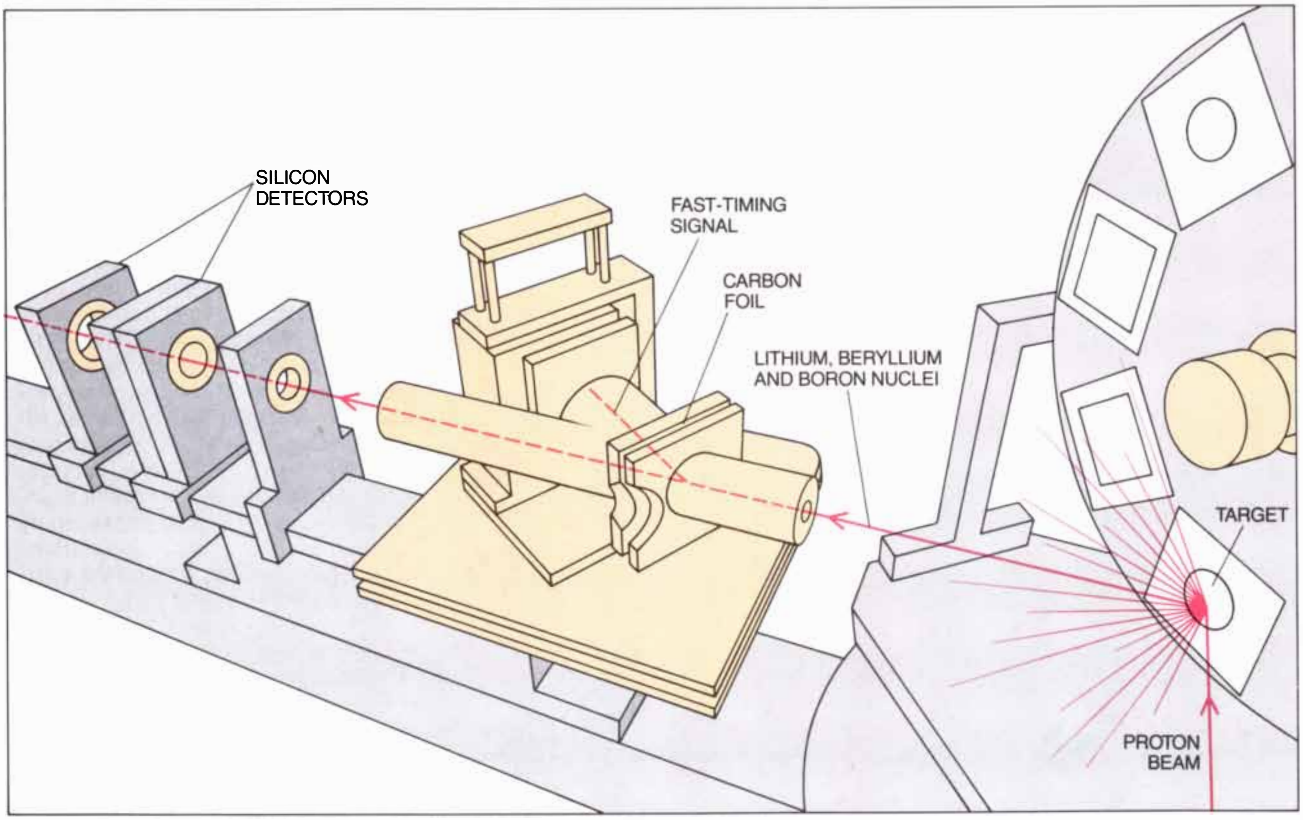

AUTHORS' APPARATUS (*top*) at the Indiana University Cyclotron Facility is employed to determine the products of medium-energy nuclear collisions in the laboratory. The collisions are initiated by generating a beam of protons or helium nuclei in a particle accelerator and aiming the beam at a fixed target containing helium, carbon, nitrogen or oxygen (*diagram*). As particles emerge from the collisions, they pass through a thin carbon foil (*bottom center*). The particles expel electrons from the foil, which start a precision clock. The clock is stopped when the particles arrive at a silicon detector (*bottom left*). The detector also measures the energies of the particles. Knowing the energy of a particle and how long it takes to travel, one can determine the particle's mass.

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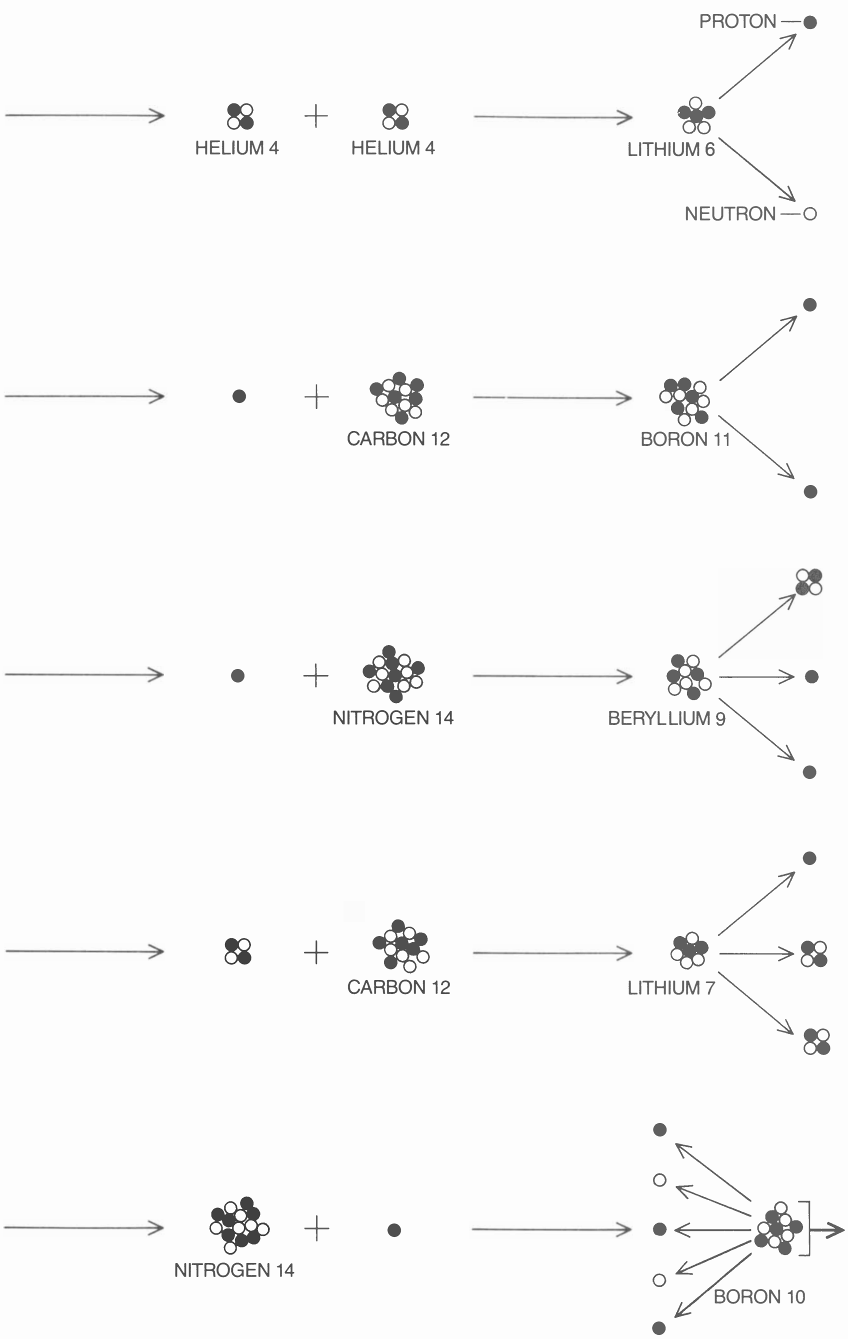
portant low-energy studies. Their data serve as essential input values for evaluating lithium, beryllium and boron production in phenomena such as low-energy cosmic rays, supernova shock waves and flare activity in protostars. At higher energies, where the data are relevant to synthesis by energetic galactic cosmic rays, extensive data have been compiled by Grant Raisbeck and F. Yiou at the René Bernas Laboratory in Orsay, France, by Harry H. Heckman and his colleagues at the Lawrence Berkeley Laboratory and by our group at Indiana University, the University of Maryland and the Livermore Laboratory. Because of these systematic studies it has been possible to make a quantitative evaluation of the various lithium, beryllium and boron nucleosynthesis theories.

The required measurements are difficult to make, as is often the case in doing nuclear-reaction-probability studies relevant to astrophysics. Although the lithium, beryllium and boron studies are not as formidable as making measurements of solar neutrino fluxes or reactions between protons in stellar burning cycles, they have nonetheless required the implementation of several sophisticated techniques to obtain the necessary experimental data. In the laboratory the astrophysical nucleosynthesis environment is simulated by collisions initiated by a beam of protons or alpha particles from a particle accelerator. The beam of particles is aimed at a fixed target containing helium, carbon, nitrogen or oxygen. The energies of the accelerated particles have to extend from a few million electron volts to several billion electron volts to reproduce the spectrum of energetic particles that are associated with flares, shock waves and galactic cosmic rays. Consequently several types of accelerators have been employed, including tandem Van de Graaff generators, cyclotrons and synchrotrons.

One of the main problems in experimentally measuring the probability of producing lithium, beryllium and boron in nuclear reactions is that the three elements typically emerge from reactions with little energy and are therefore difficult to identify. One of the most successful techniques developed to identify such low-energy particles makes use of a thin carbon foil (about one 10-millionth of a meter thick, or 1/750 the width of a human hair) and a silicon-semiconductor detector. The foil is placed in the path of the fragments emitted from the target and the detector is placed about 20 to 30 centimeters downstream from the foil. As the fragments pass through the foil they expel electrons, which start a precision clock. The clock is stopped when the fragments arrive at the silicon detector. The detector also measures the energies of the particles. Knowing the energy of a particle and how long it takes to travel between the foil and the detector, it is relatively easy to calculate the mass of the particle and thereby identify it.

Such systematic measurements have resulted in the compilation of a series of reaction probabilities as a function of bombarding energy for reactions induced by protons and alpha particles with helium 4, carbon 12, nitrogen 14 and oxygen 16. The probabilities were then used as input parameters for calculations designed to test the various models of lithium, beryllium and boron nucleosynthesis. The calculations show that the flare and shock-wave models are unsuccessful in reproducing the observed abundances of the



COSMIC-RAY INTERACTIONS with the interstellar medium have been modeled in particle accelerators. The sample reactions shown here illustrate a few of the kinds of nuclear collision that might produce lithium, beryllium and boron in deep space. Not shown are reactions in which oxygen 16, neon 20, silicon 28 and iron 56 serve as targets.

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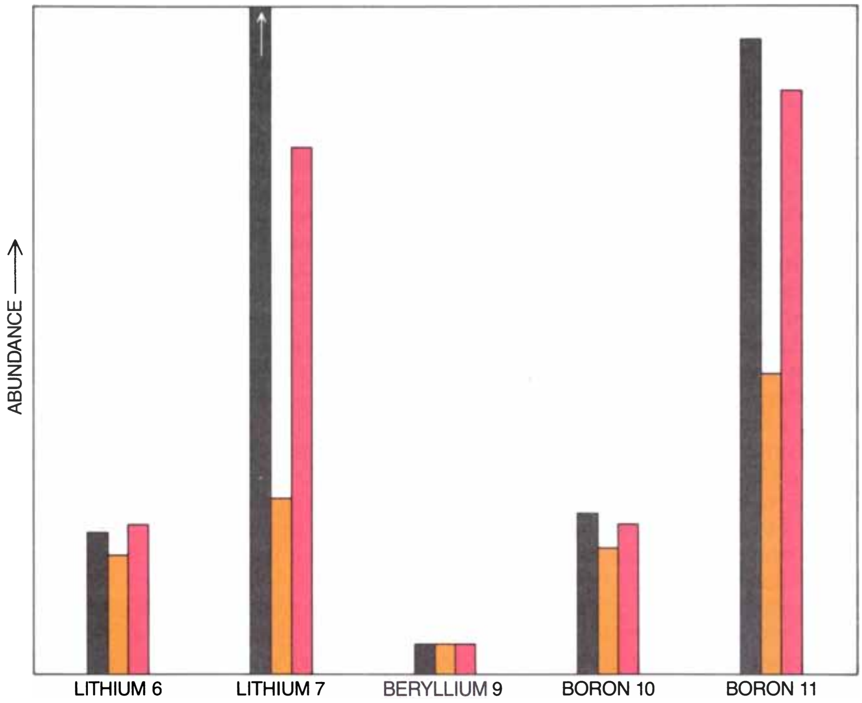
three elements. In contrast, the cosmic-ray model is quite successful.

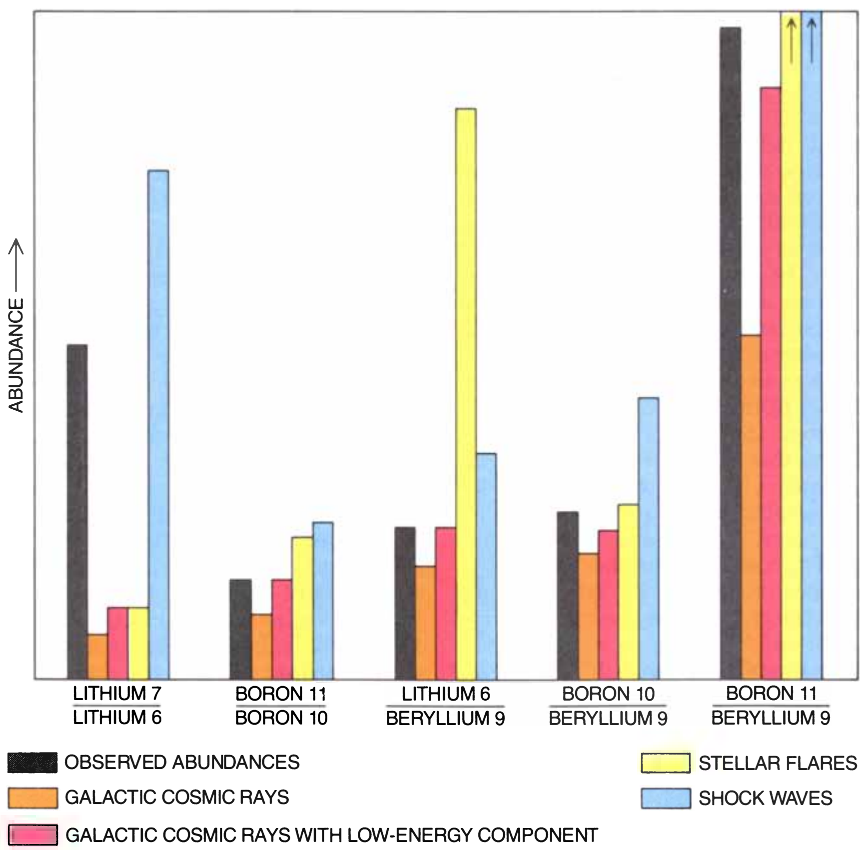
Much of the work in providing the details of the cosmic-ray model was originally done by Maurice Meneguzzi and Jean Audouze of the Institut d'Astrophysique and Reeves and independently by Henry E. Mittler, then at the Harvard-Smithsonian Center for Theoretical Astrophysics. According to the model, cosmic rays moving through the galaxy produce lithium, beryllium and boron when they collide with the heavier nuclei in the interstellar medium.

Various sources for the cosmic rays have been proposed, such as colliding plasma shock waves, supernovas and pulsars; the question is still debated [see "Cosmic Rays from Cygnus X-3," by P. Kevin MacKeown and Trevor C. Weekes; SCIENTIFIC AMERICAN, November, 1985]. Whatever the source turns out to be, the observed flux of the rays is well described as an exponentially decreasing function of the particles' total relativistic energy, which is equal to the sum of the mass and the kinetic energy of each particle. In addition a low-energy component may be present in the spectrum. The simplest version of the model assumes that the composition and the energy spectrum of the cosmic rays have remained constant over the 10- to 15-billion-year history of the galaxy. The assumption has proved to be a surprisingly good approximation.

The formation of lithium, beryllium and boron can come about in two ways. Light cosmic rays (protons and alpha particles) can interact with heavy nuclei (carbon, nitrogen and oxygen) in the interstellar medium, or heavy cosmic rays can interact with light nuclei in the interstellar medium. Either way the ability of the interstellar medium to stop the reaction products must be taken into account. In spite of the infinitesimally low density of the interstellar medium, cosmic rays travel such long distances through it that nuclear reactions are fairly likely to occur. For reactions induced by light cosmic rays on heavy nuclei, most of the lithium, beryllium and boron products become incorporated in the interstellar medium. For reactions induced by heavy cosmic rays on light nuclei, on the other hand, the bulk of the three elements becomes a part of the cosmic rays. This accounts for the high abundance of lithium, beryllium and boron in cosmic rays.

The high abundance of the three elements in cosmic rays has, in fact, become one of the most important indicators of the environment encountered by the cosmic-ray nuclei as they speed





PREDICTED ABUNDANCES of lithium, beryllium and boron for each of three theoretical models are compared with the observed abundances. The data indicate that the three elements are most likely produced during the interaction of galactic cosmic rays with the interstellar medium—the low-density clouds of gas and dust between stars. Less likely are scenarios in which the elements are synthesized during stellar flares or shock waves from, say, a supernova (the explosion of a massive star). The failure of the cosmic-ray model to predict accurately the amount of lithium 7 (*top*) can be accounted for by including the effects of the big bang; lithium 7 is thought to have been produced copiously during the birth of the universe. The discrepancy in the ratio of boron 11 to boron 10 (*bottom*) can be overcome by including a component of low-energy cosmic rays in the model.

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across the galaxy. In particular, the relative abundances of the elements serve as a measure of the amount of interstellar material the cosmic rays have traversed before reaching the earth; the more material the cosmic rays pass through, the greater the amounts of lithium, beryllium and boron produced. The presence of radioactive cosmic-ray nuclei such as beryllium 10 can even be used to measure how long the cosmic rays remain a part of the galactic environment before they escape from the galaxy or destroy themselves in collisions: about 10 million years.

It is a remarkable fact that the simple cosmic-ray model leads to predictions of the absolute abundances of lithium 6, beryllium 9, boron 10 and boron 11 that are quantitatively close to the observed abundances. The similarity places valuable constraints on the evolution of the galaxy. Specifically, excessive amounts of infalling extragalactic primordial material and large variations in the history of cosmic-ray activity would seem to be precluded, because such effects would probably have caused significant deviations from the predictions of the cosmic-ray model. The conclusion is supported by numerous data collected about light elements (particularly beryllium, which is the easiest to measure) on the surface of ancient stars, as Jean-Paul Meyer of the Service d'Astrophysique and Reeves first pointed out. (The interstellar matter was incorporated into the stars when they first condensed.) The stars, some of which are almost as old as the galaxy itself, serve as an archive of the past production of lithium, beryllium and boron.

From the observations one concludes that the abundances of beryllium nuclei have not changed by more than a factor of two for the past 10 billion years, after an early growth period. The conclusion implies the cosmic-ray production of the light elements has been more or less constant over the history of the galaxy. Some dilution of the elements has probably occurred, however, as a result of the combined effects of the ejection of beryllium-depleted material from stars and the infall of extragalactic matter.

In spite of the success of the cosmic-ray model in explaining the formation of the three light elements, there are two shortcomings. First, although the model accounts for the absolute abundances of boron 10 and boron 11 quite well, it fails to explain the ratio of boron 11 to boron 10, which is known to a much higher degree of accuracy than the absolute abundances. In particular, the predicted value of the ratio is 2.5, whereas the measured value is actually about 4.05. Second, the model predicts that there should be 10 times less lithium 7 than is actually observed.

The failure of the cosmic-ray model to predict accurately the ratio of boron 11 to boron 10 is generally reconciled in terms of a poor understanding of how many low-energy particles are found in cosmic rays. Not until satellite measurements can be obtained from deep space at distances greater than 100 times the distance between the earth and the sun will the intensity of low-energy cosmic radiation really be known.

The deepest space probe, *Pioneer 10,* which has recently left the solar system and is now at about 40 times the earth-sun distance, has already encountered examples of unexpected fluxes of low-energy particles, such as the intense radiation fields around Jupiter. The spacecraft must travel beyond the far-reaching influence of the sun's magnetic field, however, before the true spectrum of low-energy galactic cosmic rays can be observed. If the speculation of intense low-energy fluxes of interstellar cosmic rays turns out to be correct, it will be possible for very low-energy cosmic rays to form the additional boron 11 needed to produce the correct ratio of boron 11 to boron 10 without modifying the rest of the theory.

The lithium-7 anomaly can be accounted for quantitatively by including the effects of the big bang in the model. Calculations originally done by Robert V. Wagoner of Stanford University, Fowler and Hoyle show that the big bang could have produced the right amount of lithium 7 to explain the abundance of this element in nature. There is one difficulty with such a proposal, however. F. Spite and M. Spite of the Observatoire de Paris-Meudon have recently reported on the abundance of lithium on the surface of old stars called halo stars outside the disk of the galaxy. If the abundance has not changed during the evolution of the stars, it may represent the abundance left over from the big bang.

Unfortunately the measured lithium abundance on the halo stars is only about 10 percent of that measured in stars of the galactic disk. Whether the low lithium abundance does actually represent primordial big-bang material is still being debated. If it does, another source must be found for most of the lithium 7 observed in the galaxy. Possibly such a source could be red-giant stars or even supernova outbursts, as A. G. W. Cameron of the Harvard-Smithsonian Center and Fowler have suggested. We should point out that even if there is another source for lithium 7, it is unlikely to affect the validity of the cosmic-ray model.

What do the abundances of the light elements imply about the universe as a whole? The abundances of deuterium (hydrogen 2), helium 3, helium 4 and lithium 7 produced in the big bang depend primarily on the density of baryons—the class of particles whose most important members are the proton and the neutron—present at the time of synthesis. The abundances can therefore be used to infer the initial baryon density of the universe. Once the initial density has been deduced, one can calculate the current baryon density of the universe.

The calculated total mass density of the universe is usually expressed in terms of a dimensionless parameter designated by the Greek letter omega. Omega is the ratio of the calculated density to the critical density of the universe: the minimum density for which the gravitational force would be sufficient to halt the present expansion of the universe. If omega is less than 1, the universe is said to be open and will expand forever. If omega is greater than 1, the universe is closed, and it will eventually begin to contract. If omega is equal to 1, the universe will continue to expand, but the rate of expansion will slow asymptotically.

Of special relevance in estimating the initial baryon density and hence the value of omega are the abundances of deuterium and lithium 7. The production of deuterium in the big bang decreases rapidly as a function of increasing density. For lithium 7 just the opposite is true. By matching the observed abundances of deuterium and lithium 7 to the predictions of the big-bang theory of nucleosynthesis, a rather sensitive estimate of the baryon density of the universe can be made.

The analysis of the ratio of lithium 7 to deuterium indicates that omega is less than or equal to .05, which implies that the universe is open. The result is roughly equivalent to what astronomers have inferred from the motions of galaxies. There are, however, many reasons to question whether the universe is actually open. Primary among them is the fact that prevailing theory argues strongly for a value of omega equal to 1 [see "The Inflationary Universe," by Alan H. Guth and Paul J. Steinhardt; SCIENTIFIC AMERICAN, May, 1984]. If omega does equal 1, account must be taken of the missing mass, or dark matter, that eludes detection by observers and instruments alike. In order to be consistent with the results of big-bang nucleosynthesis calculations, it is generally held that

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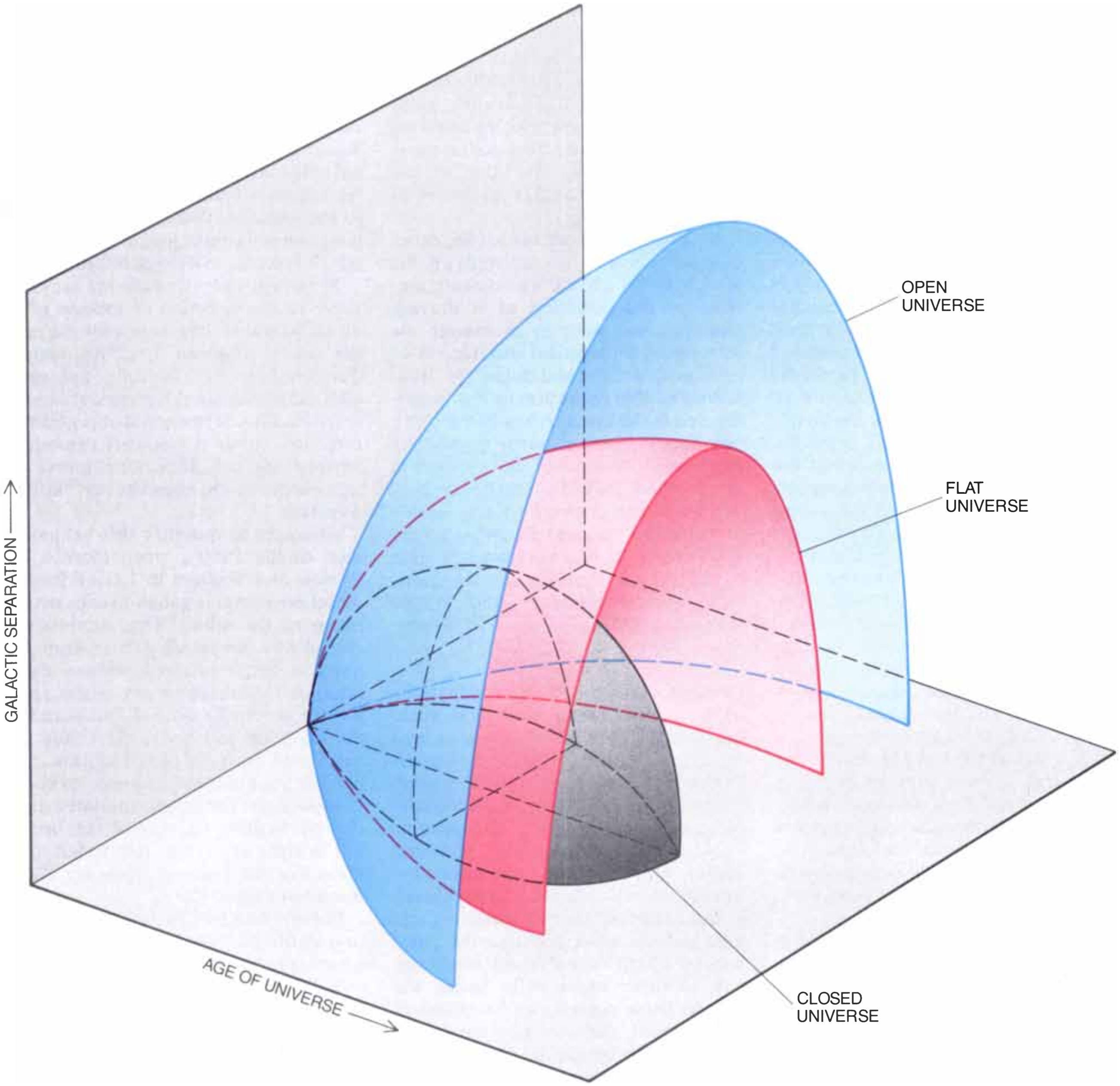
the matter must be something other than baryons. Numerous candidates have been proposed [see "Dark Matter in the Universe," by Lawrence M. Krauss; SCIENTIFIC AMERICAN, December, 1986].

Nevertheless, the possibility still remains that the dark matter, if it exists, could consist of baryons. One of us (Mathews) and co-workers at the Livermore Laboratory and investigators at a number of institutions have recently begun exploring in detail the possibility that such dark matter could have been formed if the baryon density of the universe were inhomogeneous during the big bang. The baryonic dark matter would now reside in regions that have collapsed into invisible remnants, such as black holes. The scenario could still be consistent with the big-bang nucleosynthesis of the light elements.

Although the variety of theories emphasizes the fact that the question of whether the universe is open or closed cannot be conclusively resolved as yet, the preliminary results point the way for studies that may eventually yield an answer. Moreover, the origin of the three peculiar elements lithium, beryllium and boron provides a wealth of clues about the origin and nature of the universe. From the cryptic messages being delivered by the cosmic radiation that continuously bombards the earth to the ever unfolding puzzle of the birth of the cosmos, it appears that the three elements were probably in some way a part of every high-energy event in the universe.



FATE OF THE UNIVERSE depends on its present mass density. The universe is now expanding. If the mass density is less than that for which the gravitational force would be sufficient to halt the expansion, the universe is open: it will expand forever. If the mass density is so large that the gravitational potential energy exceeds the energy in expansion, the universe is closed: it will stop expanding and ultimately collapse into a hot, dense fireball of fundamental particles. If the mass density produces gravitational potential energy that exactly equals the energy in expansion, the universe is said to be flat. The data pertaining to lithium 7 suggest that the universe is open, but the question is still far from being resolved; prevailing theory suggests that the universe is flat.

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Synapses That Compute Motion

How do nerve cells process the information they receive from the environment? Studies of cells in the eye that interpret movement may define a mechanism involved in many other neural operations

by Tomaso Poggio and Christof Koch

The brain is the most sophisticated and powerful computing machine on earth, and its components are far more perplexing than those of the present-day computer. The computational capabilities of the tiny silicon chips that make up computer hardware are familiar and explicable, since they are built by human hands. Not so the functional subunits of the brain. What elementary mechanisms does this complex piece of "wetware" use to process information? What operations do they perform? Are there biological equivalents of transistors and diodes inside the skull?

The neuron, or nerve cell, is the basic information-processing unit of the brain. Early in this century scientists realized that neurons could process information by generating an electrical impulse called an action potential. In 1943 Warren S. McCulloch and Walter H. Pitts of the Massachusetts Institute of Technology proposed a formal model for neuronal activity. In their view the neuron adds together the excitatory and inhibitory signals sent by neighboring cells, then produces an action potential if the electrical sum exceeds a certain threshold. Otherwise it is silent. It was easy to show—as McCulloch and Pitts did—that circuits consisting of such units could perform all logical operations, and that these idealized neurons could in principle be the building blocks for the most complex digital computer.

In spite of its utility, this model is in need of replacement. For many years it has been clear that nerve cells are much more complicated than McCulloch and Pitts suggested. Nerve cells exhibit a variety of information-processing mechanisms; the nerve-cell membrane produces and propagates many different types of electrical signals and can alter its electrical properties to adapt to long-lasting stimuli. Many neurons do not generate classical action potentials at all. Although the generation and propagation of the action potential undoubtedly plays a major role in neuronal information processing, there are many other processing mechanisms operating in and among cell membranes whose roles are still a mystery.

In order to explore one of the processing operations, we are studying the means by which the eye detects motion, or the direction of a moving stimulus. We want to illuminate the underlying biophysical mechanism of motion detection and define the limitations of this operation as it is implemented in the brain. Already our work has focused on a novel processing mechanism that could be involved in many other kinds of neural operations. We hope the answers to our simple questions will ultimately lead to an understanding of higher processes such as perception, thought and the transformation from sensory input to motor output that takes place in all nervous systems.

The structure of the brain reflects its functional complexity. It is made up of about 1,000 billion neurons, and most neurons receive and send signals to thousands of other cells. A typical neuron has a cell body, which harbors the metabolic machinery that sustains it, a number of threadlike branches known as dendrites and one somewhat thicker branch called the axon. Usually the dendrites receive incoming signals and the axon provides the pathway by which the nerve cell sends signals to other nerve cells. Inside the neuron these signals can be chemical or electrical; they are communicated between cells by special chemicals secreted at a junction called the synapse [*see illustration on page 48*].

The retina, a sheet of cells lining the back of the eye, detects and transmits to the brain information about the visual environment. It is not much thicker than the edge of a razor and consists of a small number of cell layers. The cells we study, called ganglion cells, are the farthest from the photoreceptor cells, which convert light into electrical signals. In between are cell layers that feed signals from the photoreceptors to the ganglion cells. Axons from the ganglion cells make up the optic nerve, which links the eye to the brain.

Most organisms that can see are sensitive to the direction of motion of a visual stimulus. The neurons in the retina that distinguish direction, called direction-selective neurons, are specialized to recognize movement in just one direction. Motion in that preferred direction elicits a vigorous response, whereas the cell does not respond to movement in the opposite, or "null," direction.

Attempts to quantify this behavior date to the 1960's, when Horace B. Barlow and William R. Levick found direction-selective ganglion cells in the retina of the rabbit. They stimulated the cells by illuminating two slits in sequences that mimicked motion, then measured the responses by monitoring electrical activity close to, but outside, the ganglion cell body. First they illuminated each slit separately and recorded the neuronal response to each illumination. Then they simulated motion by flashing the pair of slits from left to right and from right to left and measured the responses [*see top illustration on page 49*].

Barlow and Levick found that motion in the preferred direction elicited action potentials and motion in the null direction did not. They also found that apparent motion in the null direction prompted a smaller response from the ganglion cell than the illumination of a single slit did. This observation was puzzling because twice as much light struck the photoreceptors during sequential illumination. The null-direction response was much weaker than expected.

The investigators concluded that the

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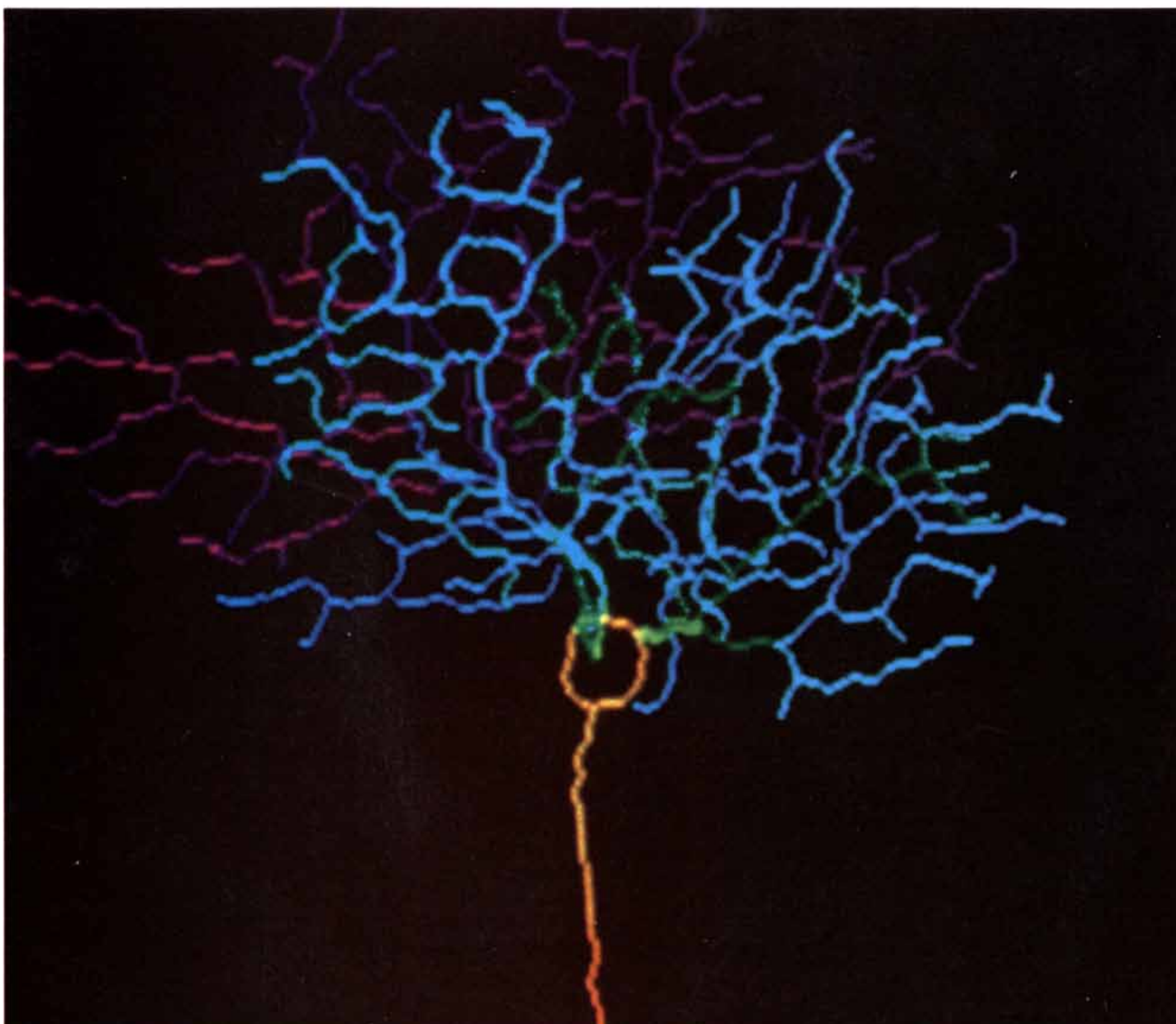
cells must achieve directional sensitivity by some kind of veto operation; that is, the weak response to motion in the null direction indicated not just a lack of sensitivity but an active damping, or veto, of an excitatory response. Neuroscientists of the day knew that nerve cells send two types of signals: excitatory signals, which promote the action potential, and inhibitory signals, which prevent it. The notion that excitation could be muffled by inhibition was not unusual. But how was inhibition triggered so selectively? After all, sequential illumination in either direction activates the same inhibitory and excitatory photoreceptors; the difference is just a matter of timing.

To explain their observations, Barlow and Levick put together a broad scheme for retinal reaction to motion; their model was built on the one proposed by the West German scientists Werner E. Reichardt and Bernhard Hassenstein in the 1950's to explain motion analysis in the visual system of insects. The theory advanced by Barlow and Levick specifies that photoreceptors connected to direction-selective cells are arranged so that a stimulus moving in the preferred direction activates excitatory cells before it reaches inhibitory cells. Hence motion in the preferred direction leaves inhibitory pulses trailing behind the excitatory pulses. This time lag is compounded, Barlow and Levick suggested, because inhibitory signals move more slowly than excitatory signals.

Therefore, when they are activated by movement in the preferred direction, excitatory signals easily outdistance inhibitory ones. They race through layers of retinal nerve cells to the ganglion cell body, where they spark action potentials. Because of the delay, the inhibitory signals arrive too late to veto the excitatory ones. If, on the other hand, motion is in the null direction, the inhibitory receptors are activated first, but the excitatory signals overtake the slower inhibitory signals. When they intercept one another, they cancel one another.

Barlow and Levick's model explains why stationary light, which activates excitatory and inhibitory receptors simultaneously, results in more excitation than light moving in the null direction, which gives inhibitory signals a head start. Furthermore, because the ganglion cell responds differentially to very small displacements of the slit in



GANGLION CELL, part of the retina of the eye, can sense the direction in which an object in the field of vision is moving. Each ganglion cell responds to movement in one direction by sending electrical impulses to the brain. It ignores motion in the opposite direction. Frank R. Amthor and his colleagues at the University of Alabama identified and stained this cell, which was isolated from the retina of a rabbit. The colors distinguish different layers of cell branches. The cell has been enlarged about 5,000 diameters.

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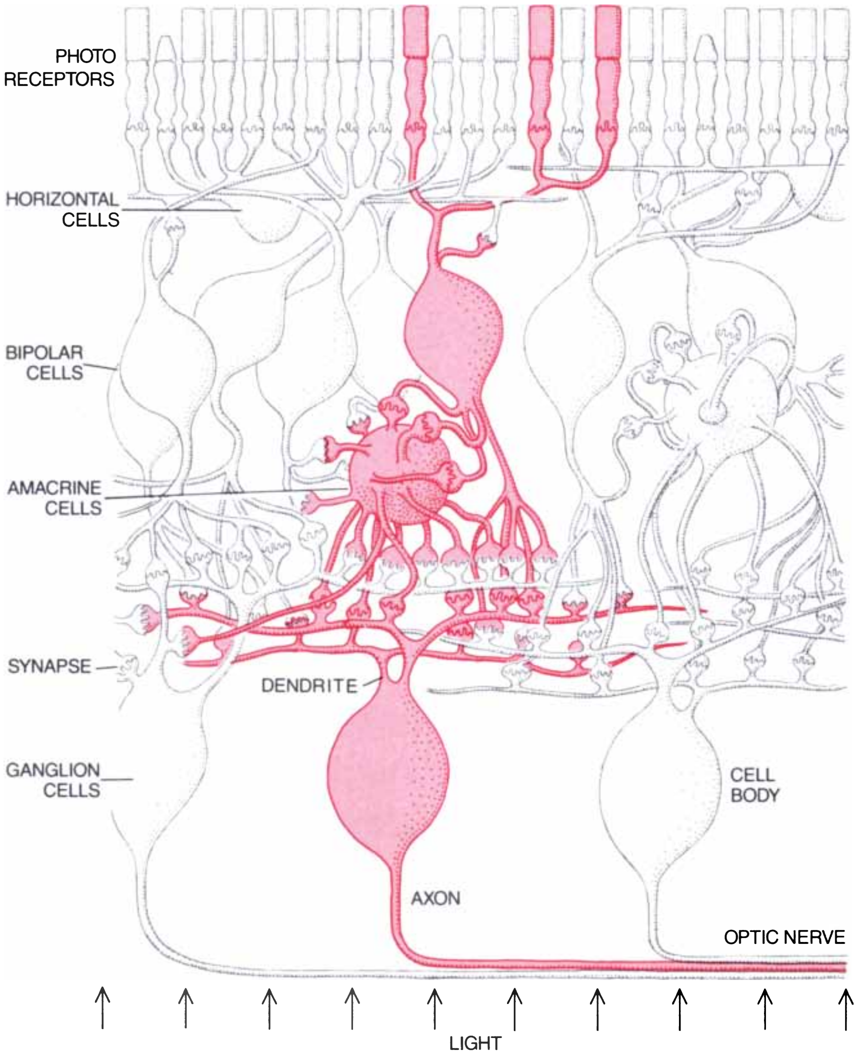
both the null and the preferred direction throughout its receptive field, it seemed that this veto operation must occur at many different places in the retinal nerve cells. Yet one question remained: What biophysical process could be responsible for the unusual veto interaction?

Understanding the generation of electrical signals in neurons requires some understanding of the events that precede them. As we have said, each branching dendrite of a neuron carries many hundreds of synapses receiving signals from "presynaptic" cells. When the action potential of a presynaptic cell arrives at the synapse, it triggers the release of a chemical messenger into the synapse. This messenger, called a neurotransmitter, diffuses across the small space between cells and binds to specialized receptors in the "postsynaptic" dendritic membrane. Neurotransmitter binding induces the opening of specialized channels in the cell membrane. The open channels allow ions, molecules or atoms that bear an electric charge, to enter and leave the nerve cell.

This opening and shutting of ion channels in the neuron membrane governs the electrical status of the cell. The most important ions taking part in this process are sodium, potassium and chloride. Pumps in the cell membrane increase the concentrations of certain ions and expel others; hence there is more potassium inside a cell than there is outside, and more sodium and chloride in the fluid surrounding the cell. The differences in concentration constitute what is called a concentration gradient for each ion.



THREE RETINAL LAYERS process visual stimuli and relay sensory information to the brain. Photoreceptors, which line the back of the retina, transform light energy into chemical and electrical signals that pass through the horizontal, bipolar and amacrine cells to the ganglion cells. Ganglion-cell axons form the optic nerve linking eye and brain.

As a consequence of ion distribution and the contributions of other charged molecules in the cell, the inside of a neuron is more negative than the outside by about 60 to 90 millivolts. (A millivolt is equal to one-thousandth of a volt; a 1.5-volt battery will power a flashlight.) This voltage is known as the resting potential because it is present when the cell is not conducting an impulse. The difference in voltage between the inside and the outside of the cell creates what is known as the potential gradient.

When synaptic stimulation opens up ion channels near the synapse, ions enter and leave the cell and the resting potential in this localized area is disturbed. The cell is said to be depolarized if this potential becomes more positive and hyperpolarized if it becomes more negative. This newly generated potential travels toward the cell body, decaying as it propagates, in a manner similar to electrical signal propagation in an underwater cable. If the final depolarization at the cell body is pronounced enough, it will induce an action potential. Therefore depolarizing stimulation is excitatory; the change in voltage is called the excitatory postsynaptic potential (EPSP). Inhibitory stimulation, which is most often hyperpolarizing, generates an inhibitory postsynaptic potential (IPSP).

Some synapses transmit excitation and some transmit inhibition, depending on which ion channels they regulate. When ion channels are open, the direction in which each ion moves is determined by the forces exerted by concentration and potential gradients. Hence sodium, a positively charged ion, diffuses into the cell through open sodium channels because both its concentration gradient and its potential gradient favor that direction. The influx of positive sodium ions causes depolarization of the nerve cell; therefore synapses that control sodium channels are excitatory.

By the same principle, potassium, which also bears a positive charge, leaves the cell when potassium channels are open. The concentration gradient encourages potassium's exit; in fact, it is so strong that it overcomes the force of the potential gradient, which works to draw positive charges into the interior of the cell. The departure of positive potassium ions hyperpolarizes the cell. Synapses that control potassium channels are therefore inhibitory.

A single nerve cell can experience many excitatory and inhibitory signals simultaneously. EPSP's and IPSP's propagate toward the cell body and can be measured as positive and negative contributions to the cellular potential.

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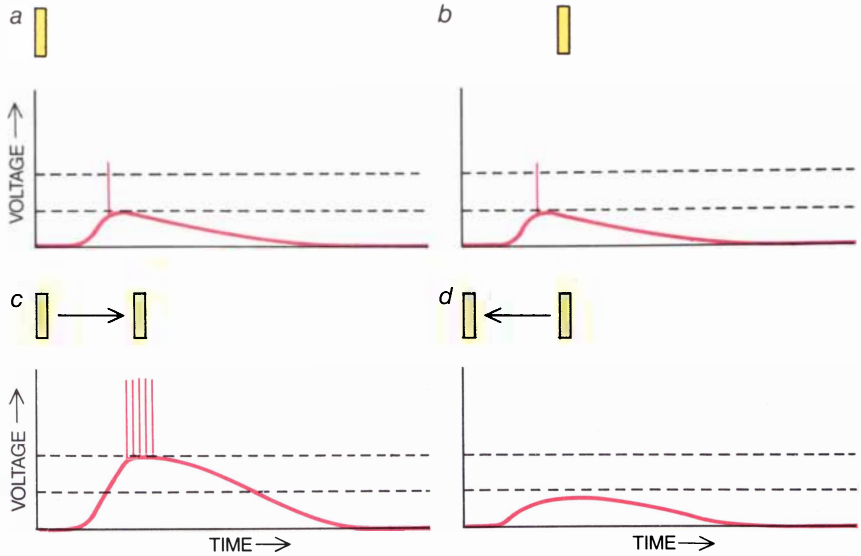
So far this view of neuronal activity does not stray from the one embodied by McCulloch and Pitts's formal neurons, and many neural functions appear to reflect this mode of operation.

In the late 1970's, however, several lines of evidence made it apparent that the ordinary interaction of excitation and inhibition could not account for the veto operation observed in motion detection. For instance, experiments that measured electrical activity inside rather than outside ganglion cells revealed the inner workings and interactions of EPSP's and IPSP's that control the generation of action potentials. They showed that when ordinary inhibition meets excitation, the net effect is usually hyperpolarization [*see bottom illustration at right*]. Intracellular recordings in turtle retinas, however, done by Piero L. Marchiafava at Italy's National Research Council in Pisa, showed that the interaction of excitation and inhibition that occurs during motion detection always results in mild depolarization rather than hyperpolarization. Indeed, hyperpolarization is never detected.

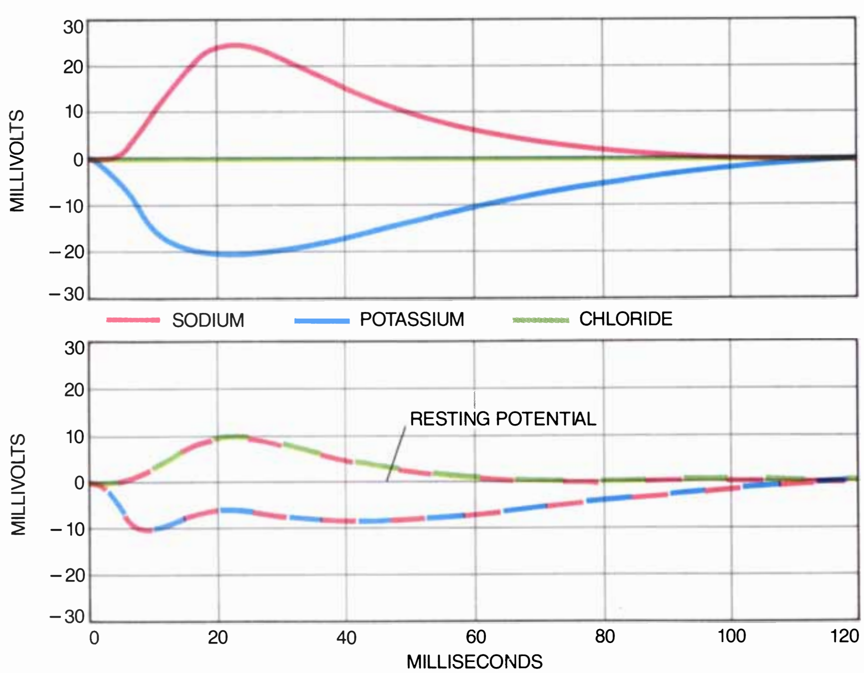
In 1978 Vincent Torre of the University of Genoa and one of us (Poggio, who was then at the Max Planck Institute for Biological Cybernetics in Tübingen) suggested a third type of synaptic mechanism that could be responsible for the veto effect observed in the detection of motion. The mechanism involves another type of inhibition called silent inhibition, which had been recognized in the 1950's; it is sometimes called shunting inhibition. We can use chloride to illustrate the basic principle, even though some experiments hint that chloride may not be the only ion involved.

Like sodium, chloride is present in a greater concentration outside the cell than it is inside; unlike sodium, chloride is negatively charged, and the potential gradient discourages the negative ions from entering the negative cell interior at rest. The concentration gradient and the potential gradient balance each other, so that when a silent inhibitory synapse signals chloride channels to open, nothing happens. Virtually no net redistribution of chloride occurs and there is almost no change in the resting potential.

On the other hand, if a silent inhibitory synapse is activated at the same time as an excitatory synapse, the sudden influx of sodium depolarizes the cell and upsets the balance between the two gradients. The repelling effect of the potential gradient decreases and the concentration gradient overcomes it, drawing in chloride ions. The net effect of the interaction is a mild depo-



ELECTRICAL ACTIVITY OF GANGLION CELLS gave early clues to the mechanism underlying motion detection. In the 1960's Horace B. Barlow and William R. Levick of the University of California at Berkeley exposed rabbit retinas to light through two slits that could be illuminated singly (*top*) or, to mimic motion, sequentially (*bottom*). Illuminating either slit individually gave rise to an action potential, an electrical spike that propagates to other nerve cells (*a, b*). Apparent motion in one direction (the "preferred" direction) generated many action potentials (*c*), whereas motion in the opposite direction (the "null" direction) usually prompted a much smaller response (*d*). From these results, shown schematically, Barlow and Levick concluded that some kind of biophysical "veto" operation was selectively blocking the excitation caused by motion in the null direction.



NERVE POTENTIALS result from changes in ion concentrations inside the cell. An excitatory postsynaptic potential, or EPSP (*red line*), is sparked by the influx of positive sodium ions that occurs when an excitatory stimulus opens sodium channels in the nerve-cell membrane. When an inhibitory stimulus opens potassium channels, positive potassium ions escape from the cell, generating an inhibitory postsynaptic potential, or IPSP (*blue*). No movement of chloride ions occurs when only chloride gates are open (*green*). If chloride channels and sodium channels open simultaneously, however, chloride ions will enter the cell and dampen the EPSP; this effect is called silent inhibition (*red and green line*). Note that ordinary inhibition can make the cell more negative as it interacts with excitation (*red and blue line*), whereas silent inhibition has a positive influence.

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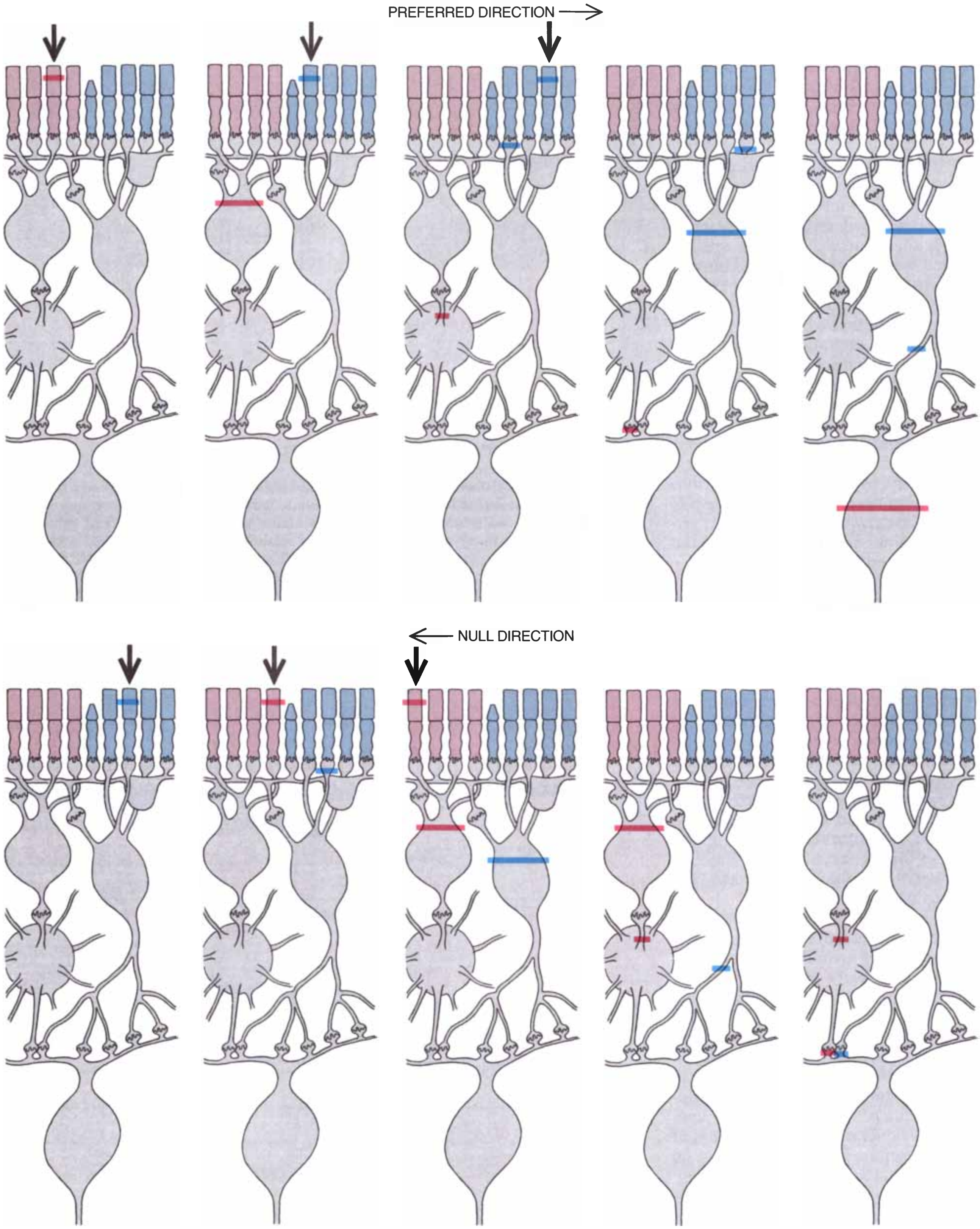

RACE BETWEEN NERVE POTENTIALS has different outcomes at the ganglion cell depending on whether motion is in the preferred direction (*top*) or the null direction (*bottom*). In this model the photoreceptors for each ganglion cell are arranged so that a stimulus (*heavy arrow*) moving in the preferred direction activates excitatory receptors (*red*) before inhibitory receptors (*blue*). The model also assumes that inhibitory signals (*blue bars*) are delayed in time with respect to excitatory signals (*red bars*). When motion is in the preferred direction, inhibitory pulses never catch excitatory impulses, which generate action potentials at the ganglion cell body. For movement in the null direction, however, the inhibitory signal arrives at the ganglion cell at the same time as the excitatory signal and prevents the generation of an action potential. The authors suggest that the mechanism by which the two signals negate each other, implementing the veto operation proposed by Barlow and Levick, might involve silent inhibition.

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larization like those Marchiafava observed in the retina of turtles.

Unless the inhibitory signal coincides with an excitatory signal, it cannot be detected through monitoring of the nerve potential; hence the name "silent" inhibition. Silent inhibition depends on excitation to activate it and, as Barlow and Levick's model predicts, excitatory and inhibitory signals coincide only when they are stimulated by motion in the null direction. For movement in the preferred direction, the inhibitory delay prevents the vetoing of excitation and the cell responds vigorously. Thus our concept of silent inhibition represents a viable implementation of the abstract models advanced by Reichardt and Hassenstein and by Barlow and Levick.

The silent-inhibition mechanism is attractive for application to direction selectivity for another reason. Our model implies that the best placement for a silent inhibitory synapse is either at the same location as an excitatory synapse or somewhere between the excitatory synapse and the ganglion cell body. The model therefore needs just a few synapses and a patch of dendritic membrane to operate. The two signals interact before they reach the cell body, thereby satisfying the observation that the veto probably occurs at many different locations in the retinal neurons.

