SCIENTIFIC AMERICAN

ECOLOGY OF COYOTES

$2.00

April 1980

Goodyear Technology brings you a new steel-belted radial for the 80's.

ARRIVA

You need a tire that's fuel efficient.

You need a tire that can give you long mileage.

You need a tire with good traction in the wet.

You need Arriva radials.

Arriva is the response of Goodyear's scientists and engineers to the challenge of the 80's.

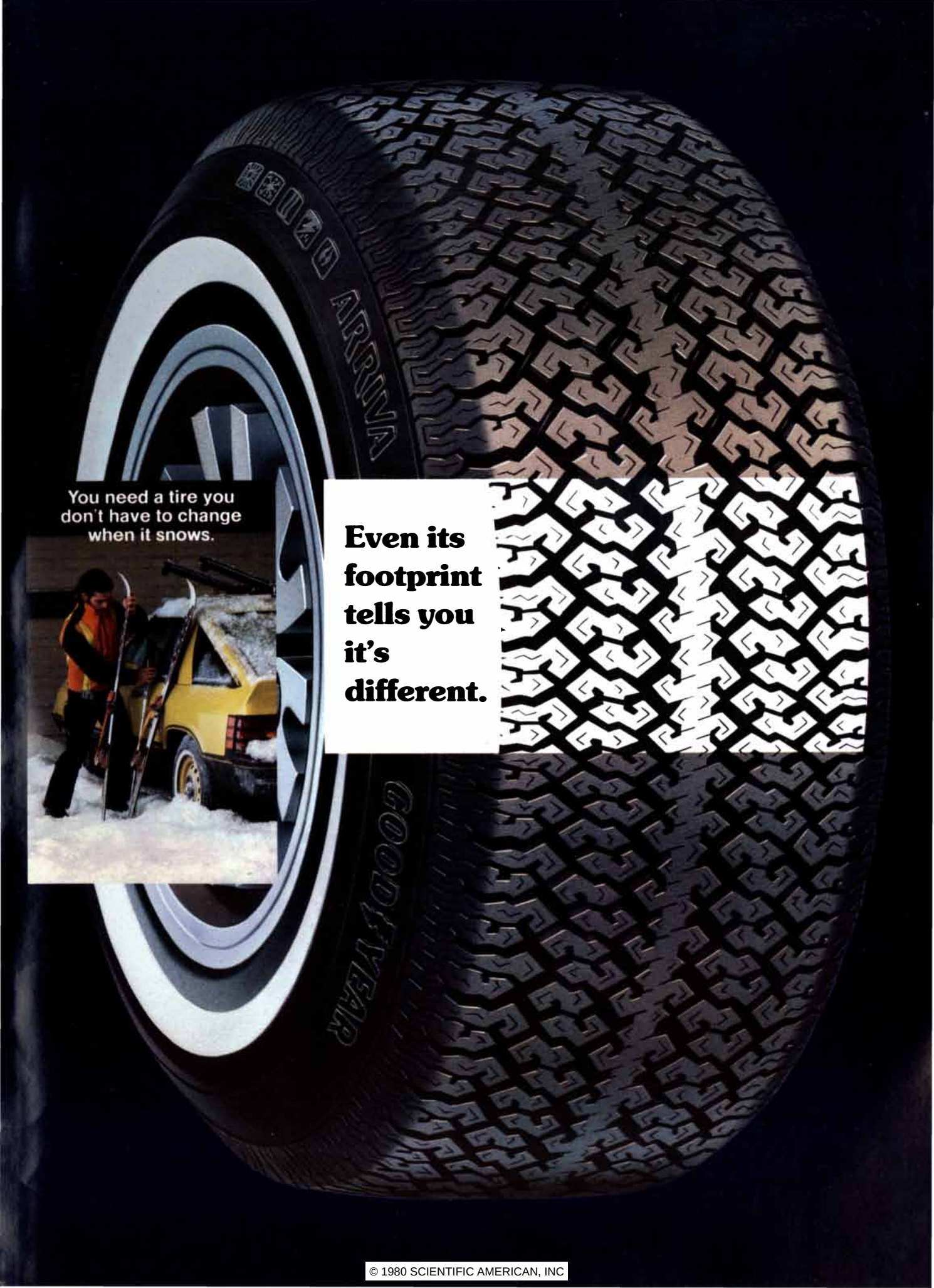
It is a new and different kind of tire. In its shape. In its tread. In its appearance. And it offers you a unique combination of features never before available in just one Goodyear tire.