We were still unsure, however, that the physiological features our model requires were realistic. What kind of proximity did inhibitory and excitatory synapses need to influence one another's potential? What were the optimal locations for synapses and the optimal configurations of dendrites? We turned to the computer for answers.

The theory we used to describe the spread of the electric potential in a nerve cell is a descendant of the theory developed by Lord Kelvin in the 19th century to analyze current flow in transatlantic telephone transmission lines. Wilfrid Rall of the National Institute of Arthritis, Diabetes, and Digestive and Kidney Diseases first applied Kelvin's analysis to the spread of potential in dendritic trees. The actual computation began at the Max Planck Institute; later we turned to a circuit-simulation program called SPICE, which was developed more than 10 years ago at the University of California at Berkeley.

We began developing our particular version about three years ago with the help of Patrick A. O'Donnell of the Artificial Intelligence Laboratory at M.I.T. From anatomical descriptions of the shape of a neuron, the length and diameter of its branches and so on our version of SPICE constructs an appropriate cable model and then assigns electrical properties to the computer-generated dendritic tree. It can plot in color the course of the nerve potential in response to the synaptic input that we dictate.

Such simulations have shown that our proposed mechanism is credible: it generates patterns of electrical activity that account for direction selectivity. Our simulations also confirmed our hunch that silent inhibition must be a very localized phenomenon, dependent for its efficacy on the relative positions of excitation and inhibition in the dendritic tree. In order to block the propagation of an EPSP, silent inhibition must occur on the direct path between the excitatory synapse and the cell body. Although these simulations assume that the dendritic membrane does not amplify excitatory signals, these limitations would still hold true if it did. Hence our simulation has enabled us to demonstrate that the veto operation takes place at many different locations within the dendritic tree and before the signals reach the cell body.

In recent years additional information has accumulated from recordings of the electrical events on the inside of direction-selective cells. How well does our theoretical model fare in view of new experimental evidence? Recordings from ganglion cells in the retina of turtles and bullfrogs support the scheme of synaptic interactions represented in our model. Furthermore, Marchiafava's more recent intracellular recordings have revealed the workings of silent inhibition that are usually invisible when inhibitory synapses are activated alone. By injecting a positive current into a cell through a recording electrode, Marchiafava managed to make the cell's resting potential more positive; then the isolated action of silent inhibitory signals appeared as hyperpolarization of the elevated resting potential.

Other investigations have disclosed the anatomy of the direction-selective cells. By injecting fluorescent dyes into the cells, Frank R. Amthor, Clyde W. Oyster and Ellen S. Takahashi of the University of Alabama obtained a clear image of the rabbit retinal cells Barlow and Levick had explored 20 years earlier. Ralph J. Jensen and Robert DeVoe, then at the Johns Hopkins University School of Medicine, carried out the same procedure on turtle ganglion cells with equal success. The cells have highly branched dendrites with extremely fine extensions, maximizing the number of sites where synaptic interactions can operate. This configuration matches our notion of silent inhibition as a distinctly localized phenomenon.

One prediction that remains to be tested is the relative location of excitatory and inhibitory synapses in the dendritic tree of the direction-selective cell. The recent discovery of the neurotransmitters that mediate the EPSP and IPSP will aid this investigation. The amino acid gamma-amino-butyric acid (GABA), a common inhibitory neurotransmitter in the central nervous system, also plays the inhibitory role in direction selectivity: direction-selective ganglion cells treated with drugs that block GABA action respond equally to motion in the null and preferred directions. With experiments of similar design Richard H. Masland of the Massachusetts General Hospital and Michael Ariel and Alan R. Adolph of the Eye Research Institute in Boston have shown that acetylcholine (ACh) acts as the excitatory neurotransmitter for motion discrimination in the retina of turtles and rabbits.

Because ACh and GABA can be labeled, it may now be possible to identify the excitatory and inhibitory synapses on stained direction-selective ganglion cells. Such work is currently in progress in the laboratory of John E. Dowling at Harvard University. We expect that the results of this experiment will be critical in confirming or refuting our model.

Our model is sufficient to account for current empirical evidence, but other models for direction selectivity have not been ruled out. For instance, it is conceivable that excitation and silent inhibition interact before reaching the ganglion cell, on the dendrites of another retinal neuron. One possible host for such interaction is the starburst amacrine cell described by Masland [see "The Functional Architecture of the Retina," by Richard H. Masland; SCIENTIFIC AMERICAN, December, 1986]. The amacrine cells lie in the intermediate layer of the retina that carries signals from the photoreceptors to the ganglion cells.

Amacrine cells are the only cells in the retina that synthesize and secrete ACh; thus they are the likeliest to provide the excitatory input to direction-selective ganglion cells. The release of transmitter from the cell might already reflect the influence of inhibition, however. Furthermore, DeVoe and his collaborators have found the first evidence for direction-selective properties in turtle amacrine and bipolar cells, which also reside in the cell layer between the photoreceptors and the ganglion cells. Their finding raises the possibility that motion may be

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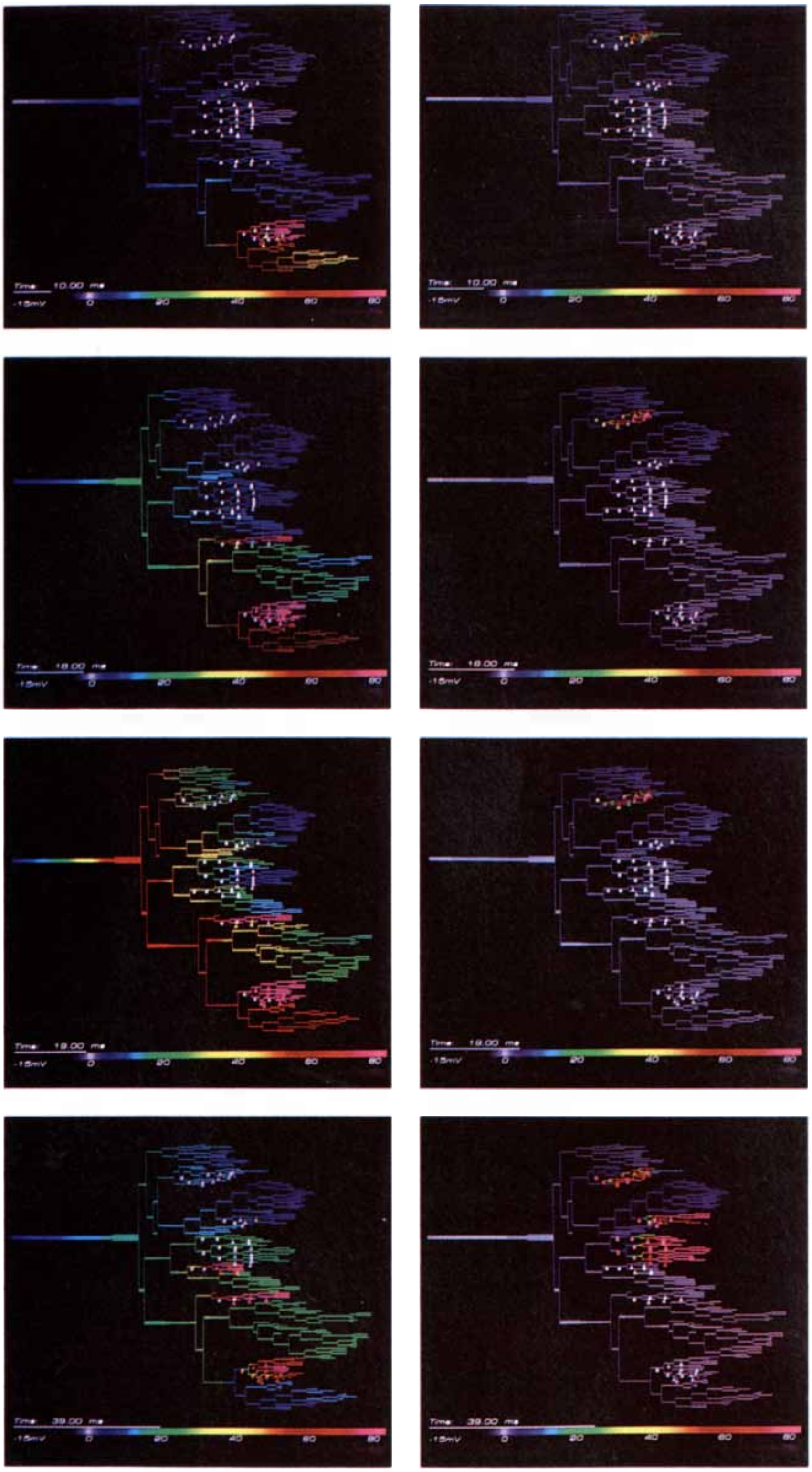

COMPUTER SIMULATIONS re-create the morphology and electrical properties of the ganglion cell on page 47. "Hot" colors, such as red, orange and yellow, indicate excitation; "cool" colors indicate inhibition. The activity of excitatory synapses (*triangles*) and inhibitory synapses (*circles*) is similarly depicted. In the left-hand sequence a stimulus moves from the bottom to the top of the frame and inhibitory responses are delayed by 20 milliseconds to model motion in the preferred direction, whereas there is no delay on the inhibitory signals in the right-hand sequence, which models null-direction stimulation. Excitatory signals reach the cell body and generate an action potential at 19 milliseconds in the left-hand sequence. The model, which was programmed by Patrick A. O'Donnell of the Massachusetts Institute of Technology, showed that excitatory and inhibitory synapses must be quite close together in order to achieve the veto effect of silent inhibition.

computed in other retinal locations instead of in the ganglion cells or in addition to them.

A combination of theory, modeling and experimentation is therefore on the verge of elucidating the mechanism underlying detection of motion in the animal retina. Why is this operation so interesting? As an important function in the first stage of vision, direction sensitivity is a worthy subject by itself. Much more important would be the understanding of an elementary information-processing mechanism that could turn up in other computational tasks. A number of researchers using different animals have proposed that the same mechanism is involved in the computation of binocular depth, visual motion discontinuities and tactile motion across the body surface.

As a computational element the synaptic veto model is attractive because of its localized action and its flexibility, particularly in contrast to action-potential generation. Because it operates on such a small scale, the mechanism could be replicated hundreds of times in the dendritic branches, establishing more or less independent subunits in a single neuron. One can think of the McCulloch and Pitts model as equating a neuron with a single transistor, whereas our model suggests that neurons are more like computer chips with hundreds of transistors each.

We call our genre of investigation the biophysics of computation; it is the study of the involvement of the various biophysical mechanisms underlying information processing by the nervous system. Of course, the biophysics of computation is not confined to the generation of the action potential and the interactions among synaptic inputs. There are many biophysical phenomena capable of processing, propagating and storing information. We have examined a variety of biophysical mechanisms; they implement operations such as filtering the signals that occur at a particular frequency, modifying the strength of connections between nerve cells and controlling with slow-acting chemicals the output of nerve cells.

Both experimentalists and theoreticians are engaged in identifying these phenomena and characterizing their roles in information processing. It may someday be possible to infer from the cellular morphology of any given neuronal circuit the operations it can perform. Thus probing the intricate secrets of the central nervous system may eventually unite the sophisticated processing of the human brain with the depth of understanding that created computers.

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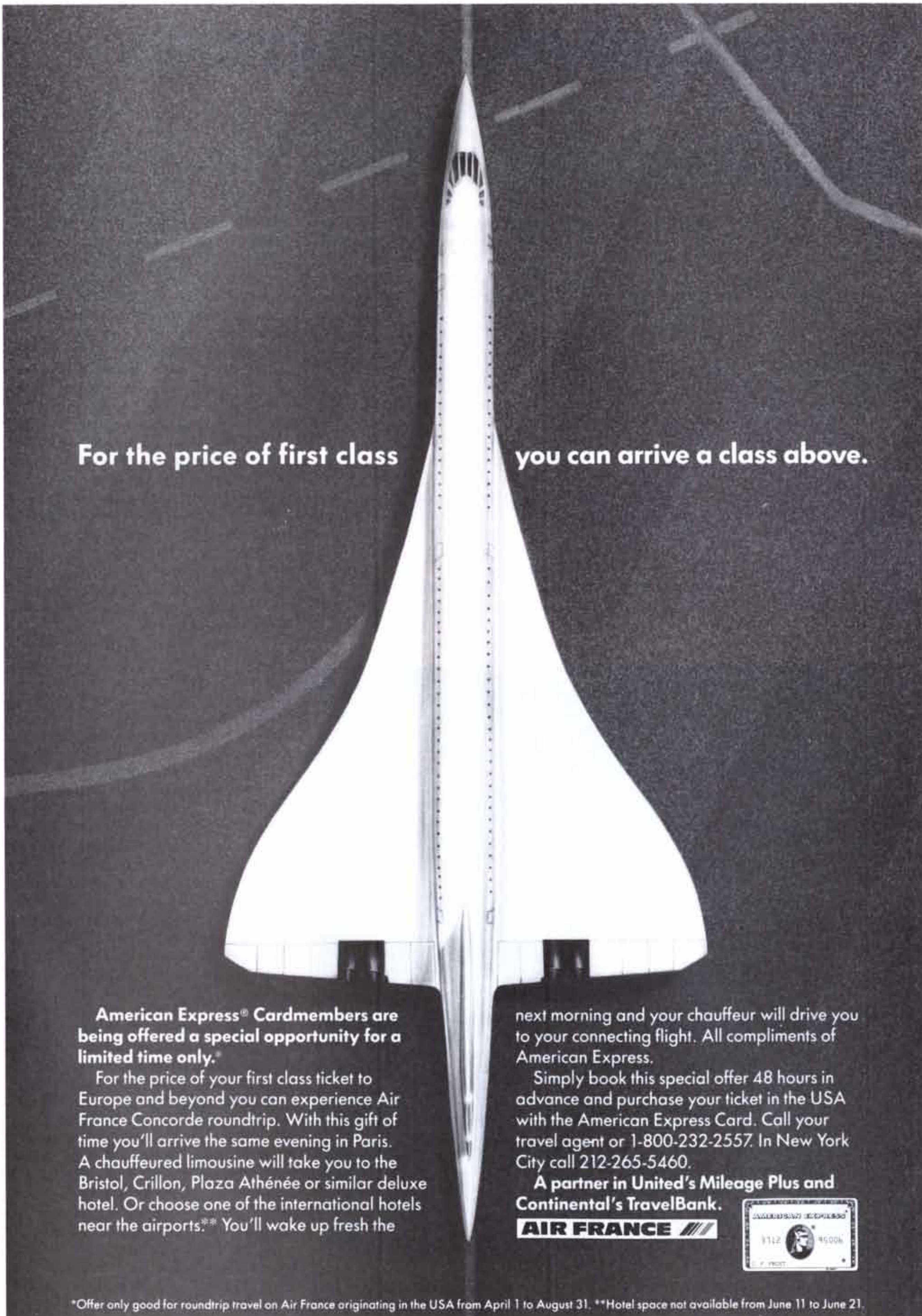

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SCIENCE AND THE CITIZEN

Supernova!

In the study of supernovas the dialectic between theory and observation has been heavily weighted toward theory. Although these stellar cataclysms can shine as brightly as galaxies, none has been clearly visible to earthly eyes since 1604. Those detected in modern times have occurred in galaxies millions of light-years away, and they yield trickles of photons that only the most sensitive instruments can discern.

Supernova 1987A, first spotted on February 24 by Ian K. Shelton of the Las Campanas Observatory in Chile, has redressed the imbalance. It sparkles vividly within the Large Magellanic Cloud, a small satellite galaxy of the Milky Way visible in the Southern Hemisphere, a mere 170,000 light-years from the earth. 1987A has showered the earth not only with photons—detectable as light, radio waves and other forms of electromagnetic radiation—but also with the elusive particles known as neutrinos, which are thought to play a crucial role in stellar evolution. This in itself is a milestone: no particles other than photons have ever been linked to a specific source outside the solar system.

From the start the flood of data from telescopes, satellites, radio observatories and other instruments has challenged existing theory. Supernovas are classified into two types on the basis of a simple observation: the spectrum of a Type I supernova does not show hydrogen, the spectrum of a Type II does. Theorists hold that a Type I derives from a dim white dwarf that has burned all its hydrogen; it explodes when it drags matter from a companion star, precipitating a thermonuclear reaction. A Type II is believed to derive from a red giant with unburned hydrogen at its perimeter and a core of heavier elements; when the core reaches a certain mass, it collapses and rebounds, thereby precipitating a shock wave that blows off the star's outer layers.

In the narrowest sense 1987A is a Type II: the outside of its expanding shell contains a great deal of hydrogen. The detection of neutrinos from the supernova seems to confirm a key hypothesis of the Type II model: that as a red giant's core collapses to a stage known as "maximum scrunch," the intense heat generates huge numbers of neutrinos; these escape in a powerful pulse as the core rebounds. At least two detectors—at Kamioka in Japan and at Fairfax, Ohio—recorded neutrino bursts that arrived about three hours before 1987A was first seen.

In other key respects 1987A has behaved as if it were produced by a relatively small star, one more likely to produce a Type I supernova. The supernova peaked in intensity within days rather than weeks and never became as bright as theorists had predicted. Even odder is the inability of astronomers to identify the progenitor star whose explosion created 1987A. Unlike a white dwarf, a Type II progenitor (whose mass should be at least eight times that of the sun, according to theory) should have been easy to detect in photographs made before the supernova exploded.

Soon after 1987A appeared investigators thought they had found a candidate in the right place: a blue supergiant named Sanduleak −69 202. Sanduleak was not exactly what theorists expected, because blue supergiants are thought to be too hot and too young to explode. The mystery deepened when readings from the satellite *International Ultraviolet Explorer* suggested that Sanduleak might be still intact. Now investigators are poring over old plates once again to see whether the image of Sanduleak actually shows two stars so closely aligned that they appeared as a single point of light, one of which exploded. Close companions of Sanduleak are also being studied.

1987A "does not seem to fit the standard picture," Roger A. Chevalier of the University of Virginia acknowledges. Some astronomers argue that the poor match of data and theory exposes fundamental weaknesses in the Type I and Type II models. David J. Helfand of Columbia University advocates scrapping the categories. "Using those terms just confuses everyone," he says. Others disagree. "The models haven't misled us," Robert P. Kirshner of Harvard University maintains. "The fact that we've seen neutrinos shows we're on the right track."

Some of the secrets of 1987A may be resolved when its brilliant outer shell, expanding more than 10,000 kilometers every second, dissipates

SUPERNOVA 1987A shines like a 4.5-magnitude star in this photograph made at the National Optical Astronomy Observatories' Cerro Tololo Inter-American Observatory.

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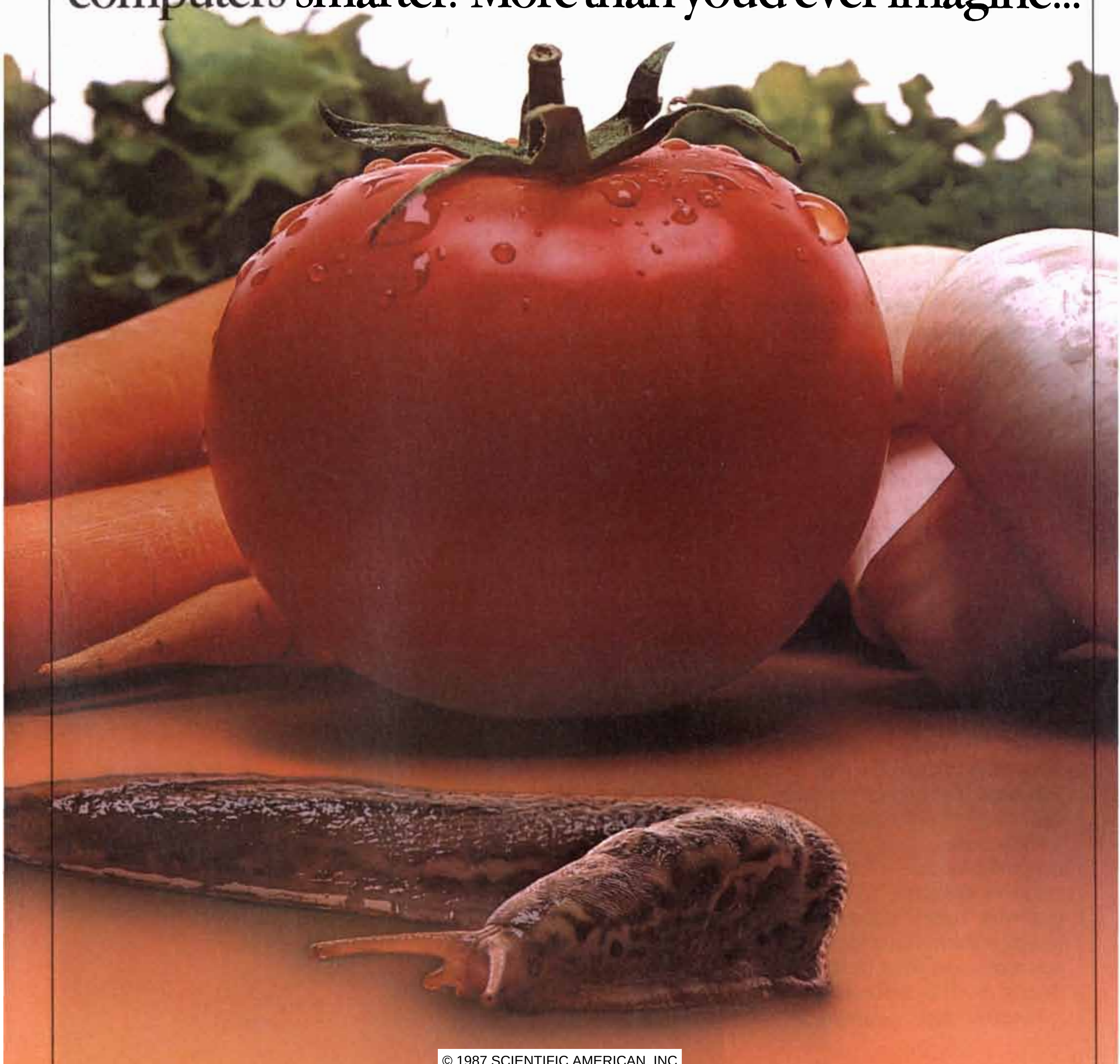
The garden slugs in a microelectronics lab at AT&T Bell Laboratories are very fussy eaters. They won't go near their favorite foods if they smell a whiff of garlic. Garlic? Garden slugs? What could that possibly have to do with making computers smarter? More than you'd ever imagine...



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AT&T Bell Laboratories: Technology for the real world

Slug as savant: "Nature has shown us there are powerful computer designs very different from conventional machines."

The common garden slug loves the enticing odors of carrot, tomato and mushroom. But it hates garlic. When scientists at AT&T Bell Laboratories "spike" these favorite foods with garlic, what happens? The slug learns. It alters its memory of the foods it once loved and avoids or rejects them.

Insights gained from studying simple central nervous systems like the slug's point to a dramatically new approach to computing. An approach that promises to make computers faster, smarter and easier for people to use.

Why study slugs? Though the slug is no Einstein, its brain's limited ability to learn—to associate new information with existing memories—makes today's most powerful computers seem primitive.

And the slug, with its neural networks comprised of a mere 500,000 nerve cells or neurons, is much less complicated to work with than people or other animals.

Microchips that mimic the brain

On functioning computer chips, microelectronics researchers have built prototype electronic neural networks.

Like biological networks of brain nerve cells, these electronic circuits use associative memory to relate incoming information to memories already stored. So they can cope with information filled with errors or ambiguity. And they can deal with "messy" information, collecting scattered facts to recognize and remember from incomplete details, much as the brain does.

One test chip, containing 54

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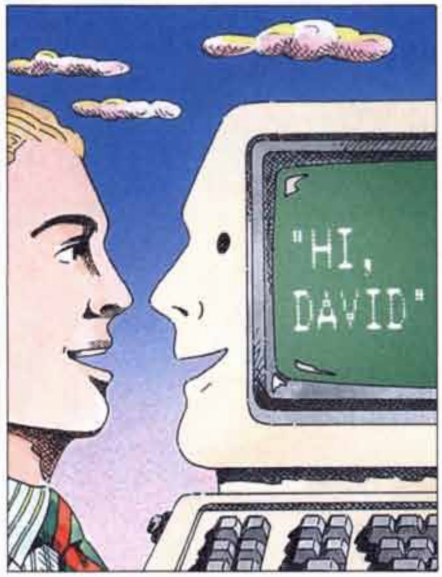
In the future, people and their computers will have a much friendlier working relationship.



"neurons" in such a "neural network," can recall memories from imperfect data within a few millionths of a second—selecting "James Lynn" from among several stored names as the correct response to the input "Jim."

Getting up to speed

By studying simple central nervous systems like the slug's, scientists at Bell Labs are also gaining valuable insights into another brain function, parallel processing. It offers an answer to a physical limitation of today's computers—speed.

Step-by-step computing can only process information one piece at a time. Parallel processing, the ability to perform several functions simultaneously, speeds things up. And the more things done together, the faster the whole job gets done.

Today's computers can only process neatly-stored information. A little human ability to deal with messiness might actually make them a whole lot smarter.

"Thinking" computers

Where is this research into associative memory and parallel processing leading? To "thinking" computers that make good judgments as well as good calculations. Computers that can perceive and learn in an imperfect world, much as people do.

In the future, working with computers will be more like working with people. The machines will understand and respond to human speech—even recognize the person addressing them.

Taking the longer view

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NOTHING ATTRACTS LIKE THE IMP

CORIANDER SEEDS FROM MOROCCO ANGELICA ROOT FROM SAXONY JUNIPER BERRIES FROM ITALY CASSIA BARK FROM INDOCHINA

further. By peering inside this envelope astronomers hope to learn what heavy elements the star contained, and in what quantities. They also hope to determine whether 1987A left a remnant, either a black hole or a neutron star, as Type II's are supposed to do. Robert E. Williams of the Cerro Tololo Inter-American Observatory in Chile points out that even if a remnant exists, it may never be detected. Black holes by definition release no detectable radiation. Neutron stars are detectable only if they are pulsars, which rotate so rapidly that they emit powerful, rhythmic bursts of electromagnetic radiation.

Hans Bethe, who won a Nobel prize in physics in 1967 for his work on stellar evolution, suggests that if new data pose new questions, theorists will revel in the challenge. "The fact that there are open questions is a good thing," he says. "It means we have more to think about and more data to hang our theories on."

Geneshot

As spring comes to Washington the seed of an ambitious project has sprouted unexpectedly at the Department of Energy. A departmental advisory committee has recommended that the agency lead an effort to develop technologies for determining the sequence of the three billion chemical bases in human DNA that spell human being. Success would potentially put human intelligence in control of the genetic destiny of our species.

If it is approved by the Administration and funded by Congress, sequencing the genome would certainly be biology's biggest undertaking. New diagnostic tests and perhaps therapies for genetic diseases would be among the early practical benefits. On the other hand, a sequencing project would require years of work by hundreds of scientists and would cost hundreds of millions of dollars.

The project was conceived and launched by Charles P. DeLisi, director of the Energy Department's Office of Health and Environmental Research. DeLisi was inspired 18 months ago by a report by the Office of Technology Assessment on techniques for detecting heritable mutations in human beings, and he soon found that scientists at the department's Lawrence Livermore National Laboratory had been thinking along similar lines.

Sequencing would first require the construction of a rough "physical map" of the genome. The Energy Department is already committed to this stage of the project, for which the technology is available. For example, new techniques for handling large pieces of DNA have been developed in recent years. Cassandra L. Smith, Charles R. Cantor and others at Columbia University have recently demonstrated the methods' usefulness by constructing a complete map of the 4.7-million-base genome of *Escherichia coli.*

With conventional techniques the cost of actually sequencing the human genome, at about $1 per base, would be a problem—a $3-billion problem, in fact. But Leroy E. Hood of the California Institute of Technology, who has pioneered the development of automated sequencing equipment, believes advances in robotics will lower costs to one cent or less per base pair within a few years; already the Japanese have made advances, and there are hopes that sequencing could be coordinated internationally. Cantor says that if the cost came down to $300 million, "you could convince people to do it over 10 years—including other biologists" who fear that the project will eat into their own budgets.

Although it would take perhaps 30,000 technician-years to do the job at current rates, DeLisi thinks the pace could be speeded up a thousandfold. The Energy Department plans to set up several centers across the country to initiate the effort and has already started mapping three chromosomes

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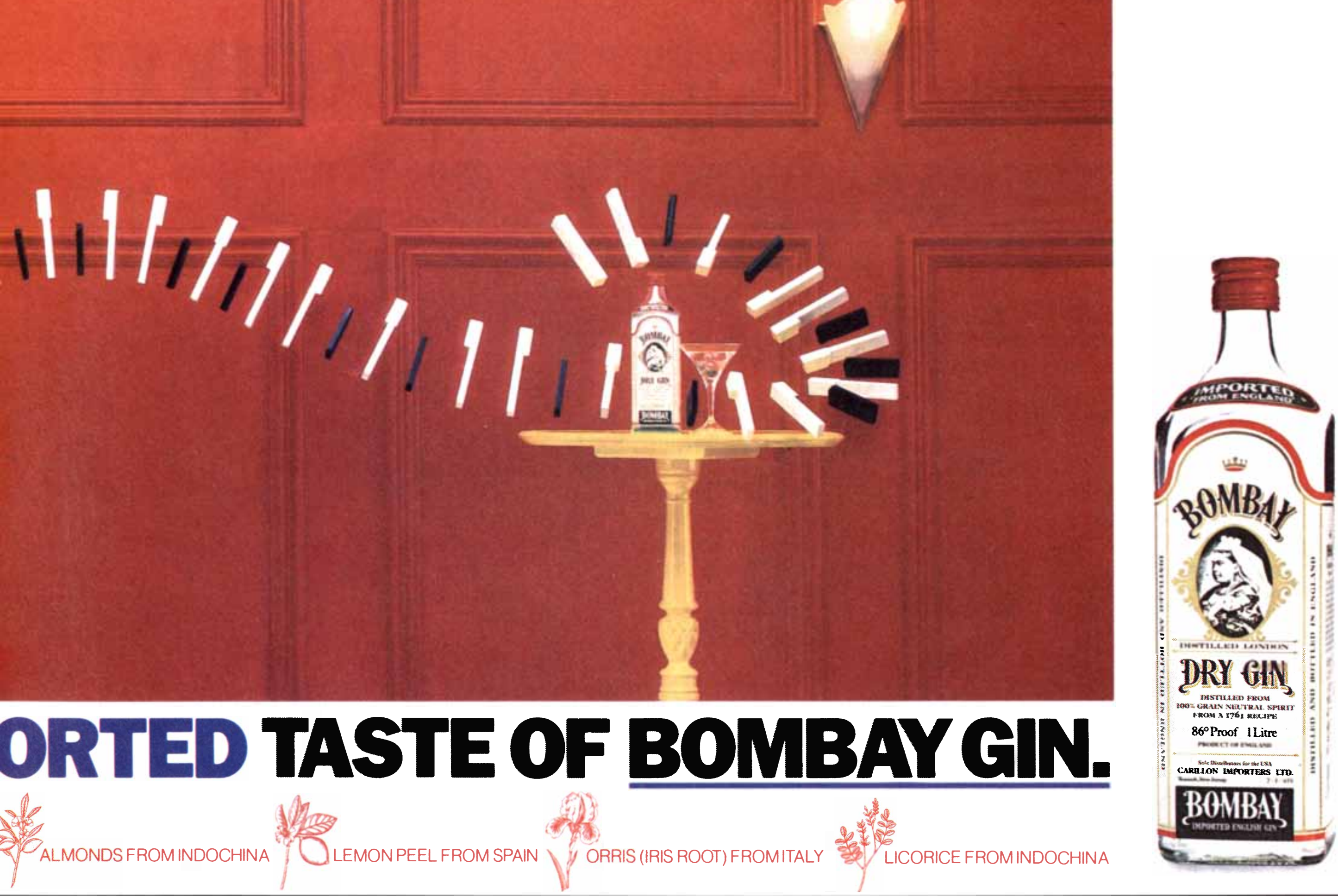

to test techniques. The budget recommended to the department for the preliminary work is $40 million in 1989, increasing to $200 million per year in the course of five years. The private sector could play an important role in the project; indeed, several entrepreneurial boats, including Applied Biosystems, Inc., which uses Hood's sequencing technology under license, may be floated if the department's program materializes.

Although virtually all geneticists support the preliminary mapping effort, many have reservations about an all-out attack on the sequence. Some think large fractions of the genome consist of meaningless "junk DNA" whose sequence will not be informative. Others agree with Hood, who thinks "a lot of the supposed junk DNA is going to turn out to be interesting in ways we don't understand."

Critics raise a further point: Why should the Energy Department lead a major research program in a field of science peripheral to energy? Straight-faced, DeLisi responds that knowing the complete genome sequence would help the department to evaluate competing energy strategies. DeLisi also points out that the department has gained expertise with human DNA through its follow-up studies of Japanese atom-bomb survivors. Furthermore, the agency has the most powerful nonmilitary supercomputers in the world. Finally, the department's claim is not exclusive. The advisory committee recommends that more than half of the mapping work should be contracted to outside laboratories.

The biomedical establishment is not convinced. Nobel laureate James D. Watson, codiscoverer of the structure of DNA and director of the Cold Spring Harbor Laboratory, says the National Institutes of Health should lead the project because he does not "yet see at DOE the expertise in molecular biology associated with NIH." James B. Wyngaarden, director of the NIH, who also chairs a White House committee on genetic sequencing, points out that the NIH is already spending $300 million per year on work that produces gene maps and sequences. While praising the Energy Department's "vision," Hood says "many of us have doubts about the intellectual viability of the national laboratories and whether they can effectively undertake big projects."

David Baltimore, a Nobel laureate and the director of the Whitehead Institute for Biomedical Research at the Massachusetts Institute of Technology, wrote recently in *Issues in Science and Technology* that a "megaproject" such as the sequencing of the human genome will "increase political control over science." Baltimore would like the sequencing to go forward at its own pace as part of "normal science," competing grant by grant with other important research projects—many of which must go unsupported. But the "Human Genome Initiative," as it has been dubbed, seems to have gained significant support in Congress.

Soviet SDI?

Is the Soviet Union planning a nationwide defense against ballistic missiles like the one sought by the U.S. Strategic Defense Initiative?

In a statement to the Senate Armed Services Committee in January, Admiral William J. Crowe, Jr., chairman of the Joint Chiefs of Staff, said "we see [the Soviets] moving toward a nationwide defense against offensive ballistic missiles—including the possibility of an Anti-Ballistic-Missile Treaty breakout." Yet President Reagan's annual report on Soviet noncompliance with arms treaties, sent to Congress in March, is more circumspect: it merely repeats previous "concerns that the Soviet Union may be preparing an ABM defense of its national territory."

Satellite reconnaissance data have done little to relieve the ambiguity. The Soviet Union is building three new

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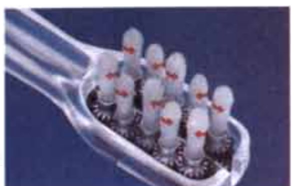

Bristles rotating 4,200 times a minute literally scour plaque off your teeth.

INTERPLAK cleans teeth virtually plaque-free.

If plaque is not removed daily, its bacterial film can lead to gingivitis, an early stage of gum disease, and tooth decay. But clinical studies have shown that manual brushing removes only some of the plaque buildup. Those same studies, on the other hand, show INTERPLAK cleans teeth and gums virtually plaque-free.

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giant phased-array radars in the western part of its territory, bringing its known total to nine. Because they are near the country's borders and point outward, the new radars are permitted under the ABM treaty—if they are to provide early warning of an attack. They could also conceivably assist battle management in a nationwide ABM system, however—and that would be forbidden.

The new radars are similar to the radar at Krasnoyarsk in Siberia, which is generally considered to be in violation of the ABM treaty because it stands deep within Soviet territory. The Administration's dim view of the radars is challenged by the Arms Control Association, a private lobbying group that marshals considerable technical experience. The ACA says Krasnoyarsk-type radars operate at a frequency (approximately 150 megahertz) that is an order of magnitude too low for an ABM system: higher frequencies are less susceptible to the blackout effects of nuclear explosions.

Several less advanced Soviet radars, previously cited as potential ABM-treaty violations because they might easily be moved, have been dismantled. Official sources say the significance of this is not clear. Peter D. Zimmerman of the Carnegie Endowment for International Peace thinks it indicates that U.S. efforts to persuade the Soviet Union to improve its treaty compliance "have borne fruit." In Zimmerman's opinion the U.S. can be "very confident" that the Soviets are not yet planning a nationwide ABM system because he sees no evidence of centralized military leadership of a coordinated program; nor, he points out, have there been any such accusations from the U.S. Government.

The fact remains that the Soviet Union has long conducted research into "exotic technologies" such as lasers and particle beams that might be elements of ABM defenses. Christer Larsson, director of the Space Media Network in Stockholm, has obtained photographs of large linear structures, fed by heavy-duty power cables, at high-altitude sites in the region of Dushanbe, close to Afghanistan. A powerful laser so positioned might blind satellites by disrupting their sensors and solar cells, according to some Pentagon-commissioned studies. Larsson says Soviet officials have declined to confirm or deny his suggestion that the pictures show "SDI-like" work.

Even if the U.S.S.R. were to push for deployment (as the U.S. is considering doing), some analysts believe alarm should be tempered. Simon Kassel of the Rand Corporation in Washington mentions free-electron lasers and microwave-generating gyrotrons as "exotic" areas in which the Soviets may have a lead. Kassel says, however, that the Soviets are still "very far from any weapons concepts" applying such technologies and have not yet mounted proof-of-feasibility demonstrations. For anything beyond this stage, Kassel maintains, "there would have to be massive [military] participation, but I don't think there is, and I don't think their industry could handle [the program] without reform."

PHYSICAL SCIENCES

Scheiner's Halo

By transforming water droplets into diamond-shaped ice crystals, two Austrian investigators have provided the strongest evidence yet that ice crystals occur in nature in more than one form. The experiments also bolster a hypothesis, advanced six years ago, that diamond-shaped ice gives rise to a rarely detected atmospheric phenomenon called Scheiner's halo.

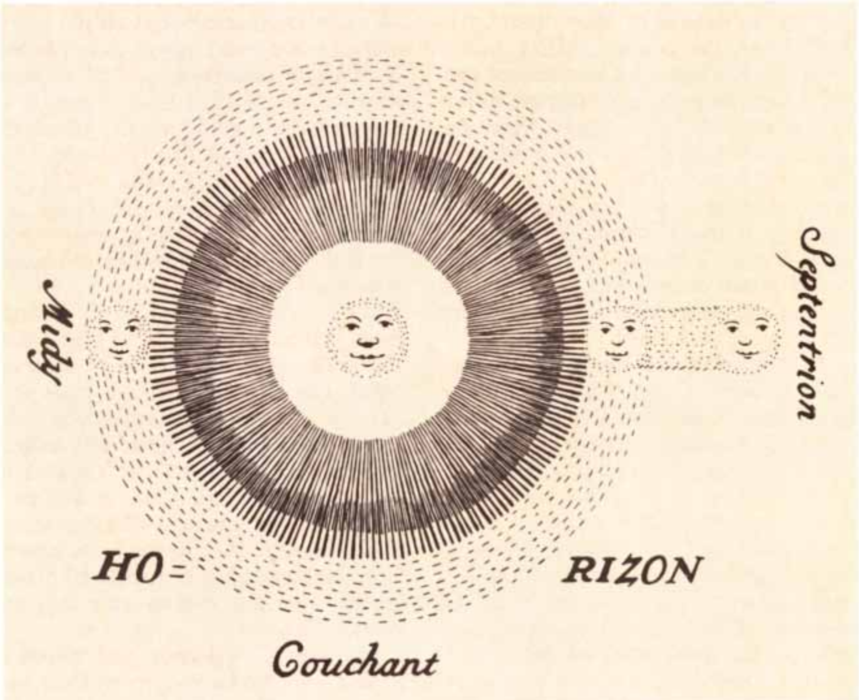
All the ice crystals found so far in nature are hexagonal. In the upper atmosphere they usually form six-sided plates or columns from several micrometers to several millimeters across. When they mass together—typically within hazy cirrus clouds at about 30,000 feet—the crystals often act as prisms, refracting light in such a way that an observer on the earth sees "halos," or rings of light, around the sun, moon or any light source.

Hexagonal crystals can produce halos of various widths. The commonest halo has a radius of 22 degrees, that is, a line drawn from the center of the light source to the observer's eye and back to the outer edge of the halo forms a 22-degree angle. The halo develops when light is refracted through the 60-degree prism formed by alternate faces on the perimeter of a hexagonal crystal. A less common halo, produced when light bends within the right-angled prism formed by the base of a column and one of its sides, has a 45-degree radius.

No matter how they are oriented, hexagonal crystals cannot produce a halo that has a radius of 27.5 degrees: Scheiner's halo. Named after Christophe Scheiner, a Jesuit astronomer who first noted it in Rome in 1629, the elusive halo has been seen only seven times in recorded history. French meteorologists filed the last known report in Paris in 1920.

In 1981 Edward Whalley of the National Research Council of Canada proposed that Scheiner's halo might be produced by diamond-shaped ice crystals—in other words, octahedrons. Whalley, an authority on the molecular structure of water, pointed out that the 71.5-degree prism formed by two opposite faces of the top of an octahedron would bend light the requisite 27.5 degrees.

The hypothesis had a weakness: in-



SCHEINER'S HALO was sketched by astronomers in Paris in 1677. The smiling faces at the left and right represent parhelions, bright spots that often accompany solar halos.

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vestigators had produced octahedral ice crystals by condensing water vapor at extremely low temperatures, but the crystals immediately deformed into hexagonal ones when exposed to atmospheric temperatures. Erwin Mayer and Andreas Hallbrucker of the University of Innsbruck have helped to solve this stability problem. They report in *Nature* having created octahedral crystals by freezing water droplets several micrometers in diameter, a size found in cirrus clouds. Very low temperatures (about −80 degrees Celsius) were still required to create the crystals, but many of them resisted transformation for half an hour or more even when warmed to above −40 degrees, a temperature common in the upper atmosphere.

Whalley thinks Scheiner's halo, although surely an extraordinary event, occurs more often than the record indicates. At least six of the seven recorded sightings, he points out, were made at manned observatories. The dearth of reports in modern times may have to do less with unfavorable atmospheric conditions, Whalley suggests, than with the growing automation of meteorological and astronomical observation.

Nuts and Jolts

Take a can of mixed cocktail nuts—say peanuts, Brazil nuts, hazel nuts and cashews—and shake it. When you open the can, the Brazil nuts, which are larger than any of the others, will have risen to the top. Why?

The question is of more than cocktail-circuit importance. Many industrial processes involve mixtures of particles or powder grains that are different sizes. Examples range from the pharmaceutical industry to paint- and glassmaking to metallurgy. In most of the processes it is considered a disadvantage if the particles segregate by size, and so it is important to understand what causes the migration of large grains to the top of the pile when the mixture is shaken.

In search of an explanation, four investigators from Carnegie-Mellon University have simulated the shaking process on a computer. They describe the mechanism that causes the segregation in *Physical Review Letters.*

The collaborators, Anthony Rosato, Katherine J. Strandburg, Friedrich Prinz and Robert H. Swendsen, simulated a two-dimensional jar of mixed nuts (or mixed powders). Their model takes the form of a two-dimensional box filled with disks of two sizes. The larger disks have twice the radius of the smaller ones. The investigators chose disks of comparable size in order to emphasize that the segregation process is not the same as the sifting that takes place when very small particles (such as grains of sand) pour through the cracks between larger particles (such as stones or gravel). Indeed, in much of their simulation they considered a box containing only a single large disk and many smaller ones; in such a system there is no way for sifting to take place.

Then what causes the segregation? The operative force is gravity. As the box is shaken or jolted, it often happens that a large disk moves enough for a small disk to fall into the gap underneath it. The reverse process, in which a number of small disks move simultaneously and thereby create a gap big enough to fit the large disk, is rare. Consequently the large disk gradually migrates up the container, even though that raises the energy of the system as a whole. Gravity makes the large disk fall up.

The work has direct applications. Suppose a pharmaceutical company wants to make a homogeneous mixture of two powders. Production engineers could start by pouring the smaller-grained powder on top of the larger-grained one and shaking the mixture to bring the larger grains up. The model of the Carnegie-Mellon group would tell them how long to shake the mass in order to get an even distribution of large grains.

Ice Age Beetles

The contemporary British climate may seem somewhat chilly, but a mere 14,000 years ago it was positively arctic. Pleistocene ice still encased much of the British Isles. Twice over the next few millenniums, however, before the Ice Age finally lost its grip, relief from the cold came swiftly, indeed almost instantaneously in geologic time, as thermal surges transformed the frigid islands into temperate zones in as few as 300 years.

These findings, reported in *Nature,* emerge from an analysis of beetle fossils collected over the past 30 years from peat bogs, dried lake beds and other sources of late Pleistocene sediments throughout Britain. The tough, chitinous husks of beetles abound in such places and are often so well preserved that the species—which number in the thousands—can easily be identified. Carbon dating of fossilized plants found with the beetles can indicate when they lived.

Timothy C. Atkinson and Kenneth R. Briffa of the University of East Anglia and G. Russell Coope of the University of Birmingham concentrated on fossils from about 350 species that are still in existence and whose climatic tolerances are well known. Coope, a pioneer in interpreting beetle fossils, says differences in the temperature ranges of species make the fossils good indicators of past climate. For example, finding fossils representing two species, one with a temperature range of −15 to 15 degrees Celsius and the other with a range of −10 to 20 degrees, in sediment from the same period suggests that temperatures at the time must have ranged between −10 and 15 degrees.

Other sources of data on paleoclimates—fossilized pollen and plankton found in ocean sediments and in polar ice cores, for example—had already shown that the waning of the Ice Age in northern Europe was delayed by a large-scale oscillation: after an early warming, during which glaciers and sea ice receded, arctic temperatures returned. Ice sheets pushed south again for perhaps 1,000 years before finally withdrawing.

The beetle-fossil evidence indicates that the warmings initiating and ending this oscillatory period, called the Younger Dryas, occurred about 1,000 years earlier and were much more intense and rapid than other data had suggested. Both warmings took place so swiftly—within 300 to 800 years, according to Coope—that they fall largely within the margin of error of carbon-dating techniques.

The first warming began in about 13,000 B.P. (before the present), when the annual mean temperature soared from eight degrees C. below zero to almost 10 degrees above. Over the next 2,000 years temperatures gradually descended to subfreezing levels, but shortly before 10,000 B.P. the climate warmed abruptly again to about 10 degrees, where, apart from some minor oscillations, it has remained.

Coope thinks beetle fossils can contribute much to modern climatic modeling (see "Climate Modeling," by Stephen H. Schneider, page 72). "The better your historical curve is, the more accurate your forecasts will be," he says. Coope's attitude may be catching: studies of beetle fossils are under way in North and South America, continental Europe and the Soviet Union.

TECHNOLOGY

Landsat Grounded?

The fledgling U.S. civilian remote-sensing industry faces a probable two-year setback because the Government is not meeting commitments to EOSAT, the company charged with establishing an independent, commer-

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cially viable remote-sensing program. Charles P. Williams, EOSAT's president, says the delay will drive potential buyers of remote-sensing data into the arms of a competing French company, SPOT-Image, and the Remote Sensing Technology Center in Japan.

EOSAT, a joint venture of the Hughes Aircraft Company and the RCA Corporation, was awarded a contract by the Department of Commerce in 1985 that undertook to provide $250 million for two new remote-sensing satellites, *Landsat 6* and *Landsat 7*. Although Congress approved the plan, EOSAT has so far seen only $90 million because of determined attempts by the Administration to block funds for the Landsat program. The *Challenger* disaster, by depriving the program of a ready launching vehicle, has substantially increased launch costs.

Set in motion in 1979 by President Carter and endorsed at the $250 million level by David A. Stockman when he directed the Office of Management and Budget, the program lacked the support of former White House chief of staff Donald T. Regan and James C. Miller III, the current OMB director. Almost before the ink was dry on the 1985 EOSAT contract, the OMB proposed reducing funding to zero. Warren D. Nichols of EOSAT's executive committee charges that "the Government reneged on its contract."

Budget-conscious executive agencies have been reluctant to rescue the program. Late last year the National Oceanic and Atmospheric Administration, the Commerce Department agency that oversees the Landsat program, submitted to Congress a financial plan for the program that was immediately rejected by a Senate subcommittee; it described a scaled-down effort with only one new satellite. "The Senate didn't believe the plan and neither did we," an EOSAT official says. The rejection froze $27.5 million in new money and $35 million in reprogrammed funds intended for EOSAT in 1987; all construction work on *Landsat 6* and *Landsat 7* halted on January 5 and several hundred workers were laid off or reassigned.

A revised plan drawn up recently by NOAA restores the second satellite and stays within the Administration's planned budget of $125 million over the next two years, but only by stretching out the program (which increases overall cost). If it is accepted by the OMB and then by Congress, the revised plan will delay the launching of *Landsat 6* until September, 1990 (from December, 1988), and that of *Landsat 7* until June, 1993. A decision must be made by July 1.

Some Government officials doubt that a commercial Landsat program is really feasible. Opinions also vary on how effectively EOSAT has marketed the data from *Landsat 4* and *Landsat 5*, which are still in operation but have exceeded their design lifetimes. Certainly the market for Landsat information has not grown as fast as had been hoped. Revenues in 1986 were $15.3 million, only about two-thirds of the estimate in EOSAT's original business plan. Furthermore, Federal agencies—which account for more than 60 percent of domestic sales—are prevented by the OMB from making commitments to purchases in future years.

One view has it that the political maneuvering in Congress is intended to pressure the Department of Defense, a major customer of the program, into offering free or subsidized launches. The demise of the Landsat program would also raise serious concerns in the Department of State, where it is seen as a valuable foreign-policy tool. Receiving stations for Landsat data are under construction in several strategically sensitive spots, including Islamabad and Riyadh, each at a cost to local governments of more than $10 million.

Lube Job

A coating developed by a National Aeronautics and Space Administration investigator could replace or supplement lubricants in some engines by enabling their hot moving parts to lubricate themselves. The coating could make it possible to create engines that work at higher temperatures and are therefore more efficient, according to its inventor, Harold E. Sliney of NASA's Lewis Research Center in Cleveland.

Sliney says his coating, called Lube PS200, can function at temperatures as high as 1,600 degrees Fahrenheit. Teflon coatings and oil lubricants start to break down at about 350 degrees F.; most solid lubricants, such as graphite, cannot operate above 900 degrees.

Lube PS200 is a mixture of chromium carbide, silver and a fluoride compound. Chromium carbide, a hard alloy with a high melting point, makes the coating durable. The silver and the fluoride compound provide the lubrication; when they are heated, Sliney explains, they tend to smear, forming a plastic, low-friction film on the coating's surface. The coating is applied by plasma spraying (hence the initials in its name): the powdered mixture is sprayed through a plasma of hot argon gas, which melts the powder before it lands on the surface. The coating is then ground to the desired thickness with a diamond grinder.

PS200 is being tested in experimental adiabatic diesel engines, which are heavily insulated to reduce heat loss and so increase efficiency. Another promising application is in the Stirling engine, in which an external energy source heats gas sealed in a chamber; the resultant flow of the gas drives a set of pistons. Invented by Robert Stirling, a Scottish clergyman, more than 150 years ago, these closed-cycle engines have never entirely fulfilled their theoretical promise, in part because few lubricants can sustain the high temperatures at which such engines work most efficiently. In experimental Stirling engines built by NASA, cylinders lined with PS200 have sustained temperatures of 1,500 degrees F.

The coating could also help to make turbine shafts and the bearings in which they spin more durable. These turbine parts, Sliney explains, are often gas-lubricated: a film of high-pressure air forms between the shaft and its bearings as they spin at high speeds, protecting them. The shaft and its bearings are nonetheless susceptible to wear during startup and slowdown or whenever the turbine is subjected to a sudden movement. Coating either the shaft or the bearings with Lube PS200 could further extend their lives.

Hypersonic aircraft of the future, whose outer surfaces would reach extremely high temperatures as they pass through the atmosphere, might also benefit from the coating. Sliney says it could protect the bearings of the plane's rudder, ailerons and other moving parts even if they were red hot.

Roughnecks

To squeeze more oil from aging fields, the roughnecks who man recovery crews often flood the rock formations with water, which forces the lighter oil upward. Even so, more than half of the oil in such fields generally goes unrecovered. Petroleum engineers believe still more oil might be coaxed to the surface with the help of microbial roughnecks: certain kinds of bacteria that occur naturally in wells.

Whereas some species hinder the recovery of oil by clogging passageways or producing sulfides that "sour" oil, others release chemical solvents that help to loosen the oil from the pores of the surrounding rock; they also release gases, such as carbon dioxide, that raise the pressure in the reservoir. The hope is that carefully selected batches of these bacteria, on being supplied with a nutrient and injected into a field, would proliferate and significantly boost production.

Experiments based on this concept have been conducted sporadically for

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more than 30 years in the U.S., the U.S.S.R. and other countries, but the outcome of these field tests was poorly recorded, according to Thomas E. Burchfield of the National Institute for Petroleum and Energy Research (NIPER), a Government-funded facility based in Bartlesville, Okla. Now investigators from NIPER, the U.S. Department of Energy and two private companies—Microbial Systems Corporation and INJECTECH, Inc.—are seeking to gather definitive data by testing the technique in an old, water-flooded oil field near Bartlesville.

The investigators have selected four bacteria: three of them grow in the absence of oxygen (two from the genus *Bacillus* and one from the genus *Clostridium*), and one is a so-called facultative anaerobe, which can grow with or without oxygen (the genus has not been disclosed). In March the bacteria were mixed with molasses, which serves as a nutrient, and were injected into a five-acre field that has 15 wells. Although under the right conditions the microbes can reproduce rapidly—doubling in number every half hour—they are expected to diffuse only slowly through the sandstone that underlies the test site. Some preliminary data should be available within six months, but it will be more than a year before all the results are in, according to Burchfield.

Even if the technique boosts recovery only slightly, he says, its low cost could make it economical for both large oil companies and smaller independent ones. Molasses is very inexpensive and the bacteria under consideration can be cultured at low cost. Moreover, Burchfield points out, once the bacteria have been established in the reservoir, simply feeding them additional molasses should keep them thriving—and working.

Technology for Sale

The Cummins Engine Company, Inc., recently started developing a new diesel engine that employs a ductile form of nickel aluminide, an alloy that has an unusual property: it gets harder as it gets hotter. Cummins was granted an exclusive license to incorporate the new material in heavy-duty diesel engines by the Oak Ridge National Laboratory, which did the original research. Such direct arrangements are currently unusual, but now that economic competitiveness has been sanctioned by President Reagan as the political watchword of 1987 they may become standard.

Federal funds account for about half of the $110 billion spent on research and development each year in the U.S., and yet only one-fortieth of the 120,000 patents issued annually stem from Federal research. This statistic "suggests that we could get more from the Federal investment," Norman J. Latker, director of Federal technology-management policy at the Department of Commerce, told a Senate subcommittee in February. Furthermore, the proportion of Federal patents that find their way to commercial application—about 5 percent—is much less than the equivalent figure for industry patents.

Until recently legal obstacles made it hard for private industry to commercialize research carried out in Federal laboratories. The Government usually owns inventions arising from work it supports. Although an agency may waive title to an invention if a private company is interested in developing it, agencies have not always been prompt to do so.

For example, between October of 1977 and December of 1985, 135 waiver requests were made to the Department of Energy for patent rights to inventions made at contractor-operated facilities. Yet as of December 24, 1985, the department had completed action on only 55 of them; five had awaited a decision for more than two years. Representative John D. Dingell, chairman of the House Committee on Energy and Commerce, wrote in February to Secretary of Energy John S. Herrington that he considered such delays "irresponsible." Ronald W. Hart, director of the National Center for Toxicological Research, says the Public Health Service's inability in the past to grant exclusive patent rights has meant that research "was everybody's property and so nobody's product." Hart says that "many inventions that could have improved public health simply languished."

All of this may be changed by the Federal Technology Transfer Act of 1986, signed into law last year and now being implemented. The statute encourages industry to make better use of Federal research by providing new incentives: for the first time all 700-odd Federal laboratories will be able to enter into collaborative research agreements with private industry and to grant companies exclusive development rights. Individual Federal employees whose inventions are taken up commercially will be awarded not less than 15 percent of the royalties, to a maximum of $100,000 per year. President Reagan is to issue an executive order instructing all Federal agencies to comply with the new act, which extends and clarifies earlier legislation.

The president has also proposed a doubling of the National Science Foundation's budget in the course of the next five years and the establishment of university-based centers for "fundamental science that directly contributes to our nation's economic competitiveness," which are to be funded through the NSF and perhaps through other agencies. Other proposals would accelerate exchanges of personnel among private companies, Federal laboratories and universities, as well as joint projects.

Latker says there is "a lot of pride and turf" that could impede the implementation of the new technology-transfer act. Still, it was only in 1984 that Oak Ridge was designated as a guinea-pig laboratory to see how incentives such as those in the new law might work. According to the laboratory's Jon Soderstrom, the number of patent applications sought by laboratory employees increased by more than 30 percent in two years.

Squeeze Me

Stretch a block of material and its girth contracts; push its ends together and its girth expands. Such behavior would seem to be predictable and universal. Yet Roderic S. Lakes of the University of Iowa has transformed foamy materials that behave as expected under deformation into foams that distend when they are under tension and become thinner when they are compressed.

Lakes reports in *Science* that the process by which he accomplished the transformation is rather straightforward: a specimen of conventional low-density polymer foam is compressed and placed in a mold, where it is heated. The foam that is then extracted from the cooled mold no longer behaves normally; its dimensions change under strain in a way contrary to what one would expect. By means of a similar procedure that involves sequential plastic deformation along each of three perpendicular axes, Lakes also invested normal metal foams with the same peculiar property.

Microscopic examination of the foams reveals the cause of their anomalous behavior: whereas the ribs of the cells constituting normal open-celled foams bulge outward, the cell ribs in Lakes's treated foams protrude inward, forming what Lakes calls reentrant structures. Under tension the reentrant-cell ribs are drawn out and unfolded, thus causing the cell to expand. Conversely, under compression the ribs collapse farther inward, resulting in an overall shrinkage of the cell's volume.

Lakes has found that his reentrant

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Nick Panaccio,
Worldwide Marketing, Unisys.

"We began to see those seats in a new way."

A major airline faced a basic marketing dilemma. They weren't selling enough seats for enough money to maximize profits.

So Unisys airline specialists sat down with the airlines management. Very quickly, they realized that airline seats should be treated like any other perishable commodity, since once the plane leaves the ground, the opportunity to sell the seats is gone forever.

"The system paid for itself in a few months."

Together, Unisys and the airline developed a program in three months that analyzed the history of recent flight experience, and identified more profitable routes and more competitive pricing. Now that program is the Unisys Airline Revenue Enhancement System, in use by airlines around the world.

"We got so close, I felt like I was working for the airline."

Nick Panaccio and his colleagues don't just help the customer, they help the industry.

UNISYS
The power of 2

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foams are more resilient than conventional foams. Whereas a conventional foam can typically be compressed by only about 5 percent of its original dimensions before it collapses abruptly, the shape of a reentrant foam can be altered by up to 40 percent of its original dimensions without collapse or any permanent deformation. Lakes also points out that an ideal reentrant foam (one that comes close to the thermodynamic limit placed on such anomalous elastic behavior) would be difficult to indent at any given point—even if the bulk material is compliant—and it would resist tearing.

What can one do with such tough, contrary foams? Lakes foresees their application in the manufacture of fasteners, sponges, shock absorbers and air filters (because any increased suction would open up clogged pores).

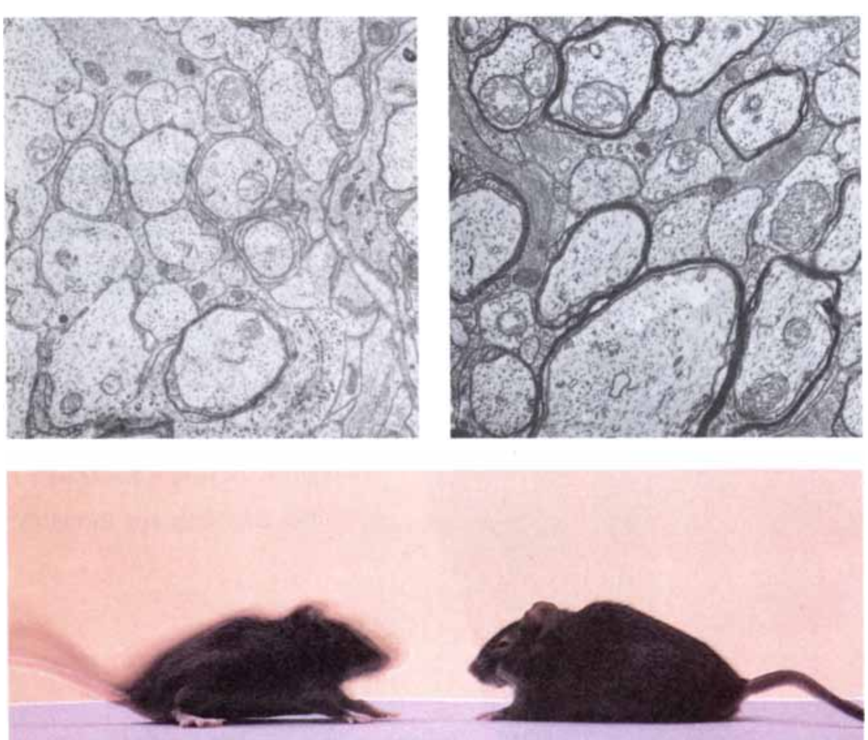
BIOLOGICAL SCIENCES

Shiverless Deportment

Because of a defect in the insulation of their nerves, mice with an inherited disease shiver uncontrollably and die young. A group of investigators from the California Institute of Technology and the Harvard Medical School has repaired the defect by genetic surgery. The success, reported in *Cell,* provides a means of exploring the role of a specific protein in nerve architecture. More generally, the work demonstrates the power of gene transfer for studying single elements of complex structures such as nerves.

Mice homozygous for the "shiverer" mutation begin to shiver about 12 days after birth and die within 90 days. Such mice lack both copies of the gene for myelin basic protein (MBP), actually a family of related proteins that account for between 30 and 40 percent of the protein in the myelin of the central nervous system. Myelin surrounds nerves and, by acting as an insulator, speeds the transmission of nerve signals and prevents signals from crossing between adjacent fibers.

To confirm that lack of the MBP gene and the protein it codes for causes the disease, the group, led by Leroy E. Hood of Caltech, artificially introduced the gene into the germ cells of afflicted mice. First Hood and his colleagues produced multiple copies of the gene, which other workers had isolated earlier, by cloning it in bacteria. Then the team put 200 copies of the gene into the nucleus of fertilized shiverer-mouse eggs and implanted the eggs in foster mothers. In one out of 300 young the transferred MBP gene was integrated into the DNA and expressed as protein.



SHIVERER MOUSE and one in which the genetic defect has been mitigated are shown under electron micrographs of optic nerves. The axons of an afflicted mouse (*left*) lack insulating myelin sheaths; in a "cured" mouse (*right*) some axons are insulated by myelin.

By crossing first-generation transgenic mice the workers produced animals carrying two copies of the new gene. These mice showed 25 percent of the normal MBP level and were essentially normal. The group then interbred mice carrying one or two copies of the transgene with animals bearing a different mutation, which reduces MBP expression to 5 percent of the normal level and causes a milder disease. The crosses yielded a population of mice in which MBP levels ranged between 5 and 30 percent of normal.

By observing the animals and examining the myelin sheath around their nerves under the electron microscope, the group was able to study how various levels of MBP affect the development of the sheath and the severity of shivering. "Mice with a minimal level of myelin," Hood says, "begin to live longer, those with a bit more no longer convulse, and those with still more (25 percent of normal) lose their shivering difficulties."

There is no shiverer disease in humans that awaits a similar cure. What is exciting about the work, according to Hood, is the demonstration of "a brand-new way to study complex entities or organelles such as nerves, ribosomes or mitochondria." By genetically manipulating their components one at a time, workers can now "vary one variable in a complex pattern of variables" in order to dissect function.

Dry Run

Land animals, it is widely supposed, evolved in the primordial soup of the seas and did not venture onto dry ground until they were quite advanced. That view appears to be inconsistent with the discovery in Pennsylvania of trace fossils of land creatures that are approximately 30 million years older than any previously found. The age of the fossils suggests that at least some animals may have evolved on dry land without any initial marine coddling.

In *Science* Gregory J. Retallack and Carolyn R. Feakes of the University of Oregon describe a series of burrows made by small, hard-shelled creatures resembling millipedes. These traces of ancient life were found in fossil soils dating from the late Ordovician period, which extended from about 448 to 438 million years ago—30 million years before the first advanced land creatures were thought to have lived.

The key term here is fossil soil. The rocks in the part of the formation where the discovery was made are not fossilized river or marine sediments, as "everyone just automatically assumed," Retallack points out. "No one

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In 1981, we introduced the world's most successful personal computer.

Here we go again.

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Introducing the IBM Personal System/2

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Five years ago, we sent our first personal computer out the door and hoped you'd find it useful.

We're pleased you did.

Over three million IBM® PCs have been put to work, doing everything from financial analysis to first-grade arithmetic.

Yet as PCs grew more popular, and as we kept improving them, one thing became clear. You needed more.

You're in a hurry, so you want PCs to respond faster.

You do many things at once and wish your PCs could too.

You want software that's more powerful, but also easier to use.

You'd like more color.

You're eager for your systems to communicate with other systems.

You want improved reliability.

And you want all this without obsoleting your investment in equipment, software and training.

So there was only one thing we could do: create a whole new system for personal computing.

The new IBM Personal System/2.™

Its heart is a new line of hardware and software, but its soul is bigger; new technology, of course, but also a new "balanced system" approach for making things work together.

It works with earlier IBM PCs so your investment is protected. It works with larger IBM systems so your future growth is protected. It works for business and education, for professional people of every stripe.

IBM Proprinter II

IBM Proprinter X24

IBM PC Convertible

Programs are here for the IBM Personal System/2.

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The next generation in

The new systems.

There are four models of the new IBM Personal System/2: Models 30, 50, 60 and 80, with a choice of configurations, with new design and components, and built not merely for speed but for well-balanced performance.

IBM Personal System/2 Model 30

IBM Personal System/2 Model 50

Model 30 is about 25% smaller than the IBM PC, does many jobs more than two times faster than the IBM PC XT,™ and comes with 640KB of memory and a 20-megabyte (MB) fixed disk if you want one. Much of what used to be optional is now standard, and improved. Graphics are spectacular. So is the value. Model 30 offers exceptional performance for the money.

Model 50, with its 80286 microprocessor, is an even bigger step forward. It has new architecture (as do the even more powerful models) that breaks old barriers. One megabyte of memory is now standard, and there's plenty of room for more. Its graphics (again, in common with the larger models) are another dimension beyond. And it finishes many jobs significantly faster than the IBM Personal Computer AT.®

Model 60 takes up less space on your desk because the computer itself doesn't sit on your desk, but rather, beneath or beside it. Equipped with a 44 or 70MB fixed disk, up to 15MB of memory and expanded expandability, it's a system for serving a very busy person, and can be a file server for

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personal computing.

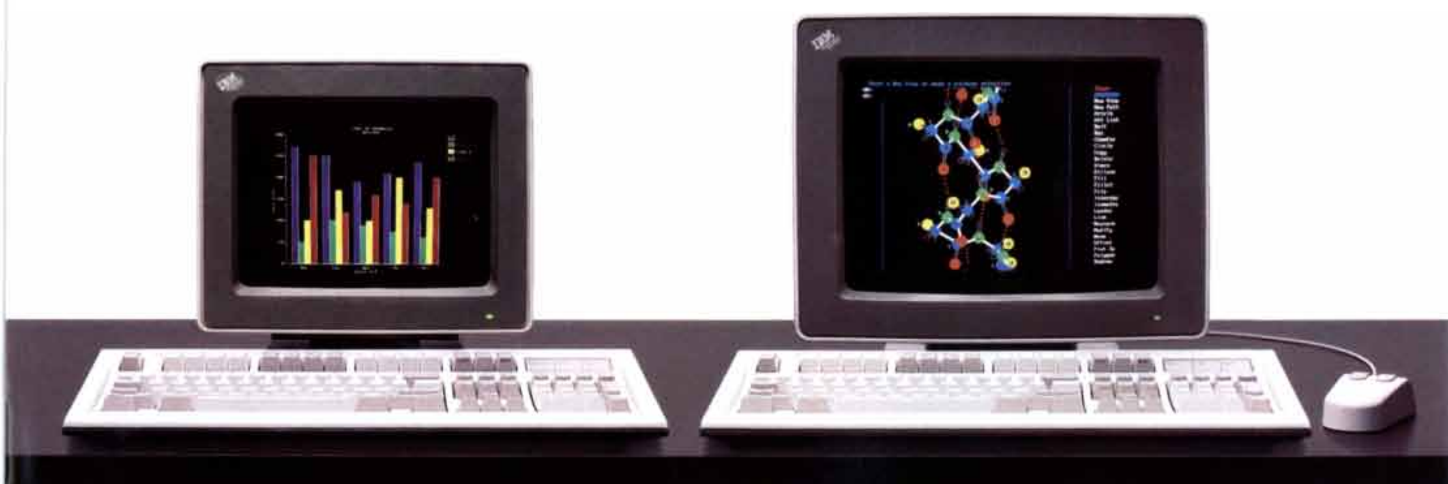
other busy persons.

Model 80. For everyone who's been waiting to experience the real power of the 80386 microprocessor, it's not just *in* this computer, we built this computer around it. Available this summer, Model 80 is a 32-bit system that does jobs up to three and a half times faster than the IBM Personal Computer AT. Up to 2MB of memory are standard, and fixed disks can be 44, 70 or 115 megabytes big. Or with two fixed disks, 230 megabytes huge. Computers this capable, and connectible, used to fill whole rooms.

The rest of this booklet tells more about the IBM Personal System/2. And how, all together, it can help make your professional life easier, more productive, and more rewarding.

The new performance.

You'll find new architecture, new integrated design and new operating systems that together lift raw power to higher levels of true performance, while cost goes the other way.



IBM Personal System/2 Model 60

IBM Personal System/2 Model 80

The new graphics.

You'll see new graphics, all standard, that redefine the words

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"colorful" and "sharp." And new displays that give your programs a heightened sense of reality.

The new connectivity.

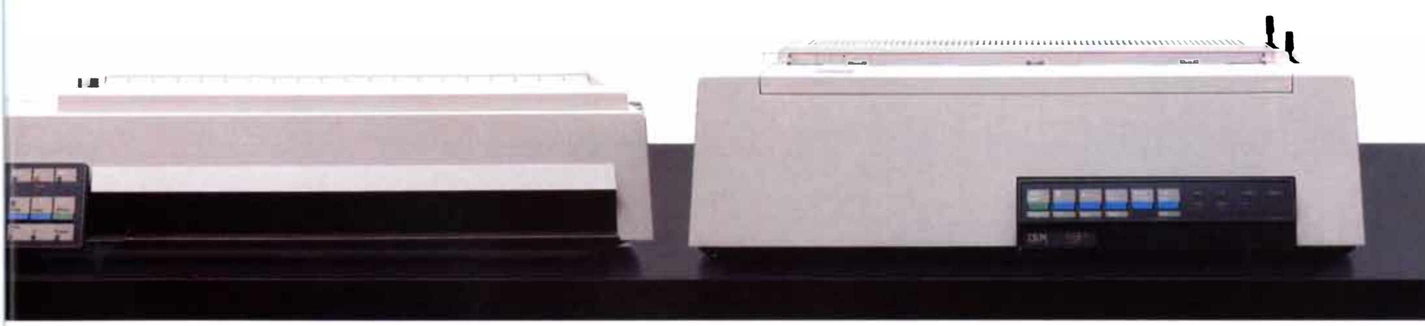
There will be new avenues for sharing information; new match-ups of hardware and software that shorten the distances and widen the roads between PCs, minis, mainframes and people.

The new media.

You'll see rugged diskettes that are half as big, but hold up to twice as much as floppies did. Plus low-cost devices for transporting your data from one generation into the next. And a new IBM 200MB optical disk drive.

The new solutions.

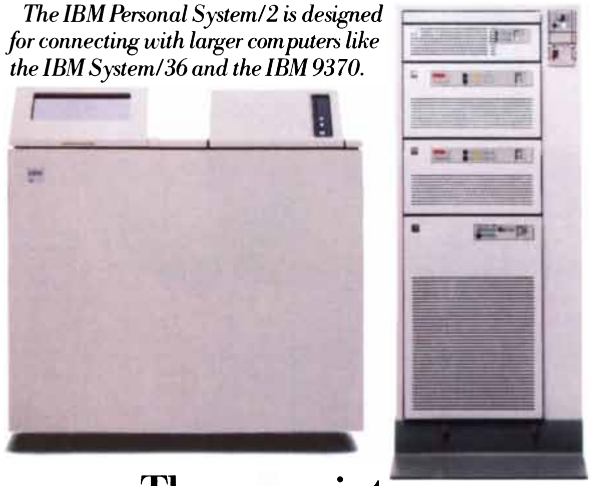
You'll discover new ways to solve problems; ideas about choosing not just software or hardware, but software, hardware and support in balance.



IBM Proprinter XL24

IBM Quietwriter III Printer

The IBM Personal System/2 is designed for connecting with larger computers like the IBM System/36 and the IBM 9370.



The new printers.

You'll see an expanded family of personal printers that fills just about any need, from economy, to speed, to the fussiest levels of document quality.

The new support.

And because it's not just what you buy but where you buy it, you'll learn how we've been working closely with the people who sell the Personal System/2 to create new levels of dealer support.

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So, it's power you wan

The new performance.

It's tempting to size up computers by the numbers, but in the IBM Personal System/2, real performance exceeds the sum of its parts.

Components were designed not just to coexist, but to cooperate; within each system, and within your total computing environment.

The IBM Personal System/2 takes up less space on your desk. The on/off switch is on the front, and monitors tilt and swivel.

So your software runs faster, and your system is more reliable.

Extras aren't extra.

You could expand earlier IBM PCs after you bought them, but the Personal System/2 is expanded before you even open the carton. Things that used to cost extra don't anymore.

Advanced graphics, parallel and serial ports, a port for pointing devices, and diagnostics are included.

And new IBM technology—our one-million-bit memory chip, high-density logic circuits, and integrated "planar boards"—is sending performance up, and costs down.

Paths to the future.

Models 50, 60 and 80 share a design that's new to personal computing. Technically it's described as parallel bus architecture (we call it IBM Micro Channel™), but think of it as a highway.

Our first PCs were built around a two-lane street. Usually that's enough, but sometimes there are traffic jams. Your sales figures might have to stand on the corner while your mailing list goes by.

The new system is like an expressway. There are more lanes open

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t?

in both directions. The ramps are more smoothly paved, and signals are better synchronized. So data can flow more freely.

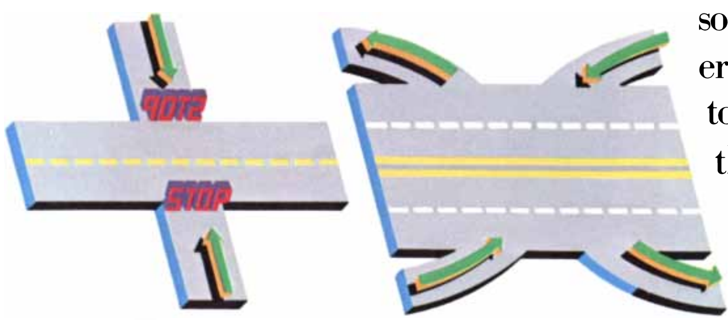
This is what the 286 and 386 chips have been waiting for. A highway to match their horsepower.

The IBM Personal System/2 Model 80 was created to unleash the power of the 80386 microprocessor.

The new operating systems.

The Personal System/2 is being introduced with a new IBM PC DOS Version 3.3 that lets you tap into the new systems immediately, and works with all previous IBM PCs as well.

There's also an IBM 3270 Workstation Program that, with PC DOS Version 3.3, helps the Personal System/2 connect with



In earlier PCs, data sometimes had to stop and wait. New IBM Micro Channel architecture is more like an expressway. Data flows more freely.

mainframes, supports more memory, and lets you run multiple applications.

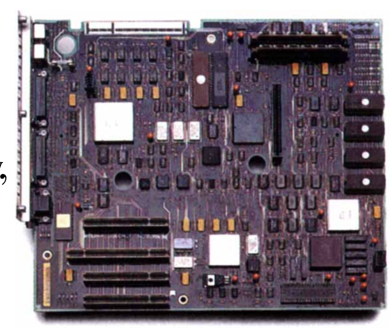
But much more is coming.

A new IBM Operating System/2™ will run on Models 50, 60 and 80. Available later on, its development is being carefully timed so that everyone involved—software makers, our dealers, you—can take full advantage of its power as easily as possible. It will do everything our existing PC DOS does (in fact, they'll get along beautifully), but it also will bring major advances.

Memory. Our new systems offer up to 16 megabytes' worth, and Operating System/2 will make these vast resources easier to access.

Multi-tasking. With IBM Operating System/2, you won't have to be a "power user" to understand how to run several programs at once. Multi-tasking will become a routine experience.

Software. Together with the new architecture and more memory, Operating System/2 will give software developers new freedom to create programs that are more powerful, better looking, and easier to use than ever before.



IBM Personal System/2 "planar boards" have many standard features that used to be options.

A bigger idea. Operating System/2 is also part of another new idea, called IBM Systems Application Architecture.

Its goal is to bring the world of IBM computing closer together; to provide a greater consistency in look, function and feel—for systems, for software and for people who use them. IBM Operating System/2 is the first step for personal computing in this promising new direction.

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It’s like having 256,00 in one box.

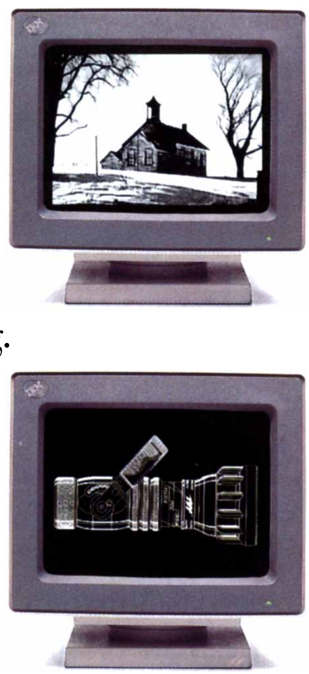
The new graphics.

Back in the dark ages of personal computing, the world was ruled by numbers and words. Graphics were a nicety, but rarely a necessity.

Welcome to the Renaissance.

The IBM Personal System/2 has a talent for graphics that’s dazzling.

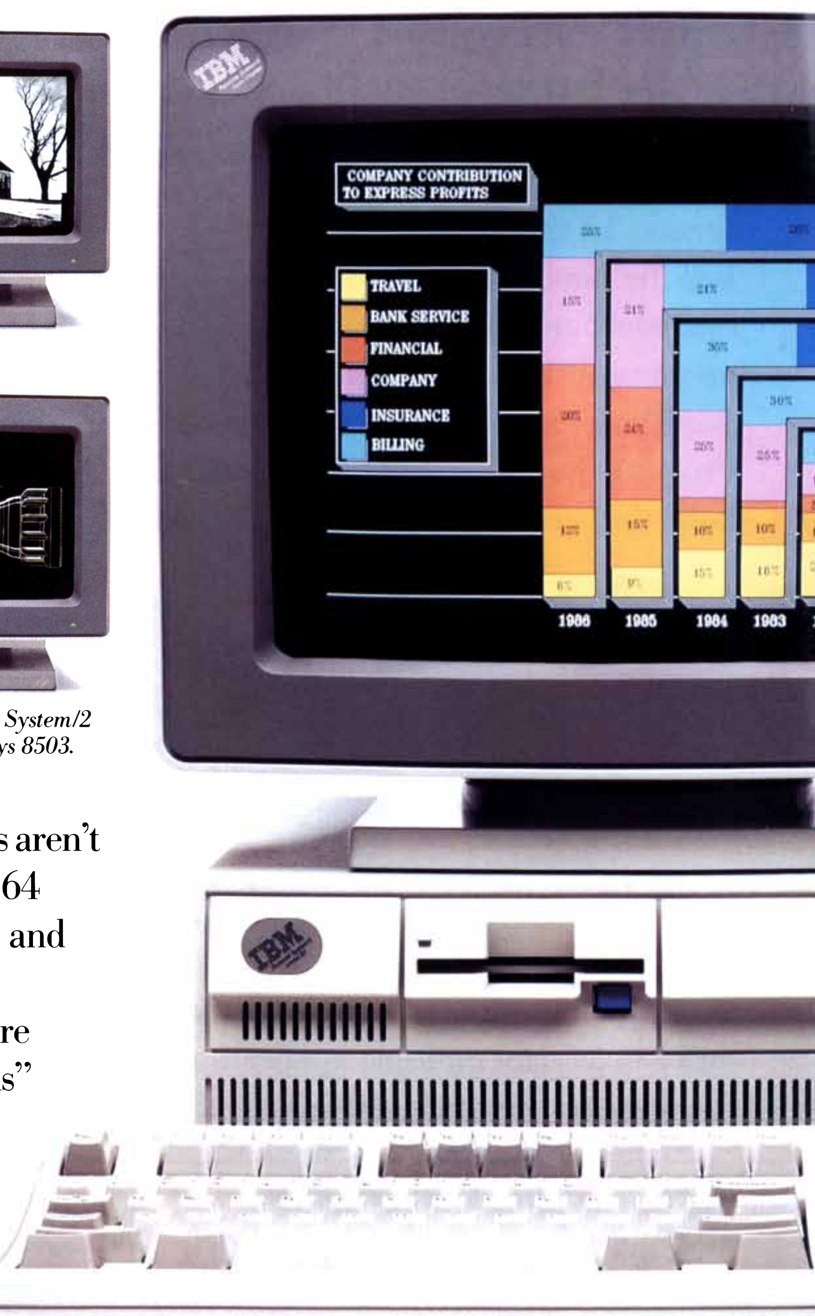
Each new system can paint up to 256 colors on the screen at once, drawing from an incredible palette of over 256,000. And not one of those colors costs a penny extra.



The IBM Personal System/2 Monochrome Displays 8503.

Even in monochrome, things aren’t monotonous. There can be up to 64 shades of gray for new dimension and contrast.

And the images themselves are greatly improved. The tiny “pixels” that create the image can now be tinier, and there can be lots more of them. Even the space between them seems to have disappeared. So pictures are



All screens in this brochure are actual and unretouched.

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0 crayons

sharp and clearly defined.

Better letters.

Equally important, letters and numbers are clean-edged and precise, looking more like they're printed than projected. After a few hours with your trusty spreadsheet, you'll appreciate that.

You'll also like the non-glare viewing surface, and mountings that tilt and swivel so your neck doesn't have to.

There are four new IBM displays, and each works with every Personal System/2 computer, all showing graphic improvements in price.

The 12″ monochrome and 14″ color displays are great for most general-purpose work. The 12″ color display is even sharper, ideal for detailed business graphics. And for design work, there's the big 16″ color display with even higher resolving power.

Your favorite programs.

Just about any program you can run on the IBM Personal System/2 will look better, and will likely be more pleasant to spend time with. Many other programs are being reworked just to take advantage of the new graphics.

But the future holds real surprises. The screens of the Personal System/2 are like a brand new kind of canvas. How the artists will use them should be something to see.

The IBM Personal System/2 Color Displays 8513.

The IBM Personal System/2 Color Displays 8512.

The IBM Personal System/2 Model 50 and the IBM Personal System/2 Color Display 8514.

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The future belongs to the well-connected.

The new connectivity.

The earliest computers were big and costly, so people shared them.

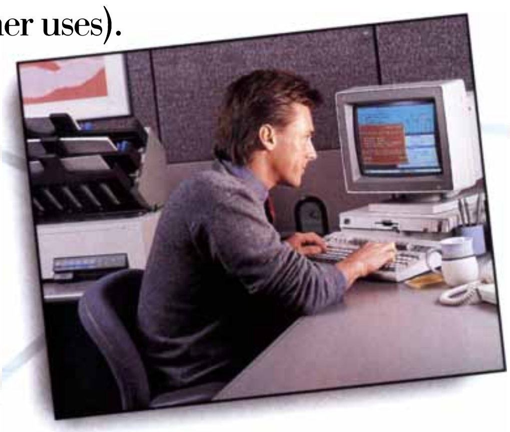
Then people wanted smaller computers just for themselves. Soon PCs were in offices everywhere. And how did people want to use them?

The managing director uses IBM 3270 Emulation and Professional Office System™ software (PROFS) for checking calendars and sending electronic mail.

For sharing things. So the idea of PC connectivity was born.

From the start, the IBM Personal System/2 was designed to connect; with other IBM personal systems, with bigger IBM systems.

Each new system comes with built-in asynchronous communications (which can save you an option slot for other uses).



An executive assistant uses IBM DisplayWrite 4 to polish up memos and reports for distribution through IBM DISOSS.

The personnel director sends bulletins using the IBM 3270 Workstation Program and PROFS.

An inventory clerk uses an inquiry to a data base to compare what's out in the warehouse with sales orders.

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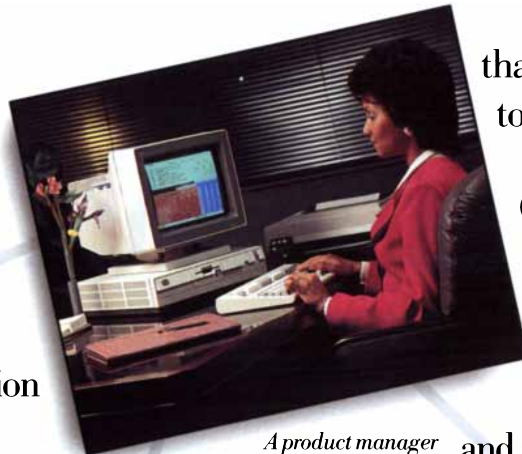


A product manager loads her spreadsheet using the IBM Token-Ring Network to access information.

So information has no trouble traveling back and forth. But the real news is what happens inside.

Going with the flow.

The new architecture in Models 50, 60 and 80 will improve the flow of traffic within the system, so when an important message comes in from corporate headquarters, it's less likely to see stop signs. And if the sender has a properly equipped IBM PC, PC XT, Personal Computer AT or IBM Personal System/2 Model 30, that's okay too—they work together.

The IBM 9370 computer stores information and provides data base management support for the business.

And as the new IBM Operating System/2 unfolds, communication will become even easier. Its multi-tasking capability will make it easier for your system to receive and store electronic mail, mainframe data, or whatever, while you're busy doing something else.

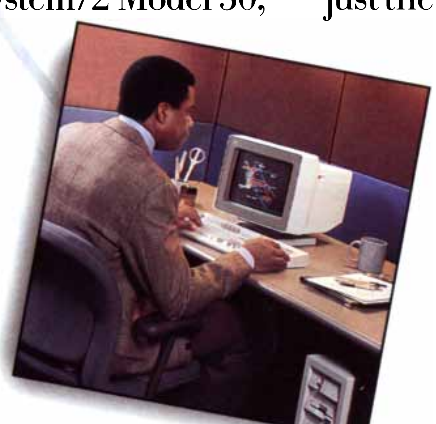
The scope of communication has been increased, too.

A wide array of local area network and connectivity products is part of the IBM Personal System/2 family, so your resources can be as broad as your needs; from the first IBM PC your company ever bought, to mid-range systems, to the biggest IBM 3090 mainframe, the lines are open.

And this is just the beginning.

Programmers work within the framework of IBM Systems Application Architecture to develop applications.

Meanwhile, from a hotel room, a salesman uses the modem in his IBM PC Convertible to send back details of a new order.



A design engineer uses an IBM Personal System/2 Model 80 to create a product accessing designs from the host computer.

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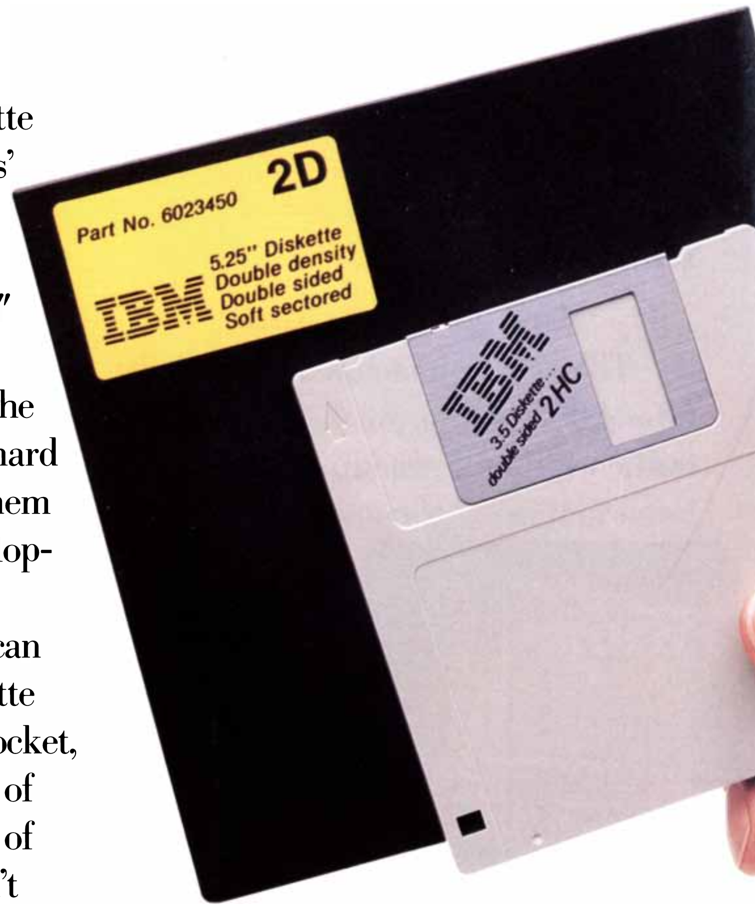
IBM just got smaller. three quarter inches.



The new media.

The amazing 5¼″ floppy diskette can hold literally hundreds of pages' worth of memos, reports and vital statistics.

So why are we switching to 3½″ diskettes?

Because they hold up to twice the information, and they don't flop. A hard plastic case protects them from mishaps that floppies are heir to.

A simple accessory kit transports data from 5¼″ to 3½″ diskettes.

So not only can you slip a diskette into your shirt pocket, you'll have fewer of them, with more of your work all in one place. You won't have to fool around with write-protect tabs anymore, either. They're built right in.

Bridging the gap.

Very nice, you say, but what about all that work on 5¼″ diskettes?

We thought about that from the very beginning, and we're offering a number of low-cost solutions to make the transition as smooth as possible.

It takes two 360KB 5¼″ diskettes to hold as much as one 720KB 3½″ diskette.

One is a simple cable adapter and software package that lets you send your data from an IBM PC, PC XT or Personal Computer AT to your IBM Personal System/2, then onto the smaller diskettes. Depending on how much data you have, the whole job could be over in one sitting.

Also available are special IBM 3½″ and 5¼″ external diskette drives, to be there

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By one and

anytime you need them, for conversions in either direction.

Software is here.

And what about software? Well, 3½″ diskettes may be new to full-sized IBM personal computers, but they're not new to personal computing.

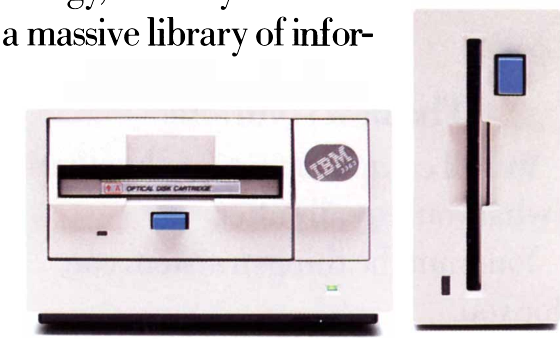
They're used, for example, by the IBM PC Convertible. So, many popular spread-sheet, word processing, data base and other programs (from IBM and other companies) are already available on 3½″ diskettes. And software makers are working to get new releases out quickly.

Optical allusion.

If a 3½″ diskette can store large amounts of information, here's a way to store gargantuan amounts.

We're introducing a 200-million-byte optical disk drive.

It works with all Personal System/2 computers and, with advanced laser technology, will let you build a massive library of information for business, science and education on removable disks you can hold in your hand.



The IBM 3363 Optical Disk Drive with "write-once, read-many" disks (left) and the IBM 3.5 Inch External Diskette Drive (right).

The IBM 5.25 Inch External Diskette Drive.

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The solution is part o system.

The new solutions.

We sell computer systems, but that's not what you're really after.

You want the things a system can do for you.

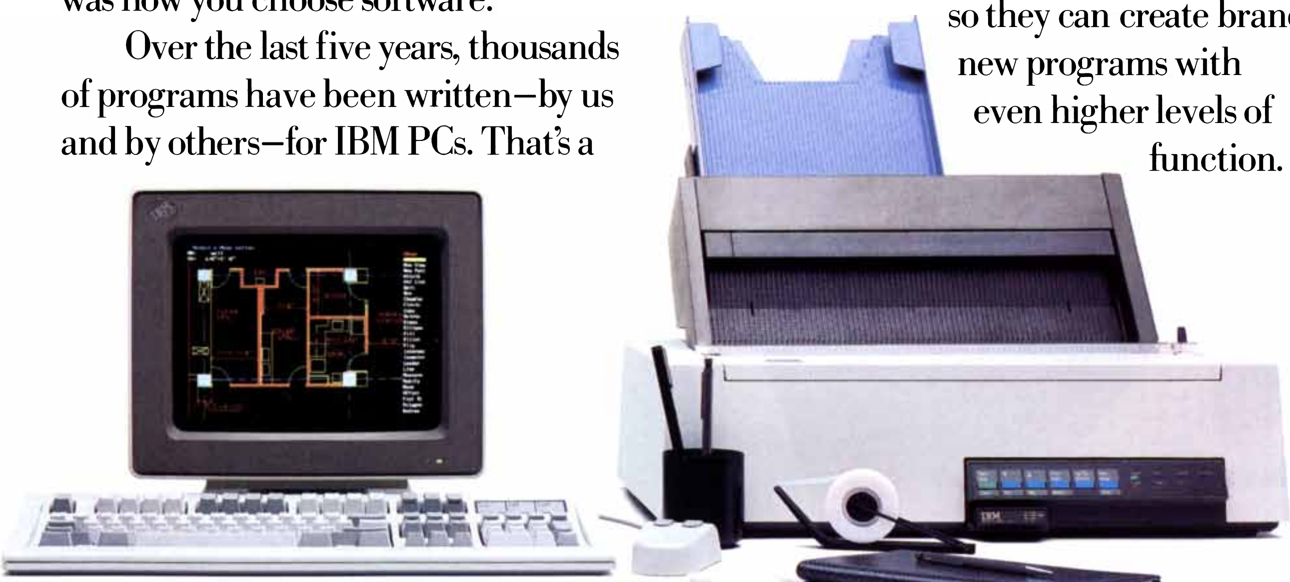
So while we were busy developing new machinery, we were also active on the software front.

One of the first things we looked at was how you choose software.

Over the last five years, thousands of programs have been written—by us and by others—for IBM PCs. That's a good thing, and we want to keep it going, so we've continued to work with independent software companies.

Getting with the program.

We're telling them about our move to 3½″ diskettes so they can convert popular programs to that size. We're showing them our new graphics so they can revise software to take advantage of them. And we're keeping them up-to-date about the new IBM Operating System/2 so they can create brand new programs with even higher levels of function.



IBM CADwrite Design and Drafting System SolutionPac for designers and engineers.

So, popular programs like Lotus 1-2-3,™ WordPerfect® and dBase III PLUS™ will be available for the Personal System/2.

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Needless to say, we've also updated our popular IBM software. IBM DisplayWrite™ 4, the IBM Assistant Series,™ IBM Business Adviser* and IBM educational programs are ready to go for the Personal System/2.

The IBM SolutionPac.™

Then we looked at software from another point of view.

With so many decisions to make, so many combinations of hardware and

IBM Business Adviser Financial Accounting SolutionPac.

software, choosing the right one can be confusing. Maybe you'd prefer "one-stop shopping."

So we created an idea called IBM SolutionPacs.

You'll be able to buy them from selected IBM Authorized Advanced Products Dealers.

What you'll get is a software package designed for your kind of business, with a hardware ensemble that's been matched to it, and tested. Plus a program of service, training and support.

Popular programs will be available for the IBM Personal System/2.

A wide range of IBM SolutionPacs is in the works. Among the first ones available are the Business Adviser Financial Accounting SolutionPac, a CADwrite Design and Drafting System for designers and engineers, a desktop publishing SolutionPac and a Doctor's Office Management package, as well as SolutionPacs for contractors and lawyers.

They will make buying easier, and should shorten the time between "I've got my computer system" and "I've mastered my computer system."

Of course, a big role is played by the new Advanced Products Dealers. Their new "whole-solution" training will make it easier for the two of you to assemble the best system for you.

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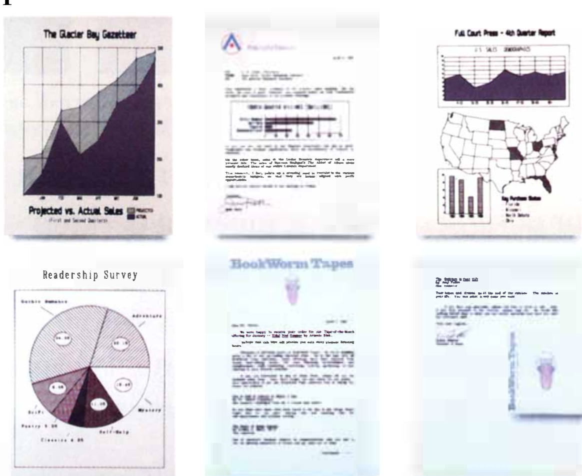
New power to the prin

The new printers.

Most of what shows up on your computer screen is seen by just one person. You.



But what comes out of your printer goes out to the world. So it has to look professional, and getting it done has to be easy; virtues that have made IBM personal printers best-sellers.

The IBM Proprinter™ and the IBM Quietwriter® Printer have earned high marks from both customers and critics.

Now our printers are even better, and we've added new members to the existing family.

The IBM Proprinter II.

What made the original Proprinter so popular was speed, versatility and convenience.

The IBM Proprinter II.

So what do you get more of in the Proprinter II? Speed, versatility and convenience.

There's now Fastfont,™ an extra-fast draft mode. Switching to "near letter quality" is faster too, because now there's a button for changing modes.

There's also a choice of typestyles, and of course you can still load envelopes from the front and put in single sheets any time you want.

The IBM Proprinter II is for anyone who wants to print text and graphics, with a printer that's fast and economical.

The IBM Proprinter X24 and Proprinter XL24.

The IBM Proprinter X24 and Proprinter XL24 are new. The "24"

The IBM Proprinter X24 with optional sheet feed.

The IBM Proprinter XL24 has a wide carriage, ideal for spreadsheets.

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ted page.

stands for 24-wire technology. What *that* stands for is new levels of Proprinter quality for everything you put on paper.

Both models print letter quality text with greater detail and graphics with better density and definition. The improvement is easy to see.

So is the performance. When compared to current, best-selling, comparably priced 24-wire printers, the Proprinter X24 and Proprinter XL24 print 1½ to 2 times the draft output in the same amount of time.*

The Proprinter XL24 has a wide carriage for spreadsheet printing, and both have an optional sheet feed for added paper-handling convenience, plus FontSet,™ an option that lets you choose from 11 other typestyles.

The IBM Quietwriter III Printer.

Earlier IBM Quietwriter printers have always been easy on the ears, but the new IBM Quietwriter III Printer is even quieter and goes nearly twice as fast, printing executive letter quality text and graphics in an executive hurry.

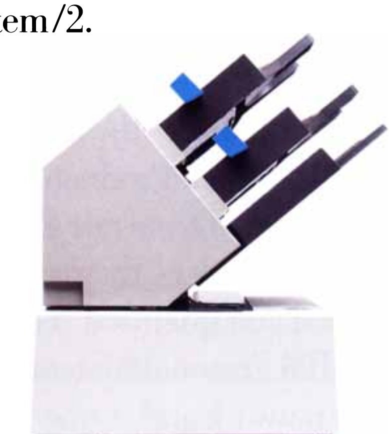
There's new flexibility in style, as well. The Quietwriter III Printer comes with four different type fonts built in and you can combine typestyles within the same document.

If that's not enough, there are optional font cartridges that give you the freedom to use up to eight typestyles on one page.

There's also a new dual-drawer sheet feed (with optional envelope feed) that lets you use letterhead stationery for the first page of a letter, then plain paper for the rest.

No matter what level of price or performance you need, there's an IBM personal printer to fit the bill. And they fit very nicely with the IBM Personal System/2.

The IBM Quietwriter III Printer with single-drawer sheet feed.



There's also an innovative multiple-drawer sheet feed.

*Based on an independent evaluation using *PC Magazine* Labs Benchmark Series

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It's not just what you b
but where you buy it.

The new support.

As we designed the IBM Personal System/2, we weren't just thinking about products. We also paid serious attention to how, and where, you buy them.

The IBM Personal System/2 offers so many possibilities, so many new ways to do things better, astute guidance must be there if you need it.

So we're raising the bar for customer support. Naturally, our IBM Marketing Representatives are fully knowledgeable about the Personal System/2. But also, we're bringing even greater levels of support from our dealers to you.

IBM Authorized Advanced Products Dealers.

Announcing the new IBM Authorized Advanced Products Dealers.

Selected from our already outstanding dealers, they're being specially trained and qualified. They will have the IBM Personal System/2 computers, IBM network and connectivity products, peripherals, new IBM Operating System/2 when it's available, and all the support you should need.

Perhaps even more important, they'll have a new focus; on systems instead of single pieces of hardware, on solutions instead of circuitry.

They'll be thinking not only about the system you buy, but also about how you'll be using it.

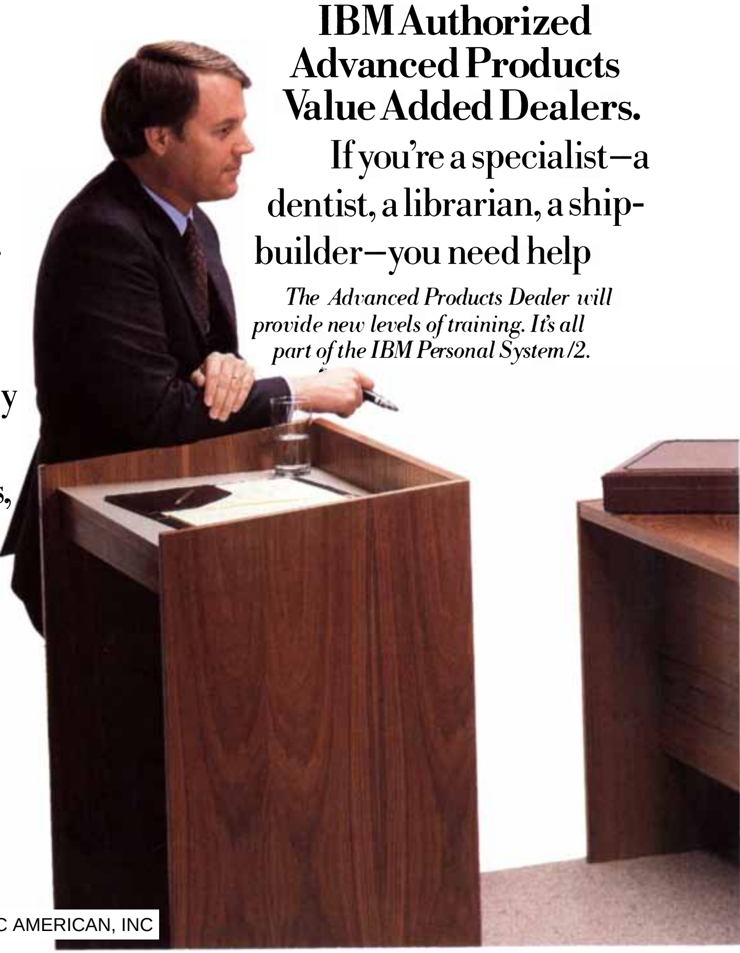
They'll offer help with learning about systems and software, connectivity, and Operating System/2.

And they're committed to new standards of training for their sales, technical support, and service people.

No matter how big your business, whether you need one computer or a whole network's worth, the Advanced Products Dealer has what you need.

IBM Authorized Advanced Products Value Added Dealers.

If you're a specialist—a dentist, a librarian, a shipbuilder—you need help



The Advanced Products Dealer will provide new levels of training. It's all part of the IBM Personal System/2.

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uy, from a special kind of dealer.

Introducing the new IBM Authorized Advanced Products Value Added Dealers.

They're specialists, too. They build enhanced systems for specific industries and now, with the entire Personal System/2 family, their building blocks are better than ever. There's an Advanced Value Added Dealer who understands your business almost as well as you do.

IBM Authorized Dealers and Value Added Dealers.

Our IBM Authorized Dealers and Value Added Dealers will have the IBM Personal System/2 Model 30 and peripherals to go with it, plus special know-how for helping people get started in computing.

IBM Marketing Representatives.

These people have special skills for helping large companies and educational institutions make the most of their investment in the IBM Personal System/2.

And now, through the IBM Customer Fulfillment Option, our customers may also work with our dealers and value added dealers to get the best of both worlds; additional support for the Personal System/2 plus the benefits of dealing with IBM directly.

Congratulations are in order.

It's not easy to qualify (and stay qualified) as an Advanced Products Dealer. Our expectations are high, as high as yours are.

So when you visit one of our Advanced Products Dealers, give them a nice pat on the back. They've just signed up for a tough course.

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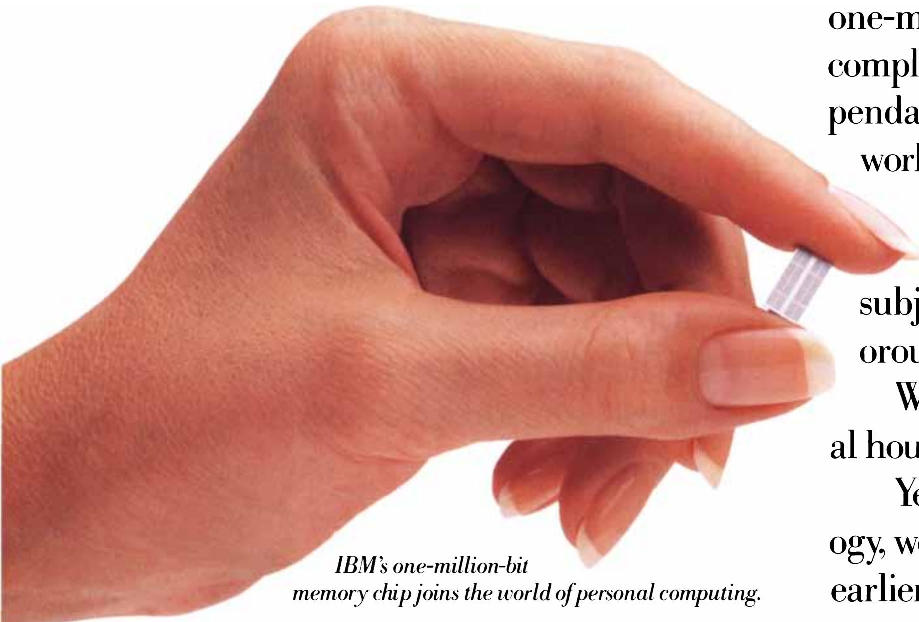
A system that's bigger sum of its parts.

A new direction.

The IBM Personal System/2 arrives in the wake of some fairly eager public speculation. So we expect there'll be a focus on "the new IBM PCs."

But our focus is different.



IBM's one-million-bit memory chip joins the world of personal computing.

While the machines are certainly key to the system, they are not The System.

It's bigger.

And it begins, not with chips or circuit boards, but with you. After all, if our products don't answer your needs, you don't need them.

So everything about the Personal System/2—how we build it, how you learn and use it, where you go to buy it, and how well it works with your other systems—is balanced to give you the highest overall performance.

A new quality.

We're making the Personal System/2 even more reliable than our earlier PCs.

With new Very Large Scale Integration technology, many pieces in a system are now replaced by one piece. Our one-million-bit memory chip reduces complexity, too. So costs go down, dependability goes up, and you get more work done in less time.

We're also using more IBM-made components, and we're subjecting our systems to more rigorous testing.

We even operate each one for several hours before it goes out the door.

Yet in creating all this new technology, we didn't forget that three million earlier IBM PCs are out in the world. So our two generations are close relatives, and your investment in equipment and training is protected.

Nor did we forget that many of you have larger IBM systems. The Personal System/2 will help you build better connections with IBM mid-range and mainframe computers.

New help.

We've also made the Personal System/2 easier to learn. New IBM manuals, tutorial

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than the

diskettes, and start-up procedures will help you get your system going quickly.

So will the people you bought it from. Our new Advanced Products Dealers and IBM Marketing Representatives won't just sell you the right system, they'll be there to help you get the most out of it. And as your needs grow, they'll be able to help you expand your system to meet new challenges.

Earlier IBM PCs and the new IBM Personal System/2 work together so your investment is protected.

A continuing tradition.

It's said in the world of computing that the only constant is change, but that's not entirely true.

In IBM's world of computing one thing holds firm, and it's the notion of partnership between our people and our customers. The Personal System/2 is a product of that partnership.

IBM people are some of the best listeners in the business, and when they hear what you want, they do something about it.

We're very proud of them all, and the more you know about the IBM Personal System/2, the more you'll understand why.

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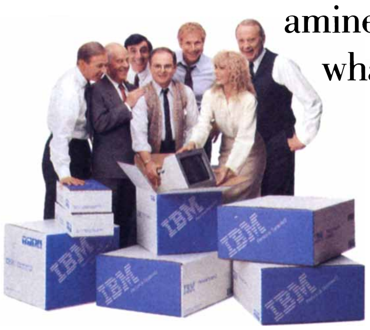
And now for the fine print.

All models include integrated display support, 256-color graphics capability, clock/calendar, and ports for serial, parallel and pointing devices. All systems use a common IBM enhanced keyboard and accept any IBM Personal System/2 monochrome or color display. All models accept the 200MB IBM 3363 Optical Disk Drive option.

	Model 30	Model 50	Model 60	Model 80
Microprocessor	8086	80286	80286	80386
Potential system throughput[1]	Up to 2½ times PC XT	Up to 2 times Personal Computer AT	Up to 2 times Personal Computer AT	Up to 3½ times Personal Computer AT
Standard Memory	640KB	1MB	1MB	Up to 2MB
Expandable to		7MB	15MB	16MB
Diskette size and capacity	3.5 inch 720KB	3.5 inch 1.44MB	3.5 inch 1.44MB	3.5 inch 1.44MB
Fixed disk[2]	20MB	20MB	44, 70MB	44, 70, 115MB
Additional Options			44, 70, 115MB	44, 70, 115MB
Maximum configuration[3]	20MB	20MB	185MB	230MB
Expansion slots[4]	3	3	7	7
Operating system(s)	PC DOS 3.3	PC DOS 3.3 and Operating System/2	PC DOS 3.3 and Operating System/2	PC DOS 3.3 and Operating System/2

1. Based on the testing described in the IBM Personal System/2 Performance Guide. Your results may vary. 2. Model 30 also comes in a diskette-based configuration. 3. Models with 44MB fixed disk expandable to 88MB. 4. Model 30 accepts most IBM PC and IBM PC XT option cards. Models 50, 60 and 80 accept new IBM Micro Channel option cards.

Now that you've read all about the new IBM Personal System/2 and examined its specifications, what should you do?



Go to your telephone. Call 1-800-447-4700 (ext. 9) and you'll learn who's the IBM dealer nearest you. (In Alaska call 1-800-447-0890, in Canada 1-800-465-6600.)

And here are two things to ask when you finally get face to face.

Ask about an IBM Credit Card. It just makes buying that much easier for a person or a business.

Or, if you prefer leasing, ask an IBM authorized dealer or IBM Marketing Representative about the IBM leasing programs.

With those formalities out of the way, you'll want to join the next generation in personal computing. The IBM Personal System/2. IBM®

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trained in soil science ever looked at them before."

How can fossilized marine mud be distinguished from fossil soil? As soil weathers, a gradient of minerals is formed. Mica and feldspar disappear from the soil surface, whereas the amount of quartz is not affected. Retallack and Feakes found that exact pattern at the Pennsylvania site. In addition, the telltale red color of highly oxidized hematite in the rock suggests the soil lay near the surface and was exposed to oxygen; rocks formed from ocean sediment, Retallack explains, are drab in color.

The amount of calcium carbonate in the rocks is another clue to their original location. This highly soluble mineral leaches out of soils in rainy environments. The abundance of calcium nodules in the fossil soil means rainfall was fairly low, and perhaps seasonal. The environment, in other words, Retallack says, "was similar to modern savannas of East Africa or northern Pakistan."

The organic remains of the creatures that excavated the burrows disappeared long ago. Yet the shape of the burrows has enabled Retallack to hypothesize that a typical individual grew to the size of a typical cockroach, had legs on each side and shed its carapace periodically.

Although the discovery encourages theories of independent terrestrial evolution of life, it is not a proof of that independence, Retallack says. The old theory that land organisms came from the sea may still be correct, but at the very least the transition took place much earlier than had been thought.

Self-Examination

A crucial event in the immune response to a pathogen rests on a paradox. *T* cells, the white blood cells that orchestrate the immune response or destroy infected tissue directly, can detect the pathogen's antigenic components only when they are associated with the body's own proteins: cell-surface molecules known as MHC proteins. What is the nature of the association between the foreign and "self" molecules, and how does it contribute to recognition by *T* cells?

Answers to these literally vital questions are now emerging, notably from work reported in *Science* by a team of investigators led by Malcolm L. Gefter of the Massachusetts Institute of Technology, Howard M. Grey of the National Jewish Center for Immunology and Respiratory Medicine and John A. Smith of the Massachusetts General Hospital and the Harvard Medical School.

"The Boys Club helped take me from the outfield to the oil field."

C.J. "Pete" Silas
Chairman & Chief Executive Officer,
Phillips Petroleum Company

"In the neighborhood where I grew up, there weren't many places for a kid to spend his time. Except maybe the streets. So it's a good thing there was a Boys Club down the road. Sure, our Club was a place where we could play ball. But it was also a place where we learned about something far more important than how to run the bases—we learned how to run our lives.