Arriva is being made in a wide range of imported and domestic sizes, for front- and rear-wheel drive.

And Arriva is available right now—to give you a great start on the 80's.

GOODYEAR

Out front. Pulling away.

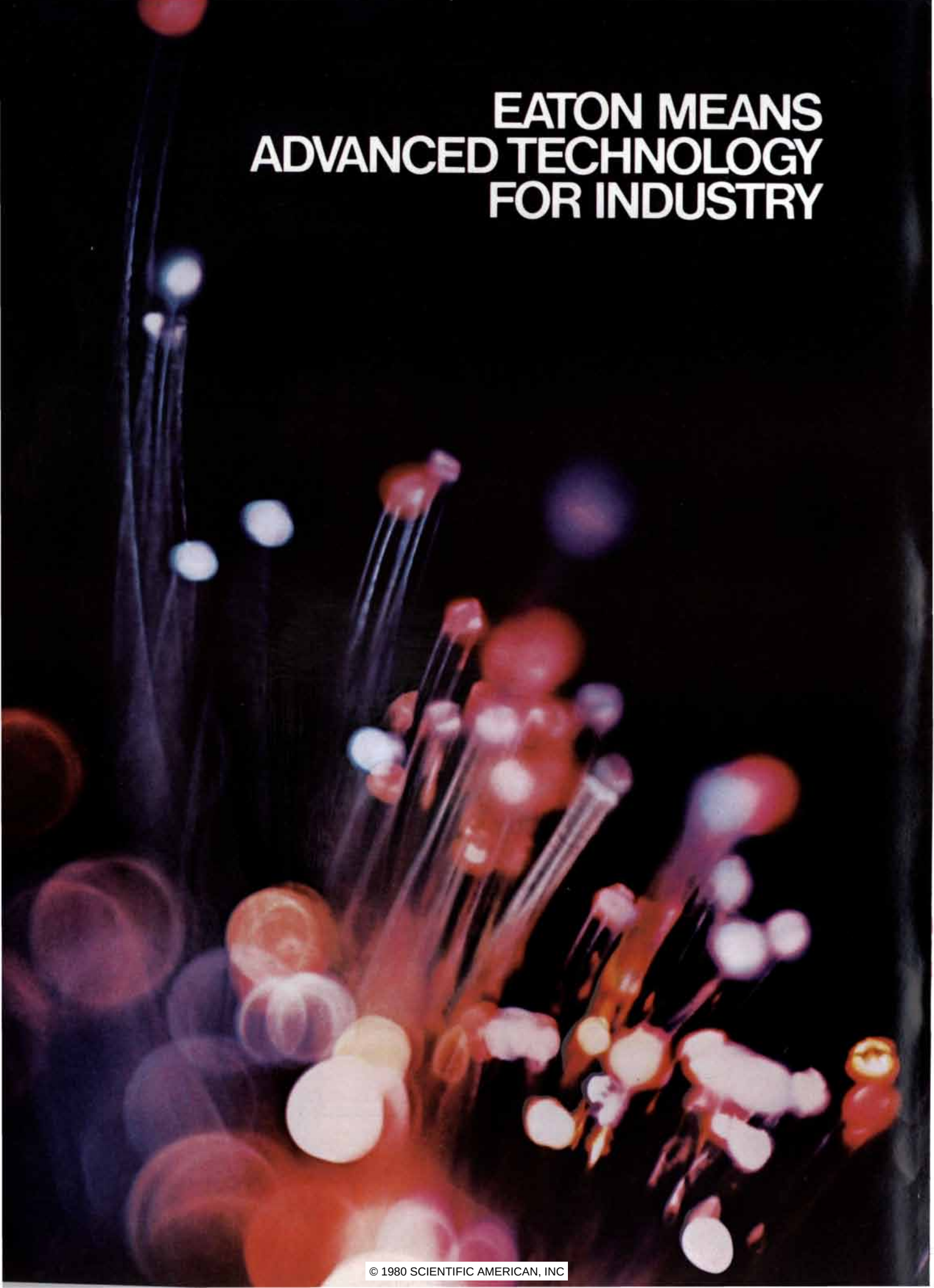


Established 1845 **SCIENTIFIC AMERICAN** April 1980 Volume 242 Number 4

ARTICLES

DEPARTMENTS

SCIENTIFIC AMERICAN (USPS 509-530), PUBLISHED MONTHLY BY SCIENTIFIC AMERICAN, INC., 415 MADISON AVENUE, NEW YORK, N.Y. 10017. CONTROLLED CIRCULATION POSTAGE PAID AT NEW YORK, N.Y. (USPS 509-530), AND AT CHICAGO, ILL. (USPS 508-030). AUTHORIZED AS SECOND-CLASS MAIL BY THE POST OFFICE DEPARTMENT, OTTAWA, CANADA, AND FOR PAYMENT OF POSTAGE IN CASH. SUBSCRIPTION RATE: $21 PER YEAR, U.S., ITS POSSESSIONS AND CANADA; $27 PER YEAR, ALL OTHER COUNTRIES. POSTMASTER: SEND ADDRESS CHANGES TO SCIENTIFIC AMERICAN, 415 MADISON AVENUE, NEW YORK, N.Y. 10017.



Fiber Optics research at Eaton seeks to apply cost and safety advantages of this dramatic new technology to industrial control systems. Eaton engineers are testing ways to transmit control impulses over optic fibers in the form of light rather than over costly copper wires in the form of electrical signals. Objectives: elimination of electromagnetic interference and the possibility of spark-induced explosions in combustible environments. Another example of Eaton technology at work for the benefit of customers. Eaton Corporation, World Headquarters, 100 Erieview Plaza, Cleveland, Ohio 44114.

DURING THE PAST FIVE YEARS, EATON:

Spent over $1 billion on research, development and expansion

Introduced over 1,000 new products or major improvements to existing products

Entered the electronics industry in a substantial way

Almost doubled annual sales, to more than $3 billion

Increased annual earnings at a compound average annual rate of 12%

...at Eaton, the use of technology means increased customer satisfaction. And corporate growth.

EATON

OLYMPUS ANNIVERSARY

"I wanted to design a camera that takes photographs no other camera can."

Such was the challenge that Maitani, the celebrated Olympus camera designer, set for himself.

If he had listened to conventional wisdom, he would have folded up his drawing board and gone home promptly at five.

Instead, Maitani persisted. And created the Olympus OM-2.