You see, a Boys Club doesn't stop at teaching young people good sportsmanship. It teaches them about friendship, good citizenship, leadership. I guess that helps explain why so many friends who were in the Boys Club when I was a member are now successful businessmen and professionals.

It's nice to know that more than 1,200,000 young people at 1,100 Boys Club facilities all across the country are getting the same opportunities we had. And more.

Today, they can learn computer skills and get vocational training at a Boys Club. They can even get help with college and career planning—the kind of help that can turn a star in the outfield into a star in any field he chooses!

Take it from me, a Boys Club gives a kid a chance to be a leader. And that's a lesson I never forgot!"

BOYS CLUB

The Club that beats the streets.

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AN INVITATION TO THE NOMINATION FOR THE KING FAISAL INTERNATIONAL PRIZES IN MEDICINE AND IN SCIENCE

The General Secretariat of King Faisal International Prize, in Riyadh, Kingdom of Saudi Arabia, has the pleasure to invite Universities, Academies, Educational Institutions and Research Centers all over the World to nominate qualified candidates for :

1. King Faisal International Prize in Medicine.
   Topic: **"LEUKAEMIA"**

and

2. King Faisal International Prize in Science.
   Topic: **"BIOLOGY"**

which will be awarded in 1408 AH / 1988 AD.

(a) The Prizes are open to persons who have done original research works in the topic of each prize which greatly contributed to the field of that prize.

(b) Selecting the winner will be decided by a Selection Committee consisting of well recognized specialists in the field.

(c) More than one person may share each Prize.

(d) The Winner's names will be announced in Jumada-al-Ula 1408H (January 1988) and the prize will be awarded in an official ceremony to be held for this purpose in Riyadh, Kingdom of Saudi Arabia.

(e) Each Prize consists of :

(1) A certificate in the name of the winner containing an abstract of the work that qualified him / her for the prize.

(2) A precious medal.

(3) A sum of three hundred and fifty thousand Saudi Riyals (SR. 350,000).

(f) The following conditions must be fulfilled.

1. A nominee must have accomplished an outstanding academic work in the subject of the prize, leading to the benefit of mankind and enrichment of human thought.
2. The prize will be awarded for the specific original research but the nominee's complete work will be taken into account.
3. The work submitted with the nomination must have been published.
4. The specific works submitted must not have been awarded a prize by any international educational institution or scientific organization.
5. Nominations must be submitted by educational institutions of Worldfame such as Universities, Academies and Research Centers. Nominations from individuals and political parties will not be accepted.
6. Nominations must give full particulars of the nominee's academic background, experience and publications, as well as copies of his / her educational certificates, if available. One coloured photo 10x15cm and three 6x9cm photographs, full address and telephone number of the nominee are also requested.
7. The nominations and selected publications (10 copies) are to be sent by registered air mail to the address stated in (10) below.
8. The latest date for receipt of the full nominations with copies of works is 29-11-1407H (25/7/1987).
9. No nomination papers or works will be returned to the senders.
10. All correspondences are to be sent, to :
    The General Secretariat of King Faisal International Prize,
    P. O. Box 22476, Riyadh 11495, Kingdom of Saudi Arabia,
    Telex: 404667 PRIZE SJ.

Before an antigen can associate with an MHC protein on the surface of a cell and trigger a *T*-cell response, the antigen-presenting cell must break it down into peptides (short sequences of amino acids, the building blocks of proteins). In earlier work the Gefter group and, independently, investigators led by Emil R. Unanue of the Washington University School of Medicine had shown that a peptide capable of stimulating a *T*-cell response in association with a particular MHC protein will bind to the same protein in the test tube. The finding suggested that the MHC protein acts as a receptor for the foreign peptide, holding it in a position that favors detection by *T* cells.

That proposal raised a question. Although the diversity of MHC molecules within a species is enormous, each individual has only a few variants. How can a handful of MHC proteins bind and present the multitude of different antigens to which an individual is exposed? Each MHC protein appears to make do with a single receptor site: the Gefter group, together with another group led by Grey, found that the binding of one peptide to an MHC molecule can prevent the binding of a second peptide with an affinity for the same MHC protein.

The question then became: How can peptides from a vast variety of antigens bind to the same site? In order to find out, the workers compared the amino acid sequences of several peptides that bind to the same MHC molecule. The similarities were striking; apparently MHC proteins select similar peptide sequences from diverse antigens for presentation to *T* cells.

The sequence information heightened the mystery of an earlier observation. One peptide, derived from a virus known as bacteriophage lambda, bound tightly to a particular MHC protein, yet the combination did not stimulate *T* cells. The peptide could only elicit a *T*-cell response in association with other MHC proteins, for which it showed less affinity in the test tube. The amino acid sequence of the lambda peptide shed no light on the anomaly: it resembled those of peptides that did stimulate *T* cells in the context of the MHC molecule.

In search of an explanation the investigators compared the amino acid sequences of the peptides with the sequence of the MHC molecule itself. They found a region of similarity, which fell within a segment of the MHC molecule that is also the domain of amino acid variations that distinguish the MHC proteins of one individual from those of another. Now the lambda peptide stood out: whereas

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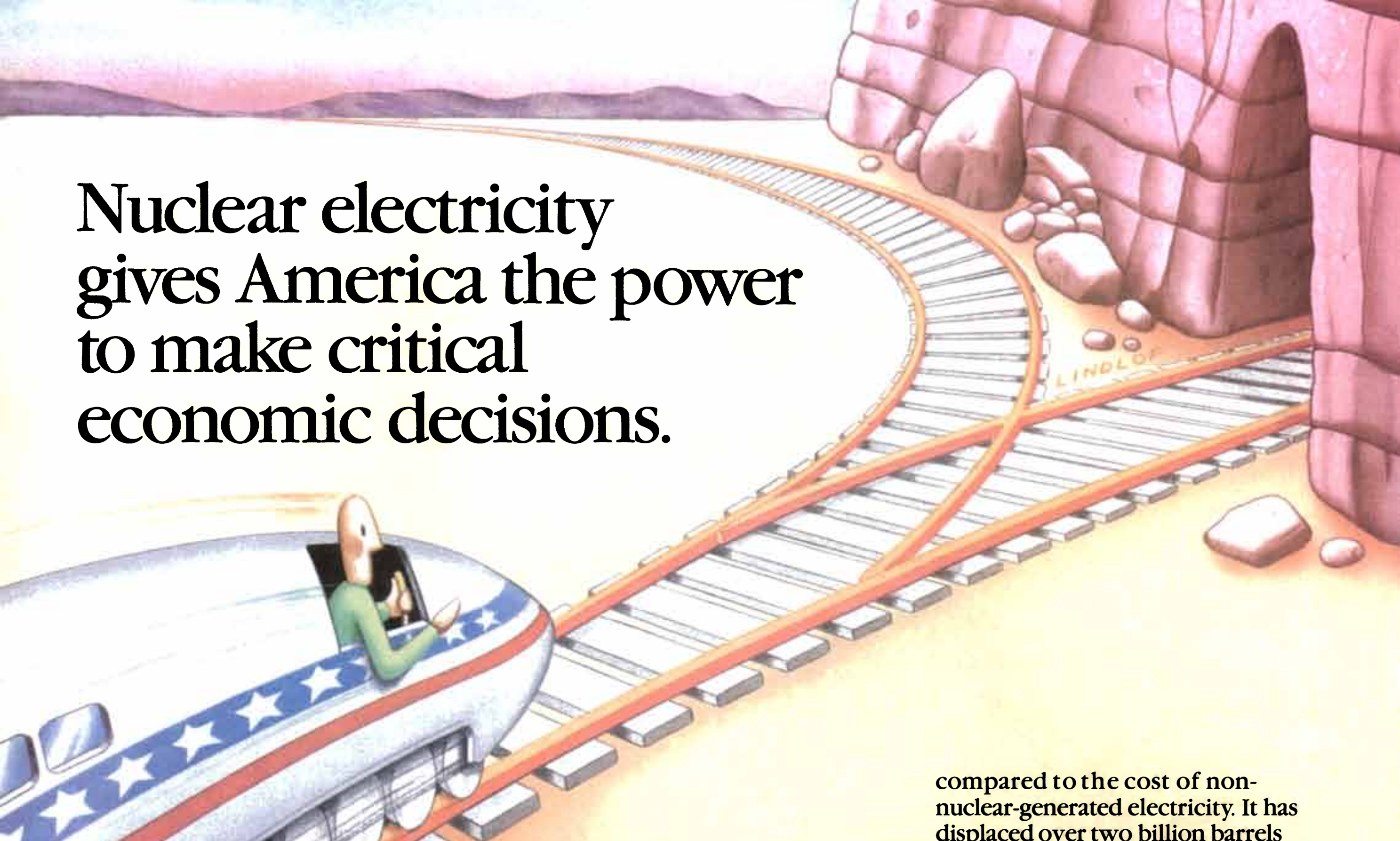
Nuclear electricity gives America the power to make critical economic decisions.



The 1973 Arab oil embargo gave America its first bitter taste of foreign oil dependence. To protect our economy, we turned to electricity. Using American resources and technology. As a result, nuclear energy has established itself as a cornerstone in rebuilding a strong economy.

The electrification of America

Electricity is the only major form of energy that has experienced overall growth since 1973. We are using 36% more now than we did then. It serves new uses in our factories and heats twice as many of our homes. Nuclear energy's contribution to our electricity supply has more than quadrupled during that time, helping fuel a 34% growth in America's economy.

There are still no guarantees against becoming too dependent on foreign oil once again. Our economy continues to require increasing amounts of electricity for its growth. And that electricity must continue to come from nuclear energy, as well as coal and other domestic sources.

The growth of nuclear energy

American nuclear electricity was born in 1956. By 1973, it had become a technology America could turn to when faced with the oil crisis. And today, over 100 nuclear plants make nuclear energy our second leading electricity source, behind coal. In fact, nuclear energy and coal together have provided over 95% of all new electricity generated in America over the past decade.

Nuclear energy also saved Americans between 35 and 62 billion dollars from 1974 to 1985, compared to the cost of non-nuclear-generated electricity. It has displaced over two billion barrels of oil. And its contribution continues to climb. The U.S. Department of Energy estimates that nuclear energy will provide 20% of our electricity by the early 1990s.

Nuclear energy for a secure future.

Nuclear energy has proven its worth to America's economy. Auburn University Dean of Engineering Dr. Lynn Weaver recently described nuclear energy as "...one of the basic props supporting the entire national economy."

Yet, in spite of all we've accomplished, the threat of foreign oil dependence remains. Difficult choices will still need to be made. But one fact has made itself very clear: the more we develop our own energy sources like nuclear energy and coal, the more we control our own economic destiny.

For a free booklet on energy independence, write to the U.S. Committee for Energy Awareness, P.O. Box 1537 (ED20), Ridgely, MD 21681. Please allow 4-6 weeks for delivery.

Information about energy America can count on

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The Questar 12, latest addition to the Questar family of fine optical instruments, now has its own Questar-designed mount. A German equatorial type, it is notable for its 360° continuous tracking in R.A. with precision tracking to better than 4 arc seconds. The Questar Mount is designed with over-sized components so that it can accommodate any Questar up to 18 inches. The standard mount shown is straightforward in design but can be modified so as to be compatible with more sophisticated tracking devices or other special equipment.

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the active peptides differed from the MHC protein at the variable sites, the lambda peptide was largely identical with the MHC sequence even there.

Even though a resemblance between a foreign peptide and a part of the MHC protein seems to be a prerequisite for binding, too close a resemblance apparently makes the bound peptide invisible to *T* cells. Gefter and his collaborators propose molecular mechanisms that might underlie these curious requirements. The segment of the MHC molecule bearing the amino acid code for "self," they suggest, has a three-dimensional geometry complementary to the part of the molecule that forms the receptor. As a result the segment can fit into the receptor as an "internal ligand." An antigenic peptide with a similar amino acid sequence and hence a similar structure can displace the internal ligand and bind to the receptor.

Gefter and his co-workers believe that model of the interaction between antigen and MHC protein, if it is broadly applicable, could resolve a central mystery of immunology: the question of how *T* cells recognize an antigen as foreign. The group proposes the recognition is based on just a few amino acid sites: those at which a foreign peptide bound to an MHC protein differs from the internal ligand. In this view *T* cells approach MHC proteins on the surface of other cells and inspect the ligand occupying the receptor. Small variations from the "self" sequence are enough to trigger an immune reaction. If a foreign peptide matches the sequence at the crucial sites, as the lambda peptide did, the *T* cell sees the sequence as "self" and does not respond.

The scheme proposed by the Gefter group can also help to account for transplant rejection, in which the graft recipient's *T* cells respond not to antigen combined with "self" MHC proteins but directly to the foreign MHC proteins on grafted cells. Gefter and his colleagues propose that the internal ligand in an MHC protein of one individual differs from the internal ligand in the corresponding protein of another individual much as an antigenic peptide would. To a *T* cell a foreign MHC molecule looks like a "self" molecule carrying an antigenic peptide. Graft rejection, Gefter says, is "just a by-product of the way the immune system works."

Protobrain

The demands on the central nervous system of the fetus change dramatically at birth. Survival, formerly a cooperative venture, becomes a soli-

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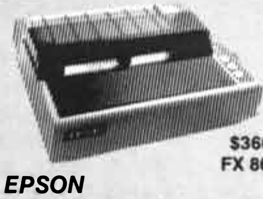

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tary chore. Perhaps it is not surprising, then, that neuroscientists have recently found evidence that the fetal brain may be qualitatively different from the brain of the adult.

Three investigators at the Stanford University School of Medicine have shown that a population of cells in the embryonic cat brain are mature, and probably functioning, nerve cells. The neurons appear when the embryo is three or four weeks old—long before any other cells in the brain's hemispheres have differentiated—and disappear about two months after birth. They populate an area of the developing brain that will later become the so-called white matter, a region distinguished by its lack of nerve cell bodies. The neurons are therefore both temporally and spatially distinct from the cells destined to make up the nervous system of the adult.

The cell population had been recognized long before the Stanford workers' report, but no one knew what kind of cells the population contained. In a recent issue of *Nature* Jerald J. M. Chun, Mark J. Nakamura and Carla J. Shatz demonstrated that the cells satisfy several criteria for active nerve cells: they bind antibodies against a nerve-cell protein, they produce chemical substances that are unique to nerve cells and, viewed with the electron microscope, they look like functional nerve cells.

By means of delicate surgical techniques the investigators labeled the cells in living fetuses and then dissected the fetuses at various intervals to trace the life history of the cell population. The work established that the cells are not the forerunners of any adult population. Most embryos make nascent nerve cells in great excess, then prune away inaccurate circuitry. This pruning, however, occurs among cell populations that persist in the adult. In contrast, the cells Chun and his colleagues identified are found in the fetus alone.

Because these cells have no adult counterpart, it is difficult to ascertain what they actually do in the developing embryo. They could be specialized regulators of fetal heart rate, respiration or hormone secretion, or signposts that direct the maturation of the adult nervous system. They could be acting as surrogates for adult nerve cells, helping to solve the logistic problem posed by a complex network the countless components of which must mature simultaneously. They may or may not be indicative of a type of fetal intelligence entirely distinct from that of the adult. These speculations are paving the way for future experimentation, and Shatz suspects that there are other populations of transient fetal nerve cells yet to be discovered.

MEDICINE AND HEALTH

Enzyme Therapy

The best way to treat a disease arising from a defect in the gene for an enzyme would be to replace the defective gene. There are still serious obstacles, however, to the implementation of gene therapy, notably the problem of regulating the gene once it has been inserted in a patient's cells. An alternative approach is to replace the enzyme rather than the gene. Workers at the Duke University Medical Center and the University of Nebraska Medical Center have reported what they call the first successful treatment of a genetic disease by means of enzyme replacement.

The disease is adenosine deaminase (ADA) deficiency, a disorder that afflicts 20 or 30 newborns in the world each year. In the absence of ADA, the DNA precursor deoxyadenosine triphosphate accumulates in cells, blocking the normal synthesis of DNA. The effect is most pronounced in lymphocytes, or immune cells. Victims of ADA deficiency have a drastically underdeveloped immune system, and unless they are treated they usually die of an infection within two years of birth. Only one in five can be treated effectively with transplants of lymphocyte-producing bone marrow from a sibling or parent.

Injections of the purified enzyme would seem a straightforward solution. The problem has been that ADA, like most enzymes, normally functions inside cells; when it is injected into the bloodstream, it is broken down rapidly, before it can be effective. Another difficulty is that at present the only economical source of ADA is animal tissue. Animal ADA would be expected to provoke an immune reaction in human patients, particularly once their immune function has improved.

The Duke and Nebraska groups appear to have circumvented both difficulties, although the results they report in the *New England Journal of Medicine* are preliminary. Instead of injecting pure ADA into the bloodstreams of their two patients, the workers injected ADA that had been chemically combined with polyethylene glycol (PEG), a waxy, nontoxic substance with a variety of medical applications. Because PEG-coated ADA is protected from breakdown by other enzymes, its half-life in the bloodstream is two or three days rather than a few minutes. The PEG also seems to prevent an immune response, probably by blocking the binding of antibodies to the enzyme.

After the two children had received weekly doses of PEG-ADA for several months, the workers report, "the principal biochemical consequences of [ADA] deficiency were almost completely reversed," and normally functioning lymphocytes appeared in the patients' blood. More important, the children have shown distinct clinical improvements: neither of them has had a serious infection, both have gained weight and both are more active than ever before.

It remains to be seen whether the improvements are lasting and whether other patients will do as well. But according to Michael S. Hershfield of Duke, the early results suggest that ADA-deficiency may one day be a manageable condition, rather like diabetes. Moreover, the technique for modifying enzymes with PEG, developed by Enzon, Inc., of South Plainfield, N.J., might be applied to other genetic and nongenetic disorders, including atherosclerosis.

SURVEY

Scared Sick

Strong links are being found between the nervous system, the endocrine system and the immune system.

The Greek physician Galen noted nearly 2,000 years ago that depressed women were more likely than others to develop cancer. Contemporary studies have found similar associations between emotional stress and illness. Theodore J. Jacobs of the Albert Einstein College of Medicine and Edward S. Charles of Columbia Presbyterian Hospital confirmed in 1980 that children with cancer are more likely than others to have experienced recent psychological trauma; and investigators at several institutions have verified that illness and death strike with more than usual frequency at people who have recently lost a spouse.

Conceivably stress could cause illness simply by diminishing a person's capacity for self-care. Yet evidence accumulates to support the proposition that stress enhances susceptibility to disease through direct connections between the nervous system and the immune system. One such connection, the suppressive effect on the immune system of glucocorticoid hormones produced by the adrenal glands in response to stress, has been known since the 1950's: stressed animals show changes in the relative numbers of dif-

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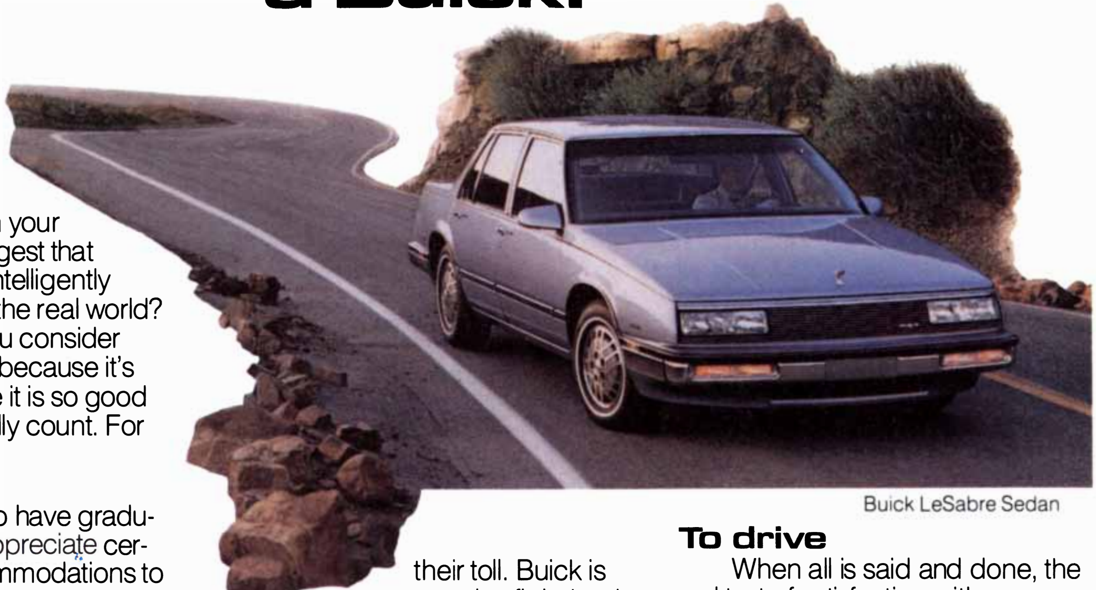

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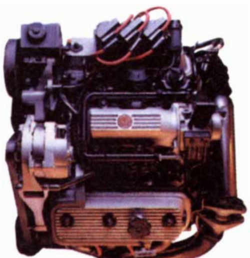

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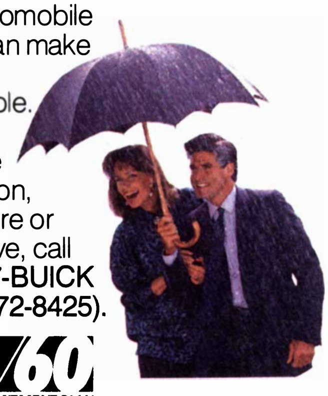

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ferent types of white blood cells, including lymphocytes.

Many other possible interactions of the central nervous system with the immune system have been discovered in the past few years. Karen Bulloch of the State University of New York at Stonybrook has shown how nerve fibers penetrate deep into lymphoid tissue such as the bone marrow and the thymus gland, where lymphocytes are produced and mature; Lewis T. Williams, now at the University of California School of Medicine in San Francisco, has demonstrated that lymphocytes have specific receptor sites for the neurotransmitters such nerve fibers release. Eli K. Hazum of the Weizmann Institute of Science in Israel has found that neuropeptides such as *beta*-endorphin bind to specific receptor sites on lymphocytes.

To take another example, macrophages (cells that are stimulated by the immune system to devour invading organisms) appear to be activated by serotonin, according to Manfred L. Karnovsky of the Harvard Medical School. Serotonin is found in blood platelets and is also a neurotransmitter; it binds to macrophages at the same sites as muramyl peptides, compounds that activate macrophages but also induce sleep.

Lymphocytes reciprocate. J. Edwin Blalock of the University of Alabama at Birmingham has shown they produce hormones such as adrenocorticotropic hormone, which affects the adrenal gland. Interferon, an immune-system protein important in fighting viral infections, has been shown to influence the neuroendocrine system.

These links have an effect. Steven E. Keller and his colleagues at the Mount Sinai School of Medicine in New York found that stress inhibited lymphocyte response to immunogenic challenge even in rats whose adrenal glands had been removed. Some workers are beginning to view the immune system and the neuroendocrine system as complementary sensoriums that routinely exchange information about the stresses they are responding to.

Such interactions appear to change immune function subtly in both animals and people facing psychological stress. Christopher L. Coe of the University of Wisconsin at Madison finds infant squirrel monkeys separated from their mothers have an immune response markedly different from that of monkeys kept with their mothers. Janice K. Kiecolt-Glaser of the Ohio State University College of Medicine finds the efficacy of DNA repair in lymphocytes is lessened in pyschologically distressed mental patients.

In spite of such suggestive findings no conclusive studies yet link stress to reduced immune function and impaired health. A first attempt has been made by Ronald Glaser and his coworkers at the Ohio State University Medical Center. Glaser took blood samples from medical students at various times in the course of a year, sometimes just after vacations and sometimes during academic examinations. As expected, immune systems were working less well at exam time. "Natural killer cells" that kill tumor cells were impaired and other cells produced diminished amounts of interferon. Moreover, the subjects' blood levels of the Epstein-Barr virus, a common latent infection, rose during examination periods.

Glaser asked the students to report on minor medical symptoms that had limited their activities, such as coughs and colds. They mentioned having had such problems more frequently at exam time, when their immune systems were compromised, than under other circumstances. Tracing such an intricate series of biological effects would have been impossible 30 years ago, when "all we could measure was death," as Marvin Stein of Mount Sinai recalls.

Why should a relation between the nervous system and the immune system have evolved that tends toward increased vulnerability? One possible explanation is that prolonged stress caused by psychological events, as opposed to short-term physical stress, is itself a recent evolutionary development, a consequence of the expansion of the human brain and an intensely social way of life. The effects of stress on the immune system might be inconsequential or even beneficial in the short term but then become harmful, for one or another reason, when stress is prolonged.

One proponent of this view is Robert Sapolsky of Stanford University. He has shown that aged rats are unable to suppress production of glucocorticoids by the adrenal glands after a stressful event has ended. Neurons in the hippocampus, a part of the brain that monitors and controls glucocorticoid levels, are killed by high levels of the hormones over the course of a lifetime. This damages the feedback system that would normally keep the levels in check.

Sapolsky is now studying the effect of behavioral dominance in wild olive baboons on health and stress, as measured by glucocorticoid levels. Preliminary observations suggest that the highest-ranking males are usually the healthiest, and that they most effectively suppress glucocorticoids after undergoing stress. It remains to be seen whether people who are good at coping with stress gain the benefit of a more responsive immune system and better health. If they do, and if impairments of the immune system can in the future be routinely assessed, the implications for health care could be far-reaching.

OLIVE BABOON seeking to raise its status engages in a threat display in this photograph made by Irven DeVore (from Anthro-Photo). Investigators are studying the baboons in Kenya to see if successful males are better able to control the response to stress.

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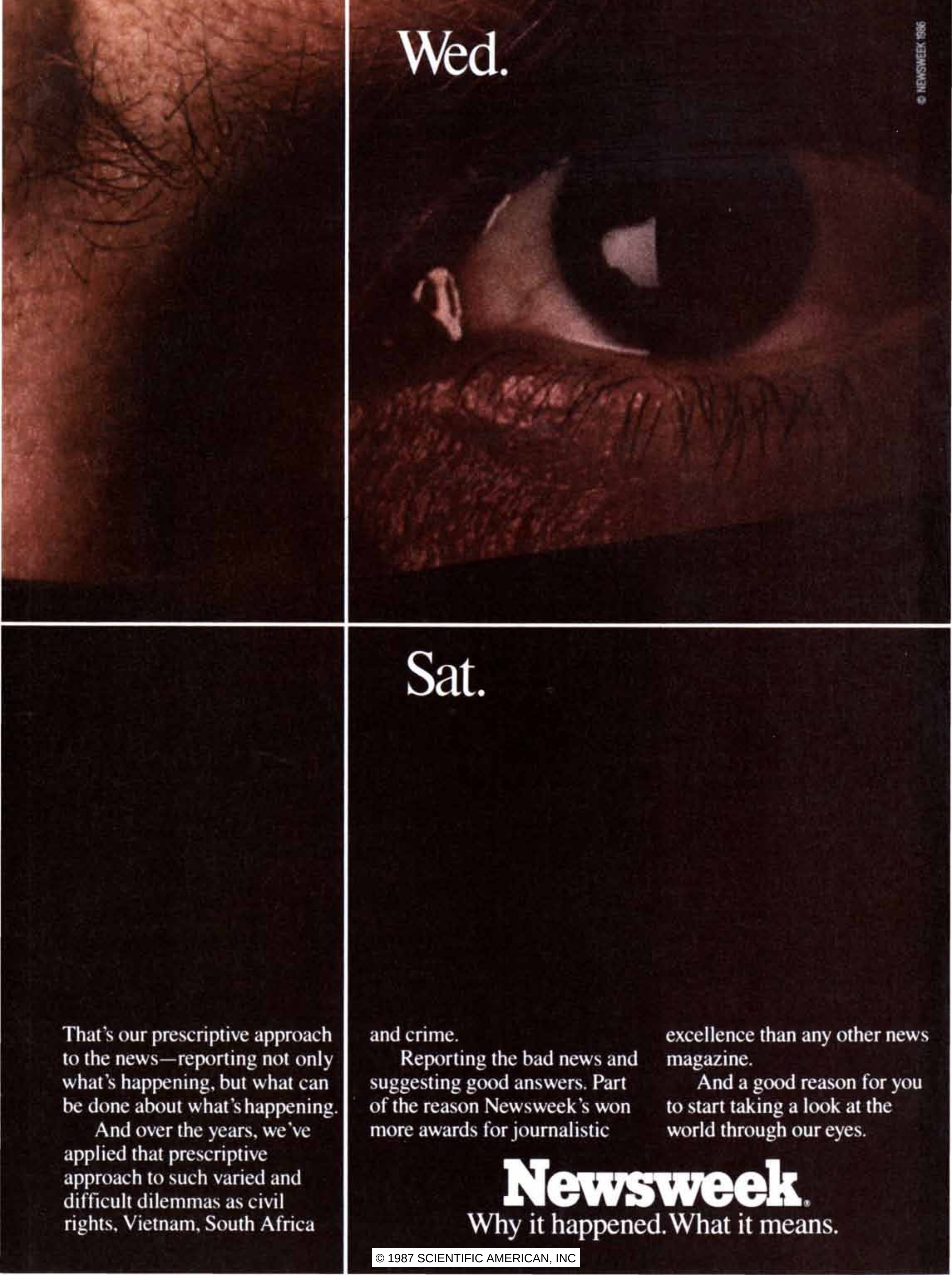

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Climate Modeling

Will the "greenhouse effect" bring on another Dust Bowl? Would nuclear war mean "nuclear winter"? Computer models of the earth's climate yield clues to its future as well as to its checkered past

by Stephen H. Schneider

The earth's climate changes. It is vastly different now from what it was 100 million years ago, when dinosaurs dominated the planet and tropical plants thrived at high latitudes; it is different from what it was even 18,000 years ago, when ice sheets covered much more of the Northern Hemisphere. In the future it will surely continue to evolve. In part the evolution will be driven by natural causes, such as fluctuations in the earth's orbit. But future climatic change, unlike that of the past, will probably have another source as well: human activities. We may already be feeling the climatic effects of having polluted the atmosphere with gases such as carbon dioxide. The effects of a nuclear war would be far more dramatic.

How can human societies prepare for so uncertain a climatic future? Clearly it would help to be able to predict that future in some detail, but therein lies a problem: the processes that make up a planetary climate are too large and too complex to be reproduced physically in laboratory experiments. Fortunately they can be simulated mathematically with the help of a computer. In other words, instead of actually building a physical analogue of the land-ocean-atmosphere system, one can devise mathematical expressions for the physical principles that govern the system—energy conservation, for example, and Newton's laws of motion—and then allow the computer to calculate how the climate will evolve in accordance with the laws. Mathematical climate models cannot simulate the full complexity of reality. They can, however, reveal the logical consequences of plausible assumptions about the climate. At the very least they are a big step beyond purely speculative "hand waving."

Mathematical models have been used to simulate the present climate—to study, for instance, the effects on the atmosphere of volcanic eruptions such as El Chichón. They are also helping to explain the evolution of past climates, including those of the ice ages and the Cretaceous period (the final age of the dinosaurs). The accuracy of paleoclimatic simulations in turn lends confidence to workers who employ the same models to simulate future climates, and who in particular try to gauge the potential impacts of human pollution and of nuclear war. In this context climate modeling is emerging as a field of more than academic interest: it is becoming a fundamental tool for assessing public policy.

Basic Elements

Although all climate models consist of mathematical representations of physical processes, the precise composition of a model and its complexity depend on the problem it is designed to address. In particular they depend on how long a period of the past or future is to be simulated. Some of the processes that influence climate are very slow: the waxing and waning of glaciers and forests, for example, or the motions of the earth's crust, or the transfer of heat from the surface of the ocean to its deeper layers. A model designed to forecast next week's weather ignores these variables, treating their present values (the extent of ice coverage, for instance) as external, unchanging "boundary conditions." Such a model simulates only atmospheric change. On the other hand, a model designed to simulate the dozen or so ice ages and interglacial periods of the past million years must include all the above processes and more.

Climate models vary also in their spatial resolution, that is, in the number of dimensions they simulate and the amount of spatial detail they include. An example of an extremely simple model is one that calculates only the average temperature of the earth, independent of time, as an energy balance arising from the earth's average reflectivity and the average "greenhouse" properties of the atmosphere. Such a model is zero-dimensional: it collapses the real temperature distribution on the earth to a single point, a global average. In contrast, three-dimensional climate models reproduce the way temperature varies with latitude, longitude and altitude. The most sophisticated of them are known as general-circulation models. They predict the evolution with time not only of temperature but also of humidity, wind speed and direction, soil moisture and other climatic variables.

General-circulation models are usually more comprehensive than simpler models in terms of the natural detail they include, but they are also much more expensive to design and run. The optimal level of complexity for a model depends on the problem and on the resources available to address it; more is not necessarily better. Often it makes sense to attack a problem first with a simple model and then employ the results to guide research at higher resolution. Deciding how complicated

NUCLEAR WAR in July would trigger widespread but transient "quick freezes" in the Northern Hemisphere, according to simulations done by the author and Starley L. Thompson of the National Center for Atmospheric Research. The maps show the model-computed surface temperatures (in degrees Celsius) on a normal day in July (*top*) and on the 10th day of a 10-day nuclear war (*bottom*). The simulation assumes that fires started by 6,500 megatons of bombs produced 180 million metric tons of sunlight-blocking smoke. The cooling effects are localized because the smoke is patchy and because they depend on local weather. Hence a single simulation cannot forecast the temperature for a specific time and place; it can only convey the type of change a nuclear war could cause.

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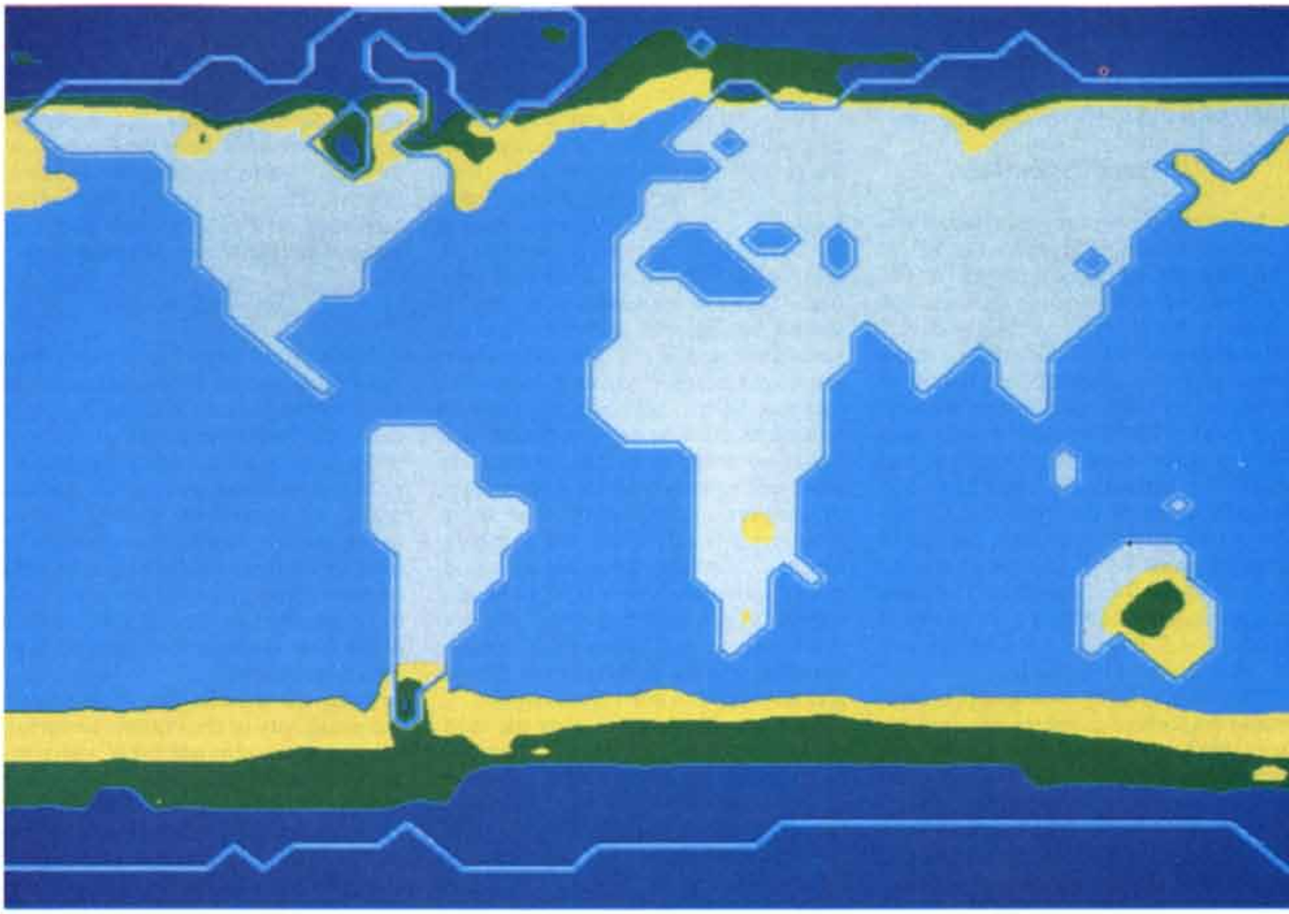

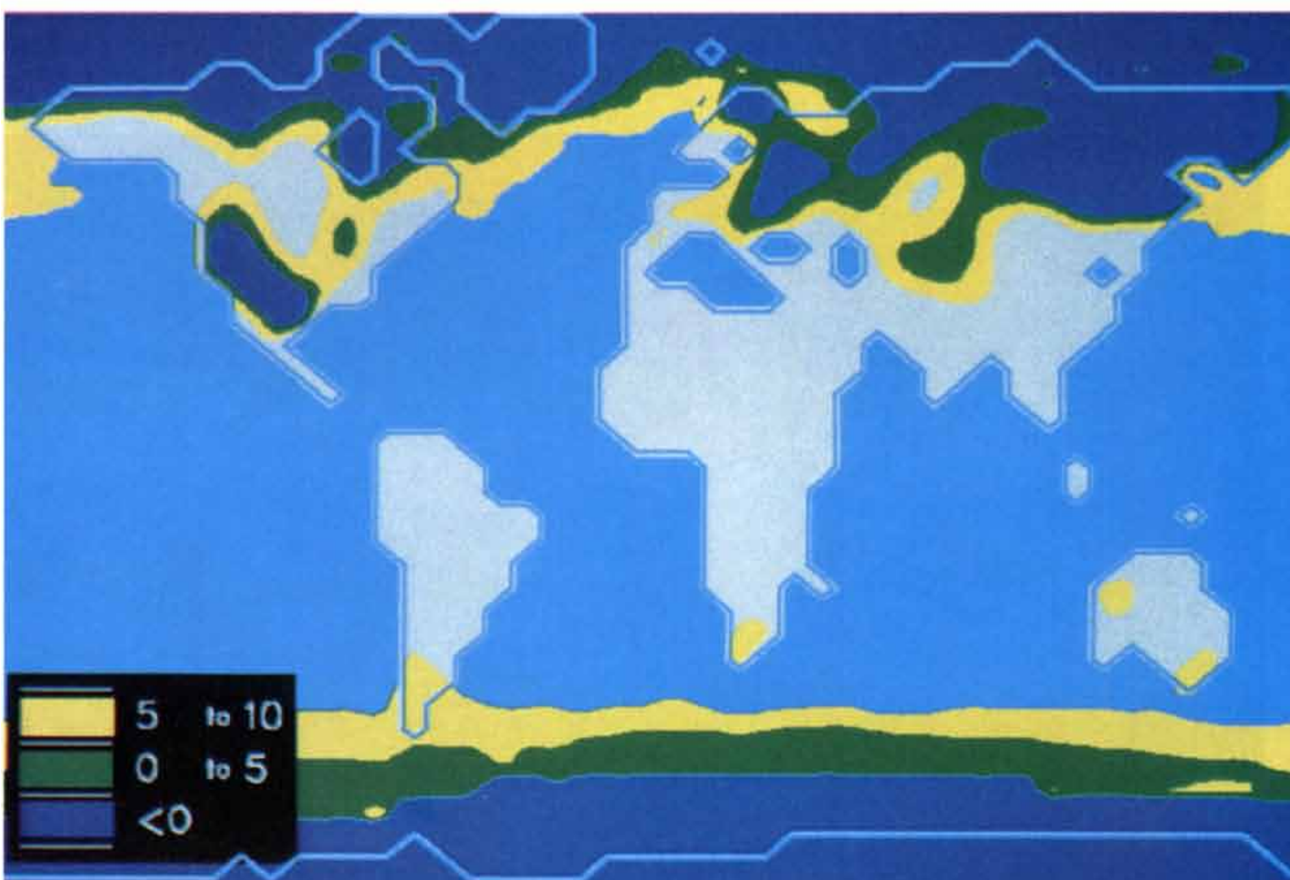

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a model to use for a given task—in other words, at what level to trade completeness and accuracy for tractability and economy—is more a value judgment than it is a strictly scientific one.

Grids and Parameters

Even the most complex general-circulation model is sharply limited in the amount of spatial detail it can resolve. No computer is fast enough to calculate climatic variables everywhere on the earth's surface and in the atmosphere in a reasonable length of time. Instead the calculations are executed at widely spaced points that form a three-dimensional grid at and above the surface. The model my colleagues and I at the National Center for Atmospheric Research use has a grid with nine layers stacked to an altitude of about 30 kilometers. The horizontal spacing between grid points is roughly 4.5 degrees of latitude and seven degrees of longitude.

The wide spacing creates a problem: many important climatic phenomena are smaller than an individual grid box. Clouds are a good example. By reflecting a large fraction of the incident sunlight back to space, they help to determine the temperature on the earth. Predicting changes in cloudiness is therefore an essential part of reliable climate simulation. Yet no global climate model now available or likely to be available in the next few decades has a grid fine enough to resolve individual clouds, which tend to be a few kilometers rather than a few hundred kilometers in size.

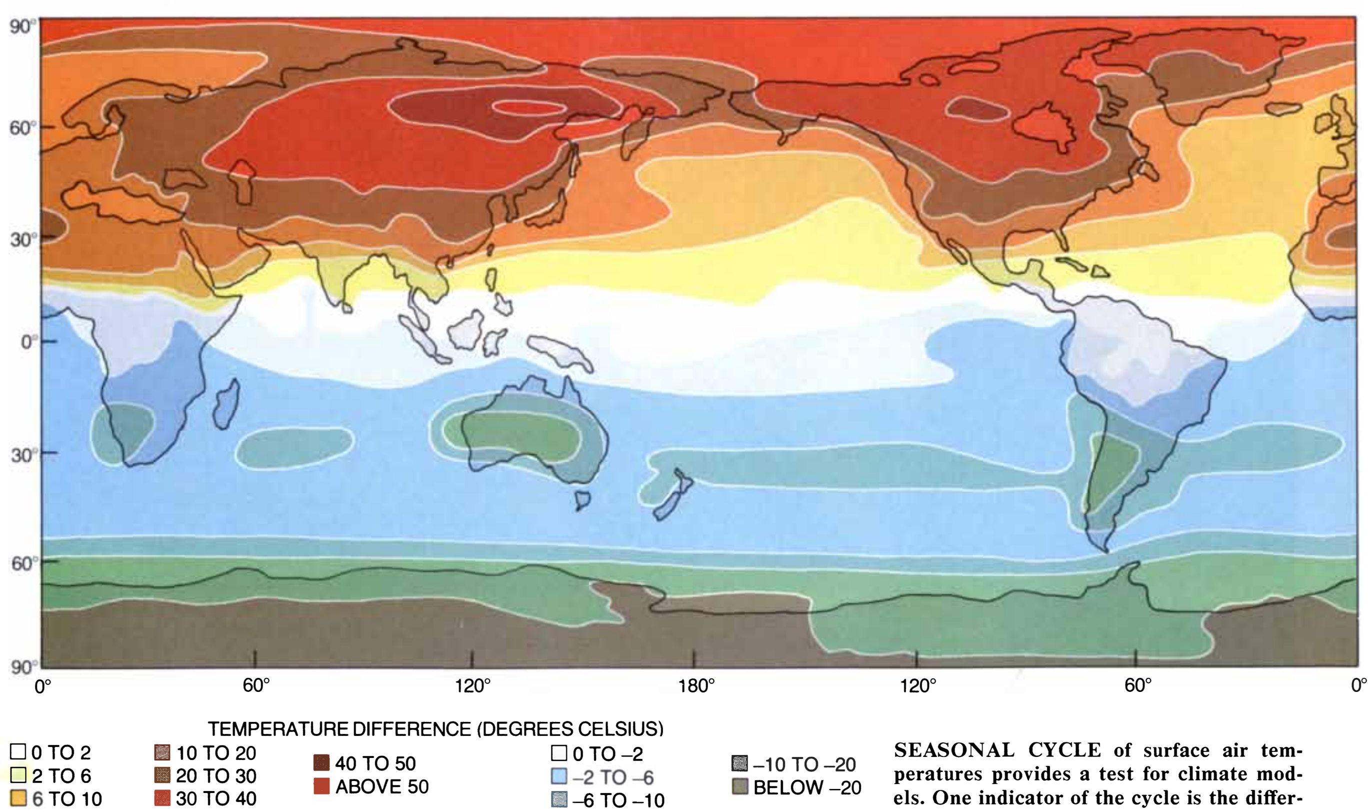
The solution to the problem of subgrid-scale phenomena is to represent them collectively rather than individually. The method for doing so is known as parameterization. It consists, for example, in searching through climatological data for statistical relations between variables that are resolved by the grid and ones that are not. For instance, the average temperature and humidity over a large area (the size of one grid box, say) can be related to the average cloudiness over the same area; to make the equation work one must introduce a parameter, or proportionality factor, that is derived empirically from the temperature and humidity data. Since a model can calculate the temperature and humidity in a grid box from physical principles, it can predict the average cloudiness in the grid box even though it cannot predict individual clouds.

To fully simulate a climate the models must take into account the complex feedback mechanisms that influence it. Snow, for example, has a destabilizing, positive-feedback effect on temperature: when a cold snap brings a snowfall, the temperature tends to drop further because snow, being highly reflective, absorbs less solar energy than bare ground. This process has been parameterized fairly well in climate models. Unfortunately other feedback loops are not as well understood. Again clouds are a case in point. They often form over warm, wet areas of the earth's surface, but depending on the circumstances they may have either a stabilizing, negative-feedback effect (cooling the surface by blocking sunlight) or a positive one (warming the surface further by trapping heat).

Climate Sensitivity

Uncertainty about important feedback mechanisms is one reason the ultimate goal of climate modeling—forecasting reliably the future of key variables such as temperature and rainfall patterns—is not yet realizable. Another source of uncertainty that is external to the models themselves is human behavior. To forecast, for example, what impact carbon dioxide emissions will have on climate one would need to know how much carbon dioxide is going to be emitted.

What the models can do is analyze the sensitivity of the climate to various uncertain or unpredictable variables. In the case of the carbon dioxide problem one could construct a set of plausible economic, technological and population-growth scenarios and employ a model to evaluate the climatic consequences of each scenario. Climatic factors whose correct values are uncertain (such as the cloud-feedback parameter) could be varied over a



SEASONAL CYCLE of surface air temperatures provides a test for climate models. One indicator of the cycle is the differ-

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plausible range of values. The results would indicate which of the uncertain factors is most important in making the climate sensitive to a carbon dioxide buildup; one could then focus research on those factors. The results would also give some idea of the range of climatic futures to which societies may be forced to adapt. How to respond to such information, of course, is a political issue.

Perhaps the most perplexing question about climate models is whether they can ever be trusted enough to provide grounds for altering social policies, such as those governing carbon dioxide emissions. How can models so fraught with uncertainties be verified? There are actually several methods. None of them is sufficient on its own, but together they can provide significant (albeit circumstantial) evidence of a model's credibility.

The first method is to check the model's ability to simulate today's climate. The seasonal cycle is one good test because the temperature changes involved are large—several times larger, on the average, than the change from an ice age to an interglacial period. General-circulation models do remarkably well at mapping the seasonal cycle, which strongly suggests they are on the right track. The seasonal test, however, does not indicate how well a model simulates slow processes, such as changes in ice cover, that may have an important long-term effect.

A second method of verification is to isolate individual physical components of the model, such as its parameterizations, and test them against real data from the field. For example, one can check whether the model's parameterized cloudiness matches the level of cloudiness appropriate to a particular grid box. The problem with this test is that it cannot guarantee that the complex interactions of many individual model components are properly treated. The model may be good at predicting average cloudiness but bad at representing cloud feedback. In that case the simulation of the overall climatic response to, say, increased carbon dioxide is likely to be inaccurate.

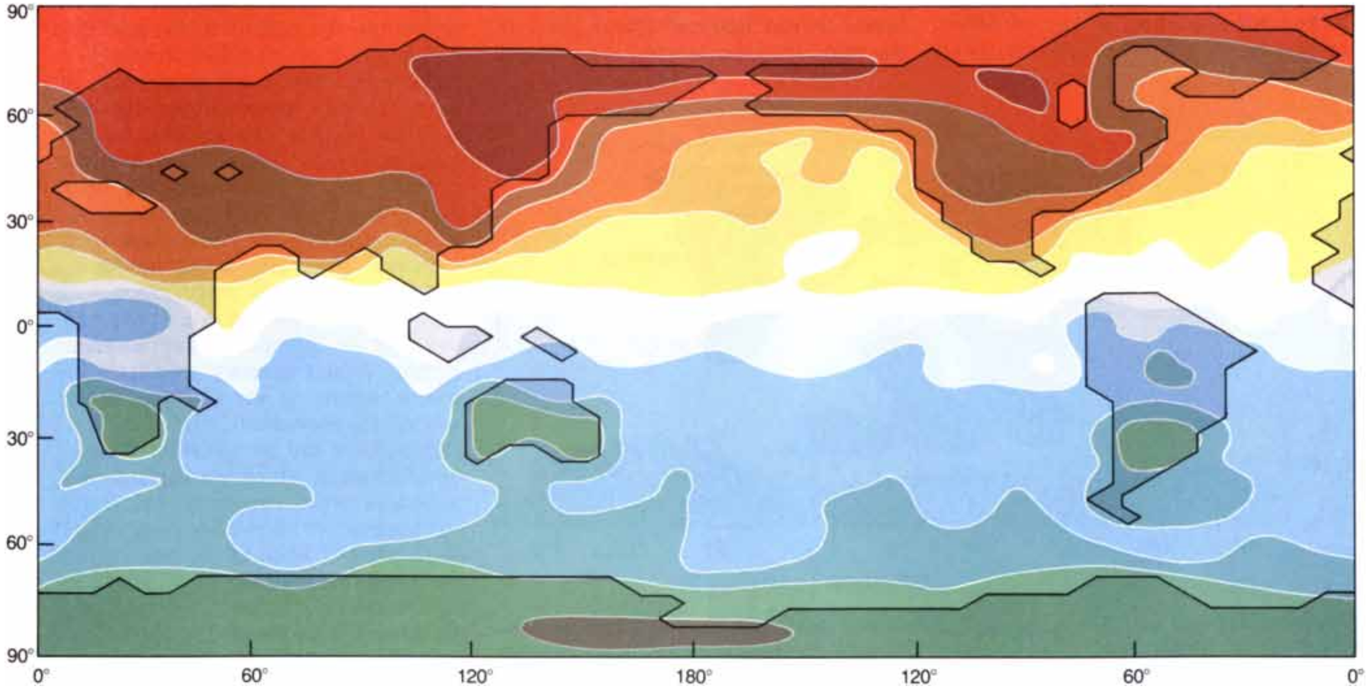
For determining overall, long-term simulation skill there is a third method: checking the model's ability to reproduce the very different climates of the ancient earth or even of other planets. The paleoclimatic simulations I shall describe below are intrinsically interesting as exercises in understanding the earth's history. As checks on climate models, however, they are also crucial to estimating its future.

Recent History

One of the most successful paleoclimatic simulations to date was done by John E. Kutzbach and his colleagues at the University of Wisconsin at Madison. Kutzbach attempted to explain the warmest period in recent climatic history, the so-called climatic optimum that took place between about 9,000 and 5,000 years ago. During that period, judging from fossil and other geologic evidence, summer temperatures within the northern continents were several degrees Celsius higher than they are now. In Africa and Asia the monsoons were more intense.

Kutzbach's simulation showed that the climatic differences could be explained by two small differences in the earth's orbit: a slightly greater tilt of its spin axis and the fact that it made its closest approach to the sun in June rather than in January, as it does now. Both these differences would have increased the amplitude of the seasonal cycle in the Northern Hemisphere. Nine thousand years ago the Northern Hemisphere received about 5 percent more solar heat during the summer and about 5 percent less during the winter than it does today. Because the summer temperature difference between land and sea was greater, the wind patterns were different and the monsoon rainfall was more intense.

Kutzbach's success was particularly encouraging to my colleagues and me at NCAR because he used the same basic three-dimensional model we do. Starley L. Thompson and I have applied the model to the problem of explaining the strikingly dissimilar climate that prevailed just two millenniums before the climatic optimum. About 11,000 years ago the earth had



ence between summer and winter temperatures. Here the observed temperature differences between August and February (*left*) are compared with the differences computed by a three-dimensional model (*right*) devised by Syukuro Manabe and Ronald Stouffer of the Geophysical Fluid Dynamics Laboratory. The model reproduces most of the real features with remarkable accuracy.

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emerged from the grip of the last ice age. Much of the warm-weather flora and fauna had begun to return to the northern latitudes, particularly in western Europe. Then suddenly that part of the planet was struck again by a dramatic cooling of nearly ice-age intensity. The cold period lasted for almost 1,000 years; it is known as the Younger Dryas, after an arctic flower.

The cooling during the Younger Dryas was most intense in the North Atlantic region, particularly on the western coast of Europe and in England. The pattern suggests an oceanic cause. A number of paleoclimatologists, including William F. Ruddiman and Andrew McIntyre of Columbia University's Lamont-Doherty Geological Observatory, have argued that, ironically, the ultimate cause of the Younger Dryas was the rapid breakup of the European and North American ice sheets between 12,000 and 10,000 years ago. The breakup would have dumped a vast amount of fresh water into the North Atlantic. Since fresh water freezes more readily than salt water, the "meltwater spike" might have produced a broad cover of sea ice that would have blocked the northern leg of the Gulf Stream, which ordinarily warms northwestern Europe.

To test this hypothesis Thompson and I ran a climate simulation in which the entire surface of the North Atlantic down to a latitude of 45 degrees was assumed to be frozen—not because we believe that was precisely what happened during the Younger Dryas but simply as a way of determining the sensitivity of the climate to sea ice. Our results support the hypothesis. During the summer the cooling effect of the frozen North Atlantic is felt primarily right along the coast of Europe; the dominant influence on inland temperatures is the strong summer sun. During the winter, however, when solar heating is reduced and when the Gulf Stream normally maintains an equable climate in western Europe by generating warm onshore breezes, the sea-ice cover leads to more widespread and severer cooling.

Other workers, notably a group at the Goddard Institute for Space Studies, have obtained similar results using different models. The temperature maps produced by the models are roughly consistent with the available geologic data. They even suggest where paleoclimatologists should dig for evidence that would further buttress the sea-ice hypothesis and the models too. The models predict, for instance, that a sea-ice increase would have had only a slight cooling effect during the summer in the Soviet Union; the Goddard model, which included the effects of the remnant European ice sheet, actually predicts warmer summers in the Soviet Union. These predictions could be tested by analyzing fossilized pollen to determine what kind of plants thrived in that region during the Younger Dryas.

The Cretaceous Period

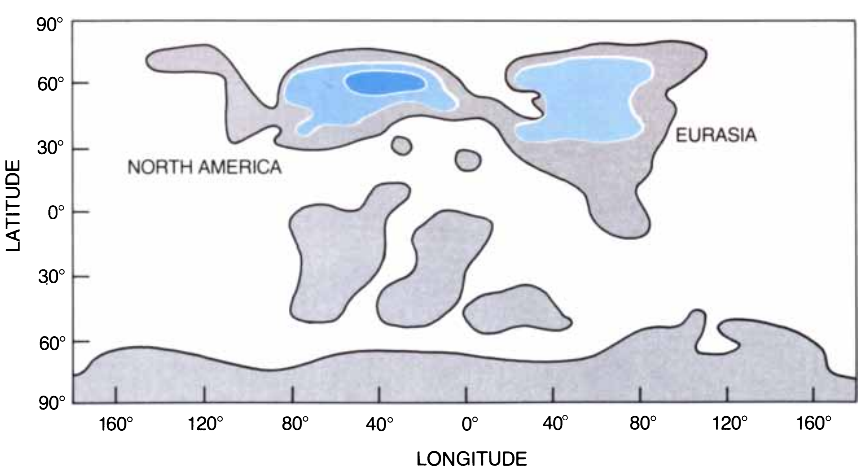
In the middle of the Cretaceous period, about 100 million years ago, broad-leaved tropical plants grew in the mid-latitudes, in what are now the temperate zones. Alligators lived near the Arctic Circle, which like Antarctica appears to have been free of permanent ice. Sea levels were hundreds of meters higher. The evidence strongly suggests that the temperature in the interiors of continents usually remained above freezing even in winter.

What could explain such a warm era? One hypothesis is that heat transport by oceanic currents, which help to spread the excess solar energy received near the Equator around the earth, was more efficient in the Cretaceous. The continents then were in different positions, and so the ocean currents must have been different too.

Eric J. Barron, now at Pennsylvania State University, and Warren M. Washington of NCAR were the first to test this hypothesis with a three-dimensional climate model. They did not explicitly model the transport of heat in the ocean; instead they assumed that the sea-surface temperature everywhere was at least 10 degrees C., which implies a large poleward heat transport. They found that, contrary to the usual interpretation of the geologic evidence, the continental mid-latitudes still got cold in winter and the temperature fell well below freezing in the Antarctic. When Barron, Thompson and I ran a simulation incorporating a more extreme (and unrealistic) assumption—an ocean that transported heat with perfect efficiency, so that its temperature everywhere was a warm 20 degrees C.—the discrepancy between model and evidence got worse: the middle of the northern continents got even colder in winter.

Actually that is not surprising. By fixing the sea-surface temperature at a globally uniform 20 degrees, we had eliminated the temperature gradient between the Equator and the poles that is the chief driving force of the earth's atmospheric circulation. Consequently the winds in our model became too feeble to carry much heat onto the continents. In order to test adequately the hypothesis that enhanced oceanic heat transport produced the warm climate of the Cretaceous, we needed a more realistic model.

Hence we did an additional set of simulations in which sea-surface temperatures were explicitly calculated but were never allowed to drop below 20 degrees C. even at the poles. With the temperature of the tropical oceans now between 25 and 30 degrees C., the model incorporated a substantial temperature gradient. Accordingly its winds were more vigorous. And yet, even though the model planet as a whole was considerably warmer than the real earth is today, it was not warm enough. Below-freezing temperatures



CRETACEOUS CLIMATE was much warmer than today's climate. Fossil evidence suggests that the temperature on the northern continents generally remained above freezing even in winter. (The continents are shown in roughly the positions they occupied 100 million years ago.) The map represents an attempt to model this warm climate by assuming that ocean currents transported much more heat than they do now, so that the sea-surface temperature everywhere was at least 20 degrees Celsius. Under this extreme assumption, however, the air temperature in January would still have dropped to almost the freezing point (*light color*) or even well below freezing (*dark color*) in North America and Eurasia.

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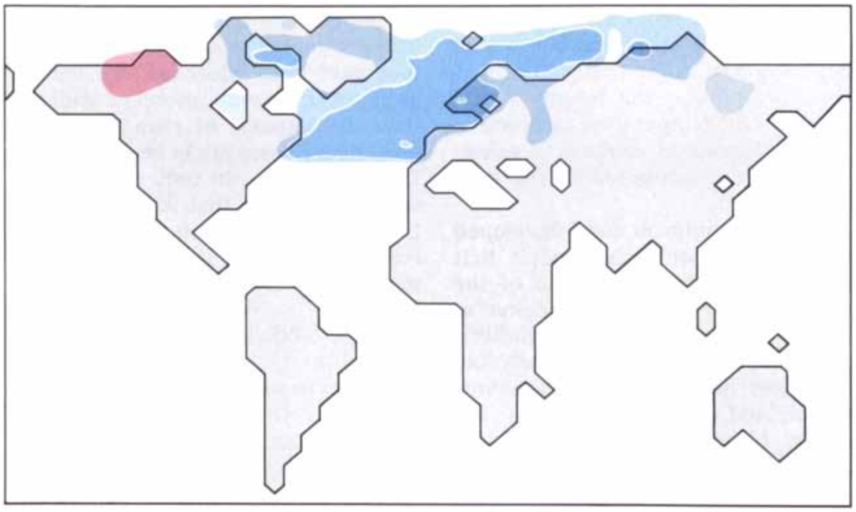
were still widespread within the continents. Evidently the warm oceans and enhanced heat transport we had hypothesized were still not enough to overcome the fact that in winter the continents receive little sunlight and radiate a lot of heat out to space.

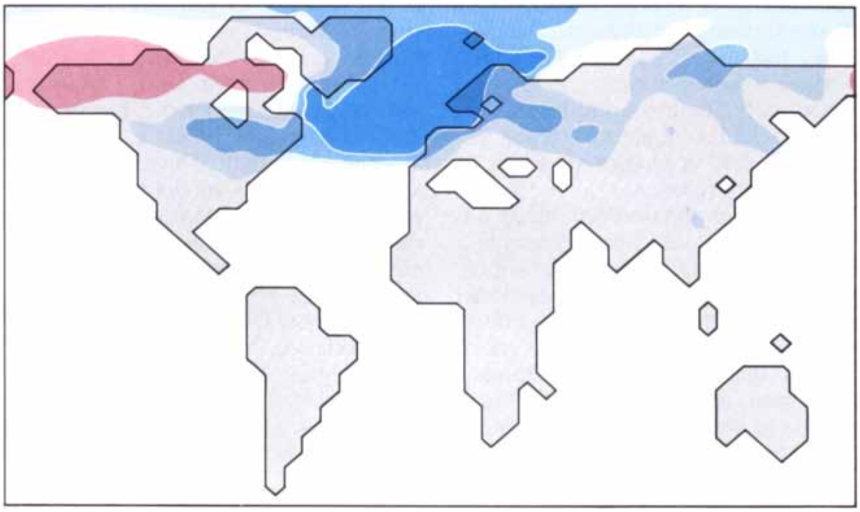
My colleagues and I strongly suspect that some other mechanism must have helped to keep the Cretaceous climate warm. The best candidate, it seems to us, is an enhanced greenhouse effect due to the presence in the atmosphere of elevated levels of carbon dioxide. Recent geochemical models support this view. Carbon dioxide and other gases escape from the earth's interior, notably at midocean rifts, where two of the plates that make up the earth's surface spread apart and molten rock rises into the gap. The mid-Cretaceous, most investigators agree, was an era of rapid plate motion, and so it should have been an era of high carbon dioxide emissions. The geochemical models suggest that the atmosphere then may have contained between five and 10 times more carbon dioxide than it does now. In an extreme form the Cretaceous period may have foreshadowed the type of climate that human beings are in the process of creating today.

The Modern Greenhouse

There is no doubt that the concentration of carbon dioxide in the atmosphere has been rising; it is roughly 25 percent higher now than it was a century ago. It is also broadly accepted that when the carbon dioxide concentration rises, the temperature at the earth's surface must rise too. Carbon dioxide is relatively transparent to visible sunlight, but it is more efficient at absorbing the long-wavelength, infrared radiation emitted by the earth. Hence it tends to trap heat near the surface. That is the greenhouse effect, and its existence is not questioned. It explains the very hot temperatures on Venus (whose thick atmosphere is mostly carbon dioxide) as well as the frigid conditions on Mars (whose carbon dioxide atmosphere is very thin).

What is not certain is the precise amount of warming and the regional pattern of climatic change that can be expected on the earth from a significant increase in the atmospheric concentration of carbon dioxide and other greenhouse gases. (The cumulative effect of chlorofluorocarbons, nitrogen oxides, ozone and other trace gases could be comparable to that of carbon dioxide over the next century.) It is this regional pattern of changes in temperature, precipitation and soil moisture that will determine what impact the





YOUNGER DRYAS was a period of dramatic cooling that began suddenly about 11,000 years ago, just as the earth was warming up after the last ice age. The relapse, which was most intense along the northwestern coast of Europe, may have been triggered by the formation of a broad ice cover in the North Atlantic. The maps show NCAR simulations of the temperature changes that would result if the surface of the Atlantic were frozen as far south as 45 degrees north. In the summer (*top*) the cooling effect of the sea ice would be felt primarily along the coast, but in the winter (*bottom*) it would be more widespread.

greenhouse effect will have on ecosystems, agriculture and water supplies.

A number of workers have attempted to model the possible climatic impacts of carbon dioxide. Most of them have followed the same approach: they give the model an initial jolt of carbon dioxide (usually doubling the atmospheric concentration), allow it to run until it reaches a new thermal equilibrium and then compare the new climate to the control climate. In one of the most widely cited results, Syukuro Manabe, Richard T. Wetherald and Ronald Stouffer of the Geophysical Fluid Dynamics Laboratory at Princeton University have found that both a doubling and a quadrupling of atmospheric carbon dioxide would produce a summer "dry zone" in the North American grain belt, but that soil moisture in the monsoon belts would increase. The G.F.D.L. model reached its new equilibrium after several decades of simulated time.

In reality, however, the approach to equilibrium would probably be much slower. The G.F.D.L. model omitted both the horizontal transport of heat in the ocean and the vertical transport of heat from the well-mixed surface layer to the ocean depths. Both processes

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would slow the approach to thermal equilibrium; the real transition would probably take more than a century. Heat transport in the oceans would also affect the temperature response to a realistic, gradual increase in greenhouse gases, as opposed to the one-time injection.

In 1980 Thompson and I developed simple one-dimensional models that demonstrated the importance of the transient phase of warming. Regions at different latitudes approach equilibrium at different rates, essentially because they include different amounts of land; land warms up faster than the oceans. Hence during the transient phase the warming and other climatic effects induced by the enhanced greenhouse effect could well display worldwide patterns significantly different from the ones inferred on the basis of equilibrium simulations. Furthermore, the social impact of climatic changes would probably be greatest rather early, before equilibrium has been reached and before human beings have had a chance to adapt to their new environment.

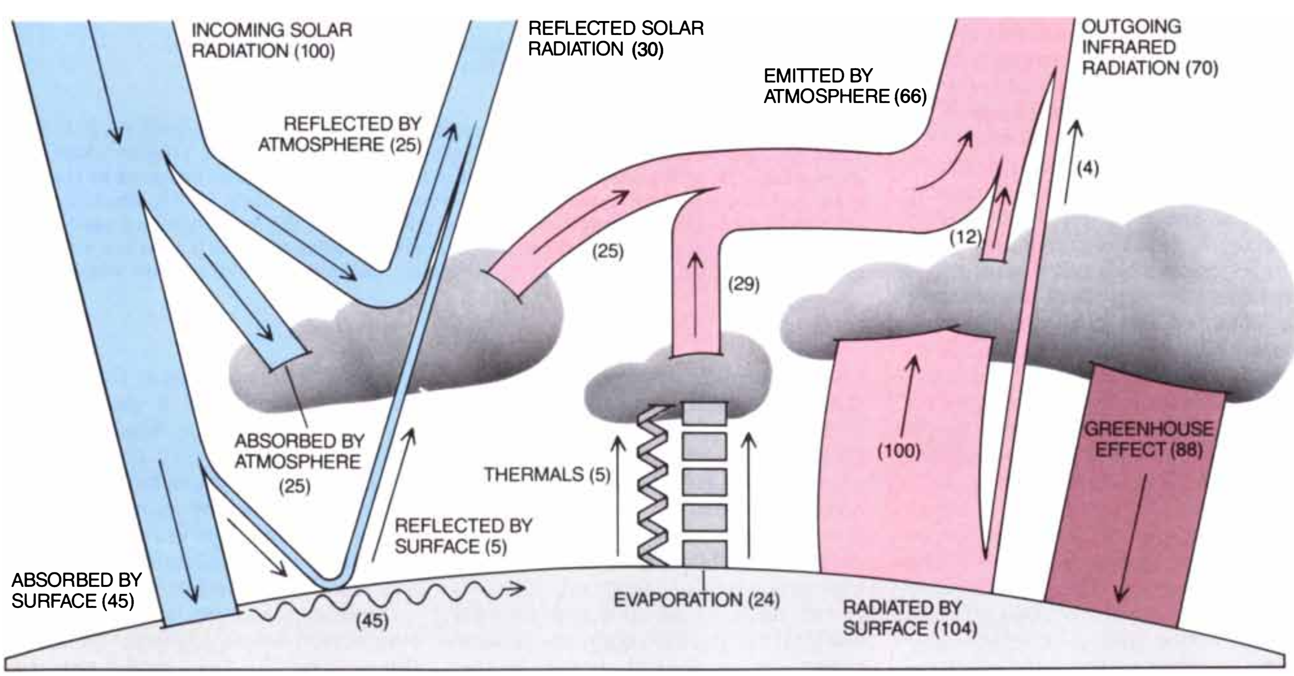
To represent the transient phase adequately one would need to couple a three-dimensional model of the atmosphere with a three-dimensional model of the ocean that includes the effects of horizontal and vertical heat transport. A handful of coupled models have been run, but none for long enough to simulate the next century. The coupled models are still too uneconomical for that task, and they are also not yet trustworthy enough. Once they have been improved, one will be able to state with more confidence how the impacts of rising levels of greenhouse gases might be distributed. Until then one can only cite circumstantial evidence that the impacts are likely to be significant: the earth is already more than .5 degrees C. warmer than it was a century ago.

Nuclear Winter

Efforts to model the comparatively short-term climatic effects of a nuclear war do not share the ocean-model problems of the greenhouse studies, but those results too are laden with uncertainty. Since the first calculations were made in 1982 by Paul J. Crutzen of the Max Planck Institute for Chemistry in Mainz and John W. Birks of the University of Colorado at Boulder, it has been clear that smoke from the thousands of fires ignited by nuclear explosions might block a significant amount of sunlight. The first and best-known attempt to model the resulting changes in surface temperature was a study called the TTAPS study, after the names of its authors [see "The Climatic Effects of Nuclear War," by Richard P. Turco, Owen B. Toon, Thomas P. Ackerman, James B. Pollack and Carl Sagan; SCIENTIFIC AMERICAN, August, 1984]. The TTAPS study predicted that temperatures over land would drop between 20 and 40 degrees C. in the aftermath of a large but plausible war involving a 5,000-megaton nuclear exchange. Since the cooling was projected to persist for many months, it seemed to justify the epithet "nuclear winter."

From the start the authors of the TTAPS study acknowledged the deficiencies of their model. There were three major ones. First, the model ignored winds: it was a one-dimensional model that represented only the vertical structure of the atmosphere. Second, it ignored oceans: the predictions of cooling over land were made for an all-land planet and thus omitted the warming effect of heat carried inland from the oceans by onshore winds. Finally, the model ignored the seasons by using an annual average for the solar energy input. In short, the TTAPS study was a first-generation assessment whose conclusions were bound to be modified.

Some of the first modifications came from a study done by Curt Covey, Thompson and me using the three-dimensional NCAR model. As expected, we found that the oceans moderate the chilling effect of the nuclear smoke cloud. In mid-latitude, mid-continental areas of the Northern Hemisphere the average temperature drop in our July simulation was about half the drop predicted by the TTAPS study; along western coasts the cooling was less by a factor of 10. Moreover, the temperature change showed a great seasonal dependence. The cooling was



GREENHOUSE EFFECT arises because the earth's atmosphere tends to trap heat near the surface. Carbon dioxide, water vapor and other gases are relatively transparent to the visible and near-infrared wavelengths (*blue*) that carry most of the energy of sunlight, but they absorb more efficiently the longer, infrared wavelengths (*red*) emitted by the earth. Most of this energy is radiated back downward (*dark red*). Hence an increase in the atmospheric concentration of greenhouse gases tends to warm the surface.

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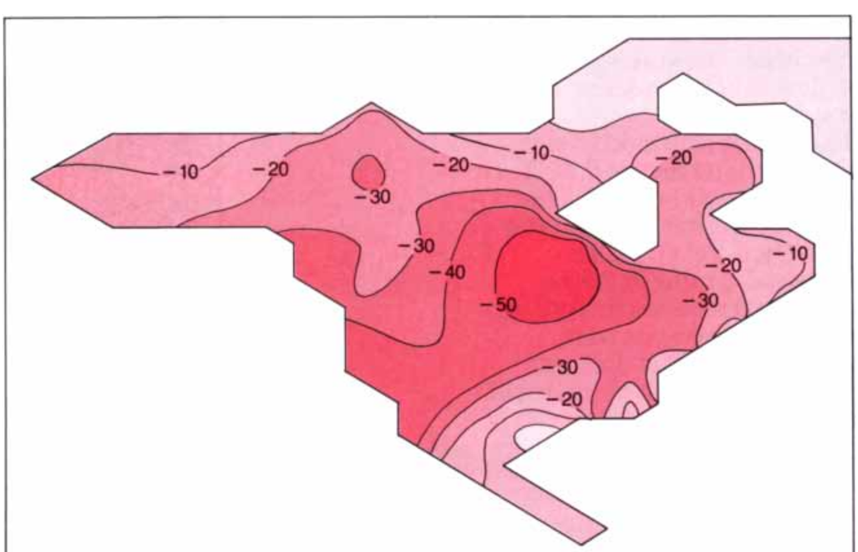
pronounced only if the nuclear war was assumed to take place in the northern spring or summer. If the war were to start in the fall or winter, when northern latitudes receive little sunlight anyway, its climatic consequences would be relatively small.

Nevertheless, our most important finding was to confirm the basic TTAPS conclusion that the climatic effects of a nuclear war could be severe. Although the average decrease in temperature would be much smaller than the TTAPS study had predicted, our model showed that localized cooling could be dramatic. Even a few days of dense smoke high overhead could drop the surface temperature on land to near freezing in midsummer. Such transient "quick freezes" could strike anywhere in the war latitudes—in Texas, for instance—even if the overall size of the nuclear smoke cloud was several times smaller than the TTAPS group had assumed. The location of the quick freezes would depend on local weather conditions. Specifically, the freezes would strike wherever the air was not humid enough to produce ground fog and the winds were not strong enough to disrupt surface inversions (stable air layers). The war's climatic effects would thus be distributed by a kind of weather roulette.

More recent studies (by Thompson, by Michael C. MacCracken's group at the Lawrence Livermore National Laboratory and by Robert C. Malone's group at the Los Alamos National Laboratory) have confirmed our basic results. We had found localized freezes even though the limitations of our model forced us to assume that the initial smoke cloud would be uniformly distributed between 30 and 70 degrees north. In the later, more realistic simulations, the war generates thick, patchy clouds that carry freezing conditions with them as they drift around the Northern Hemisphere.

The most plausible of the recent calculations show an average temperature drop over land of between 10 and 15 degrees C. for a summer war. Elsewhere I have suggested that "nuclear fall" might be more appropriate than "nuclear winter" as a metaphor for such climatic changes, but in using that phrase I certainly did not mean to conjure up pleasant images of colorful autumn leaves. A nuclear fall in July could, as autumn does each year, end the growing season in much of the Northern Hemisphere. Even in areas where the temperature does not drop below freezing, the disruption of monsoon rainfall might have a disastrous effect on food supplies. Indeed, while refined climate models have been lowering the original estimates of a nuclear war's cooling effects, a general awareness has been growing that the earth's biota can be highly sensitive even to small climatic disturbances.

Moreover, the climatic effects of a nuclear war might not be limited to the first weeks after it ended. Particularly in the summer some of the patchy smoke would tend to rise into the stratosphere, eventually producing a thin, fairly uniform veil that could cover the entire Northern Hemisphere for months. Some smoke would probably spread across the Equator as well. The veil could lead to abnormal killing frosts in the late spring or early fall. By slightly cooling the northern continents it might also cause a substantial reduction in the life-giving monsoon rains. In the aftermath of a nuclear war, present scientific knowledge suggests, the earth would not be consigned to the insects, and the human species would almost certainly not become extinct. But the climatic effects might nonetheless be calamitous, and they could extend the impact of the war to billions of people who live far from the blast zones.



DOUBLING OF ATMOSPHERIC CARBON DIOXIDE would turn the Great Plains into a dry zone in the summer, according to a model devised by Manabe and Stouffer. The map shows the percentage change in soil moisture (for the period from June through August) that would result once the model atmosphere reached a new thermal equilibrium.

Uncertainties

That said, I do not want to minimize the uncertainties that surround all the nuclear-winter simulations. The accuracy of a climate model, as I have explained above, can never be proved conclusively; it can only be verified by circumstantial evidence, such as the model's ability to simulate past climates or the seasonal cycle. In the case of nuclear winter the greatest source of uncertainty lies not in what the models include but in what they must leave out.

For example, no climate model can predict how much smoke there will be on the first day of a nuclear war or how high the plumes will rise; the values of such crucial variables have to be assumed. If the bulk of the smoke rises to an altitude of several kilometers, it will lie above most of the water vapor in the atmosphere, and the rate at which it is rained out of the atmosphere will be slow. In that case the likelihood of severe, hemispherewide climatic effects would be high. Conversely, if smoke is washed out at a higher rate than most models have assumed, a climate disaster on a hemispheric scale would be much less likely.

The nuclear-winter issue illustrates a general point I want to stress again. Climate models do not yield definitive forecasts of what the future will bring; they provide only a dirty crystal ball in which a range of plausible fortunes can be glimpsed. They thereby pose a dilemma: we are forced to decide how long to keep cleaning the glass before acting on what we think we see inside.

The dilemma is perhaps less acute in the case of nuclear war, whose consequences would in any event be catastrophic, than it is in the case of atmospheric pollution. At present we are altering our environment faster than we can understand the resulting climatic changes. If the trend does not stop, we shall eventually either verify or disprove the climate models—by means of a real, global experiment whose consequences we shall not escape.

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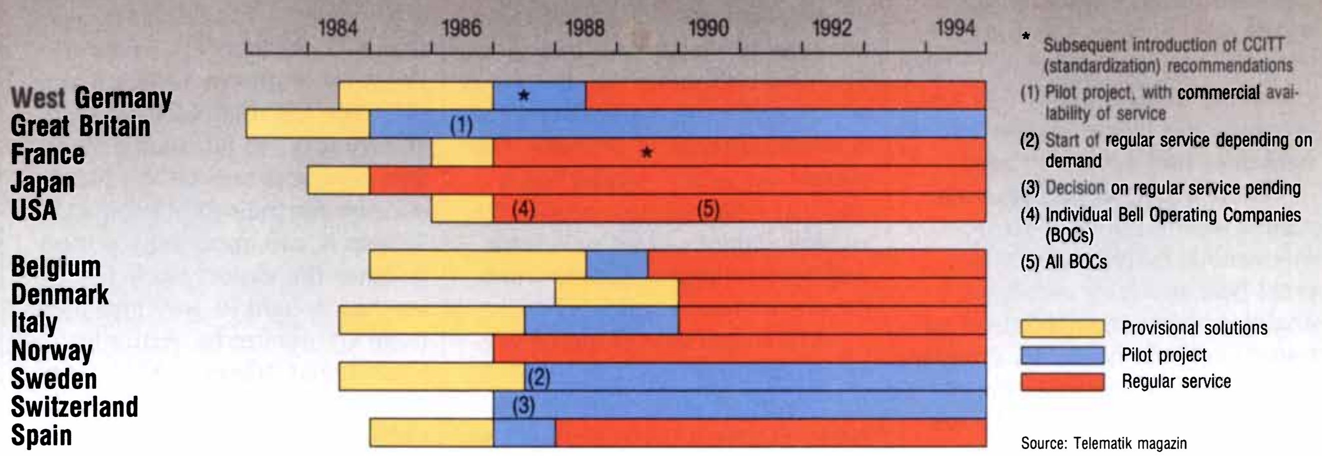
TELECOM '87

PREVIEW

The March of ISDN Worldwide



A Report by Andrew Hargrave

The 1983 TELECOM exhibition in Geneva signalled major advances in the technologies and structures of world telecommunications. The initials ISDN (Integrated Services Digital Network) made their first appearance, foreshadowing a convergence and integration of computers and telecommunications on a scale never before imagined. Since then there has been rapid progress in planning — and to a certain degree implementing — ISDN which will eventually produce a global network of voice, data, text and vision transmission available to both business and private users.

TELECOM 87, to be held in Geneva in October this year, will, in the words of Mr. Richard E. Butler, Secretary General of the organizers ITU (International Telecommunications Union), "enable us to assess the results of all the work carried out in connection with the ISDN concept ... and also demonstrate the benefits of telecommunications to the user."

Mr. Butler stressed the need for standardization, with special emphasis on compatibility between products developed by the industries of the various countries. "Provided they comply with the standards established by the ITU, and in particular by the CCITT (International Telegraph and Telephone Consultative Committee), these industries will be able to supply products designed for interactive operations. This is what we hope to show at the exhibition."

Alongside the exhibition, the World Telecommunications Forum will address some major issues, such as "whither telecommunications?"; its economic impact; relations between respective suppliers of computer services and of telecommunications equipment; the effect on the user; its role in improving production and speeding industrial research. "These are all fundamental questions which call for discussion," said Mr. Butler.

They are also the main themes of this report—the first of a two-part survey on international telecommunications.

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Telecommunications in a Flux

Until relatively recently—the late 1960s—global telecommunications had presented a tidy pattern. National postal/telecommunications administrations were ordering, maintaining and renewing autonomous networks normally from their national suppliers. They gradually provided, it is true, services additional to the voice-telephone, mail and telegraph, such as telex and facsimile transmission and, of course, television and radio for news, entertainment, sports, etc. Service was fragmented, too: the transmission and exchange of information—of text, graphics and vision via the public network—had not yet arrived.

There were, of course, companies selling public electromechanical systems (Strowger, cross-bar) and later electronic analog systems, beyond their national frontiers. For L. M. Ericsson of Sweden, for instance, the national base was too small to sustain and expand the company.

TABLE I
World public switching equipment sales of leading manufacturers

Company	Sales of public switching equipment in $ million
AT&T (US)	1350
Northern Telecom (Canada)	1000
NEC/Fujitsu/Hitachi (Japan)	1000
Siemens (West Germany)	950
ITT (US[1])	850
Ericsson (Sweden)	750
Alcatel/Thomson (France)	700
GTE (US)	350
Plessey (UK[2])	260
GEC (UK)	260
Italtel (Italy)	180
Philips (Netherlands[3])	130
Stromberg-Carlson (US[4])	70
Others (inc. Nokia, Finland)	120
	7970

1) Now Alcatel NV through merging Alcatel/ITT telecommunications interests
2) Involved in talks on merging certain System X functions
3) Set up APT to cater for world telecommunications sales outside US
4) Subsidiary of Plessey, mainly for US switching
Source: UK Monopolies and Mergers Commission, 1985, or nearest year

ITT, of the US, sought to bypass the AT&T monopoly in the national telecommunications service—in both telephony and switching equipment—by exporting their equipment through major subsidiaries such as CGCT in France, SEL in West Germany and others in the UK, Italy, Belgium, Spain and elsewhere.

Among the most spectacular events of recent years has been the merging of Alcatel (telecommunications subsidiary of the CGE group) of France and the telecommunications division of the US concern ITT in January this year. The new company, Alcatel NV, is registered in the Netherlands but is headquartered in Brussels. The merger (in which Alcatel has a majority holding) has created the world's largest public switching and second-largest telecommunications company (after AT&T).

AT&T itself set up four years ago a jointly owned company -APT- with Philips, of the Netherlands, Europe's top electrical and electronics concern alongside Siemens, of West Germany.

North America (mainly the US) is, as Table II indicates, the largest single market in the world for public exchanges: hence the intense interest shown by leading European suppliers, especially since the deregulation of local telephony and the breakup of the AT&T monopoly.

The declining value of sales in Europe, at any rate, is largely due to the price advantage of digital hardware compared with its analog predecessor. (In the US, there are now virtually no analog replacements).

The greater openness and diversity of the US public switching market has enabled Northern Telecom, of Canada, with its most up-to-date systems to challenge successfully AT&T on its home ground.

Altogether, about a dozen major suppliers vie for the world's digital public switching contracts—far too many, according to most experts. In addition to AT&T and APT, Alcatel-ITT, Siemens, Ericsson, Northern Telecom and GTE, the UK manufacturers GEC and Plessey, so far unable to obtain contracts outside the home country for their joint product System X, are apparently poised to enter the export market. Plessey has bought its way into the huge US market by acquiring Stromberg-Carlson, manufacturer of small and medium-sized public exchanges. Italtel, telecommunications subsidiary of the Italian state-owned information technology group STET, is also a recent entry on the global scene with its up-rated UT series, as is Telenokia, of Finland. Nor can the powerful Japanese trio, NEC (already active in the US), Hitachi and Fujitsu, be expected to stay out of Europe while digitalizing the home telecommunications network.

TABLE II
Estimated public exchange sales revenue: $ million

	1985	1986	1986–1990[1] (annual average)
US	2,249	2,459	2,000
Europe	2,977	2,724	2,365
(of which digital)	931	1,070	1,626

1) Forecast
Source: Dataquest, August, 1986

Views differ whether the speedy advance and turmoil in the world's communications industry is mainly technology or user driven: a matter of varying attitudes by individual PTTs, business and private subscribers in the various countries—the advanced industrial countries in the main.

There is no doubt, however, about the concept which symbolizes progress in telecommunication technology in the remaining years of this century and beyond. It is ISDN.

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TELECOMMUNICATIONS TODAY
TELECOMMUNICATIONS TOMORROW

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ISDN: Now a Reality

"The biggest machine ever built, the international telephone network, is being revolutionized by the smallest machine ever devised, the microchip ...". So says the European Commission's Information Technologies and Telecommunications Task Force which claims that the new services represented by ISDN "will be commonplace from 1988 onwards."

ISDN, as already indicated, integrates voice, data, text and vision in a single service. It is characterized not only by the linking of these functions in a single, terminal-assisted instrument panel, but by the speed of transmission (the Task Force suggests, teletex will be 100 times faster than today's telex; facsimile copiers will transmit at a rate of a page per second); but also by improved quality of sound; by caller identification; by extra security; by group conferencing in sound and vision; by access to new commercial services.

Above all, ISDN promises to be cheaper, much cheaper than the present separately operated and billed services, though this depends on the pricing structures of PTTs as well as the prices of the ingredients: central computers, microprocessors, optic fiber cables, instruments, components and the most expensive single item in systems "architecture", software.

The European Commission, in addition to calling for the adoption of common (CCITT, No 7) standards by PTTs of the 12 member countries, based first on 64 Kbits/s and possibly later on 2 Mbits/s digital switching, has also set a timetable for the coordinated introduction of ISDN in Europe. It has hopes, too, of those standards being adopted by Japan and the US. The timetable envisages a three-stage development in the 1990s:

— Expansion and digitalization of existing telephone networks
— Additional integrated services — ISDN
— Introduction of broadband communications to add vision to sound, text and data exchange facilities.

As to specific target dates, the Commission has urged that by 1993, 80 percent of the subscribers in the European Community should have access to ISDN and, by the same year, 5 percent of subscriber lines—the "critical mass"—should be connected to it. The whole program is estimated by the Task Force to cost $40 billion.

TABLE III
Telephone networks densities world comparisons 1984/85

Country	No. of lines in service (millions)	No. of lines per 100 pop.	No. of residential connections per 100 households
Sweden	5.1	61.5	111.4
US	114.3	48.3	96.7
Canada	11.2	44.6	109.3
West Germany	24.9	40.7	87.6
France	22.1	40.2	98.0
Australia	6.2	39.5	91.3
Netherlands	5.6	39.0	82.8
Japan	44.4	37.0	80.2
UK	20.8	36.9	78.4
Italy	16.5	28.9	68.5
Spain	8.7	22.5	58.0

Source: ITU

Battle of the Systems

The flagship of telecommunication vendors competing in an over-supplied international market are the digital switching systems. The more modular (capable of up-rating), flexible, reliable and economical they are—or claim to be—the greater their chances of acceptance, at least theoretically. For there are other criteria, perhaps more decisive: the main one is politics, the preferences of the governments or the telecommunications administrations concerned, fortified or pushed by local pressures. That is why all the contenders for the purchase of CGCT, France's ailing denationalized second digital switching supplier, have armed themselves with a French partner: APT with SAT, Siemens with Jeumont-Schneider, Ericsson with Matra. CGCT is manufacturing the E10-B, France's Alcatel-designed system. Whoever wins possession of CGCT—and it was, at the time of writing, going to be strictly on technical merit —would introduce a second switch into the French network: APT's 5ESS PRX, Siemens's EWSD, Ericsson's AXE. Or it could even be Northern Telecom's DMS 100, as the Canadian supplier was also invited to tender.

Although CGCT provides only about 16 percent of French switching, an outside system, rival to France's own in what has hitherto been a purely national market, will give a powerful psychological and publicity boost to the successful contender; and so has Ericsson's break-through in the UK, adding AXE to the home-grown System X in the digital network.

Only in Italy among the major European countries have competing systems managed to secure a substantial market share alongside the home suppliers through subsidiaries: FACE (System 12) and FATME (AXE). Even part of Italy's so-called "national system" was supplied by an outsider—GTE of the US—though more than half the requirements were met by Italtel, which is rapidly uprating its own UT system to provide exchanges with capacities of up to 100,000 (later 200,000) lines. Under Italy's digitalization program, however, suppliers will eventually be limited to two: UT and System 12 (now supplied by the Alcatel group) or AXE.

The size of the US market (about 40 percent of the world's public switching sales), has ensured a head-start for AT&T, with 31 million lines installed or on order (29 million in the US). Alca-

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tel-ITT's 39 million lines (installed or on order) are divided between E10 and System 12 while Ericsson's almost 17 million AXE lines have been sold to 66 countries—the largest geographical spread in the world for any single system.

Table IV gives a fair indication of how the competing major systems have fared in terms of installed lines.

TABLE IV
Sales of major digital systems, 1985

Systems/Company	No of lines installed 000s	market share %
5ESS-PRX (AT&T — APT)	5,555	18.1
DM Series — Northern Telecom	5,269	17.2
E10-B/E10-MT — (Alcatel)	3,600	11.7
AXE — Ericsson	2,900	9.4
System 12 — ITT (now Alcatel)	2,883	9.4
EWSD — Siemens	2,479	8.1
GTD — GTE	1,903	6.2
NEAX 61E — NEC (Japan)	1,750	5.1

1) System X deliveries, by GEC and Plessey, began only in 1985: they were at the time of writing only confined to the UK (1 million lines delivered by March this year). Italtel's UT series, too, are relatively recent in their uprated form. Stromberg-Carlson (Plessey's US subsidiary): Century series are designed mainly for small to medium-sized exchanges. Telenokia's (Finland) DEX series are designed principally for rural networks.

Source: Northern Business Information

Transmission: The Fiber Optic Route

Although the next generation of satellites will be able to carry a great deal more traffic, escalating demand—especially for Europe-wide and later global DBS (Direct Broadcasting Satellites)—planned by existing and emerging networks—foreshadows increasing strain on the land and undersea cable systems. The significance of fiber optic development in this context alone cannot be underestimated.

The speed of replacing copper by optic fiber is, of course, a question of national investment priorities and consequently varies from country to country. All the US, Japanese and European PTTs as well as the major public switching suppliers are involved, some of the latter on their own, others in association with optic fiber specialists. Siemens, for instance, has a joint operation with Corning Glass, of the US—Siecor—to supply optic fiber for the West German and other networks. Italtel, state-owned, is negotiating with Fiat-owned Telettra specializing in transmission for a merger which would raise the new group's Italian market share in transmission equipment to well over 50 percent.

The Shape of New Generations to Come

Overcapacity in both public and private switching systems is stressed by all the major players; but there is also the technological aspect to global telecommunications. Several executives interviewed emphasized the point: there are too many systems and some will, perhaps over the next decade, come to the end of their technological cycle. For the cycles themselves are getting shorter.

One reason may be that several of the present digital switching systems are "hybrids"—i.e. developed from analog predecessors. According to Dr. Hans Baur, telecommunications chief and member of the Siemens management board, Northern Telecom's DMS is the only genuine digital system conceived as such—which, says Dr. Baur, explains partly its outstanding success in the US and increasingly elsewhere,

Mr. F. C. Kuznik, vice-president marketing of APT, talks of "three generations" of switching systems, starting with Alcatel's E10 in the early 1970s— now balanced in the merged group with ITT's third-generation System 12 alongside Siemens' EWSD and AT&T-Philips's 5ESS PRX.

In the 1990s, Dr. Baur reckons, telecommunications companies would have to gain a market share of around 15 percent to recover their costs comfortably. Mr. Kuznik puts it even higher—15 to 18 percent, a share, as already noted, achieved only by three of the players—AT&T, Northern Telecom and Alcatel-ITT, the last-mentioned with two systems—or even three, if Thomson's E10-MT is counted.

Mr. Kuznik foresees in the 1990s not so much companies as "alignments" behind five technologies, a couple from North America, one from Japan, a couple from Europe ... (Dr. Baur speaks of "five or six"). They may come from mergers along the lines of Alcatel-ITT, or firm alliances such as AT&T and Philips; or limited partnerships such as GEC and Plessey (in respect of System X); or partial takeovers such as Siemens-GTE; or the proposed Italtel-Telettra deal. The escalating cost of developing new technologies—put at $1 billion per switching system some years ago by the then Philips chief executive Dr. Wisse Dekker, with ongoing development costing around $200 million a year (Mr. Kuznik)—is one of the main factors of limiting the number of future participants. Its globality is stressed in the strongest terms by Mr. Philippe Gluntz, executive vice-president and chief operating officer of Alcatel NV: "We are one of the few manufacturers able to offer the whole range of telecommunications equipment: digital switches, all kinds of transmission products from copper cables and fiber optics to satellite communications; all types of business systems from digital PABXs to microcomputers or electronics sub-sets, word processors, etc."

Resources in terms of funds and range of products are vital for the prospective telecommunications survivors: but so is the technology of the 21st century.

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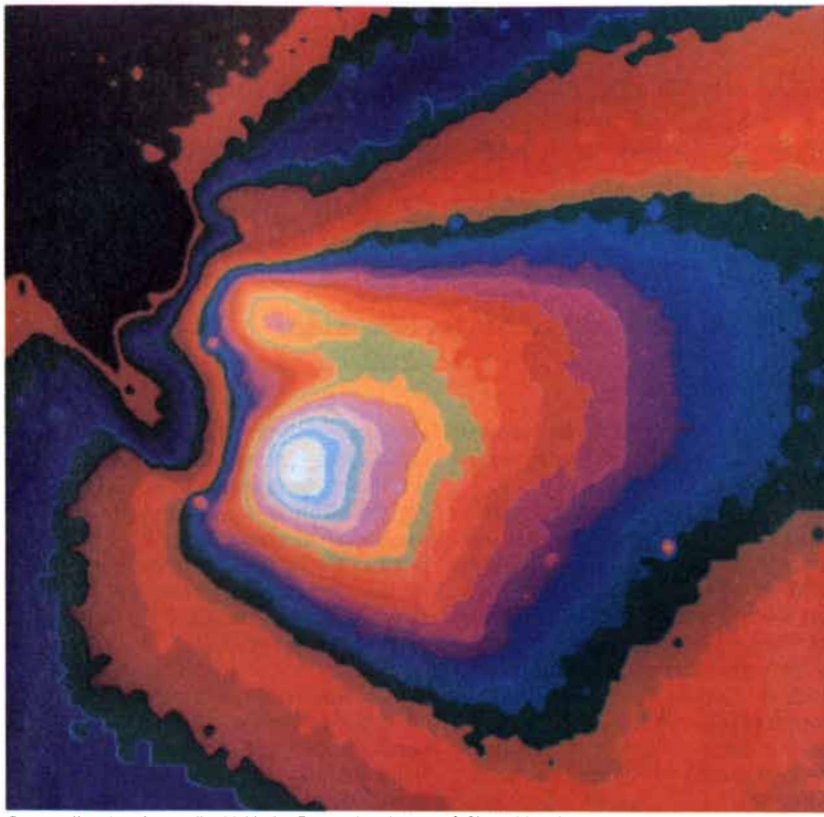

Comet Halley. Photo from Halley Multicolor Camera aboard spacecraft Giotto (Max-Planck-Institut für Aeronomie, Lindau/Harz).

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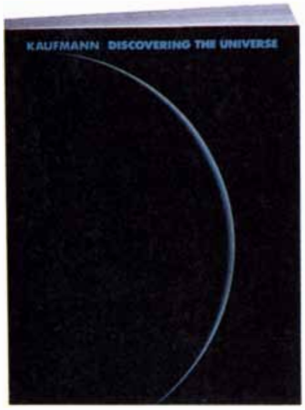

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Glucose and Aging

Once considered biologically inert, the body's most abundant sugar can permanently alter some proteins. In doing so it may contribute to age-associated declines in the functioning of cells and tissues

by Anthony Cerami, Helen Vlassara and Michael Brownlee

As people age, their cells and tissues change in ways that lead to the body's decline and death. The cells become less efficient and less able to replace damaged materials. At the same time the tissues stiffen. For example, the lungs and the heart muscle expand less successfully, the blood vessels become increasingly rigid and the ligaments and tendons tighten. Older people are also more likely to develop cataracts, atherosclerosis and cancer, among other disorders.

Few investigators would attribute such diverse effects to a single cause. Nevertheless, we have discovered that a process long known to discolor and toughen foods may also contribute to age-related impairment of both cells and tissues. That process is the chemical attachment of the sugar glucose to proteins (and, we have found, to nucleic acids) without the aid of enzymes. When enzymes attach glucose to proteins, they do so at a specific site on a specific molecule for a specific purpose. In contrast, the nonenzymatic process adds glucose haphazardly to any of several sites along any available peptide chain.

On the basis of recent in vitro and in vivo studies in our laboratory at Rockefeller University, we propose that this nonenzymatic "glycosylation" of certain proteins in the body triggers a series of chemical reactions that culminate in the formation, and eventual accumulation, of irreversible cross-links between adjacent protein molecules. If this hypothesis is correct, it would help to explain why various proteins, particularly ones that give structure to tissues and organs, become increasingly cross-linked as people age. Although no one has yet satisfactorily described the origin of all such bridges, many investigators agree that extensive cross-linking of proteins probably contributes to the stiffening and loss of elasticity characteristic of aging tissues. We also propose that the nonenzymatic addition of glucose to nucleic acids may gradually damage DNA.

The steps by which glucose alters proteins have been understood by food chemists for decades, although few biologists recognized until recently that the same steps could take place in the body. The nonenzymatic reactions between glucose and proteins, collectively known as the Maillard or browning reaction, may seem complicated, but they are fairly straightforward compared with many biochemical reactions.

They begin when an aldehyde group (CHO) of glucose and an amino group (NH_2) of a protein are attracted to each other. The molecules combine, forming what is called a Schiff base [*see illustration on page 93*]. This combination is unstable and quickly rearranges itself into a stabler, but still reversible, substance known as an Amadori product.

If a protein persists in the body for months or years, some of its Amadori products slowly dehydrate and rearrange themselves yet again—into new glucose-derived structures. These can combine with various kinds of molecules to form irreversible structures we have named advanced glycosylation end products (AGE's). Most AGE's are yellowish brown and fluorescent and have specific spectrographic properties. More important for the body, many are also able to cross-link adjacent proteins.

The precise chemical structure of advanced glycosylation end products and of most AGE-derived cross-links is still not known. Nevertheless, some evidence suggests that AGE's are often created by the binding of an Amadori product to glucose or another sugar. Such end products would form bridges to other proteins by binding to available amino groups. In some instances two Amadori products may instead merge, creating an AGE that is also a cross-link. The one glucose-derived cross-link whose chemical structure is known appears to be just such a combination. It is 2-furanyl-4(5)-(2-furanyl)-1*H*-imidazole, or FFI. First isolated in the laboratory (from a mixture of the amino acid lysine, the protein albumin and glucose), FFI has since been found in the body.

The realization that the browning reaction could occur in—and potentially damage—the body emerged from studies of diabetes, a disease characterized by elevated blood-glucose levels. In the mid-1970's one of us (Cerami) and Ronald J. Koenig examined a report that the blood of diabetic individuals contained higher than normal levels of hemoglobin A_{1c}: a variant of the protein hemoglobin, which is the oxygen-carrying component of red blood cells. Curious about why the levels were elevated, the two investigators attempted to determine the molecule's structure.

Hemoglobin A_{1c} is an Amadori product. Moreover, as is true for the amount of Amadori product formed in foods, the amount of hemoglobin A_{1c} formed is influenced by the level of glucose in the blood: when the glucose level is high, the amount of Amadori product is also high. (Workers in our laboratory and elsewhere have since identified more than 20 Amadori proteins in human beings and have consistently found two or three times as much product in people with diabetes as in nondiabetics.)

The hemoglobin findings reveal that glucose, which bathes tissues and cells throughout the body, is not the inert biological molecule most biologists thought it was. Although the sugar does not react while it is in its usual ringlike formation, the ring opens often enough to enable Amadori products and other substances to form. Glucose remains the least reactive sugar in the body, but it has the greatest

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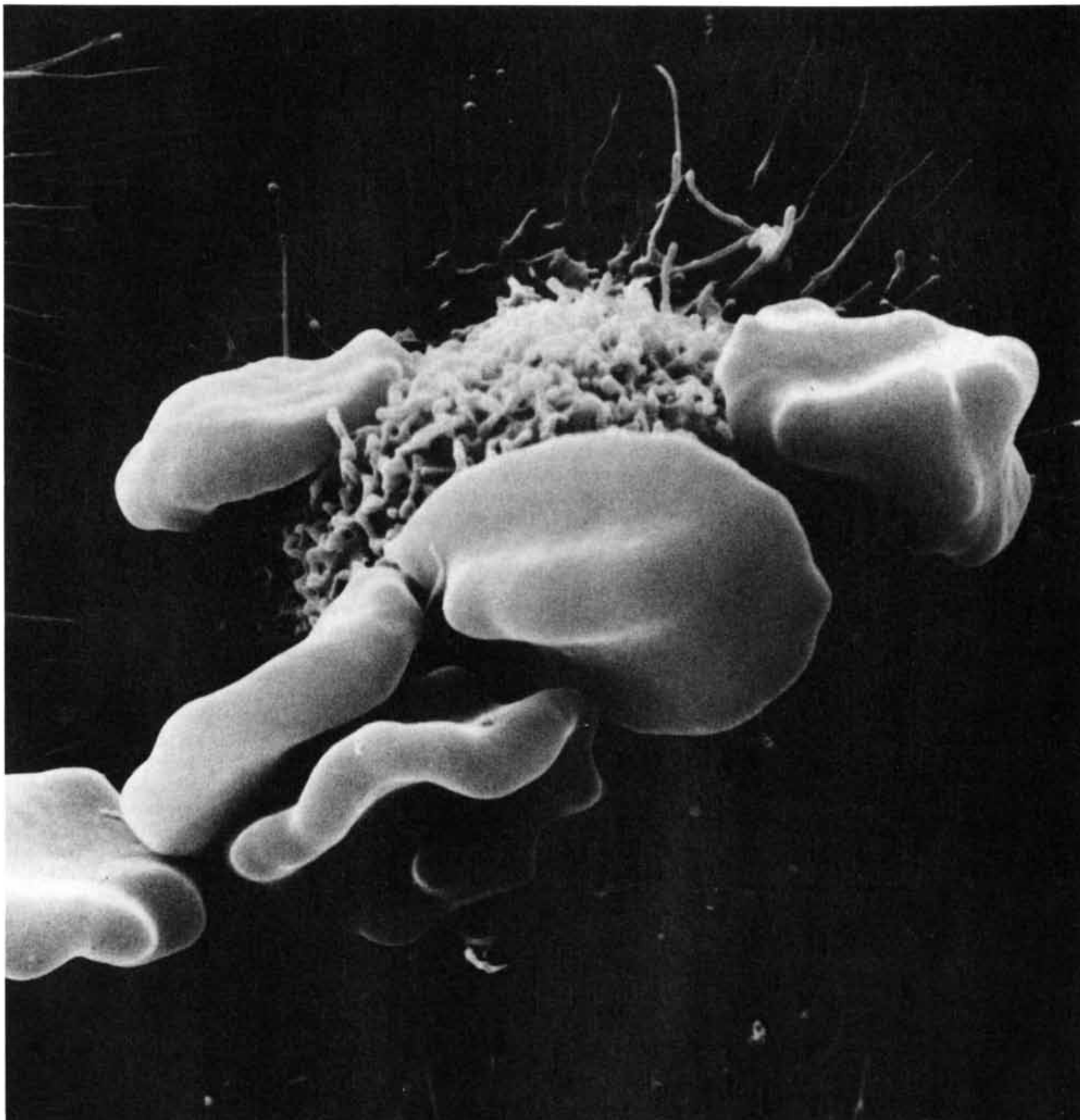
potential effect on proteins because it is by far the most abundant variety.

The fact that glucose is reactive suggested to Cerami that excess blood glucose in people with uncontrolled diabetes might be more than a marker of the disease. If the sugar could bind nonenzymatically to proteins in the body, he reasoned, excessive amounts could potentially contribute to diabetic complications: the host of disorders, ranging from impaired sensation to kidney failure, that often disable people with diabetes and shorten their life. In particular, it seemed possible that high levels of glucose could lead to an extensive buildup of advanced glycosylation end products on long-lived proteins. The accumulation of AGE's in turn might undesirably modify tissues throughout the body.

Such musings soon led to a suspicion that glucose could also play a role in the tissue changes associated with normal aging. The effect of diabetes on many organs and tissues is often described as accelerated aging because several of the complications that strike people with diabetes—including senile cataracts, joint stiffness and atherosclerosis—are identical with disorders that develop in the elderly; they merely develop earlier. If excess glucose



MACROPHAGE (*rough-surfaced body at center*), **a cell that removes debris from tissues, is about to ingest red blood cells** (*smooth disks*) **to which advanced glycosylation end products, or AGE's, have been attached. AGE's are molecules derived from the combination of glucose and protein without the aid of enzymes. The authors postulate that AGE's gradually accumulate on long-lived proteins and cells, forming cross-links that impair tissues. Macrophages try to remove AGE-altered proteins but lose efficiency as people age. The cells are enlarged 10,000 diameters in this micrograph, made by David M. Phillips of the Population Council.**

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does in fact hasten the onset of these ills in people with diabetes, normal amounts could conceivably play a role in the slower onset seen in nondiabetics as they age.

Our laboratory's studies of senescence (which complement our ongoing studies of diabetes) began with an attempt to determine whether advanced glycosylation end products do in fact accumulate on, and form cross-links between, long-lived proteins in the body. Major constituents of the lens of the eye—the crystallin proteins—became the first objects of study because once these proteins are produced they are believed to persist for life; they therefore fit the profile of proteins that could amass advanced glycosylation end products. Also it seemed likely that a buildup of such AGE's and of AGE-derived cross-links could help to explain why lenses turn brown and cloudy (that is, develop senile cataracts) as people age. In support of this idea, workers elsewhere had previously found two types of cross-link in aggregates of crystallin proteins from human senile cataracts. One bridge was pigmented, suggesting that it could be an AGE. The other type was a disulfide bond formed between sulfhydryl (SH) groups of the amino acid cysteine.

In test-tube experiments Cerami, Victor J. Stevens and Vincent M. Monnier showed that glucose could produce a cataractlike state in a solution of the proteins. Whereas glucose-free solutions containing crystallins from bovine lenses remained clear, solutions with glucose caused the proteins to form clusters, suggesting that the molecules had become cross-linked. The clusters diffracted light, making the solution opaque. Analysis of the links between the molecules confirmed that both the disulfide and the pigmented types were present. The group has also discovered that the pigmented cross-links in human senile cataracts have the brownish color and fluorescence characteristic of advanced glycosylation end products. In fact, some cross-links can be chemically identified as the advanced glycosylation end product FFI.

Combined with other evidence, the above data suggest that nonenzymatic glycosylation of lens crystallins may contribute to cataract formation by a two-step mechanism. Glucose probably alters the conformation of proteins in ways that render previously unexposed sulfhydryl groups susceptible to combination with nearby sulfhydryl groups. Hence disulfide bonds develop, initiating protein aggregation. Later Amadori products on the proteins become rearranged, enabling FFI and other pigmented cross-links to form, discolor the lens and make it cloudy.

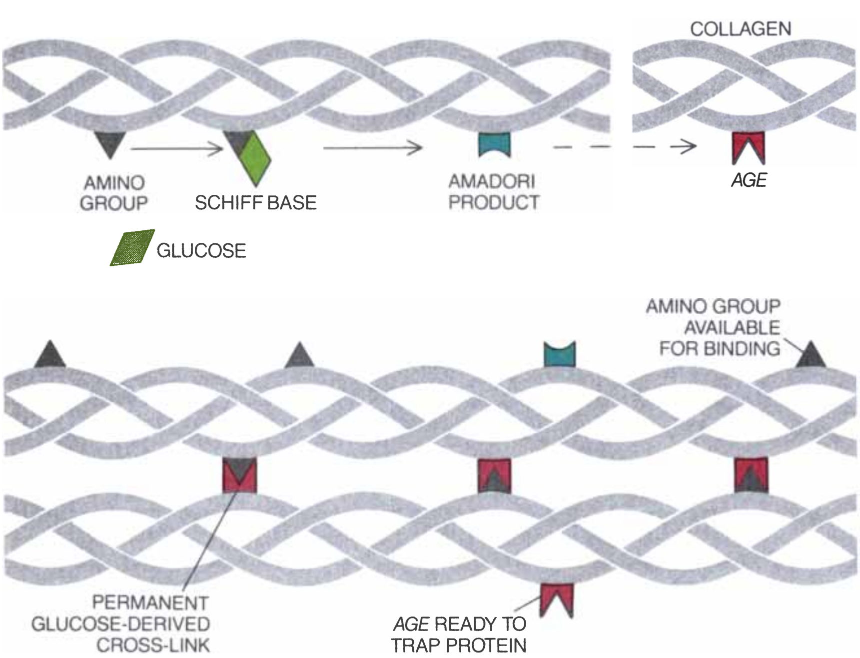
Convinced that at least one class of proteins undergoes the browning reaction and forms undesirable cross-links, we and our colleagues turned to the body's most abundant protein: collagen. This long-lived extracellular protein glues together the cells of many organs and helps to provide a scaffolding that shapes and supports blood-vessel walls. It also is a major constituent of tendon, skin, cartilage and other connective tissues. In the past 25 years various investigators have shown that collagen builds up in many tissues, becoming increasingly cross-linked and stiff as people age.

Studies of the dura mater, the collagen sac separating the brain from the skull, provided early evidence that advanced glycosylation end products could collect on collagen. Monnier, Cerami and the late Robert R. Kohn of Case Western Reserve University found that the dura mater from elderly individuals and from diabetics displays yellowish brown pigments whose fluorescent and spectrographic properties are similar to those of advanced glycosylation end products formed in the test tube. As would be expected, protein from people with diabetes had accumulated more pigments than the protein of nondiabetics. In nondiabetics the amount of pigment attached to the protein increased linearly with age.

Evidence suggesting that glucose induces collagen not only to form AGE's but also to become cross-linked comes from several studies. On the basis of work by other investigators, it has long been known that fibers from the tail tendons of older rats take longer to break when they are stretched than fibers from younger animals, indicating that the older fibers are more cross-linked and less flexible. Monnier, Cerami and Kohn therefore attempted to mimic the effects of aging by incubating tendon fibers of young rats with various sugars. The fibers gradually accumulated advanced glycosylation end products and showed a concomitant increase in breaking time.

More recently we have evaluated the cross-linking of both purified and aortic collagen. In the first instance the protein was incubated with glucose in a test tube; in the second instance it was essentially incubated in the body of diabetic animals that had high blood-glucose levels. In both conditions our chemical tests unequivocally showed that the glucose led to extensive cross-linking.

Although we suspect that the formation of glucose-derived cross-links between long-lived proteins helps to account for many symptoms of aging and for many complications of diabe-



FORMATION of glucose-derived cross-links, shown highly schematically, begins when glucose attaches to an amino group (NH_2) of a protein (*top*), such as collagen. The initial product, known as a Schiff base, soon transforms itself into an Amadori product, which can eventually pass through several incompletely understood steps (*broken arrow*) to become an AGE. In many instances AGE's are like unsprung traps (*red symbol*), poised to snap shut (*bottom*) on free amino groups of any nearby protein and to form cross-links.

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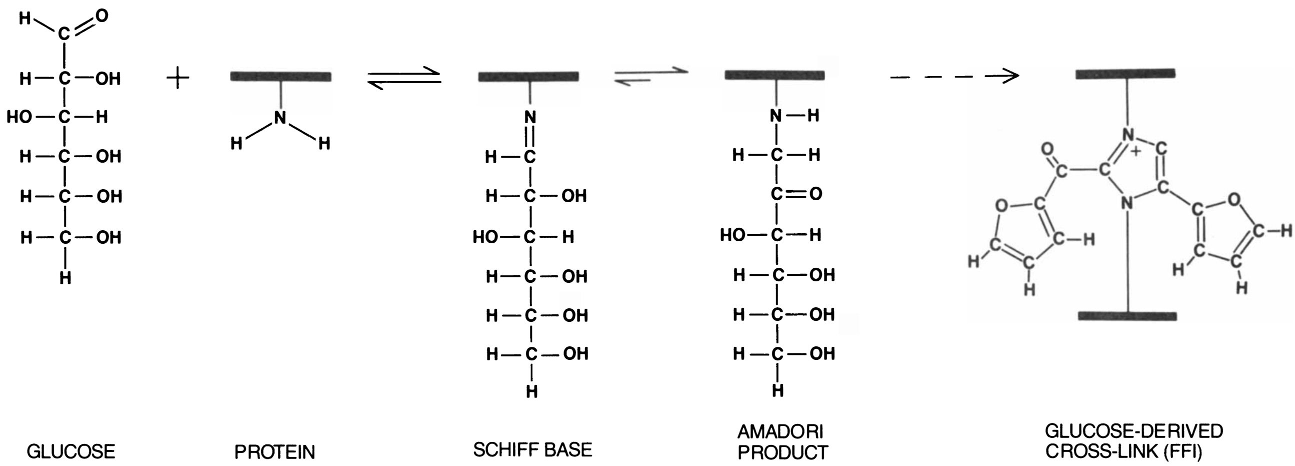

CHEMICAL STRUCTURE is known for glucose-protein Schiff bases and Amadori products. Workers have yet to learn the structure of most AGE's and AGE-derived cross-links, but one link has been identified: 2-furanyl-4(5)-(2-furanyl)-1*H*-imidazole, or FFI.

tes, such bridges are not the only ones that can potentially damage the body. We have shown that AGE's on collagen in artery walls and in the basement membrane of capillaries can actually trap a variety of normally short-lived plasma proteins. Even when collagen is incubated with glucose and then washed so that no free glucose is present, the long-lived protein can still covalently bind such molecules as albumin, immunoglobulins and low-density lipoproteins.

This binding may help to explain why both people with diabetes and the aged are prone to atherosclerosis: a buildup of plaque in arterial walls. The plaque includes smooth-muscle cells, collagen (which is produced by the smooth-muscle cells) and lipoproteins (the cholesterol-rich proteins that are the primary source of fat and cholesterol in atherosclerotic lesions).

No one yet understands the exact processes leading to atherosclerosis. It is conceivable that glucose contributes to plaque formation by causing advanced glycosylation end products to develop progressively on collagen in the vessel walls. Once those substances form, collagen may trap low-density lipoproteins from the blood—which in turn can become attachment sites for other lipoproteins.

In theory, glucose-altered collagen could also trap von Willebrand factor, a protein that is believed to promote the aggregation of platelets (sticky bodies involved in blood clotting). The platelets may release a factor that stimulates the proliferation of smooth-muscle cells, which produce extra collagen. Other glucose-related events may further promote plaque formation [*see illustration on page 95*]. More studies are needed to determine the extent to which any of the postulated events take place and how they might interact with various other processes that contribute to atherosclerosis.

Protein trapping and cross-linking may also help to explain the thickening seen in the basement membrane of capillaries as people grow older (and the more rapid thickening in people with diabetes). In people with diabetes, thickening of a specialized basement membrane in the kidney, the mesangial matrix, promotes renal failure. In nondiabetics the consequences of renal basement-membrane thickening are less clear, although we suspect the process may help to decrease the aged kidney's ability to clear wastes from the blood. Elsewhere in the body thickened capillaries become particularly narrow or occluded in the course of time in the lower extremities, where gravity increases the rate of protein trapping by vessel walls. Such narrowing can contribute to the impaired circulation and loss of sensation often found in the feet and legs of both diabetics and older nondiabetics. In order to function properly, the sensory nerves need an adequate supply of blood.

Because aging takes place at the level of the cell as well as of tissue, our laboratory has recently begun to examine the effects of glucose on the material that controls cell activity: the genes. At least in resting cells, the nucleic acid DNA, which contains amino groups, is long-lived. It therefore can potentially accumulate advanced glycosylation end products. These AGE's might then contribute to known age-related increases in chromosomal alterations or to declines in the repair, replication and transcription of DNA. Such genetic changes are believed to impair the body's ability to replace proteins critical to normal cell function and survival. Nonenzymatic glycosylation might also cause mutations that affect the activity of the immune system or lead to some types of cancer.

Richard Bucala, Peter Model and Cerami have found that incubating DNA with glucose does indeed cause fluorescent pigments to form. The pigments do not build up as quickly as they do on proteins, because the amino groups of nucleic acids are significantly less reactive than the amino groups of proteins.

No one has yet investigated the effects of AGE's on the nucleic acids of mammalian cells, but the group's studies of bacteria suggest that nonenzymatic glycosylation may well interfere with the normal functioning of human genes. When a bacteriophage (a bacterial virus) with a DNA genome was incubated with glucose and then inserted into the bacterium *Escherichia coli,* the phage's ability to infect *E. coli* cells was shown to be reduced. The degree of reduction depended on both the incubation time and the concentration of the sugar.

Bucala and his fellow workers also found that adding the amino acid lysine to a mixture of DNA and glucose hastened the loss of viral activity. Presumably the sugar reacted with the amino acid, forming an "AGE-lysine" that quickly bound to the DNA. Because both protein and glucose are present in mammalian cells, it seems likely that a similar reaction might account for the finding that protein covalently attaches to the DNA of aged cells. The effects of such protein binding to genetic material are not known.

Just how the attachment of glucose or a glycosylated protein to DNA interfered with the bacteriophage's normal activity is also not clear. In anoth-

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er study, though, sugar was shown to cause a mutation in DNA. The workers isolated plasmids (extrachromosomal pieces of bacterial DNA) carrying genes that make *E. coli* resistant to the antibiotics ampicillin and tetracycline. Then they incubated the plasmid with glucose-6-phosphate, a sugar that reacts more quickly than glucose, returned the DNA to bacterial cells and exposed the cells to an antibiotic. Most of the cells exposed to tetracycline died, whereas most exposed to ampicillin lived. Clearly some of the incubated plasmids kept the ampicillin-resistance gene but had lost the activity of the tetracycline-resistance gene.

Further study showed that most of the tetracycline-resistance genes had been altered by deletions or insertions of DNA. We suspect that those genes had collected advanced glycosylation end products and that the resulting mutations arose when the bacteria attempted to repair the DNA altered by AGE's. This conclusion is supported by the finding that bacterial cells lacking a DNA-repair enzyme did not have mutations in the DNA.

In order to better determine the effects of advanced glycosylation end products on the DNA of human cells, we are developing new methods for measuring both AGE's and glycosylated proteins on DNA. In addition we need to learn more about the cell's mechanisms for repairing glycosylated nucleic acids.

The ultimate goal of our research into both aging and diabetes is to find ways of preventing or delaying their debilitating effects. If our glycosylation hypothesis is correct, such effects might be mitigated either by preventing the formation of glucose-derived cross-links or by increasing the activity of biological processes that remove AGE's.

On the first front we, along with Peter C. Ulrich in our laboratory, have developed a promising drug called aminoguanidine. This small molecule, in the class of compounds called hydrazines, reacts with Amadori products. It apparently binds to carbonyl groups and in so doing prevents the Amadori products from becoming advanced glycosylation end products.

In test-tube studies of the drug we incubated albumin either with glucose alone or with glucose and aminoguanidine. Advanced glycosylation end products formed in the first mixture within half a week and increased progressively with time. In contrast, the aminoguanidine mixture produced an equal amount of Amadori product but resulted in marked inhibition of AGE formation. Similarly, when we incubated collagen with glucose, the protein became extremely cross-linked, whereas the addition of aminoguanidine blocked nearly all glucose-derived intermolecular bridges.

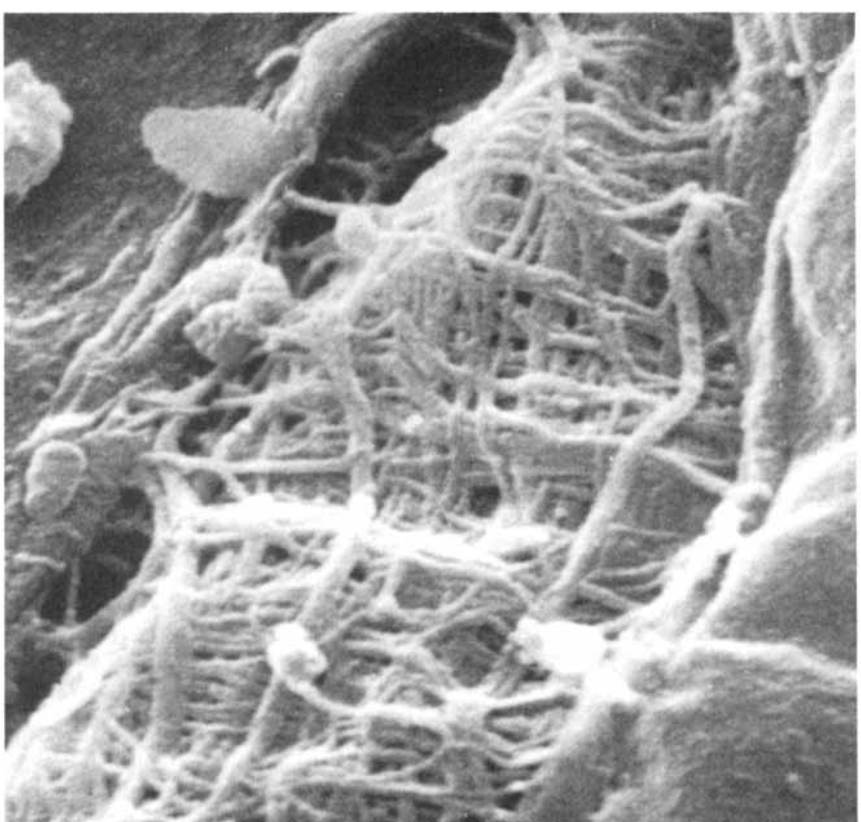
Parallel findings come from studies of diabetic rats. Animals treated with aminoguanidine amassed fewer advanced glycosylation end products in the aorta, and fewer cross-links, than untreated rats. In a separate group of diabetic rats we have shown that aminoguanidine prevents both the trapping of immunoglobulin in the basement membrane of renal capillaries and the trapping of plasma lipoproteins in the arterial wall.

We are now planning trials of aminoguanidine in human subjects. If the drug is shown to be safe, we hope to conduct long-term trials of its ability to prevent diabetic complications. Because diabetes is in some ways a model of aging, success in such trials might eventually help to justify studying the ability of aminoguanidine (or similar compounds) to prevent disorders related to age in nondiabetics.

We are also studying the other approach to treatment: increasing the activity of the body's AGE-removal system. Even if the production of advanced glycosylation end products could not be prevented, an effective AGE-removal system might help to counteract any dangerous buildup on proteins. Macrophages, the scavenger cells that remove debris from tissues, apparently constitute one such removal system.

This property of the scavenger cells became clear about three years ago when we examined peripheral-nerve myelin: the complex mixture of long-lived proteins that forms an insulating sheath around nerve fibers. We incubated isolated myelin with glucose for eight weeks to mimic the effects of long-term exposure to glucose in the body. Then we introduced macrophages into the mixture. The cells ingested more myelin than they did when the substance had not been exposed to sugar. They also took up more myelin from diabetic animals than from nondiabetic ones, presumably because the diabetic animals had a greater amount of advanced glycosylation end products.

More recent evidence indicates that



FIBRILS of collagen, the most abundant protein in the animal world, are enlarged 26,000 diameters in this scanning electron micrograph of chick-embryo collagen made by Christine McBride and David E. Birk of the University of Medicine and Dentistry of New Jersey in Piscataway. As animals and people age, cross-linking of the protein molecules in such fibrils causes tissues throughout the body to stiffen. The exact nature of all cross-links is not known, but evidence suggests that many of them may be AGE-derived.

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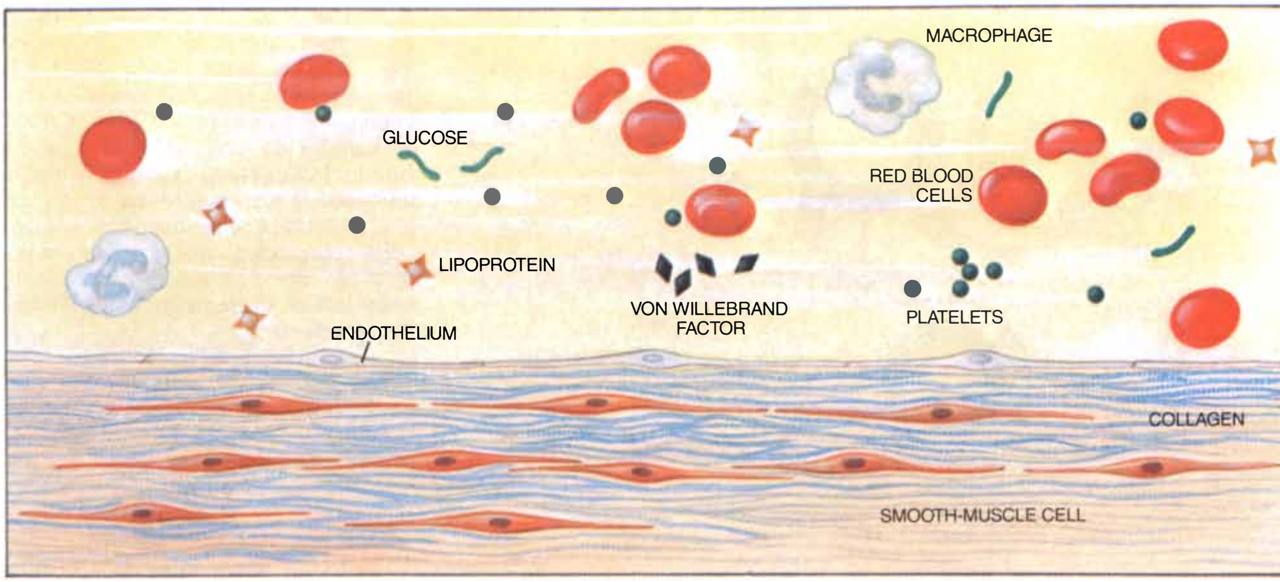

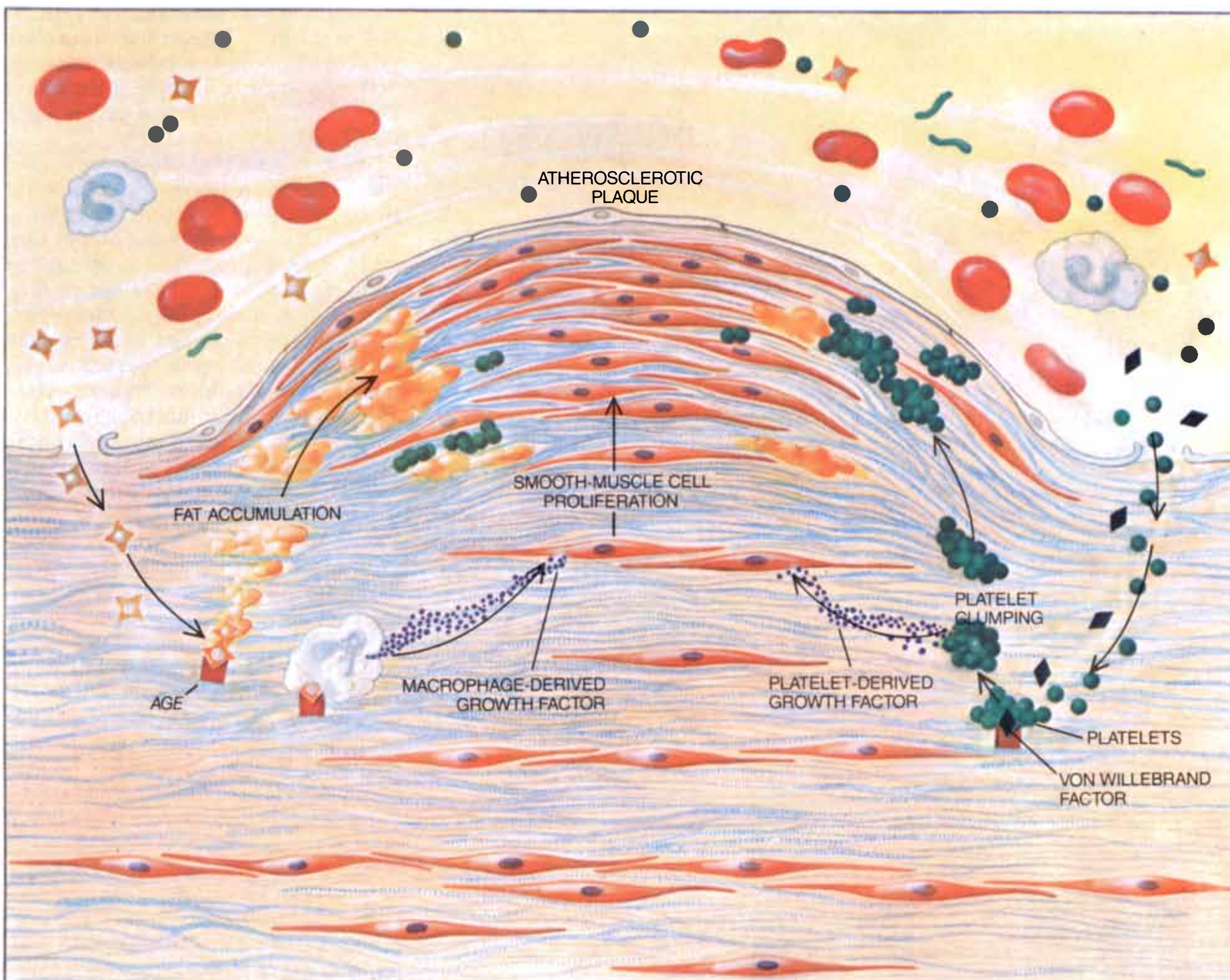

GLYCOSYLATION END PRODUCTS are suspected of contributing to atherosclerosis, and thus to coronary disease, by several pathways. When the inner lining of a healthy blood vessel (*top*) is damaged, plasma proteins leak into the arterial wall (*bottom*). AGE's on collagen in the wall then trap low-density lipoproteins (LDL), which accumulate to form cholesterol deposits in atherosclerotic plaques. Macrophages attempt to remove the captured lipoproteins and in the process secrete a factor that stimulates smooth-muscle cells to proliferate and make new collagen (*blue*). Finally, AGE's on collagen may trap von Willebrand factor, a protein that causes platelets to adhere to the vessel wall. Like macrophages, activated platelets secrete a cell-proliferation factor.

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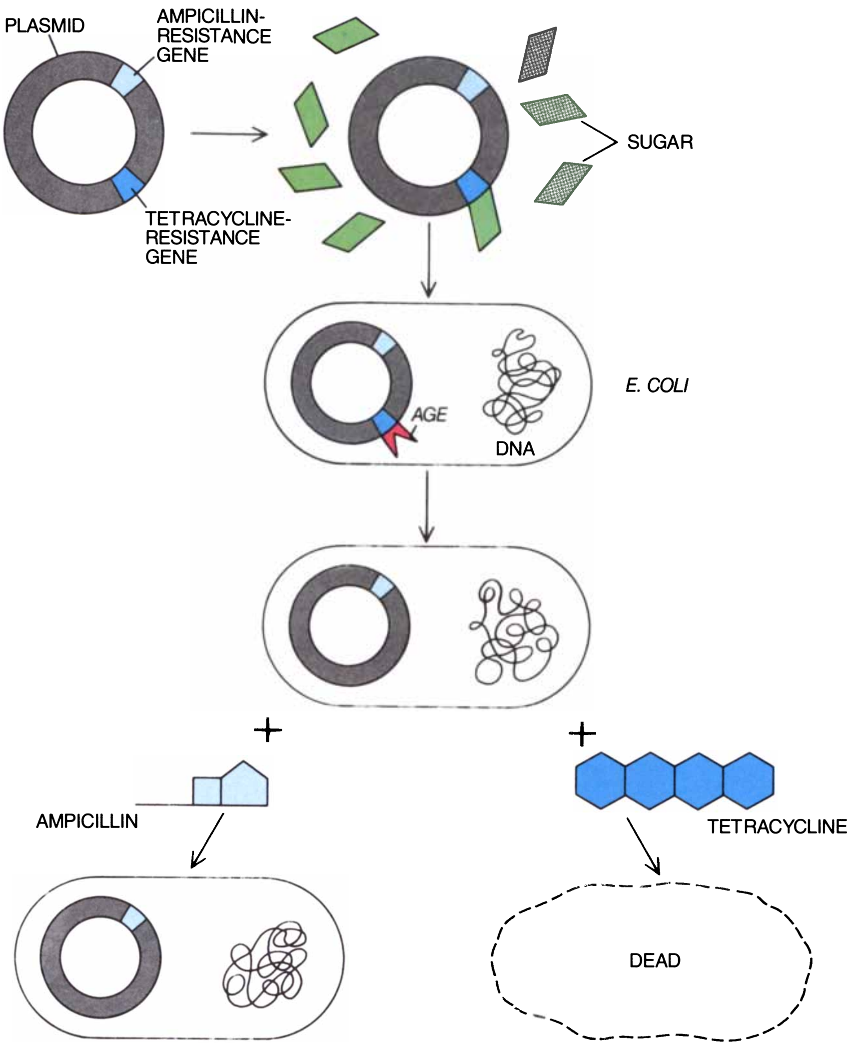
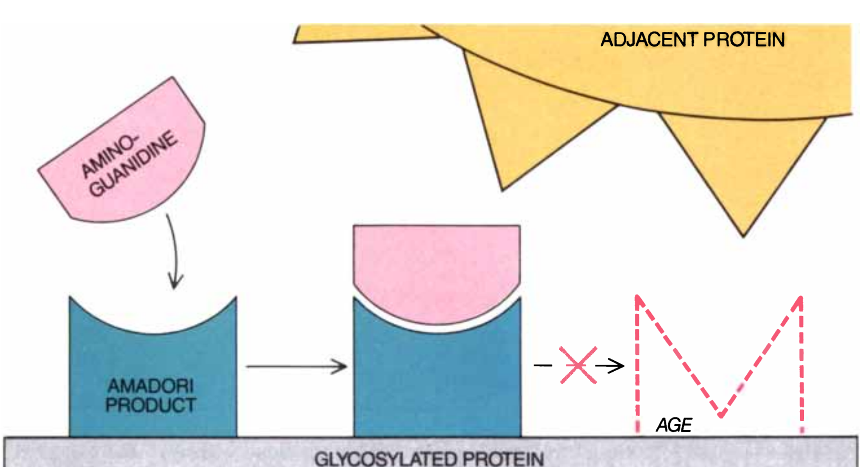


PLASMID, an extrachromosomal circle of bacterial DNA, underwent mutation as a result of being incubated with sugar, suggesting that glucose may contribute to some of the genetic damage seen in humans as they age. After incubation, plasmids carrying genes that render the bacterium *Escherichia coli* resistant to the antibiotics ampicillin and tetracycline were inserted into *E. coli*. In the presence of ampicillin the bacterial cells reproduced normally, but in the presence of tetracycline most cells died. Apparently bacterial enzymes attempted to repair tetracycline-resistance genes that accumulated AGE's.



AMINOGUANIDINE, an experimental drug developed in the authors' laboratory, interferes with the ability of Amadori products to undergo changes that could normally result in the formation of cross-links. The drug's safety and efficacy in humans are under study.

the signal for protein uptake by macrophages is specifically the advanced glycosylation end product. We have found, for example, that a mouse macrophage has an estimated 150,000 receptors for the AGE's that form on albumin. Macrophages attempt to ingest any protein attached to the advanced glycosylation end product FFI, but the cells' receptors do not appear to react with any non-AGE substances that accumulate on proteins, including Amadori products.

The affinity of macrophages for FFI, and for advanced glycosylation end products in general, became dramatically apparent when we attached FFI and other AGE's to membrane proteins of normal red blood cells. Mouse macrophages took up the altered cells much more avidly than they take up normal cells. (In addition to supporting the contention that macrophages are an AGE-removal system, this discovery suggests that advanced glycosylation end products have at least one constructive role in the body: they may indicate that a cell is aged and should be removed.)

Why do AGE's build up on proteins if the body has a system for removing them? We do not have an answer, but a few explanations seem likely. For one thing, the end products may generally form in locations that are not readily accessible to macrophages. Moreover, the highly cross-linked proteins that eventually accumulate appear to be increasingly difficult to remove. Also, as people age, their macrophages may become less efficient as a disposal mechanism. In support of this last notion we have very recently discovered that the number of AGE receptors on mouse macrophages declines as mice grow older.

We are currently seeking drugs that increase the removal rate of unwanted advanced glycosylation end products, but a successful treatment will have to dissolve the end products without excessively damaging irreplaceable proteins. In the case of myelin, for instance, excess AGE-stimulated uptake of old or damaged protein could erode the myelin sheath, which is essential for nerve functioning.

Additional evidence must be gathered before we can say with certainty that nonenzymatic glycosylation of proteins contributes to the cell and tissue changes characteristic of aging. The data collected so far do indicate that our hypothesis is a promising one. More important, the findings raise the exciting possibility that treatments can one day be developed to prevent some of the changes that too often make "aging" synonymous with "illness."

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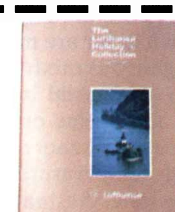

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Reappearing Phases

Matter becomes more orderly as it is cooled. Some systems, however, seem to become disordered again as the temperature continues to fall. The reason lies in the interplay between energy and entropy

by James S. Walker and Chester A. Vause

When a beaker of water is put in a freezer, it solidifies to form ice. When a bar of hot iron is refrigerated, it may become magnetically polarized. When samples of certain metals, such as aluminum, are cooled to extremely low temperatures, they become superconducting, losing all resistance to the flow of electric current. When certain homogeneous mixtures of liquids are cooled, they become immiscible, dividing to form two distinct liquids separated by a boundary called a meniscus.

These phenomena are examples of phase transitions. A sample of matter is said to be in a certain phase (such as the solid phase or the superconducting phase) when it has a certain well-defined set of macroscopically observable properties (such as hardness or lack of resistivity). The phase of a sample of matter is really an indication of the degree of order or disorder inherent in the molecules or atoms of which the sample is composed. The molecules of an ice crystal, for example, are far more orderly than those in liquid water. In a magnetized bar of iron the magnetic field associated with each atom is aligned in an orderly way with the fields of all the others, creating a single strong field; in unmagnetized iron the fields of the atoms are oriented randomly. Two liquids separated from each other are more orderly than a homogeneous mixture is.

When a material is cooled, its constituent molecules or atoms come to be arranged in a more orderly fashion. The high-temperature phase becomes unstable, and the material undergoes a transition to a more orderly phase. When water vapor is cooled, for example, it is transformed from the gaseous to the liquid phase and then to the solid phase. In some materials, however, the normal sequence seems to reverse itself. As these materials are cooled they pass from one phase to a second, more ordered one, as would be expected. On being cooled further, however, they are transformed back into the first phase: the first phase reappears! How can such a transformation take place? It seems to violate a primary requirement of thermodynamics, namely that materials become more ordered as their temperature is lowered.

Reappearing phases are actually a direct consequence of the interplay between energy and entropy, or disorder, as that interplay is expressed in the motions and interactions of the molecules that make up the materials. Reappearing phases can be of great utility in studying physical systems because they make it possible to gain a more thorough and accurate description of these microscopic interactions than would otherwise be possible.

A relatively simple example of reappearing phases is seen in systems known as binary liquid mixtures: mixtures of two kinds of liquid. Imagine pouring two liquids, such as coffee and cream or oil and water, into a beaker and stirring them. If the two liquids mix together (as coffee and cream do), filling the beaker with a single, homogeneous fluid, the mixture is said to be in the miscible phase. If, on the other hand, the liquids remain distinct, they are said to be immiscible; when oil and water are poured together, for example, they form two coexisting liquids (one is mostly oil and the other is mostly water) separated by a meniscus. We shall refer to this coexistence of two liquids as the immiscible phase.

Certain binary liquid mixtures can be either miscible or immiscible depending on the temperature. The immiscible phase, in which molecules of different types are segregated to different parts of the container, seems to be the most highly ordered of the two. One would expect, then, that mixtures would change from miscible to immiscible as the temperature is lowered. This transformation is indeed the one seen in most binary liquid mixtures.

As the chemist Basil McEwen of His Exalted Highness the Nizam's College in Hyderabad, India, discovered in 1923, however, not all binary mixtures follow such a straightforward sequence. McEwen studied various binary mixtures that are miscible at high temperatures. When he cooled them, they became immiscible, as he had expected. What was unexpected was that when he lowered the temperature even further, some of his samples became miscible again—and were therefore seemingly more disordered at low temperatures than they had been at intermediate temperatures. Since McEwen's time it has been found that reappearing miscible phases, although

MISCIBILITY OR IMMISCIBILITY of a pair of liquids reveals the degree of disorder or order inherent in the constituent molecules. The immiscible, or separated, phase seems to be more orderly than the miscible, or homogeneous, phase; one would therefore expect it to appear at low temperatures. Nevertheless, some mixtures, such as those shown here, separate as the temperature is lowered and then mix again as they are cooled further, indicating that there is some kind of hidden order in the "reappearing" miscible phase. The ampules contain various proportions of butyl alcohol (*pink*) and water. At 90 degrees Celsius all the mixtures are miscible. After the temperature has been lowered to 70 degrees, they are all immiscible. At 20 degrees they are again fully mixed; this is the reappearing miscible phase. At −20 degrees one (*far left*) has frozen and three are miscible, while two (*far right*) show a reappearing immiscible phase. The ampules that have a cloudy color (the middle two at 88 degrees and the third from the left at 50 degrees) are at critical points, when the two coexisting liquids of the immiscible phase are identical and so the immiscible phase is indistinguishable from the miscible one. The apparatus and the photographs are the work of Christopher M. Sorensen of Kansas State University.

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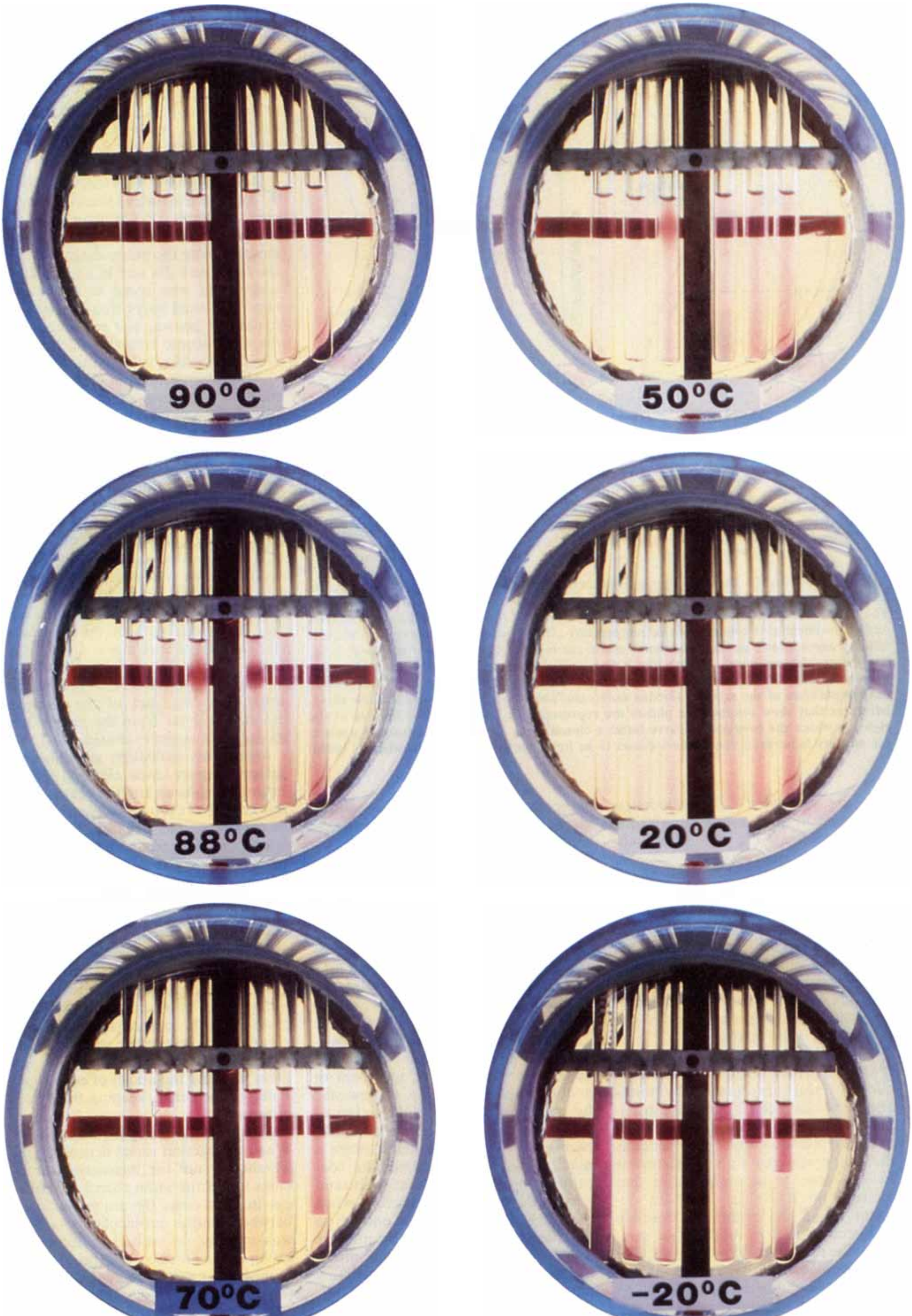

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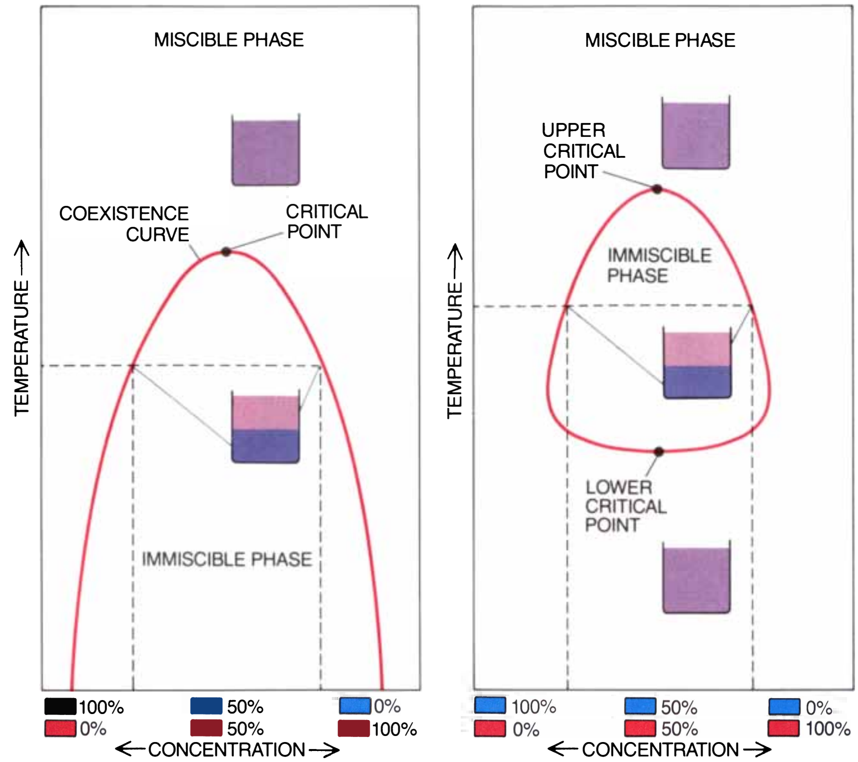

PHASE DIAGRAMS show whether a given mixture of two liquids will be miscible or immiscible at a given temperature. The diagram at the left is applicable to most mixtures. The horizontal axis represents the relative proportions of the ingredients in the mixture, and the vertical axis corresponds to temperature. If the point representing a mixture is above a curve known as the coexistence curve, the mixture is miscible. If the point is below the coexistence curve, the mixture is immiscible. It separates into two liquids whose concentrations can be determined by plotting the points at which the line representing the temperature of the mixture (*broken horizontal line*) intercepts the coexistence curve. Mixtures that show reappearing phases are represented by diagrams like the one at the right, in which the coexistence curve forms a closed loop. As the temperature of a miscible mixture is lowered, the mixture comes to be first immiscible and then miscible again.

they are somewhat rare, nonetheless are found in quite a few binary mixtures. How are we to understand such contradictory phenomena?

A first step in understanding the behavior of binary liquid mixtures is to depict that behavior in what is known as a phase diagram. A phase diagram of a binary liquid mixture is a graph; the vertical axis represents temperature and the horizontal axis represents the relative proportions of the two liquids in the mixture.

The central feature of the phase diagram is a curve called the coexistence curve. Mixtures represented by points above the coexistence curve are miscible; mixtures represented by points below the curve are immiscible. Hence as the temperature of a given mixture is lowered, the point representing that mixture on the phase diagram descends from the region of miscible mixtures to that of immiscible mixtures: the mixture becomes immiscible as it is cooled. The shape of the coexistence curve indicates, for any given temperature, the precise compositions of the two fluids into which the immiscible mixture divides. (Neither fluid is pure; each is composed primarily of one of the pure liquids with a small admixture of the other liquid.) There is one point on the curve that is special; it is the point at which the liquids above and below the meniscus come to have the same concentration. At this point, which is called the critical point, the miscible and immiscible phases are indistinguishable.

In phase diagrams representing mixtures that have reappearing phases the coexistence curve takes the form of a closed loop. Mixtures represented by points lying to the right or left of the loop never become immiscible, no matter how low the temperature is made. Mixtures at intermediate concentrations are miscible at high temperatures, become immiscible when the temperature is lowered enough so that the point representing the mixture is inside the closed loop, and are miscible again when the point representing the mixture descends through the bottom of the loop. Phase diagrams containing closed loops have two critical points. One of them, called the upper critical point, is at the top of the loop, and the other, the lower critical point, is at the bottom.

Phase diagrams represent the behavior of a mixture as seen on a macroscopic level. That is, they show the behavior of the bulk liquid. To understand why the phase diagrams take the form they do, and in particular to understand why some of them contain the closed loops that indicate reappearing phases, one must consider the microscopic behavior of the individual molecules in the liquids.

All molecules attract or repel other molecules because of an interaction called the van der Waals force. The van der Waals force is electrical in origin, although it affects electrically neutral atoms and molecules. The negative charges within a molecule are contained in a "cloud" of electrons that surrounds the positively charged atomic nuclei making up the molecule's core. The electron cloud of a molecule can become displaced; that is, it can shift its position in such a way that it is no longer centered on the nuclei. Then one part of the molecule (the part of the core that is not as fully surrounded by the electron cloud) has an excess of positive charge and the other part (the part of the electron cloud that is far from the nuclei) has an excess of negative charge.

When two molecules are close together in space, their electron clouds become displaced and the excess positive charge of each molecule is attracted to the excess negative charge of the other; the molecules are attracted to each other. The displacement of the electron clouds is not static: they fluctuate rapidly as the molecules tumble and rotate randomly. As the molecules move toward each other their electron clouds become displaced still further, making the attractive force stronger.

The molecules are not drawn infinitely close, however. When they are close enough so that their electron clouds begin to overlap, the electrons of each molecule repel those of the other one and the nuclei of each repel those of the other, keeping the molecules apart.

In general the strength of the van der Waals interaction varies depending on whether or not the interacting molecules are of the same chemical makeup. In most cases the attractive force between unlike molecules is much weaker than the attractive force between like molecules. In general a pair of molecules held together by a strong force has lower energy than a pair of

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molecules held together by a weak force: it takes more energy to separate the strongly held molecules. In many cases the energy of a pair of like molecules that are close together is much lower than the energy of a pair of unlike molecules that are close together.

This experimental fact makes it possible to begin to understand the phase diagrams. As a result of the van der Waals force, a mixture of two liquids is at its lowest energy when most of a given molecule's neighbors are of the same chemical species as that molecule. In terms of energy, then, the most favored situation is for all molecules of a given type to cluster together. This, of course, is simply a description of the immiscible phase.

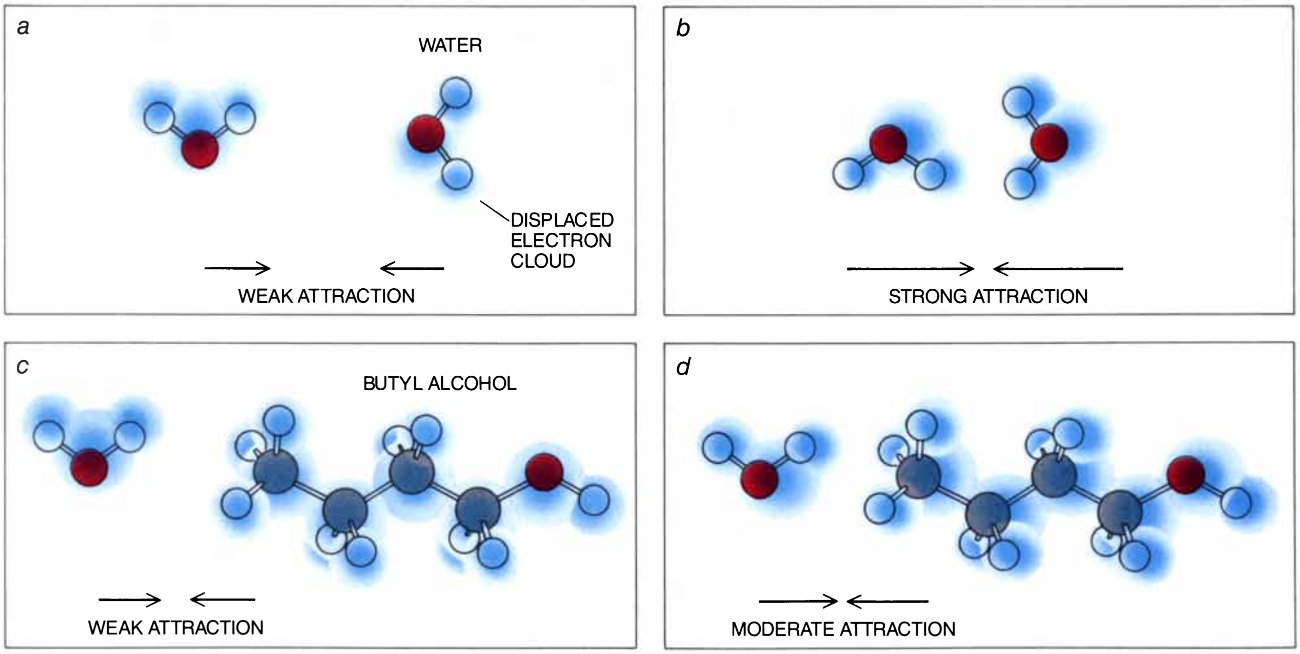
Considerations of energy alone are not sufficient, however, for understanding the behavior of a physical system. Why, for example, are binary mixtures miscible at all—even at high temperatures—if mixing increases the energy of the mixture? The answer lies in another aspect of thermodynamics, which is just as important as energy: entropy. The entropy of a physical system, in simple terms, can be thought of as a measure of the system's randomness, or disorder.

The reason mixtures become miscible at high temperatures is expressed in a fundamental principle of thermodynamics: A system tends to minimize not its energy but rather a quantity known as its free energy. The free energy of a system is equal to the energy of the system minus the product of its temperature and its entropy. At a given temperature the free energy can be minimized either by decreasing the system's energy or by increasing its entropy. When a system is at a low temperature, changing its entropy makes very little difference in its free energy (because it is the temperature times the entropy that is the relevant quantity). At low temperatures, then, minimizing the free energy is essentially the same as minimizing the energy. At high temperatures, on the other hand, changing the entropy by even a small amount has a large effect on the free energy, and so at high temperatures systems tend to maximize their entropy.

At low temperatures binary liquid mixtures become immiscible because that minimizes their energy. At high temperatures they become miscible because that maximizes their entropy. (A miscible mixture has what might be called compositional entropy: the two types of molecules are distributed randomly.) Every physical system makes such compromises between the lowest total energy and the highest total entropy. This competition between low energy and high entropy underlies the formation and stability of all the various phases of matter. The free energy is the final arbiter in determining the nature of the equilibrium phase.

The concepts of energy and entropy make it possible to describe the microscopic events responsible for the common miscibility phase diagrams, in which mixtures are miscible at high temperatures and immiscible at low temperatures. How do these concepts explain reappearing phases? Since the influence of entropy decreases with decreasing temperature, it seems out of the question that a mixture would become miscible again at low temperatures, increasing its compositional entropy. The very existence of the reappearing phase indicates that the microscopic picture of the system described above is incomplete.

What has been left out? The answer, which was first suggested in 1937 by Joseph O. Hirschfelder, David Stevenson and Henry Eyring of Princeton University, involves a kind of intermolecular interaction known as hydrogen bonding. Hydrogen bonds are attractive forces between molecules that can sometimes be stronger than van der



VAN DER WAALS FORCE, which draws molecules toward each other, is often stronger when the attracted molecules are identical. At relatively long range (*a*) the electron cloud of each molecule can shift its position in relation to the atomic nuclei making up the molecule's core. The molecules then have regions of excess negative charge (where the electron cloud has moved far from the core) and excess positive charge (where the core is near the edge of the cloud). The positively charged end of each molecule is attracted to the negatively charged end of the other, and they are drawn together. When the molecules are closer (*b*), the displacement of the electron clouds is greater and so the attraction is stronger. (The displacement is not static; the positions of the electron clouds fluctuate as the molecules tumble.) The strength of the long-range van der Waals effect is about the same even when the molecules are not identical (*c*). At shorter ranges (*d*), however, the clouds of such unlike molecules are often not displaced as far as the clouds of identical molecules would be, and so the force is not as strong as the force that attracts identical molecules at close range. Hence it is often energetically favorable for mixtures to separate so that neighboring molecules are usually identical.

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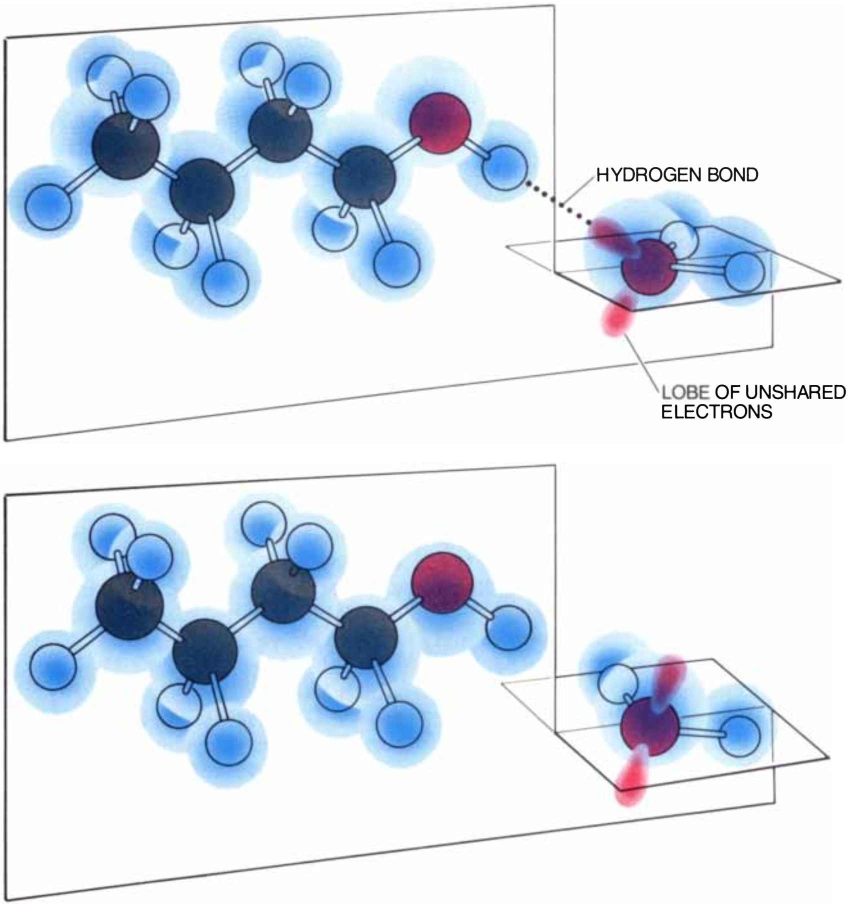

HYDROGEN BONDING can hold molecules together in a specific orientation. In a hydrogen bond (*top*) the nucleus of a hydrogen atom from one molecule is attracted to a lobe of unshared electrons from an electronegative atom (such as an oxygen atom) in another molecule. (The lobe is a region in which there are electrons that do not participate in the bonds holding the second molecule together.) If the molecules are not oriented so that the hydrogen can align with the lobe (*bottom*), the molecules will not bond.

Waals forces but are always considerably weaker than the bonds that hold atoms together to form molecules.

Unlike van der Waals forces, which affect all molecules, hydrogen bonds can be formed only by certain kinds of molecules. They form when the nucleus of a hydrogen atom in one molecule is partially stripped of its electron by an electronegative atom (such as an oxygen atom) in the same molecule. Then the hydrogen nucleus is attracted to the electrons of an electronegative atom in a neighboring molecule. In a sense the two electronegative atoms share the hydrogen nucleus, and the molecules are bonded.

Hydrogen bonding, like the attractive van der Waals force, lowers the energy of the system, because molecules bound together are at a lower energy than free molecules. What about the entropy? Suppose in a certain mixture only unlike molecules can form a hydrogen bond. Then hydrogen bonding would require that a molecule's nearest neighbor be an unlike molecule. If hydrogen bonding between unlike molecules were a dominant effect, it would raise the compositional entropy of the mixture, promoting the miscible phase. One might think, then, that hydrogen bonding would occur at high temperatures, when the entropy is high. Actually just the opposite is the case: hydrogen bonding occurs primarily at low temperatures. Why?

The reason is that there is a subtle way in which hydrogen bonding actually reduces the total entropy of a system rather than increasing it. Molecules can form hydrogen bonds only when they are in certain orientations in relation to each other, so that the hydrogen nucleus in one molecule can align with the electrons in the electronegative atom of the other molecule. Typically, hydrogen bonds have an angular spread of only 10 degrees; in other words, if the relative orientation of two bonded molecules changes by more than 10 degrees, the bond breaks. Hydrogen bonds break easily, but while they last they hold the bonded molecules in a single relative orientation. Molecules that are not hydrogen-bonded are free to tumble about, taking on any orientation at all. Such molecules therefore have high "orientational entropy," whereas hydrogen-bonded molecules have very low orientational entropy.

The orientational entropy lost in forming a hydrogen bond between unlike molecules is much greater than the compositional entropy that is gained. The effect of hydrogen bonding between unlike molecules, then, is to lower the total energy of the system while also lowering the total entropy (compositional entropy added to orientational entropy). When the system is at low temperatures, the lowered energy brought about by hydrogen bonding has a large effect on the free energy of the system and the lowered entropy has only a small effect. Hydrogen bonds are therefore thermodynamically stable at low temperatures. At high temperatures, on the other hand, the entropy becomes more important; the low entropy of a hydrogen bond then has a large and unfavorable effect on the free energy, and hydrogen bonds tend not to form.

We can now explain the reappearing phase in terms of the underlying microscopic events. At high temperatures the mixture is miscible and the entropy is high. The component molecules are mixed together randomly (giving the mixture high compositional entropy) and are oriented randomly with respect to one another (giving the mixture high orientational entropy). As the temperature is lowered, energy becomes more important. Eventually the lowered energy associated with the van der Waals attraction has a larger effect on the free energy than the compositional entropy does. The mixture then becomes immiscible: like molecules tend to lower the energy by grouping together, rather than raising the entropy by mixing with unlike molecules.

As the mixture's temperature is lowered further in the immiscible phase, another interplay of energy and entropy emerges. In this case it is an interplay between the orientational entropy of the immiscible phase and the lowered energy due to hydrogen bonding. Eventually the temperature gets low enough for the low energy of hydrogen bonding to have a greater effect on the system's free energy. At that temperature the mixture becomes miscible again. This mixture has the same macroscopic properties as the high-temperature miscible mixture. The miscible phase has reappeared.

For what range of temperatures and

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concentrations will the mixture remain immiscible before the miscible phase reappears? In other words, how large is the closed loop on the phase diagram and what shape does it have? In our own work over the past several years we have developed a theory to determine how the sizes and shapes of closed loops depend on various experimental parameters.

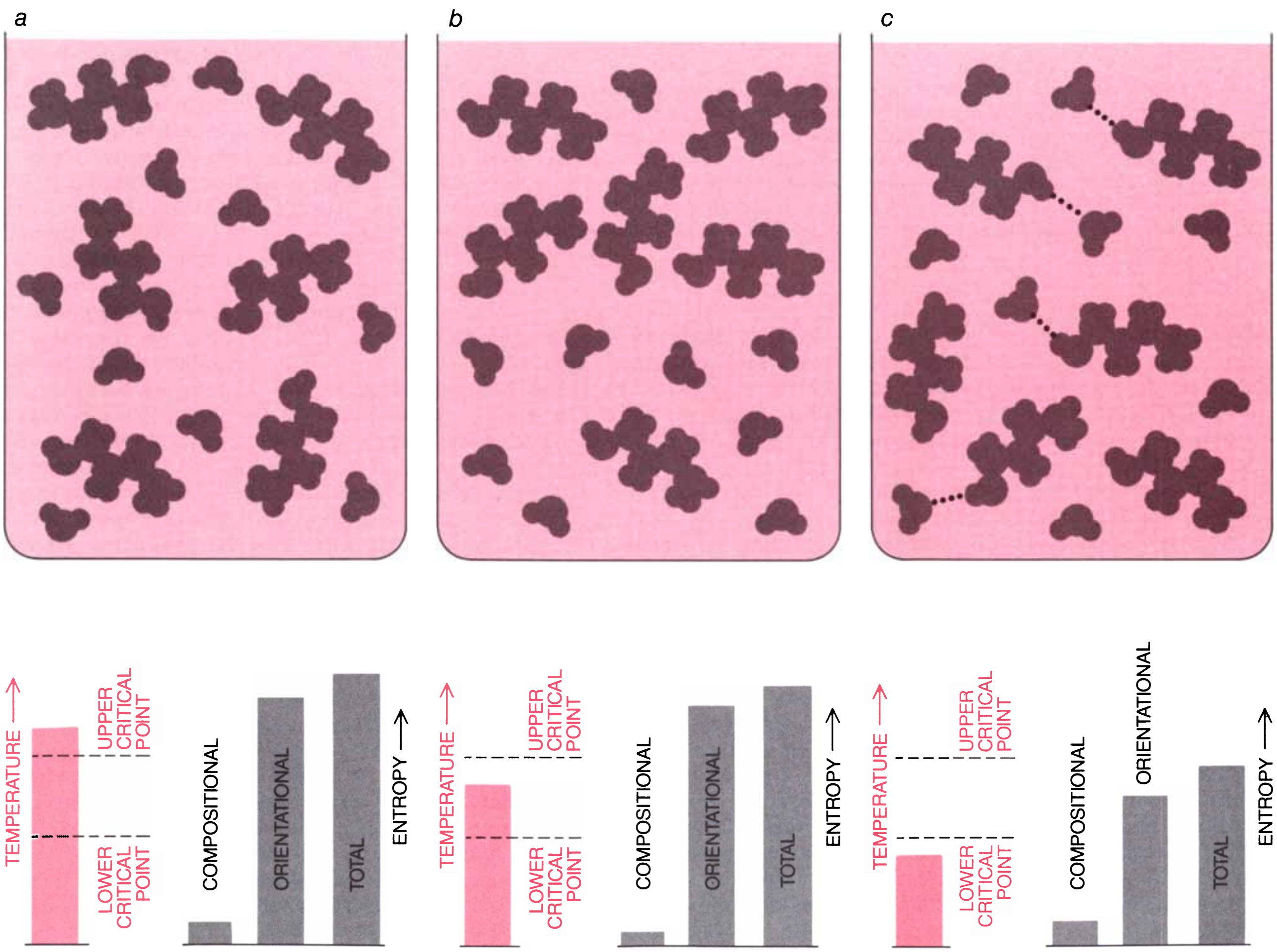
One particularly important parameter is the strength of the hydrogen bond, or, to put it another way, the amount by which the energy of two molecules is lowered when they enter into a hydrogen bond. When the hydrogen bond is infinitely weak, that is, when molecules of the two liquids in the mixture do not form hydrogen bonds at all, there will be no reappearing miscible phase. One example of such a case is the mixture of glycerol and methyl ethyl ketone, which hydrogen-bonds only very weakly and displays no reappearing miscible phase.

What about cases in which the hydrogen bond is stronger? In calculations based on our theory we have achieved good quantitative agreement with the phase diagrams for three experimental systems that were among Basil McEwen's original samples. In order of increasing hydrogen-bond strength, the systems are glycerol mixed with benzylethylamine, glycerol mixed with *m*-toluidine and glycerol mixed with guaiacol. (In this last system a small amount of water must also be added in order to weaken the hydrogen bond between glycerol and guaiacol, which would otherwise bond so strongly that the mixture would never become immiscible.) The closed loop becomes progressively smaller as the hydrogen-bonding strength increases. This makes sense intuitively; the stronger the hydrogen bond is, the sooner it will be energetically efficient for the mixture to lose orientational entropy by hydrogen bonding.

These various mixtures might seem to be distinct cases, each rather different from the others. The mixture of glycerol and methyl ethyl ketone has no closed loop at all and the other mixtures have loops that differ greatly from each other in size and shape. Yet these cases can all be linked together in a single, three-dimensional phase diagram called a global phase diagram.

In the global phase diagram, as in standard two-dimensional phase diagrams, the vertical axis represents temperature and one of the horizontal axes represents the relative concentration of the two liquids in the mixture. The third axis represents the strength of the hydrogen bond.

The three-dimensional phase diagram is shaped roughly like a section from the nose of a jet airplane. In the



ENTROPY, or disorder, of a mixture declines as the temperature is lowered, even if the mixture has a reappearing miscible phase. At high temperatures (*a*) the molecules are fully mixed, resulting in some degree of "compositional entropy." They are also oriented randomly with respect to one another, leading to a high "orientational entropy." At intermediate temperatures (*b*) the mixture is immiscible and the component molecules separate; the compositional entropy therefore decreases. At low temperatures (*c*) many unlike molecules are hydrogen-bonded to each other in the reappearing miscible phase. The compositional entropy therefore increases, but the orientational entropy decreases dramatically because hydrogen-bonded molecules are held in a single relative orientation. Even though the molecules in the reappearing phase are mixed, the total entropy is lower than in the immiscible phase.

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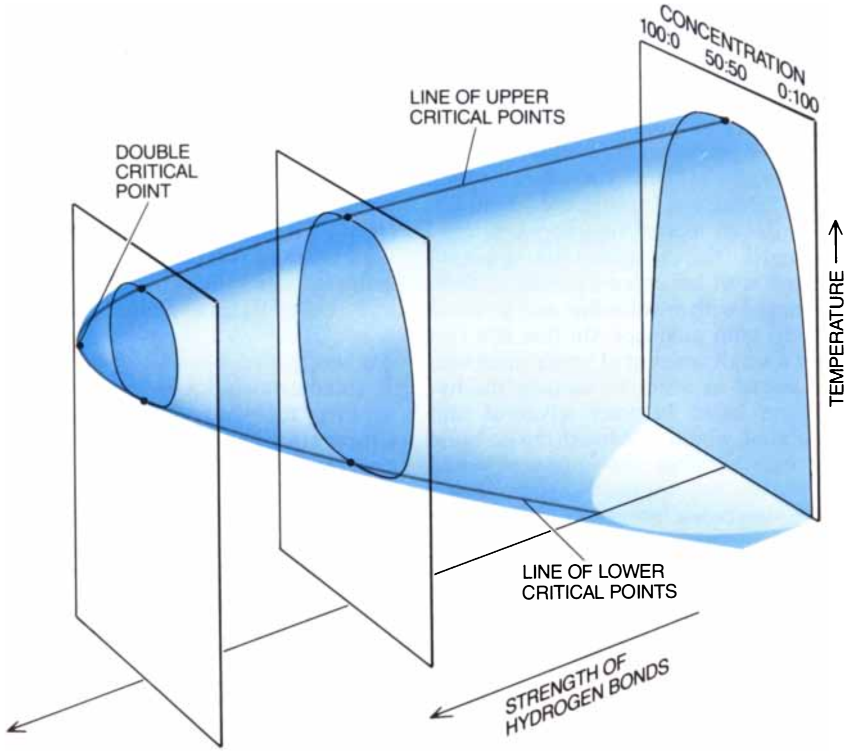

GLOBAL PHASE DIAGRAM shows how the phase diagrams of binary liquid mixtures depend on the strength of the hydrogen bonds that form between unlike molecules. Every "slice" through the global phase diagram represents the phase diagram of a mixture that has a particular hydrogen-bonding strength. When the hydrogen bonds are weak (*far right*), the mixture has the typical dome-shaped phase diagram that indicates there is no reappearing phase. When the bonds are stronger (*center and left*), the region representing the immiscible phase closes to form a loop, and the mixture has a reappearing phase.

region where hydrogen bonding is weak it has a high, domed shape with no bottom, representing systems in which the hydrogen bond is too weak to promote a reappearing immiscible phase. As the strength of the hydrogen bond is increased the bottom of the dome closes off to form a loop, which shrinks as the bonding gets stronger. At very high bonding strengths the loop of immiscibility shrinks until it disappears completely; here systems are miscible no matter what the relative proportions of the ingredients are. The loop changes not only in size but also in shape, from a region where it has an arched top and a flat bottom (at low bonding strengths) to regions where the top and bottom are virtually mirror images of each other. Any "slice," or cross section, of this three-dimensional structure is a phase diagram describing the behavior of a particular mixture.

In order to test this model experimentally one makes a small change in the bonding strength of a given system and notes the corresponding changes that occur in the system's phase diagram. One can then compare the new phase diagram with the slice of the global phase diagram that corresponds to the new bonding strength.

One way to change the bonding strength of a mixture is simply to change one of the component liquids: different pairs of component molecules bond together with different strengths. A more precise way of changing the bonding strength, which eliminates the complicating factors inherent in changing the chemical nature of the mixture, is to change the pressure exerted on the system. Most experiments are carried out at atmospheric pressure, but if, for example, the pressure is increased, the molecules will be forced closer together. As a general rule, molecules hydrogen-bond more strongly as they are brought closer together. Increasing the pressure therefore causes the hydrogen bond to strengthen, shrinking the loop of immiscibility on the phase diagram. At high enough pressures the loop vanishes and the mixture remains miscible at all temperatures.

Another way to alter the bonding strength is to add a small amount of some third component that is miscible with the binary mixture. (If only a small amount of the third liquid is added, the mixture still behaves in most ways like a binary mixture.) As we have already mentioned, adding water to the mixture of glycerol and guaiacol decreases the bonding strength. This happens because some of the guaiacol bonds to water instead of to glycerol, decreasing the average bonding interaction between guaiacol and glycerol and thereby causing the immiscible phase to appear.

One particularly interesting kind of experiment can be done in this system of guaiacol, glycerol and water. It involves changing the bonding strength in such a way that the loop of immiscibility just vanishes. As the loop vanishes the upper and lower critical points merge; that is, the temperature at which the mixture becomes immiscible is precisely the same as the temperature at which it becomes miscible again. The merger of the upper and lower critical points forms what is known as a double critical point.

A mixture at a double critical point has some unique properties. One such property concerns certain mathematical entities known as critical exponents. Critical exponents describe the rate at which a phase transition occurs when an external parameter, such as the temperature or the pressure, is varied [see "Problems in Physics with Many Scales of Length," by Kenneth G. Wilson; SCIENTIFIC AMERICAN, August, 1979]. What is special about critical exponents is that they are universal constants. For example, the value of the critical exponents describing the rate at which a mixture becomes immiscible as the temperature is varied near the critical point are the same for all binary liquid mixtures. Moreover, the critical exponents describing many other kinds of phase transitions are identical with the exponents describing the miscibility-immiscibility transition. For instance, the same numerical values of the critical exponents that describe the transition from miscibility to immiscibility also describe the rate of any transition between the liquid and gaseous phases at that transition's critical point!

At double critical points the values of certain critical exponents are precisely twice their normal value. This result was predicted nearly 20 years ago, and it was verified in 1985 by two experimental groups—Roger G. Johnston and Noel A. Clark at the University of Colorado at Boulder, who collaborated with Pierre Wiltzius and David S. Cannell at the University of California at Santa Barbara and, independently, G. A. Larsen and Christopher M. Sorensen of Kansas State University. These groups confirmed the

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prediction by measuring the light-scattering properties of mixtures that were held at the right hydrogen-bonding strength, temperature and composition to produce a double critical point.

As interesting as those experiments are, they do not exhaust the possibilities of reappearing phases in binary mixtures. Suppose that like molecules, as well as unlike ones, can hydrogen-bond to each other. (For example, in the mixture of water and butyl alcohol a water molecule could become hydrogen-bonded to a butyl alcohol molecule, but it could also become hydrogen-bonded to another water molecule.) Suppose further that a pair of bonded like molecules would have even lower energy than a pair of bonded unlike molecules. In this case there would be two reappearing phases. At high temperatures the mixture would be miscible. As the temperature was lowered it would become immiscible. As the temperature was lowered further it would become miscible again, and finally, at very low temperatures, it would become immiscible again. In this second immiscible phase like molecules would be hydrogen-bonded to each other, losing both compositional and orientational entropy in order to lower the energy.

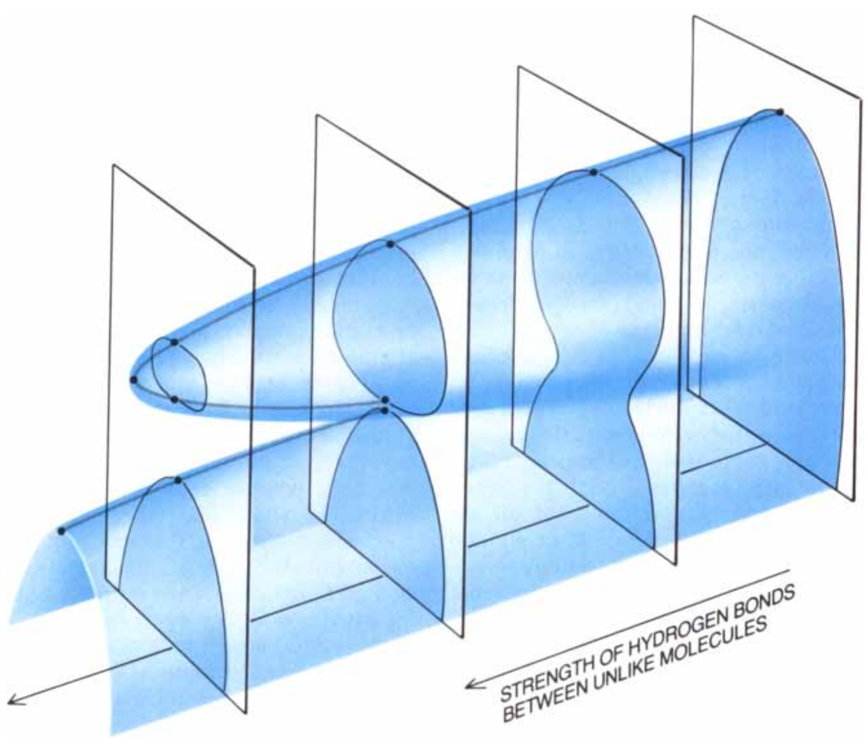
Experimental evidence suggests that some mixtures could be manipulated to have still more unusual properties. Suppose a molecule in the mixture is able to form two hydrogen bonds at once. Then the mixture's phase diagram might have several closed loops. It is possible to envision a mixture having as many as five critical points. Such a mixture would pass, as the temperature is lowered, from miscible to immiscible, back to miscible, back to immiscible, back to miscible again and finally back to immiscible again!

In this article we have concentrated on reappearing phases in binary liquid mixtures, the medium in which they were first discovered. There are a number of examples in other kinds of systems as well. One such case is found in superconductivity. Certain metals can be in either the normal phase or the superconducting phase. In the normal phase they are like any other conductor: they have a finite resistance to the passage of electric current. When the temperature is made very low, however, these metals suddenly lose all resistance to electricity, becoming superconducting. The superconducting phase is due to a certain kind of long-range order (called Cooper pairing) among the electrons in the metal. The superconducting phase is therefore more ordered than the normal phase that is seen at high temperatures. As G. Riblet and K. Winzer of the University of Cologne discovered in 1971, however, certain superconductors, when cooled to even lower temperatures, become normal again.

Another kind of reappearing phase is found in adsorbed monolayers, which are single layers of molecules formed on a solid surface [see "Two-dimensional Matter," by J. G. Dash; SCIENTIFIC AMERICAN, May, 1973]. In these systems the adsorbed molecules are relatively free to move along the surface of the solid, but a strong attractive force keeps them from leaving the surface. The adsorbed systems behave as though they were two-dimensional, but they display phases that are analogous in many ways to three-dimensional gases, liquids and solids. When the rare gas krypton is adsorbed on graphite, it forms a two-dimensional liquid phase at about 130 degrees Kelvin (130 degrees Celsius above absolute zero). It freezes into a two-dimensional crystal when it is cooled to about 125 degrees K. and melts to form the liquid phase again at about 120 degrees.

Since reappearing phases are seen in such a wide variety of systems, it is clear that the microscopic events underlying each occurrence must be quite different. Nevertheless, a common thread connects all these examples: phase changes are caused by the competition between energy and entropy, and reappearing phases indicate the existence of interactions that lower the entropy in some "hidden" way while at the same time lowering the energy of the system as a whole.

Binary liquid mixtures are a particularly good medium in which to study the thermodynamics of reappearing phases. The temperatures required are easily accessible and various parameters can be manipulated rather easily to test theoretical methods and descriptions. Those theoretical methods and descriptions can then be applied in other realms, in which the reappearing phases are more difficult to study experimentally.



TWO REAPPEARING PHASES can result when like molecules as well as unlike molecules form hydrogen bonds, as this global phase diagram shows. In the diagram the strength of hydrogen bonds between like molecules is constant and the strength of hydrogen bonds between unlike molecules varies. When the hydrogen bonds between unlike molecules are weak (*right*), the mixture has the standard dome-shaped phase diagram. As the strength of the bonds increases, the region representing the immiscible phase becomes pinched and then splits into two regions. As the temperature of the mixture is lowered, the mixture is therefore first miscible, then immiscible, then miscible again and finally immiscible once more. In the lower (reappearing) immiscible phase, like molecules are hydrogen-bonded to each other, lowering both the compositional and the orientational entropy of the mixture. The leftmost slice in this diagram represents the phase diagram of the mixtures of butyl alcohol and water shown in the photographs on page 99.

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The Detonation of Explosives

A detonation sweeps through an explosive as a supersonic shock wave driven by the energy-releasing chemical reactions the wave induces. A comprehensive theory that describes the process is still lacking

by William C. Davis

In 1846 the Italian chemist Ascanio Sobrero noted that combining nitric acid and glycerol resulted in a liquid substance with peculiar properties. The substance exploded violently and in a markedly different way from black powder, the most widely used explosive at that time. Whereas black powder does not explode unless it is confined so that its combustion gases can generate high pressures, small quantities of the oily liquid exploded much more powerfully than black powder even when the liquid was unconfined. Sobrero had discovered not only a new compound, nitroglycerin, but also a completely new physical process by which substances can explode, namely detonation.

As the news of Sobrero's discovery spread, others tried to apply it. The tireless Swedish inventor Emanuel Nobel tried adding nitroglycerin to black powder in an unsuccessful effort to increase the powder's effectiveness. In 1863 his son Alfred reasoned that a new kind of explosive deserved a new kind of initiator. Whereas black-powder charges had always been set off by flame, the younger Nobel developed a detonator that reliably set off nitroglycerin "by percussion or sudden pressure," as stated in its patent.

Substances that explode in the same way as nitroglycerin does are called high explosives to distinguish them from such substances as black powder, known as low explosives, which simply burn extremely briskly. Although Alfred Nobel and others after him devised a wide variety of powerful and safe high explosives and detonators, in most cases they relied more on hunches and even on sheer serendipity to guide them than on a clear understanding of the physics and chemistry of detonations.

That trial-and-error approach to the development of high explosives persisted until only a few decades ago, when investigators first began to transform the study of explosives from an empirical science to a science based on a solid theoretical foundation. The transformation is still not complete, but current research efforts are likely to quicken the pace. Progress in theoretical analysis, backed up by new computational methods, are helping to elucidate the structure of the inhomogeneities that seem to play an important role in the way a detonation propagates in an explosive. Advances in experimental techniques, such as laser spectroscopy, are yielding data from which the complex equations can be derived that describe the behavior of materials under the extreme conditions of pressure and temperature found in detonating explosives. These investigative efforts will ultimately provide what is still lacking today: a comprehensive theory of detonation.

Ironically, it was a completely new type of explosive process—a nuclear chain reaction—that stimulated the modern theoretical study of detonation. Nuclear weapons rely on high explosives for the rapid assembly of key reacting components. Hence the assembly process calls for chemical explosives whose blast effects can be precisely controlled. The stringent requirement brought about a radical change in the explosives industry. All the attributes of a sophisticated technology—accuracy, predictability and tailoring to fine gradations—were suddenly demanded of explosives.

Engineers soon began to see precision explosives as compact energy sources of exceedingly high power that, although of short duration, are safe, reliable, controllable and, best of all, inexpensive. Thereafter it did not take long for a variety of new applications to be devised. Explosives are attached to the support columns and beams of old buildings and detonated in precise sequence to demolish the structures into neat piles of rubble. They are invaluable in metalworking to harden, form, weld and clad metal sheets or tubes. Indeed, in certain situations explosive welding is the only practical way to bond incompatible metals, such as aluminum and steel.

In some devices explosives are set off so that they force metal plates to collide violently, causing a high-velocity jet of metal to shoot out from between the plates. Such explosive-generated jets are capable of piercing the hardest materials and are used to penetrate armor, perforate oil pipes and cut up steel structures. Explosive cutters operating on the same principle are installed in structures that have to be sheared instantly while they are under great stress, as in the separation of missile or rocket stages.

Explosions can also be applied to generate the pressures and temperatures needed to make diamonds from graphite, to fuse metal and ceramic powders and to cause some otherwise impossible chemical reactions to proceed. Perhaps less well known is the development of explosive-driven magnetic field compressors that attain field strengths up to 10 million times the strength of the earth's magnetic field. Such magnetic fields can generate enormous pulses of electricity.

In spite of the variety of modern applications of explosives, detonation science has not yet reached maturity for several reasons. First of all, the theoretical calculations are intrinsically difficult. Whereas tractable, linear processes are common in many fields of classical physics, detonation is an exquisitely nonlinear process. Nonlinear processes are much harder to model mathematically than linear ones: the equations are hard to solve and the few solutions obtained are usually of no practical importance.

Second, detonation problems operate on two widely different dimensional scales: the region in which critical chemical reactions take place in the

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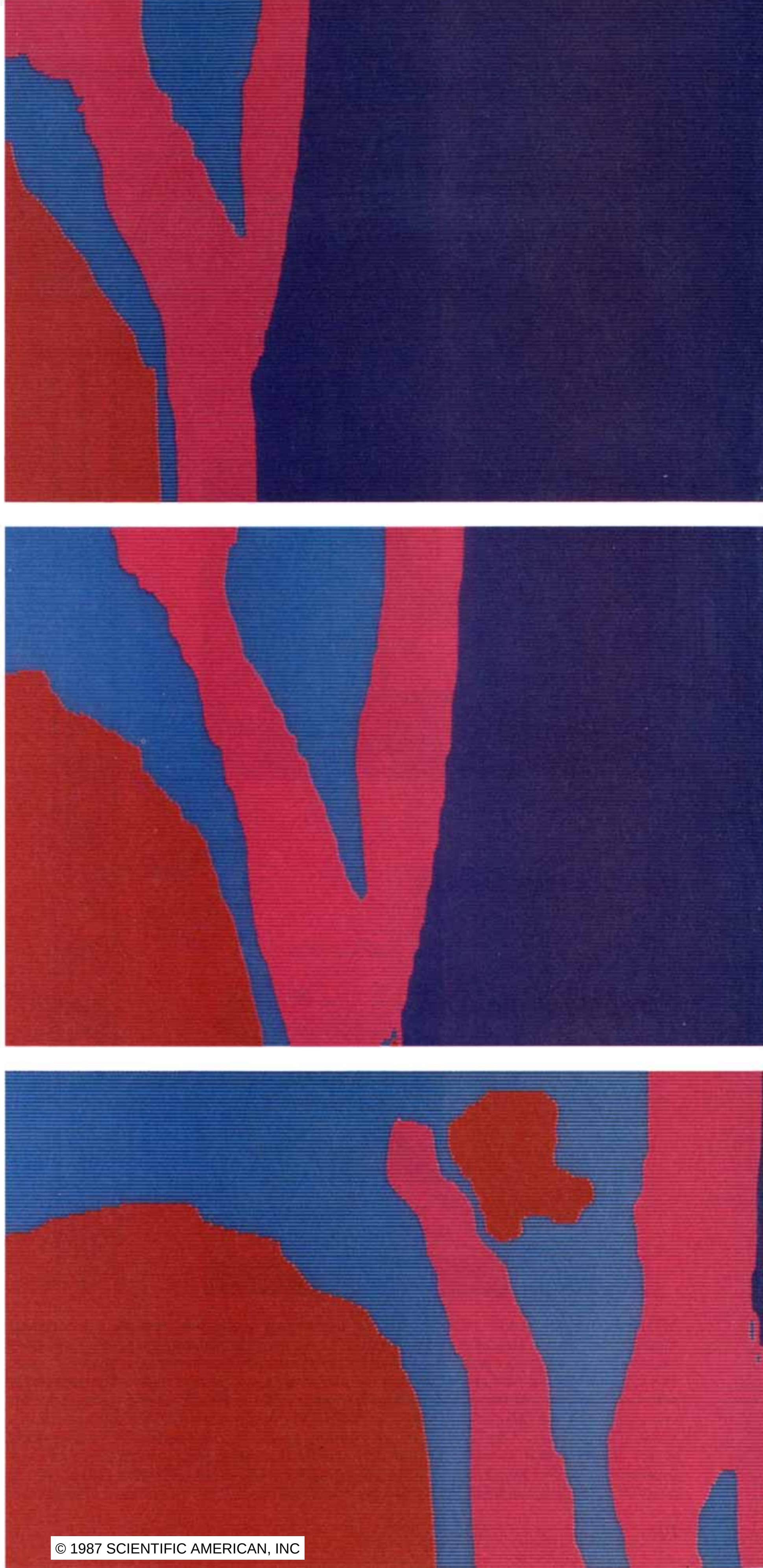
explosive, called the reaction zone, is usually between 100 and 1,000 times smaller than the region in which the explosion products deposit their energy. Yet the way explosion products transfer their energy to inert surrounding material affects the way the explosive chemical reactions proceed, and the study of the two processes cannot be easily uncoupled.

Third, there is a dearth of information about the chemical and physical properties of materials subjected to the extremely high temperatures and pressures that prevail in an explosion. The relation between pressure, volume and temperature for a given chemical mixture (known as the mixture's equation of state) and how the mixture reacts to form new chemical mixtures under such conditions are virtually unknown. Without that knowledge one is reduced to constructing theories devoid of a description of the actual material properties; the theory's inherent defects must then be corrected by adjusting artificial parameters according to experimental results.

Yet experiments are costly and are tricky to carry out. The explosive components are unavoidably destroyed and must be painstakingly built for each measurement. Needless to say, most such experiments cannot be done indoors; they require a large area of isolated land into which people are not likely to stray. To make matters even more complicated, the conditions that need to be measured in a detonating explosive approach the limits of the measurable. Peak pressures in explosives can reach values 500,000 times ambient air pressure and the detonation propagates through the explosive at velocities of up to 10 kilometers per second (30 times faster than the speed of sound in air). The chemical reactions involved in detonation are timed in nanoseconds (billionths of a second) and take place in a layer between .01 and one millimeter thick. Instruments that have the necessary time and spatial resolution have only recently become available, and their proper oper-



DETONATION WAVE moving from left to right through an explosive gas in a tube is depicted by colored zones in this set of computer-generated pictures. Navy blue represents low-temperature, unreacted gas; turquoise and red represent high-temperature, completely reacted gas. An intermediate-temperature, partially reacted state is depicted in pink. The detonation wavefront—actually a shock wave—has a transversely propagating component that causes a pocket of incompletely reacted gas to form behind it. The pictures were generated at the Laboratory for Computational Physics of the Naval Research Laboratory.

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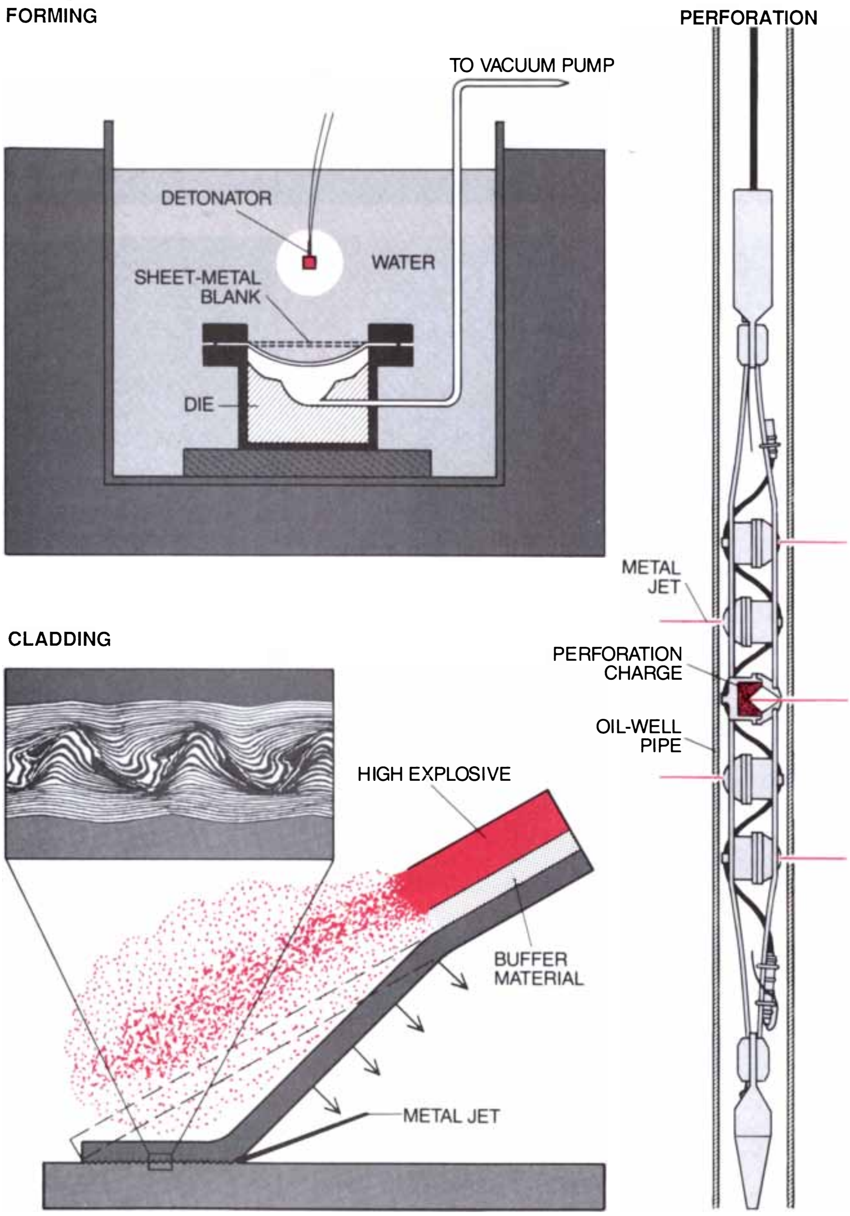
ation in the midst of an explosion is, to say the least, difficult to achieve.

It is therefore not surprising that the first significant steps toward a theory of detonation were taken in the last quarter of the 19th century with the study not of explosions but of a closely related phenomenon: shock waves. In formulating the basis for a theory of shock-wave propagation 19th-century investigators considered a simple construct: a long cylinder filled with a fluid and fitted with a piston at one end [*see top illustration in box on page 110*]. If the piston is instantaneously accelerated into the fluid, the fluid immediately in front of the piston will move at the same velocity as the piston. Hence at the start of the piston's motion the plane that separates the moving fluid from the stationary fluid will be close to the piston. Because the thickness of the layer of moving fluid rapidly increases as the piston travels down the cylinder, however, the plane does not remain near the piston but quickly outdistances it. Indeed, the plane travels faster down the cylinder than the piston (whose velocity is equal to the velocity of the moving fluid), since for every unit of distance the piston travels, the plane has traversed that distance and the increment of thickness added to the layer of moving fluid by the piston's motion.



MODERN APPLICATIONS of high, or detonating, explosives include the forming, cladding and perforation of metals. In explosive forming the powerful pressure pulse generated by an underwater detonation forces a metal sheet to conform to the shape of a die. In explosive cladding a metal plate that is lined with high explosive and buffer material is set at an angle to a thicker metal plate. Detonating the explosive at the juncture of the two plates lays the thinner plate down on the thicker plate with such force that the plates are welded together. A by-product of the cladding process is the creation of a high-velocity jet of metal that shoots out from between the colliding plates. Such a jet can cut through the hardest materials. It is the operating principle of a perforation charge, which generates a pipe-puncturing jet by forcing a conical metal liner to collapse explosively.

Such a moving plane, which separates stationary material from material that is in motion, constitutes a shock wave. When the fluid velocity is very low, the shock wave is weak and its velocity approaches that of a sound wave in the stationary fluid. For higher fluid velocities, however, the shock wave travels faster than the speed of sound in the stationary fluid.

Clearly, as the piston advances, the fluid occupying the volume between it and the shock wave (the so-called shocked fluid) becomes compressed and its pressure increases. By applying the fluid's equation of state (which describes the way its pressure, temperature, volume and composition affect one another) and the fundamental physical principles of conservation of mass, energy and momentum across the shock wave, it can be shown that the pressure in the shocked fluid is uniquely determined by the material constituting the fluid as well as by the material's velocity. On the other hand, the shocked fluid's pressure and material velocity are uniquely determined by the shock-wave velocity. Hence the velocity of the shock wave fixes the state of the shocked fluid.

Investigators who studied explosive gases noted that a detonation propagates as a wave through gas much as a shock wave does, and in 1899 the English chemist David L. Chapman proposed that a detonation wave sweeping through an explosive gas could actually be considered a self-sustaining shock wave. Chapman maintained that a shock wave traveling through a high explosive precipitates in its wake chemical reactions that supply enough energy to drive the shock wave forward through the explosive.

If this was the case, the equations that describe shock waves could also be used to describe detonation waves—as long as they reflect the state of the exploded rather than the unexploded gas. Some further analysis, however, revealed an important difference between shock and detonation waves: while weak, low-velocity shock waves are possible if the illustrative piston is moved quite slowly, detonation waves are always strong and always propagate at a high velocity. The slowest

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detonation wave is still a very strong wave. For it the shock-wave equations yield a single solution for the pressure and material velocity of the detonated gas, but for faster detonation waves there are two possible solutions.

Chapman resolved the indeterminacy by relying more on aesthetics than on rigorous analysis: since a detonation wave was observed to travel at a single characteristic velocity depending only on the explosive through which it propagated, he reasoned that the conditions for detonation likewise had to be defined by a singular state. He therefore postulated that the pressure and material velocity for the detonation state of an explosive gas were defined by the unique minimum detonation-wave velocity. Chapman calculated detonation velocities according to this proposition and compared them with measured velocities; they showed remarkable agreement.

At about the same time in France the physicist J.-C. Émile Jouguet, who had been working along similar lines, showed that the minimum detonation-wave velocity corresponds to the velocity of a sound wave in the hot, compressed, moving detonation products found in the shocked explosive. This meant there was a physical explanation for the fact that a stable detonation wave propagates under the condition described by the minimum detonation velocity, as Chapman had conjectured: if a detonation wave were made to travel at a velocity greater than the minimum detonation velocity by a sufficiently strong initiating shock wave, a rarefaction would eventually travel through the detonated explosive and catch up with the overdriven wave to slow it down.

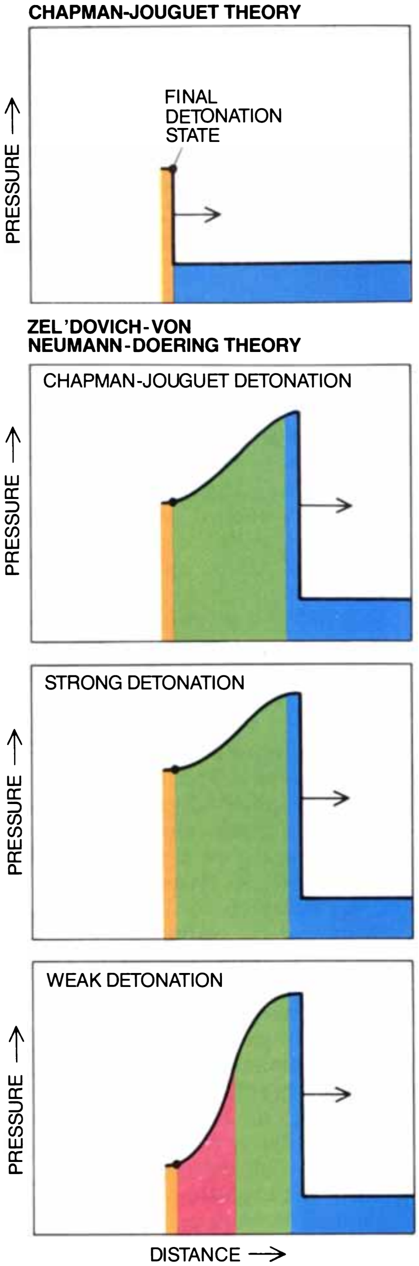
The process can be understood by referring back to the cylinder example. When the piston driving the shock wave in the cylinder is stopped, the velocity of the material just in front of the piston quickly slows to zero and the pressure correspondingly drops to a low value to form a rarefaction. The rarefaction propagates forward as a sound wave. From its lagging position the rarefaction weakens the shock wave, enabling it to draw closer. The closer to the shock wave the rarefaction approaches, the more the shock wave is slowed down, until it too is traveling at the speed of sound in the shocked material.

Jouguet's arguments about how a shock wave might speed up to attain the minimum detonation velocity, called the Chapman-Jouguet velocity, were more complicated and not as convincing. Nevertheless, investigators could not dispute the experimental data, which seemed to confirm the theory's accuracy of prediction. Indeed, the theory outlined by Chapman and Jouguet is still the framework on which the most widely accepted theories of detonation are constructed.

The Chapman-Jouguet theory was unsatisfactory in that it lacked a detailed explanation for what takes place physically in a detonation wave. Nevertheless, the fact that it adequately predicted the final state of a gas right after it has been detonated satisfied practical-minded engineers. Knowledge of the final state of a detonation reaction was of great importance to them, because this state is the initial one from which to calculate the expansion of the explosion products (primarily nitrogen, water vapor, carbon monoxide, carbon dioxide and solid carbon in the form of soot). The expansion of the explosion products, like the expansion of steam or hot combustion gases in an engine cylinder, is the means by which energy is transferred to the surrounding medium (whether it is the casing of a hand grenade or the rock in a quarry face) to do what is technically known as work.

Strictly speaking, calculations based on the Chapman-Jouguet theory were valid only for the detonation of explosive gases, because only for them were equations of state known. Nevertheless, explosion engineers assumed that the theory would be applicable to liquid and solid explosives, if a reasonable approximation to an equation of state could be found for a high-density mixture of solid and gaseous materials. Such an equation can theoretically be derived from fundamental principles by considering the forces between molecules, the shapes of the molecules as they are subjected to high pressure, and the way different molecules mix in the product gases. The investigators of the first half of the 20th century, however, could derive these equations of state only empirically, that is, by directly measuring how the various properties of a material are affected if one of the properties is varied. Empirically derived equations of state, while they were not scientifically enlightening, nonetheless enabled engineers to calculate the state of a shocked explosive with a degree of accuracy sufficient for most engineering purposes at that time.

The first significant attempt to explain the underlying physics of how chemical reactions are initiated by the shock wave and how they transfer energy to the overall flow of the explosion products came from the theoretical work of Yakov B. Zel'dovich in the Soviet Union, John von Neumann



VISUALIZATION of a detonation wave varies according to theory. The Chapman-Jouguet theory treats a detonation wave as a discontinuity between two distinct pressure and chemical states: the low-pressure, undetonated explosive and the high-pressure, detonated explosive. The Zel'dovich–von Neumann–Doering theory separates the discontinuous pressure increase from the energy-releasing chemical reactions (*green*), which proceed in a zone of appreciable thickness. Moreover, the transition from unreacted to completely reacted explosive is accompanied by a fall in pressure. Although the final detonation state can be identical with that predicted in a Chapman-Jouguet detonation, other states are also possible. In a strong detonation, greater initial and final pressure states are exhibited. In a weak detonation an energy-absorbing reaction (*red*) coupled with the energy-releasing reactions allows a final state with a lower pressure to be reached.

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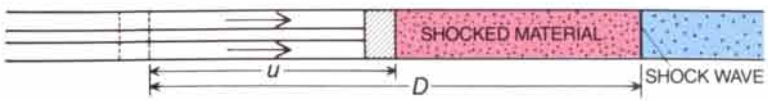
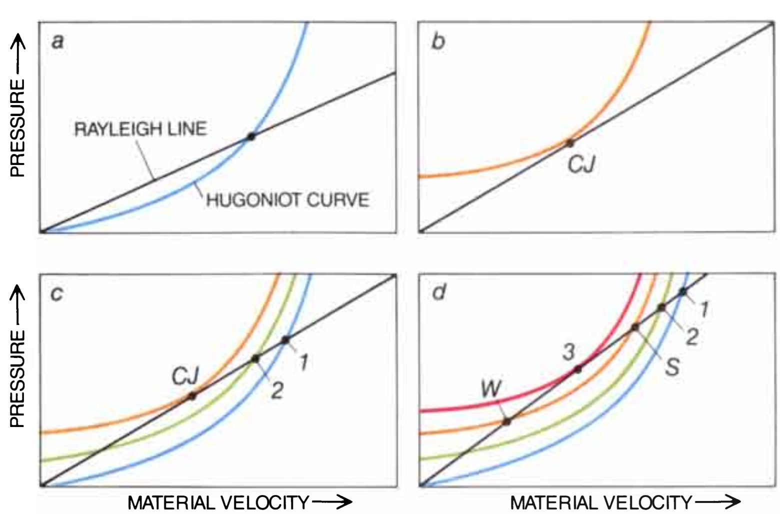
Hugoniot Curves and Rayleigh Lines

Their points of intersection graphically represent the state of a detonating explosive



SHOCK WAVE can be visualized as a plane separating moving (*red*) from stationary (*blue*) fluid in a cylinder with a moving piston. Its velocity is greater than the piston's velocity (which is equal to the velocity of the moving fluid): the piston has traveled a distance *u* while the shock wave has traveled a greater distance *D*.

A plot of all possible pressure values in shocked material (material behind a shock wave) for all possible values of the material's velocity is called a Hugoniot curve (*a*). All the possible states (pressure and material velocity) of a shocked material for a given shock-wave velocity can also be depicted in the Hugoniot-curve coordinate system as a straight line, called a Rayleigh line, whose slope is proportional to the shock-wave velocity. The final state of a material subjected to a shock wave of a given velocity can then be graphically determined by the point where its Hugoniot curve (*blue*) intersects the Rayleigh line. If the material undergoes detonation (*b*), its Hugoniot curve (*orange*) must be shifted upward, since the pressures of all possible states have been increased. According to the Chapman-Jouguet theory, the point where the Rayleigh line is tangent to the Hugoniot curve for the completely reacted explosive (*CJ*) specifies the state from which the explosion products expand to do work on the surrounding material. *CJ* also fixes the detonation-wave velocity, which is given by the slope of the Rayleigh line. The Zel'dovich–von Neumann–Doering theory (*c*), for which the same graphical analysis can be applied, requires Hugoniot curves for the partially reacted explosive (*green*) as well as for the unreacted and completely reacted explosive. The final state can still be *CJ*, but the explosive is at a higher pressure in its unreacted state (*1*) and partially reacted state (*2*) before reaching the Hugoniot curve for completely reacted explosive. A higher detonation-wave velocity (a steeper Rayleigh line) results in what is called a strong detonation (*d*). In such a case the final state (*S*) has a higher pressure and material velocity than *CJ*. Under certain conditions a temporary state is possible whose Hugoniot curve (*red*) lies above the curve for completely reacted explosive. In such a case, called a weak detonation, the explosive can attain a state (*3*) below *S*, which allows it to reach a final state (*W*) that has a lower pressure and material velocity than *CJ*.



in the U.S. and Werner S. Doering in Germany. The three investigators arrived at the same conclusions independently and more or less simultaneously in the early 1940's. Their key insight was to take a shocked material's temperature and pressure as givens and to concentrate on how chemical reactions in the shocked material proceeded. In other words, a shock wave in an explosive material is treated simply as a discontinuity in the material's properties: the material behind the infinitesimally thin shock wave is at high pressure and temperature, whereas the material in front of it is not. The explosive's chemical reactions, in contrast, are treated as taking place behind the shock wave in a short but finite time and in a steady reaction zone of small but appreciable thickness.

This notion compelled the three investigators to reconsider the Chapman-Jouguet theory, which takes only an explosive's final, detonated state into account. They maintained that directly behind the shock wave the explosive is in a state where no chemical reaction has yet taken place; farther back, at the end of the reaction zone, a state is reached in which all energy-releasing chemical reactions have been completed. Between the shock wave and the far end of the reaction zone must lie other states for partially reacted explosive. Hence there is actually a sequence of chemical states in the reaction zone, and each state has its unique pressure and material velocity.

The Zel'dovich–von Neumann–Doering (ZND) model for detonation finally enabled scientists to give a fair description of how a detonation proceeds: a shock wave propagating into undisturbed explosive material instantaneously compresses and heats it enough to initiate chemical reactions that, over the course of several nanoseconds, release energy. The energy in turn preserves the conditions of high pressure and temperature necessary to drive the shock wave forward. When the reactions have run to completion at the end of the reaction zone, the gases expand to do work. The reactions are only slightly perturbed by the expansion that occurs behind the zone.

The velocity of the detonation wave must at least be equal to the Chapman-Jouguet velocity. If it is equal, the final state of the explosive (and the initial state from which the explosive products expand to do work) is identical with the final state specified by the Chapman-Jouguet theory. If the velocity is greater, two possible final states could result, one with higher pressure and material velocity than is stipulated by the Chapman-Jouguet theory and one with lower pressure

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and material velocity. (These two theoretically allowable detonation states are essentially the ones Chapman had avoided dealing with by arbitrarily limiting himself to uniquely defined detonation states.) Although its equations allowed two final states, the ZND theory rejected the physical existence of the state with the lower pressure and material velocity because there appeared to be no reaction pathway to it; all reactions had run to completion by the time the state with higher pressure and material velocity had been reached. A detonation that produces a final state with a higher pressure and material velocity than the state expected from the Chapman-Jouguet theory is said to be a strong detonation.

In the event of a strong detonation, however, Jouguet's argument of a half century earlier (that a rarefaction can catch up with an overdriven detonation wave to slow it down) still applies. The detonation wave therefore eventually slows down, reaching the minimum possible detonation-wave velocity for the completely reacted explosive, that is, the Chapman-Jouguet velocity. The ZND theory seemed to confirm that the Chapman-Jouguet state was in fact the appropriate state from which to start the expansion of the explosive products in calculating the energy transferred to the surrounding material.

The ZND theory was initially received with disbelief and incredulity by detonation scientists. It seemed to go against common sense. The theory held that pressure should fall while the reaction proceeds as a result of the fact that the propagating detonation was treated as a steady-flow problem, for which the equations balancing momentum and energy across the detonation wavefront required such an effect. Most investigators were convinced that the pressure ought to rise. Since the predicted drop in pressure was an extremely rapid effect (lasting on the order of a nanosecond), detonation scientists, who at that time were able to measure detonation phenomena only in terms of microseconds (millionths of a second), had to judge the theory on the strength of its underlying arguments. After much initial debate the ZND model of a detonation became widely accepted, and about a decade later experiments finally confirmed the fleeting pressure drop predicted by the ZND theory.

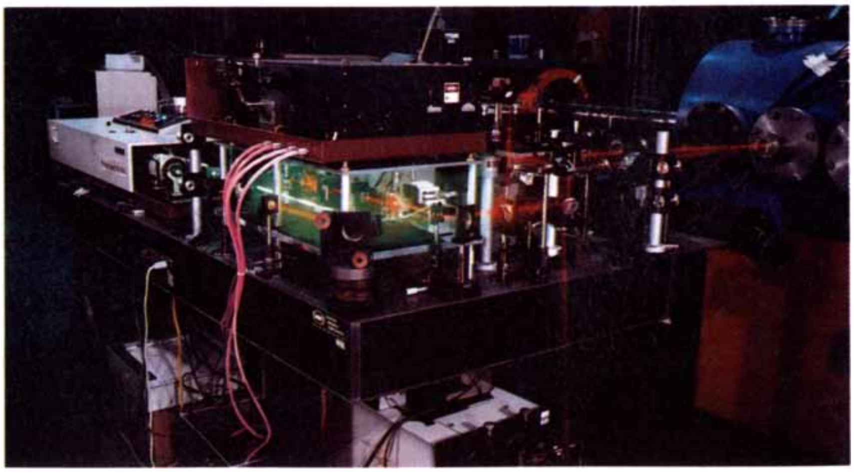
Even as he was first laying out the principles of his theory, however, von Neumann pointed out a major "loophole," through which could be reached the disallowed state of a detonation with a greater-than-minimum velocity. Although it took most physicists about 20 years to figure out what von Neumann meant, the point is actually easy to understand if one considers a small refinement in the details of the energy, or heat, released by the explosive.

According to the ZND theory, account had to be taken of the states of the partially reacted explosive. Consider what could happen if an explosive reaction proceeds in two steps, the second of which absorbs part of the heat released by the first. In other words, the first step is exothermic and the second is endothermic. If the first step is much faster than the second, the heat released by an explosion would increase as it does in a one-step reaction, but it would eventually reach a maximum and then drop to a lower, final level. During the time of maximum heat release, momentary states could be attained that provide a pathway for the explosive reaction to proceed to a state with a lower pressure and material velocity than the state specified by the Chapman-Jouguet theory, which considers only the final heat-output level of such a reaction and ignores the way heat output may have varied in getting there [*see box on preceding page*].

Studies done by William W. Wood, Zevi W. Salsburg, Jerome J. Erpenbeck and others at the Los Alamos Scientific Laboratory in the early 1960's showed that this type of detonation reaction, variously called a weak, eigenvalue or pathological detonation, can also be achieved by coupling energy-absorbing processes other than endothermic chemical reactions to a primary, exothermic reaction. For example, real detonations (as opposed to the idealized types I have been discussing so far) do not experience smooth, regular combustion in the reaction zone. Instead the reaction zone is heavily crisscrossed by pressure waves propagating at a right angle to the direction in which the detonation wave is traveling. Such crisscrossing waves set up turbulent flows that drain energy from the explosive chemical reactions. The net result is much like the chemical system of exothermic reaction followed by endothermic reaction: chemical reactions release heat, which is then dissipated in turbulent flow. It is probably because of turbulence that the final state of detonated gases has been shown to be different from a Chapman-Jouguet state and closer to the one predicted by assuming that a weak detonation occurs.

There is yet another way to produce a weak detonation, and this one probably manifests itself more often in everyday detonations (as opposed to experimental detonations, which are often initiated as plane waves). An unconstrained detonation wave expanding from its point of initiation attains a curved shape, much like the ripples that arise when a pebble is dropped into a pond. This type of expanding detonation wave can in fact be considered to have a heat-absorbing mechanism, because the diverging flow of material diverts energy in directions different from the direction of motion. In practical applications almost all detonations are initiated at a point (or in some small region) and expand, so that in fact almost all real detonations are weak ones and not Chapman-Jouguet detonations.

Although it is clear that there is in reality an intimate relation between the chemistry and the fluid mechanics of detonations, both the Chapman-Jouguet and the ZND models treat the



LASER-SPECTROSCOPY experiment at the Los Alamos National Laboratory provides data on the composition and vibrational states of material at extreme pressures and temperatures. Such data are required to understand the behavior of detonating explosives.

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two processes as distinct and independent in order to make the analysis of a detonation more tractable. It had been thought that even if turbulence or other similar small-scale perturbations arose from the mechanical flow of material in the reaction zone, the effects of such perturbations on the chemical reactions would be small enough not to warrant any qualitative change in the detonation models.

Most workers now believe that the effects are not negligible and that detonation theory must be extended to take into account the effects of turbulence and of curved detonation waves, both of which are influenced by the type of inert material that surrounds the explosive. In addition, experiments have revealed that the reaction rate of an explosive (and therefore the thickness of the reaction zone) can be varied by mixing inert or catalyzing particles in the explosive material. Hence the chemical purity and homogeneity of an explosive can significantly affect its detonation behavior.

Other small-scale effects also have to be treated as significant contributors to the dynamics of detonation. Small pockets of unreacted explosive can become trapped behind the detonation front as transverse pressure waves interact with the shock wave. Tiny fluctuations in density or temperature in an explosive can produce regions of higher temperature called hot spots, which disturb the propagation of the shock wave by detonating before the surrounding explosive does. These localized perturbations are difficult to model, because they operate on a dimensional scale that is even smaller than the scale of the reaction zone. To make matters even more complicated, recent equation-of-state calculations have suggested that the dense explosion-product gases may not mix in the expected way; the gases may separate into two distinct fluids during detonation. If this turns out to be correct, yet another dimensional scale would have to be considered.

Fluid mechanics is just now advancing to a stage where real progress in computing these important details can be made. In this context the development of more powerful computers and new methods for averaging the effects of intricate microscopic events will contribute greatly to the understanding and prediction of complex fluid flows arising from the interactions of shock waves and the explosive material at the detonation front. Similarly, theoreticians who apply the equations of statistical mechanics and chemical kinetics to derive respectively equations of state and chemical-reaction rates must rely on experimentalists to provide raw data and to verify predictions. In this connection laser spectroscopy, which makes it possible to probe chemical phenomena on time scales of less than 100 trillionths of a second, will be a major help to both the experimentalists and the theoreticians.

FIREBALL of a nighttime explosion of a 50-pound mixture of ammonium nitrate and fuel oil results from the afterburning of the explosion products; paraffin and sulfur have been added to the mixture to enhance the effect. The streaks at the base of the fireball are tracks made by turbulent burning during the expansion of the explosion-product gases.

Scientists who study explosions are spurred on by being constantly reminded that current detonation theory is incomplete. An important example of the need to refine the theory is a mode of explosion called low-velocity detonation, which workers first noted many years ago. If an explosion is initiated with a strong detonator, the detonation wave proceeds through the explosive charge at high velocity, typically between 6,000 and 8,000 meters per second in an ordinary dynamite. This high-velocity mode seems to be the one that current theory seeks to describe (at least in an idealized way) as either a Chapman-Jouguet detonation or, more probably, a weak detonation. In contrast, if the detonator is weak, the wave proceeds at low velocity, between 2,000 and 3,000 meters per second, and only part of the explosive reacts quickly. Clearly, factors other than those covered by the ZND theory are at work in such detonations.

Another type of behavior the current theory does not describe is the transition from burning to detonation. If a large pile of explosive at a manufacturing plant is ignited accidentally, it will burn briskly but quietly for a while—just as many nonexplosive materials do. If the pile is big enough, however, the flame front will accelerate into the material and the pressure in the material will increase. As the pressure increases, the explosive material begins to flow, compressing and heating the material at an appreciable distance ahead of the flame. Then the explosive suddenly undergoes high-velocity detonation—without an external initiating shock wave. So far no one has come up with a convincing theory that accounts for this process.

The problems I have cited are just two samples of those facing physicists and chemists who study high explosives. They will be difficult to solve, but their solution could increase the safety and efficiency of explosives so as to keep pace with the ever more demanding specifications of modern explosion engineering.

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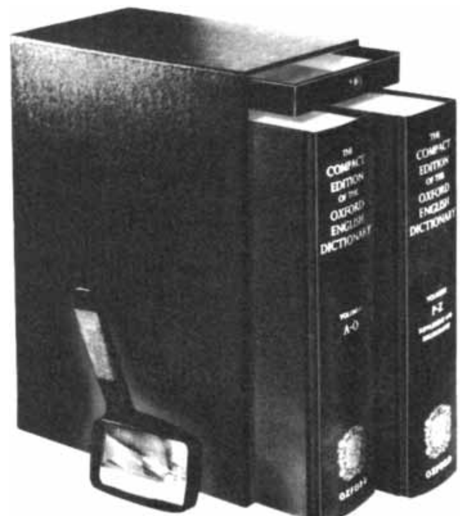

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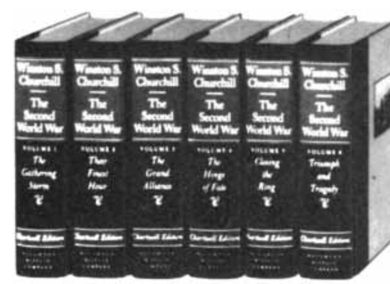

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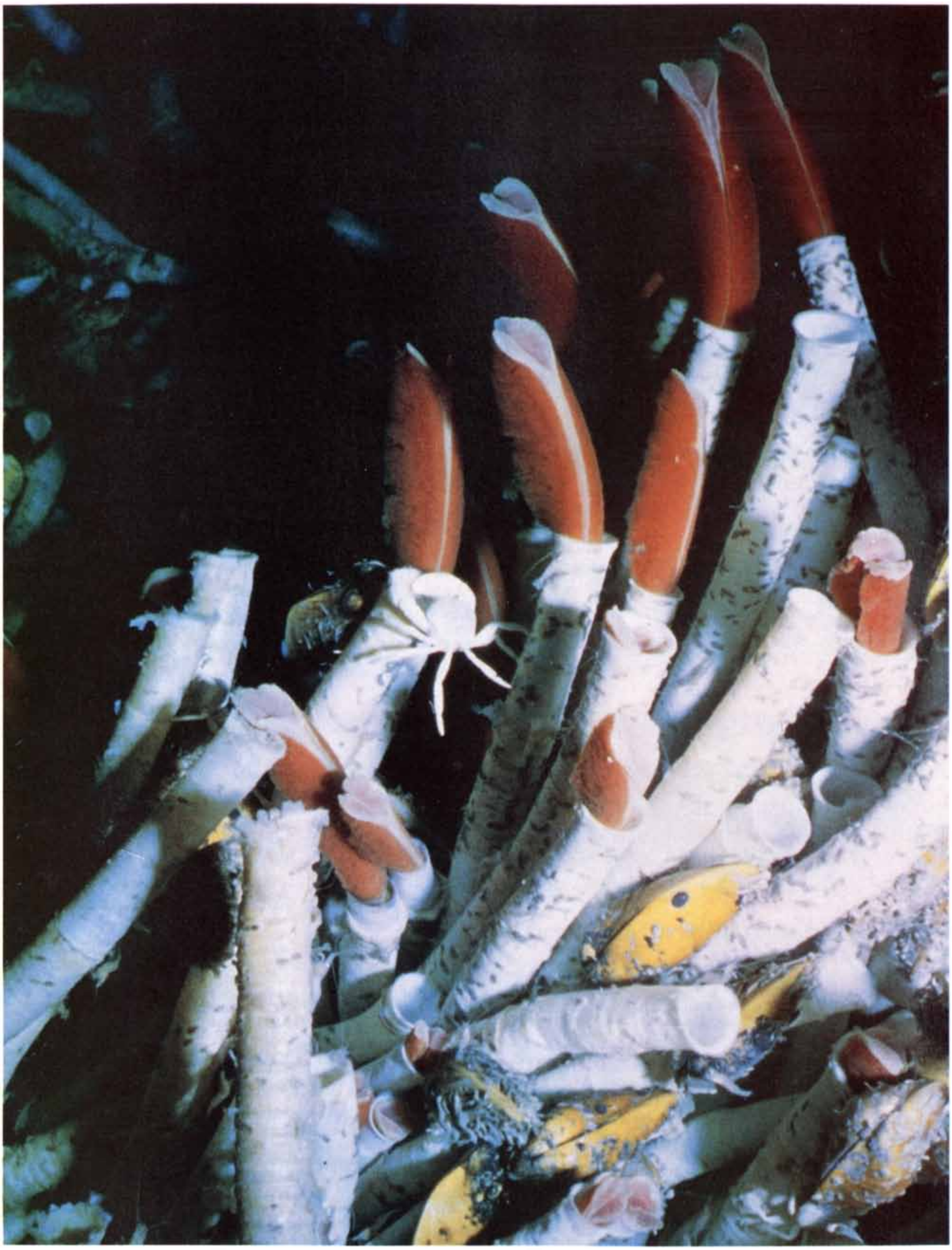

HYDROTHERMAL-VENT COMMUNITIES consist of an array of unusual invertebrate species. Dense clusters of tube worms as much as one meter long are anchored to the basaltic rock along vent openings. Living among them are vent mussels (*yellow*) and vent crabs. (The crab near the center of the photograph may be attempting to feed on a tube worm.) Smaller invertebrates can be seen clinging to the worms and to the shells of the mussels. The photograph was made from the research submarine *Alvin* by R. R. Hessler of the Scripps Institution of Oceanography on an expedition to the Galápagos Rift vent site in the East Pacific Ocean.

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Symbiosis in the Deep Sea

The remarkable density of life at deep-sea hydrothermal vents is explained by the mutually beneficial symbiosis of invertebrate animals and sulfide-oxidizing bacteria that colonize their cells

by James J. Childress, Horst Felbeck and George N. Somero

Biologists categorize many of the world's environments as deserts: regions where the limited availability of some key factor, such as water, sunlight or an essential nutrient, places sharp constraints on the existence of living things. Until recently the deep sea was considered to be such a desert, where the low abundance of organisms stems from the extreme limitation of the food supply.

Yet there is one habitat in the deep sea where the density of life equals, if it does not surpass, what is found in any other marine ecosystem. It is the system of hydrothermal vents, or deep-sea hot springs, situated at seafloor spreading centers. The vents, discovered only 10 years ago, are found along ridges at the bottom of the ocean where the earth's crustal plates are spreading apart.

It was at a spreading ridge in the Pacific Ocean, 320 kilometers northeast of the Galápagos Islands, that geologists on the research submarine *Alvin* in 1977 discovered an oasis of densely packed animal life 2,600 meters below the surface. Here were species previously unknown to science, living in total darkness in densities enormously higher than had ever been thought possible in the deep sea. Giant tube worms as much as one meter long, large white clams 30 centimeters in length and clusters of mussels formed thick aggregations around the hydrothermal vents. There were smaller but nonetheless significant numbers of shrimps, crabs and fishes.

Such biological density was completely unexpected, and also very puzzling. Any ecosystem depends on the presence of primary producers: autotrophic (self-supporting) organisms that synthesize their own reduced carbon compounds, such as carbohydrates, from carbon dioxide. Green plants that convert carbon dioxide into carbohydrates in the presence of sunlight are called photoautotrophs, and they are the primary producers in most marine and terrestrial ecosystems.

Yet clearly photosynthesis is impossible at the depth of the vents. Not enough light penetrates beyond the upper 200 or 300 meters of the ocean's surface to support photosynthesis. Below the sunlit surface the density of life falls off rapidly because there is less food. The organisms that live in the deep sea depend on organic matter that drifts down from the sunlit "euphotic" zone to the ocean floor. Most organic matter is synthesized, consumed and recycled in the euphotic zone, and only a small fraction sinks to the deep sea. Yet at the vents life was blooming 2,600 meters below the surface of the ocean. What unique feature of the hydrothermal-vent system could explain the abundance of life at these depths?

It seemed possible that the density of life at these deep-sea hot springs might be explained on the basis of temperature. In contrast to most of the deep sea, which is very cold (from two to four degrees Celsius), the vent waters have average temperatures ranging from 10 to 20 degrees. Observations made over the past six years have shown, however, that the warm temperatures do not account for the unique fauna of the vent ecosystem.

Instead there is a better explanation for these teeming oases of life at the bottom of the ocean. Water samples taken from the vent sites and analyzed by John M. Edmond of the Massachusetts Institute of Technology and his colleagues indicated that these underwater hot springs, like many hot springs on land, are rich in hydrogen sulfide. This energy-rich but highly toxic compound is found at high levels in the water that flows from cracks in the ocean floor [see "Hot Springs on the Ocean Floor," by John M. Edmond and Karen Von Damm; SCIENTIFIC AMERICAN, April, 1983].

For years biologists had known that sulfide-rich habitats, such as terrestrial hot springs, support large numbers of free-living bacteria. Like green plants, they are autotrophs, but they get energy for carbon fixation—the conversion of carbon dioxide into organic molecules that serve as nutrients—not from the sun but from the oxidation of hydrogen sulfide.

Holger W. Jannasch of the Woods Hole Oceanographic Institution and David Karl of the University of Hawaii at Manoa isolated bacteria from the vent waters and did a series of experiments demonstrating that some species of vent bacteria are indeed autotrophic and depend on hydrogen sulfide and other reduced forms of sulfur for their metabolic activities. These sulfide-oxidizing bacteria might form the base of the vent food chain by providing food for the animal species.

Although they are very distantly related, green plants and sulfur bacteria are functionally similar in an important way: both are primary producers. Whereas green plants are photoautotrophs, sulfur-oxidizing bacteria capable of using an inorganic energy source to drive carbon dioxide fixation are called chemolithoautotrophs: they are literally consumers of inorganic chemicals that can exist autonomously—without an external source of reduced carbon compounds. Both fix carbon dioxide through a series of biochemical reactions collectively known as the Calvin cycle. The Calvin cycle functions in much the same way for bacteria as it does for green plants; the end product for both is reduced carbon [*see illustration on page 117*].

It appeared, then, that the sulfur bacteria were in effect serving as the "green plants" of the vents and that their "sunlight" was hydrogen sulfide and other reduced carbon compounds. A major complication of this simple model was soon recognized: one of the

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dominant vent animals, the tube worm *Riftia pachyptila,* seemed to lack any means of harvesting the abundant crop of sulfur bacteria proliferating in the waters all around it.

Riftia is a strikingly unusual creature by conventional anatomical standards. It is essentially a closed sac, without a mouth or a digestive system and with no other means of ingesting particulate food. At its anterior tip there is a bright red branchial (gill-like) plume where oxygen, carbon dioxide and hydrogen sulfide are exchanged with the ambient seawater. Below the plume there is a ring of muscle, the vestimentum, that anchors the worm in its white tube. Most of the rest of the animal consists of a thin-walled sac that contains the worm's internal organs. The largest of them is the trophosome, which occupies most of the body cavity. As its name ("the feeding body") suggests, the trophosome contributes significantly to the worm's nutrition—but it lacks a channel through which particulate materials from the outside world can enter the worm. The big question was how, in view of its unusual anatomy, *Riftia* manages to obtain the nutrients it needs for survival.

Microscopic studies done by Colleen M. Cavanaugh of Harvard University and her colleagues and parallel biochemical studies done by us provided the first clues. Examination of the trophosome of *Riftia* revealed that it is colonized by vast numbers of sulfur-oxidizing bacteria. We recognized that the bacteria and *Riftia* had established what is known as an endosymbiotic relation.

Symbiosis is the co-occurrence of two distinct species in which the life of

LARGE VENT CLAMS, ***Calyptogena magnifica,*** **cluster along cracks in the sea floor where sulfide-rich water is vented at a site on the East Pacific Rise. The clams' feet penetrate the cracks, where the sulfide concentration is highest. Cobweblike growths on the rocks are colonies of free-living sulfur-oxidizing bacteria. The painting is based on a photograph made by Kenneth L. Smith, Jr.**

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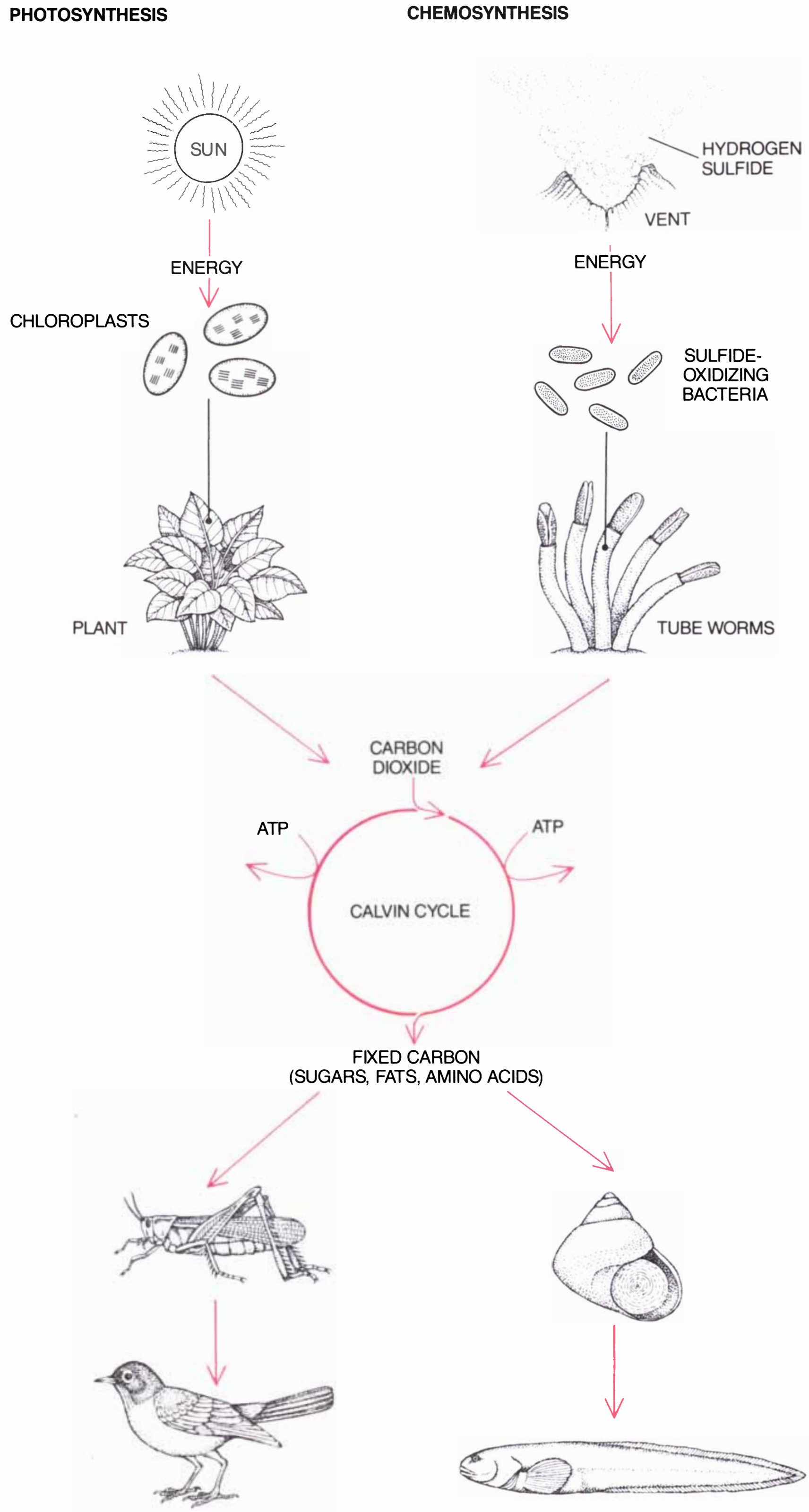
one species is closely interwoven with the life of the other. Symbioses vary from relations that are beneficial to one partner and harmful to the other (parasitism) to relations from which both the partners benefit (mutualism). When one species, known as the symbiont, lives within the body of the other, known as the host, the relation is called endosymbiotic.

The *Riftia*-bacteria endosymbiosis is mutualistic. The tube worm receives reduced carbon molecules from the bacteria and in return provides the bacteria with the raw materials needed to fuel its chemolithoautotrophic metabolism: carbon dioxide, oxygen and hydrogen sulfide. These essential chemicals are absorbed at the plume and transported to the bacteria in the trophosome by the host's circulatory system. The worm's trophosome can be thought of as an internal factory, where the bacteria are line workers producing reduced carbon compounds and passing them to the animal host to serve as its food.

The ability of *Riftia* to absorb sulfide from vent water and transport it to the bacteria in its trophosome without either poisoning itself or degrading the sulfide presented a major puzzle. Hydrogen sulfide is a highly toxic compound, comparable to cyanide in its ability to block respiration, the process whereby the animal uses oxygen. In most animals sulfide inhibits respiration in two ways: by blocking oxygen's binding sites on its major carrier, the hemoglobin molecule, and by poisoning an important respiratory enzyme, cytochrome *c* oxidase. Studies of *Riftia* showed, however, that sulfide has no effect on oxygen binding and that the worm's respiration rate is substantial even in the presence of sulfide concentrations lethal to most animals.

We wanted to know how aerobic respiration in *Riftia* is possible in the presence of high sulfide concentrations. Clearly *Riftia* had three obstacles to overcome. First, it needed to evolve a special transport system to extract sulfide from vent water. Second, it needed to transport sulfide in its blood without allowing the sulfide to compete with oxygen for binding sites on the hemoglobin molecule or to react with oxygen. (In the presence of oxygen, sulfide is highly unstable, decomposing rapidly to oxidized forms such as thiosulfate and elemental sulfur.) Third, it needed a mechanism to prevent sulfide from diffusing into its cells and poisoning respiration.

We collaborated with Mark A. Powell (who is now at the University of California at Davis) and Steven C. Hand (now at the University of Colo-



PHOTOSYNTHESIS and chemosynthesis are compared. The energy sources differ, but the conversion process and end products are the same. In photosynthesis light is absorbed by the chloroplasts of plants and drives carbon fixation by the Calvin cycle, a process yielding sugars, fats and amino acids that enter the food chain, passing from herbivores to carnivores. In chemosynthesis energy is provided by hydrogen sulfide issuing from vents in the ocean floor. It is taken up by free-living bacteria and also absorbed by vent animals such as the tube worm, which transport it to endosymbiotic bacteria. In the bacteria it is oxidized, providing energy for the Calvin cycle. The end products enter the food chain, passing directly from lower-order carnivores to higher-order ones.

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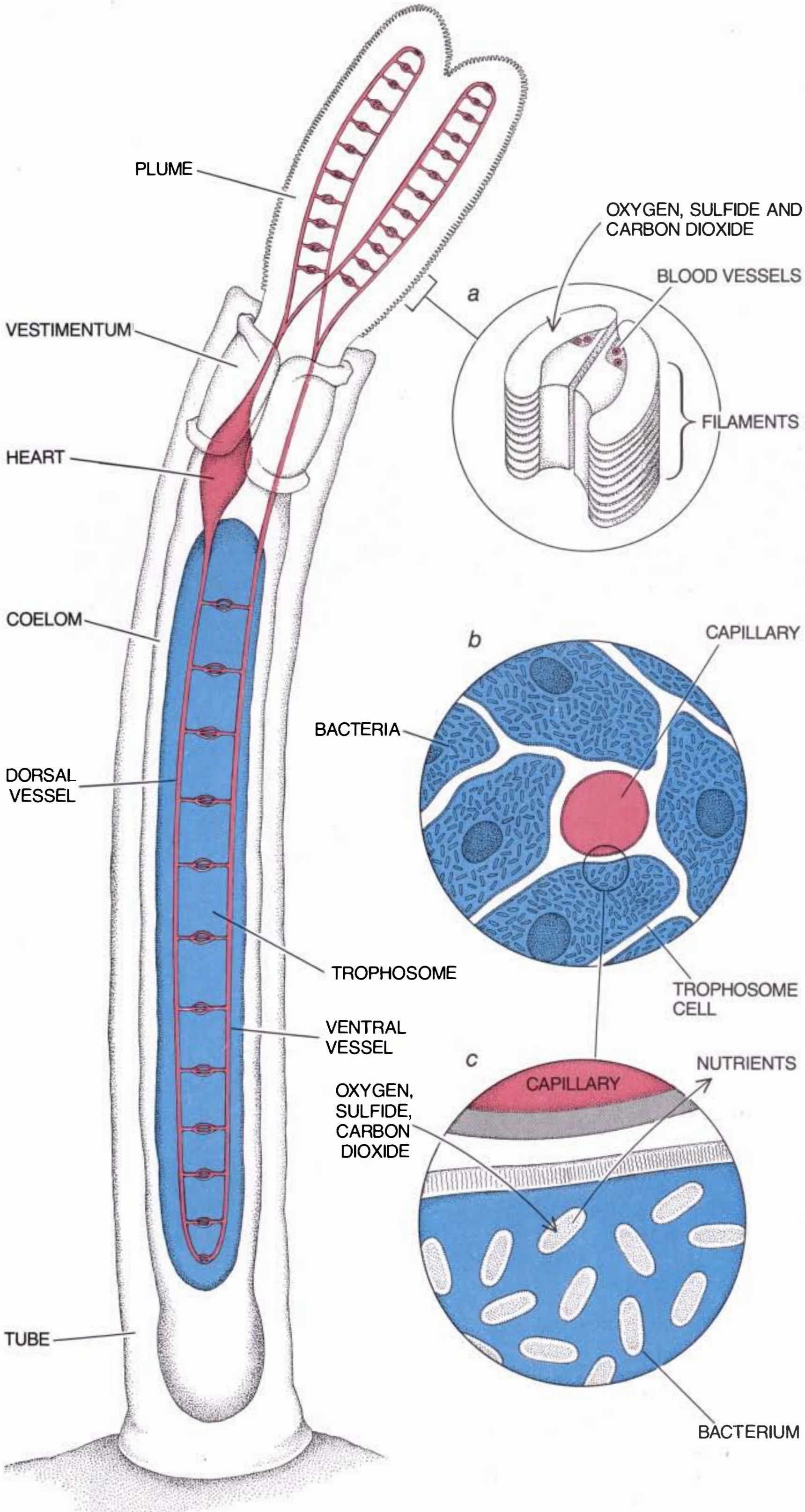

TUBE WORM *Riftia pachyptila* is anchored inside its protective outer tube by a ring of muscle, the vestimentum. At its anterior end is a respiratory plume. Oxygen, sulfide and carbon dioxide absorbed through the plume filaments (*a*) are transported in the blood (*red*) to the cells of the trophosome (*blue*). The trophosome, site of chemosynthesis, represents one-sixth of the mass of the animal and fills up much of the coelom, or body cavity. Dense colonies of endosymbiotic bacteria live within the trophosome cells (*b*). Oxygen, sulfide and carbon dioxide pass from the capillaries of the worm to the bacteria (*c*). Nutrients pass from the bacteria to the capillaries for distribution throughout the animal.

rado at Boulder) to isolate cytochrome *c* oxidase from plume cells and examine its behavior in the presence of sulfide. Cytochrome *c* oxidase is responsible for the final step in the chain of metabolic reactions known as oxidative phosphorylation, the most important process by which adenosine triphosphate (ATP), the major energy currency of the cell, is synthesized in aerobic (oxygen-using) organisms. In most animals minute concentrations of sulfide are enough to inhibit cytochrome *c* oxidase. We first hypothesized that *Riftia* might have evolved a sulfide-insensitive form of the enzyme. Experiments showed this is not the case: highly purified cytochrome *c* oxidase from *Riftia* is just as sensitive to sulfide poisoning as cytochrome *c* oxidase from other animals.

We noted in experiments with the enzyme that its sensitivity to sulfide depended on the extent to which we isolated it from other proteins of the plume. As we went through successive purification steps we observed a substantial decrease in the bright red color of our preparation, and with it an increase in the sensitivity of cytochrome *c* oxidase to sulfide poisoning. The color change suggested that something in the blood was protecting cytochrome *c* oxidase from the toxic effects of sulfide. We proved this by adding a minute amount of whole blood to a poisoned enzyme system. Almost immediately the cytochrome *c* oxidase activity returned to a normal, uninhibited level. The observation showed that a blood component—perhaps hemoglobin—was binding sulfide more strongly than the sulfide-sensitive cytochrome *c* oxidase system was, thereby preventing poisoning of respiration. This discovery and simultaneous studies of the worm's hemoglobin done during a 1982 expedition to the East Pacific Rise vent site indicated that hemoglobin is indeed a key player in the worm's internal transport system.

Riftia has a rich blood supply: the deep red of the branchial plume is due to the presence of a large volume of hemoglobin-rich blood, which accounts for more than 30 percent of the worm's total volume. The total concentration of hemoglobin per liter—approximately half what it is in human blood—is extremely high for an invertebrate. Moreover, *Riftia* hemoglobin is very different from human and other vertebrate hemoglobins. It is large, with a molecular weight of as much as two million daltons (human hemoglobin has a molecular weight of 64,000 daltons). Rather than being contained within red blood cells, it circulates freely in the serum. It also has an unusually high affinity for oxygen as well

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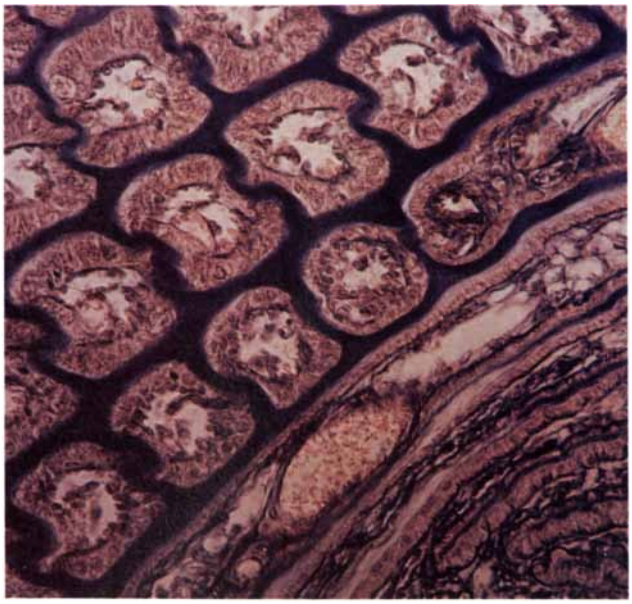

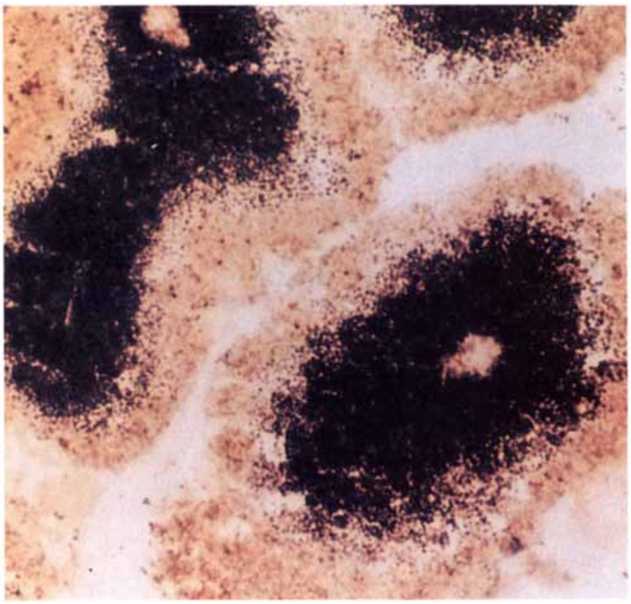

PLUME FILAMENTS (*left*), **where respiratory gases are exchanged in *Riftia*, are seen in cross section, enlarged 380 diameters, in a photomicrograph made by Charles R. Fisher, Jr. Each filament has a central cavity through which blood vessels run. A thin section of trophosome (*right*) was stained with benzyl viologen, which darkens on exposure to hydrogen sulfide. The sulfide is seen to be localized in the bacteria. The trophosome cells are enlarged 135 diameters in the micrograph, made by Mark A. Powell.**

as an unusually high carrying capacity for oxygen. *Riftia* hemoglobin is thus well adapted for extracting oxygen from the vent waters and transporting it to the cells of the tube worm and to its symbiont.

There is an even more important and striking difference between the hemoglobin of *Riftia* and other hemoglobins: the tube-worm molecule can bind both oxygen and hydrogen sulfide simultaneously. This discovery, made by Alissa J. Arp (who is now at San Francisco State University) and us, suggested that the site where sulfide binds to the molecule is different from the site where oxygen binds. Charles R. Fisher, Jr., of the University of California at Santa Barbara showed that the *Riftia* hemoglobin molecule stabilizes mixtures of oxygen and sulfide, preventing the spontaneous oxidation of sulfide. We therefore concluded that hemoglobin plays a dual role in the tube worm: it prevents sulfide from poisoning respiration and it also protects sulfide by allowing it to be transported to the trophosome without being oxidized.

After it is unloaded in the cells of the trophosome, the sulfide is oxidized. The oxidation takes place in the bacterial symbionts, as was demonstrated by a special staining procedure that signals the presence of hydrogen sulfide. Further investigation by our group showed that the sulfide oxidation drives the synthesis of ATP and the fixation of carbon dioxide. Moreover, we showed that the activity of the Calvin cycle is approximately the same in the trophosome bacteria as it is in the leaves of a green plant.

Studies of other vent animals reveal that *Riftia pachyptila* is not the only hydrothermal-vent species that has evolved a symbiotic relation with sulfur bacteria. The large white clam, *Calyptogena magnifica,* and the mussel, *Bathymodiolus thermophilus,* also depend on chemosynthetic endosymbionts for food. But these species have evolved quite different approaches to the same problem.

In *Calyptogena* the bacteria are not in an internal organ but in the gills, where they can readily obtain oxygen and carbon dioxide from the respiratory water flow. The basic metabolic plan is the same, however: the bacteria oxidize sulfide and supply the clam with fixed carbon compounds. Like other invertebrates harboring sulfur bacteria as endosymbionts, *Calyptogena* has a greatly reduced ability to feed on and digest particulate foods.

Still, we were puzzled at first by the data from water and blood samples. The clams must be concentrating sulfide in their blood, because the sulfide level there is orders of magnitude higher than the concentration in the ambient water. Because of the way the clams are oriented in the vent waters, however, the sulfide concentration in the water bathing their gills is low. From what source, then, do these giant clams obtain sulfide to feed their endosymbionts? The path turns out to be indirect. Apparently the clams absorb sulfide through their large, elongated feet, which extend into the hydrothermal vents, where the concentrations of sulfide are highest. Once it is absorbed through the clam's feet, sulfide is transported by the blood to the bacteria in the gills.

Transport of sulfide in the blood of *Calyptogena* is a very different process from the one described for *Riftia*. The clam's hemoglobin (which is incorporated within the animal's red blood cells) is irreversibly poisoned by sulfide, and so it cannot serve as a sulfide-transport protein. *Calyptogena* has overcome the problem of sulfide poisoning by evolving a special sulfide-transporting protein. It is an extremely large protein and it circulates in the serum rather than in the red cells. The protein has a dual function: it protects the animal's hemoglobin and cytochrome *c* oxidase from sulfide poisoning and also protects sulfide against oxidation on the way to the gills. The binding of sulfide to the protein is reversible: it is off-loaded to bacteria in the gill (by mechanisms not yet understood), where it is oxidized to provide energy for the Calvin cycle.

Much less is known about symbiosis in *Bathymodiolus thermophilus.* Like the giant clam, the mussel has bacterial symbionts in its gills, but the pathways of sulfide transport and metabolism are not yet understood. Kenneth L. Smith, Jr., of the Scripps Institution of Oceanography has, however, carried out an interesting series of experi-

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ments demonstrating that the relation between these deep-sea mussels and the vent water is obligatory. When he moved mussels away from the immediate vicinity of a vent to a more peripheral region, they showed clear signs of starvation. Such starvation is a naturally occurring process at hydrothermal-vent sites. Individual vent sites are active for only a few decades at most. Large numbers of dead mussels and clams litter sites where water flow has ceased, indicating that for these animals survival is not possible without a supply of sulfide.

Growth rate serves as another indication that symbiosis is effective in meeting the nutritional requirements of the animal hosts. The rapid turnover of life at these vent sites is reflected in the accelerated growth and the quick attainment of reproductive age that are observed in these animals. Work done by Richard A. Lutz of Rutgers University show that the clams and mussels of the vents grow as fast as the fastest-growing bivalves found in shallow waters.

The tube worm, the clam and the mussel, the largest and most dominant numerically of the vent species, owe their ecological success to their symbiosis with sulfur-metabolizing bacteria. Many of the smaller and less conspicuous vent animals lack symbionts. They obtain their nutrients either by filtering particulate food, such as bacteria, from the water or by feeding on the animals that do contain symbionts. We have observed vent crabs, for example, in the act of feeding on the respiratory plume of *Riftia*.

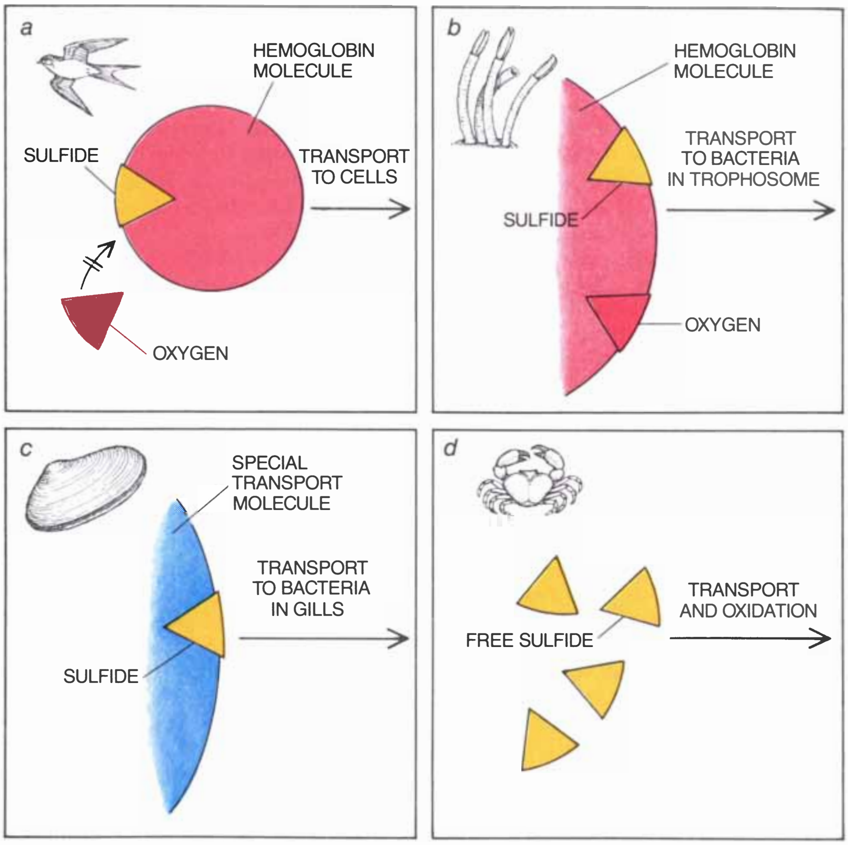
The symbiont-free animals are interesting objects to study in their own right. Because sulfide is readily absorbed across the surface of an invertebrate's body, the symbiont-free animals, like the symbiont-containing species, have had to evolve mechanisms to prevent sulfide poisoning. With the collaboration of Russell Vetter of Scripps and Mark Wells of Santa Barbara, we examined these mechanisms in the vent crab.

The animal's heart rate and the beating of its scaphognathites (appendages that drive the flow of respiratory water) did not change when we raised sulfide concentrations well above normal levels in ambient seawater, and the level of sulfide in the crab's blood increased only minimally. Because we could not isolate from the crab's blood a sulfide-binding protein comparable to the tube worm's hemoglobin, we assumed this species must have evolved some different strategy for detoxifying sulfide. We found that the crab can detoxify the sulfide it absorbs by oxidizing sulfide to thiosulfate, a much less toxic form of sulfur. The process is carried out in the crab's hepatopancreas, a tissue similar in function to the vertebrate liver.

We wondered whether, in the symbiont-containing animals, each host was colonized by only a single type of bacterial symbiont. Recent studies of the sequences of a particular ribonucleic acid (the 16S RNA) of bacterial ribosomes, done by Daniel Distel and our group in collaboration with Norman R. Pace of Indiana University, indicate that the relation between a sulfur-metabolizing bacterium and its animal host is species-specific, that is, each host species harbors a unique strain of bacteria. In spite of the fact that many types of sulfur bacteria have entered into this kind of symbiosis, no one bacterium seems to have adapted itself to more than one species of host. Presumably endosymbiosis with sulfur bacteria originated independently and repeatedly in diverse animal groups.

Our discoveries at deep-sea vents have stimulated surveys of a wide range of sulfide-rich environments, including mangrove swamps, petroleum seeps, sewage outfall zones and marshes. The surveys have revealed that the kinds of sulfur-based symbioses first discovered in the deep sea are widespread, and that various other energy-rich inorganic molecules, such as methane, can be exploited in analogous symbioses between other invertebrates and bacteria. These diverse symbioses have been described in disparate animal groups, including some smaller tube-worm relatives of *Riftia*, clams of a number of different families, various mussels and several groups of small marine worms.

As our studies progress we expect to find further instances in which animals rely on chemolithoautotrophic symbionts, thereby gaining the ability to tolerate and exploit habitats the animals could not colonize successfully without bacterial partners.



SULFIDE IS HIGHLY TOXIC to most animals (*a*). It poisons respiration at two levels: in the blood, where it binds to hemoglobin, and in cells, where it inhibits the respiratory enzyme cytochrome *c* oxidase (not shown). Animals associated with sulfide-rich hydrothermal vents have evolved different strategies to avoid sulfide poisoning. The tube worm *Riftia pachyptila* (*b*) has a separate binding site on its hemoglobin molecule for sulfide and so can transport oxygen and sulfide simultaneously in its bloodstream. The vent clam *Calyptogena magnifica* (*c*) has a special transport protein to carry sulfide to bacteria in its gills. The vent crab *Bythograea thermydron* (*d*) lacks endosymbiotic bacteria; it is able to detoxify sulfide by oxidizing it to nontoxic thiosulfate in its liverlike hepatopancreas.

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THE AMATEUR SCIENTIST

Concerning disappearances, including the Cheshire cat's odd vanishing act

by Jearl Walker

"I wish you wouldn't keep appearing and vanishing so suddenly: you make one quite giddy!"

"All right," said the Cat; and this time it vanished quite slowly, beginning with the end of the tail, and ending with the grin, which remained some time after the rest of it had gone.

"Well! I've often seen a cat without a grin," thought Alice; "but a grin without a cat! It's the most curious thing I ever saw in all my life."

—Lewis Carroll,
Alice's Adventures in Wonderland

The "Cheshire-cat effect" is one of two disappearing acts that have attracted my attention because of their curious visual aspects. The other one is the "rhino-optical effect." In the former you look simultaneously at two scenes by means of a mirror held in front of one eye; if something moves in one scene, the other scene may disappear for several seconds. Sometimes the erasure is incomplete. If the partially erased scene is a face, a smile on the face might survive, leaving an eerie view reminiscent of Lewis Carroll's Cheshire cat. In the rhino-optical effect you see an object when you look away from it but it vanishes when you look directly at it.

The Cheshire-cat effect was discovered accidentally in 1978 by Sally Duensing and Bob Miller at the Exploratorium, a science and perception museum in San Francisco. They were investigating binocular fusion, the process by which your brain fuses the separate scenes viewed by your eyes. Since the eyes function with only a slight difference in perspective, you are normally not aware of the fusion. Sometimes it takes place even when the eyes are viewing different scenes. Look at your hand with your left eye and at a reflection of a hole in an otherwise featureless plane with your right eye. Because of fusion, what you perceive is your hand with a hole in it.

Duensing and Miller first employed a mirror stereoscope to separate the views. When someone looked into the device, the left eye saw a person's face (reflected twice by mirrors) and the right eye saw an illustration of a window with four panes (reflected twice by another set of mirrors). In the perceived composite view the part of the window that overlapped the face usually disappeared. Presumably the complexity of the face weakened the brain's ability to fuse the two scenes completely.

To simplify the experiment the investigators substituted a thin horizontal bar for the illustration of the window and placed behind the face a featureless white backdrop. A woman taking the test said the part of the bar seeming to overlap the face was fainter and blurrier than the rest of the bar. To determine what part of the bar was missing one of the investigators pointed toward it. When the hand entered the field of view of the observer's right eye, she exclaimed that the face had completely disappeared. Although the view of the face by the observer's left eye was still unobstructed, none of the face surfaced at the conscious level. It was as though a magician had waved a hand through a scene to make a person disappear.

The erasure of part of a view from one eye is triggered by motion in the field of view of the other eye. Duensing and Miller demonstrated the effect with a variety of moving objects, including a length of string and a spot of light. Even apparent motion serves: when one of the mirrors in front of the right eye is moved slightly, the apparent motion of the scene viewed by that eye erases the scene recorded by the other eye. The erasure can last for as long as five seconds if the eyes are kept stationary and there is no motion in the erased field of view. If the eyes move, the missing scene immediately reappears.

Duensing and Miller next replaced the bar with a featureless white background but kept the face in front of the observer's left eye. They found that erasure is sometimes incomplete. If the hand moved through only part of the right-eye view, the corresponding part of the left-eye view disappeared but the rest remained. Even when the hand swept through the right-eye view, part of the left-eye view might remain. The surviving section tended to be where the observer fixed the gaze of her left eye. If she looked directly at the smile on the face, the smile survived the erasure. Since the smile was then superposed on the background seen by the right eye, it seemed to float in space.

In one trial Miller looked into the stereoscope and Duensing sat where he could see her face with his left eye. When he swept his hand across his right-eye view of the white background, he fixed his gaze on one of her eyes. Her face disappeared except for that eye. She then pointed to the other eye. Miller saw the hand but it pointed to an empty region in his view. Presumably the hand became visible because its motion forced erasure of the corresponding part of the background seen by the right eye. Erasure can thus be turned on and off at will by an appropriate motion in one of the fields of view. Moreover, it is selective with respect to the parts of the view that are affected.

The direction in which a hand or an object moves in a field of view is usually not important, but erasure is more certain and complete if the motion is fairly slow. Erasure always requires that the eyes be held as stationary as possible. If they follow the moving object, erasure does not occur.

To test how motion can selectively erase part of a view, Duensing and Miller arranged for an observer to see two fields containing shapes [*see lower illustration on page 124*]. When hands were waved in the upper left of the left-eye view and the upper right of the right-eye view, the top half of the fused view was immediately erased. Any of the geometric shapes could be erased by moving a hand through the corresponding field of view for the opposite eye.

In a related test an observer saw a different face with each eye. If the faces were stationary, they could be partially fused. When part of one face moved, the corresponding part of the

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other face disappeared. For example, if one person rolled his eyes, the other person's eyes disappeared. If both people rolled their eyes, fusion was reestablished, with the perplexing result that two irises moved in each of the two eye sockets of the composite face.

In binocular viewing one eye dominates the other in determining what perspective is brought to consciousness. Test yourself by focusing on a nearby object. Close your left eye and note the perspective your right eye has of distant objects. Repeat the procedure using only your left eye. With both eyes open, which of the monocular perspectives more closely matches the perspective of the distant objects now seen binocularly? In my case the left eye usually dominates. In the Cheshire-cat effect does a wave of a hand in the field of view of the dominated eye erase the view of the dominant eye as readily as the other way around? For me it does. A few of the people I tested report that erasure is more easily triggered by motion in one view than it is in the other.

Erasure can be modified by the illumination of the two scenes. Duensing and Miller found erasure is more complete when the background seen by one eye is bright. If the face is also well illuminated and the observer fixes his gaze on the eyes, the eyes will end up glowing when a hand is waved through the other scene.

A Cheshire-cat demonstration is now an exhibit at the Exploratorium. A person sits in a booth while someone else sits on the other side of a counter running across the booth. Both sides of the booth are covered uniformly with white Formica circles. In front of the observer is a vertical rod to which a double-sided mirror is hinged. By rotating the mirror about the rod the observer can choose which eye sees the featureless Formica reflected in the mirror. In either position one eye views the second person. To erase that person's face the observer moves a hand across the reflected Formica.

You can produce the Cheshire-cat effect by simpler means. Prop a pocket mirror vertically at the edge of a table or hold it with a steady hand. Turn it so that it reflects the scene on your right. The scene should consist of a vertical white surface bearing a simple line drawing. A large sheet of white paper with a few dark lines will serve. Put your face at the edge of the table and adjust your view so that your right eye sees the reflection of the white surface and your left eye looks across the table. Have someone sit on the other side of the table in sight of your left eye. To eliminate part or all of the person's face, pass your right hand through the reflected view of the white surface. To eliminate your view of the line drawing, pass your left hand through the view from your left eye.

In a similar arrangement I substituted a portable television set for the white surface. My right eye saw the screen and my left eye saw my wife working at the table. When the characters on the screen were stationary, I could partially fuse the two views. When a character moved, gestured or spoke, the corresponding part of the view of my wife was erased. When the

The disappearing Cheshire cat

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scene changed as the camera switched to a new angle, my wife totally disappeared for several seconds. Try as I might, I could not overcome the phenomenon by concentration.

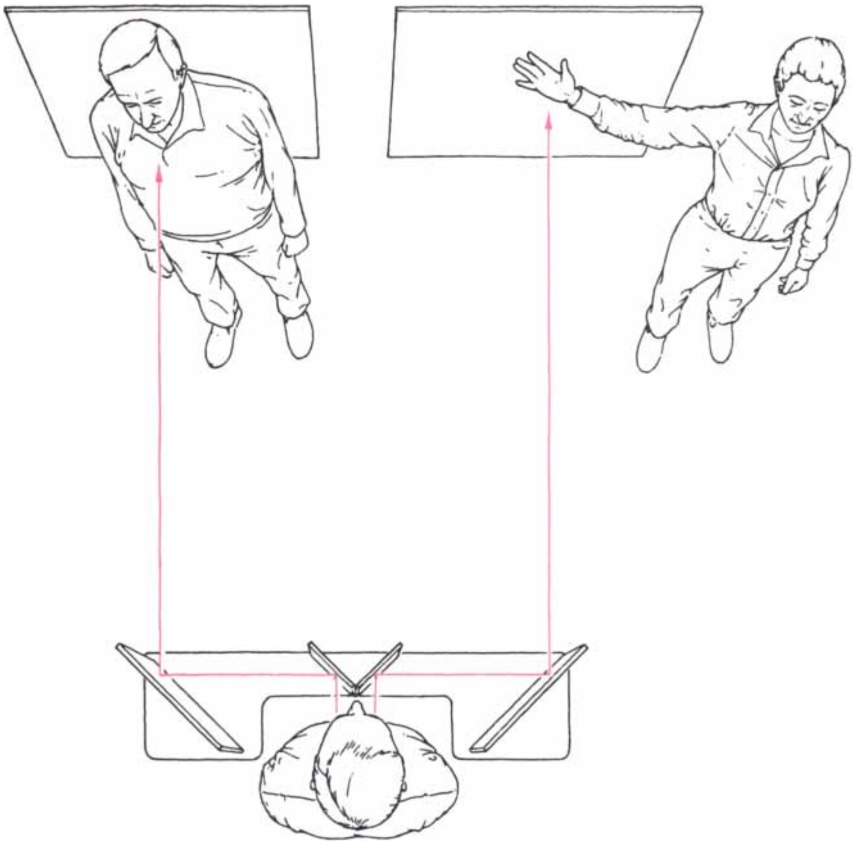
I was also able to demonstrate erasure without a mirror. After securing the unbound end of a writing tablet with a rubber band, I propped the tablet upright on a table with the long side horizontal and at right angles to the table edge. I positioned my head so that the tablet bisected my view. My left eye saw the tablet's colorful cover and my right eye saw the drab cardboard backing. The tablet occupied about 84 degrees in the nasal field of view of each eye. Usually my left eye dominated, but there was a perplexing fusing of the two views with frequent oscillations between them. When I moved my hand through either view, the view from the other eye was eliminated for a few seconds.

Duensing and Miller learned during their investigations that the Cheshire-cat effect had been reported in 1965 under the name of movement masking by G. C. Grindley and Valerie Townsend of the University of Cambridge. Their experimental arrangement was similar to the setups I have described. An observer sat with his chin on a rest that kept his head stationary. The left eye saw a white cardboard screen and the right eye saw an identical screen reflected from a mirror. A black wood arm was pivoted in such a way that it could rotate across the field of view of the right eye at a controlled rate.

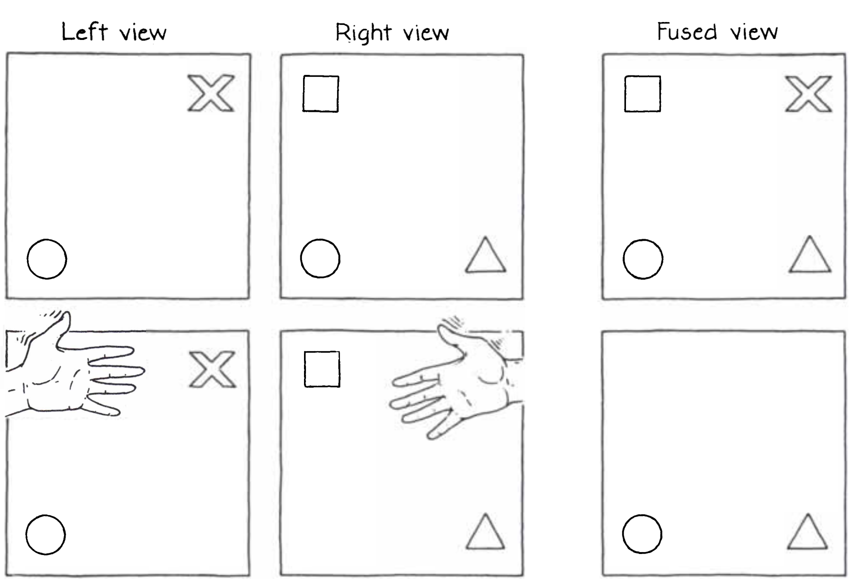
A small x and a square were marked on the cardboard seen by the left eye. The observer fixed his gaze on the x. When the wood arm was rotated, it appeared to cross over the square because of the observer's fusion of the two scenes. The motion often resulted in the brief disappearance of the square. Usually the square disappeared just as the arm seemed to pass over it, as though it were rubbed out by the arm. In other trials the square disappeared just before or after the arm seemed to pass over it. Most of the 50 subjects experienced all three effects during the tests. They found the erasure by the arm eerie. One of them reported, "You see that there is a connection but cannot feel at all sure about the exact sequence."

The square sometimes disappeared only in part, growing faint on one side or another. The duration of its disappearance was hard to predict. Sometimes it came back suddenly and at other times it came back slowly. Grindley and Townsend suggested that the sudden reappearance might be due to a saccadic eye movement, an involuntary jerk of the eye. Presumably the apparent motion of the left-eye scene resulting from the saccadic movement caught the attention of the brain, restoring perception of the square. When the observers were told to follow the rotation of the arm, the square never disappeared.

In another set of trials two squares were placed at the same height on the cardboard seen by the left eye. The wood arm was shortened so that it appeared to pass over only the square on



A stereoscopic arrangement devised by Sally Duensing and Bob Miller



The setup for demonstrating selective erasure

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the right. Most often only that square disappeared, but occasionally both of them vanished. Grindley and Townsend also experimented with complex displays in one or both views. When the arm passed over an object seen by the right eye, an object in the corresponding position in the view from the left eye disappeared. Sometimes when the arm seemed to touch the edge of a drawing or something that could be interpreted as being solid, the entire object immediately disappeared.

Erasure depended on the rotational speed of the arm. It was most frequent when the arm moved at 20 degrees per second. It was half as frequent when the speed was decreased to five degrees per second or increased to 90 degrees. The duration of erasure did not seem to be influenced by the rotational speed.

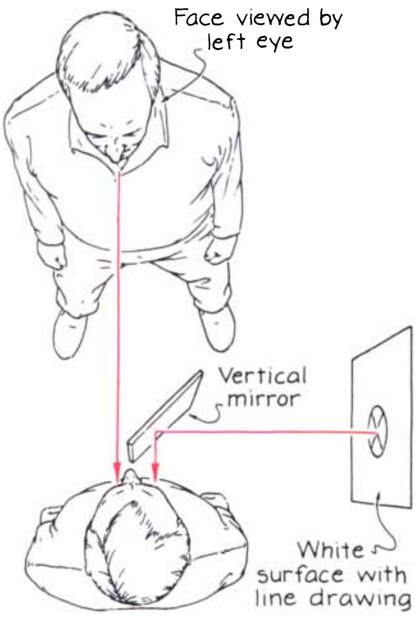
Grindley and Townsend also found that the proximity of the square and the point on which the left eye was fixated strongly affected the ability of the wood arm's motion to erase the square. They mounted the square on the right-hand side of the cardboard seen by the left eye and had the observer fix his view at a point to the left of the square. First he viewed a point far from the square. After a number of trials he moved his fixation point closer to the square for more trials. As the fixation point approached the square, the freqency with which the square disappeared fell off.

How does the human visual system achieve the Cheshire-cat effect? I am not certain of the answer but can offer a speculation. Normally the system attempts to fuse the views from the eyes to produce a single, sensible view. The point of concentration is wherever the eyes are focused, because that point produces an image on the fovea of each eye. The fovea produces the most acute vision. The other parts of the scene appear as less distinct images on the rest of the retina. Perhaps as an aid to survival the visual system is "wired" to be alert to motion in the peripheral part of the view.

Look straight ahead at a stationary scene. Wave your right hand on the far-right side of the scene in such a way that your left eye cannot see the motion. If your eyes were seeing separate scenes as in the demonstrations of the Cheshire-cat effect, the motion would erase the far-right section of what you see with the left eye. Since your eyes are seeing approximately the same scene from slightly different perspectives, there is no apparent erasure. I believe that in fact there is an erasure but that there is no evidence for it after fusion brings the scene to consciousness. Either the erasure is too far from the line of sight to gain attention or all the detail lost by the left eye is filled in by the right eye.

I tested my hunch by placing two brightly colored, separated objects on the opposite side of the room. Then I positioned two nearby obstacles so that only my left eye saw the colored objects. When I fixed my gaze on a point between the colored objects, I saw both of them because my left eye was dominant. When I waved my hand at the far right of my right-eye view (my left eye could not see the motion), the rightmost object disappeared. The object at the left was still visible. It is evident that I can erase part of a scene in normal viewing.

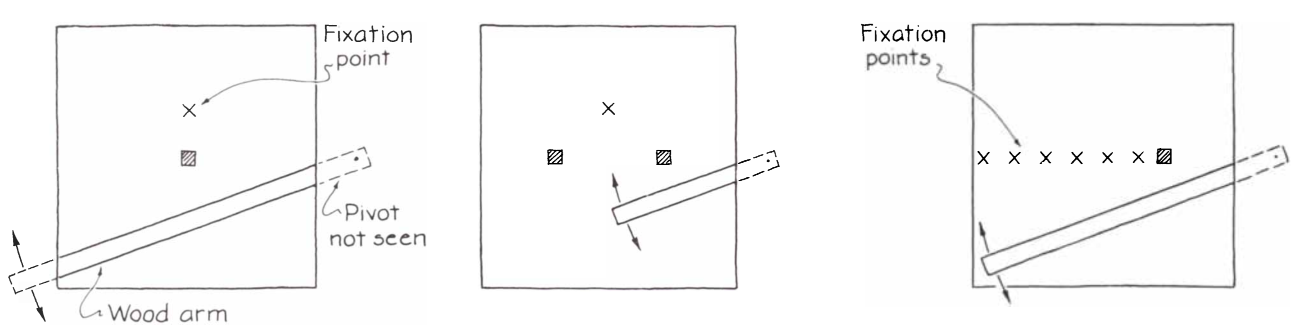
Why, during a Cheshire-cat effect, does motion through the full view of one eye sometimes leave part of the view of the other eye unerased? What survives is the part that produces an image on the fovea of the eye in which erasure seems to take place. Erasure is due to a warning system monitoring what is seen with the rest of the retina. For the same reason erasure is absent if your eye follows the moving object. Since the object then always produces an image on the fovea of that eye, the warning system leading to an erasure of the view from the other eye is not triggered.



Surface and mirror

The rhino-optical effect was named by Alistair P. Mapp and Hiroshi Ono of the University of York in England. The name stems from the fact that the eyes of a rhinoceros are separated by a large protrusion of the skull. The effect is easily demonstrated. If you wear glasses, remove them. Close your left eye and fix the view from your right eye on an object directly in front of you. Slowly bring a finger of your left hand forward from your left ear, being careful not to move your right eye. When the finger first moves into view, hold it steady in that position. Without turning your head, rotate your right eye toward the finger in order to see it. If the protrusion of the bridge of your nose is large enough, the finger disappears behind it. If you turn your eye forward again, the finger reappears.

A similar disappearance of an object viewed directly was described in 1844 by the British investigator David



Fused views in experiments by G. C. Grindley and Valerie Townsend

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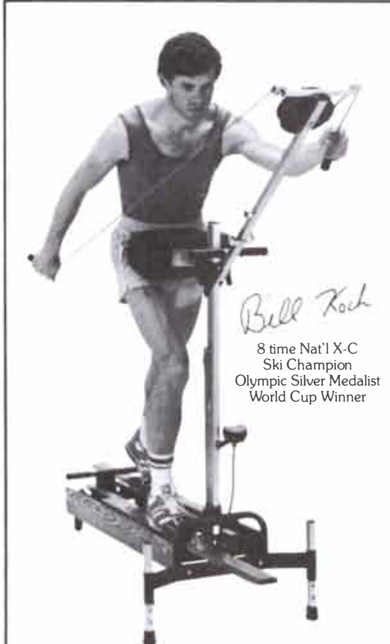

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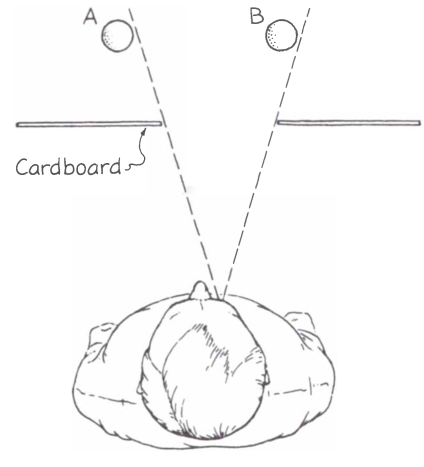
Brewster, who is remembered for his work in optics and vision. To repeat his demonstration cut a rectangular opening in a sheet of cardboard. Hold the sheet several centimeters in front of your right eye and close your left eye. Have someone place two narrow objects several centimeters away from the other side of the sheet. While you fix your gaze on the left side of the opening, have object *A* positioned so that it is barely occluded by that side of the opening. Have object *B* positioned so that its right side is barely visible along the right side of the opening. When the objects are in place, you can see *B* but not *A*. Without moving your head shift your gaze to the right side of the opening. *A* appears and *B* disappears. If you again turn your gaze to the left side of the opening, *A* disappears and *B* reappears.

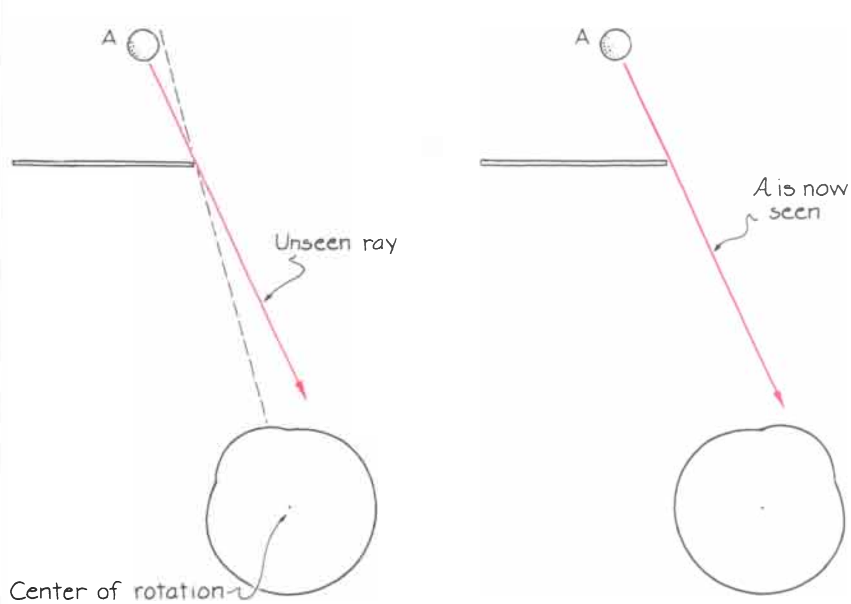
Brewster termed this effect ocular parallax. In the rhino-optical demonstration the bridge of your nose functions as the left side of the opening and your finger serves as object *A*. The finger is visible only when you look away from it. Both demonstrations depend on the fact that the region in which the light rays are refracted by the eye (in the cornea and the lens) is separated from the center point about which the eye rotates. Assume that all the refraction in the eye can be represented by a lens at the front of a spherical eye. When the eye looks directly at *A*, none of the light rays from it reach the lens and so *A* is not seen. The rays that travel toward the eye are blocked by the obstacle (either the bridge of the nose or the left side of the rectangular opening). The rest of the rays travel in the wrong direction.



Ocular parallax

When you rotate the eye rightward about its center point so that it looks directly ahead, the action moves the lens into some of the rays from *A* that skirt the edge of the obstacle. The lens refracts those rays onto the retina so that *A* is seen. The image is blurry but recognizable.

Mapp and Ono found that the rhino-optical effect does not work for everyone. If the bridge of the nose is flat, as it was in the case of the East Asians they tested, the observer sees the finger better when the eye rotates to view it directly. You can obtain a similar result if you look directly ahead with your right eye only (your left eye is closed) while moving a finger of your right hand forward from your right ear to the point where the finger first becomes visible. When you then rotate your eye toward the finger, more of the finger becomes visible.



The effect of eye rotation

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Improved access to a new generation of giant Intelsat satellites is planned. Intelsat VI, designed and built by Hughes Aircraft Company, is a series of five of the world's largest, most powerful commercial communications satellites. Each will have the capacity to carry 120,000 telephone calls and at least three television channels simultaneously. Making this possible is the use of very advanced digital modulation techniques. Design changes, the result of a system modification contract from the International Telecommunications Satellite Organization (INTELSAT), also will more than double the downward signal capacity of the satellite's spot beams, permitting greater coverage of North America and more connections with Europe. Called the satellite of the 21st century, each satellite in the Intelsat VI series stands 39 feet high and will use terminals as small as two feet in diameter. The first Intelsat, built by Hughes more than 20 years ago, was 4½ feet high and required Earth terminals nearly 100 feet in diameter.

An infrared viewer found potential trouble spots in a large pharmaceutical plant during a five-day survey of a 57-building complex. Hughes' Probeye® infrared viewer scanned 5,000 areas of potential trouble and pinpointed 60 hot spots, most of which were in the electrical systems and motors. For example, the Probeye unit showed a heat buildup of 120°C at three cartridge-type fuses. Also, a 75°C rise was discovered at another electrical connection. The fuse could have failed during a production run, resulting in costly downtime. The Probeye viewer sees heat the way a camera sees light, converting it instantly into an image seen through the eyepiece.

Infantry squads can maintain communications under polar conditions thanks to the Hughes AN/PRC-104 manpack radio, now the standard U.S. military field-communications system. It weighs only 14 pounds yet its lithium batteries provide enough power for voice communications at ranges of more than 1000 miles. It operates reliably at temperatures well below -50 degrees centigrade and can be used in total darkness by operators wearing the thickest mittens. Designed to meet a military specification of 2500 hours between failures, its actual record in the field far exceeds that requirement with an average of 4000 hours of fault-free operation.

U.S. Navy F/A-18 pilots will be able to see as though it were daylight while conducting low-altitude, high-speed missions at night using a Thermal Imaging Navigation Set (TINS) system developed by Hughes for McDonnell Aircraft Company. The TINS features a thermal sensor that displays a TV-like image of the terrain ahead on the pilot's head-up display. Ground objects and terrain are clearly viewed in a one-to-one real scene projection. Pilots are able to see in total darkness and through battlefield smoke and haze. TINS will be carried in a pod and mounted in a fixed, forward-looking position. Hughes will build five development systems, one of which will be used for flight testing. Delivery of these units is scheduled for fall of 1987.

Hughes Missile Systems Group is advancing every phase of research, development, and manufacturing technology as it applies to tactical guided missile systems and strategic defense. Opportunities for engineers and scientists are in analog/digital circuit design; high-voltage power supply design; transmitter and radome design; electro-optical design; IR imaging sensors; focal plane arrays; mechanical engineering; production design and systems engineering. Send resume to Hughes Engineering Employment, Dept. S9, 8433 Fallbrook Ave., Canoga Park, CA 91304. EOE. U.S. citizenship required.

For more information write to: P.O. Box 45068, Los Angeles, CA 90045-0068

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