The fully automatic Olympus OM-2 is the only camera that measures the light *during* exposure.

Because two sensors read the light that reflects off the film surface the instant the shutter opens.

So the shutter may stay open for up to two minutes as the camera adjusts for changes in light and automatically closes at the precise moment perfect exposure has been achieved. No other camera can do it.

Maitani

The OM-2 also embodies all that Olympus SLRs are justly famous for. It's a light, compact, rugged camera with a bright viewfinder and well-proportioned controls.

And that's just the beginning. You can snap on a five-frame-per-second motor drive, or a winder, or a 1,000mm lens, or any of 300 plus components from the stellar Olympus OM system.

The Olympus OM-2 is what happens when a brilliant designer sets his sights on the impossible.

To create what's possibly the world's ultimate camera.

For information write Olympus, Woodbury, N.Y. 11797.

OLYMPUS® OM-2

THE COVER

The painting on the cover depicts a coyote (*Canis latrans*) that has been fitted out so that its behavior in the wild can be investigated (see "The Social Ecology of Coyotes," by Marc Bekoff and Michael C. Wells, page 130). Even when the animal cannot be identified visually by the colored tags that have been put on its ears, it can be tracked by means of a small radio transmitter held against its throat by the collar around its neck. Coyotes are found in diverse habitats in Canada, the U.S. and Central America, and such radiotelemetry has been useful in the study of wide-ranging movements of individual animals and groups.

THE ILLUSTRATIONS

Cover painting by Marvin Mattelson

Page	Source
19–27	Ilil Arbel
38–39	Frank R. Porschatis, *The Salt Lake Tribune*
40–42	Adolph E. Brotman
43	U.S. Army
44–45	Adolph E. Brotman
46	U.S. Army
49	Francis Van Noten, Royal Museum of Central Africa, Tervuren, Belgium
50–52	Andrew Tomko
53–54	Alan D. Iselin
55	Andrew Tomko
57	Richard L. Naeye, Milton S. Hershey Medical Center, Pennsylvania State University (*left*); Ilil Arbel (*right*)
58	Ilil Arbel
59–60	Richard L. Naeye, Milton S. Hershey Medical Center, Pennsylvania State University
61	Ilil Arbel
62	Richard L. Naeye, Milton S. Hershey Medical Center, Pennsylvania State University
75	Fritz Goro
76–94	Bunji Tagawa
99	Fritz Goro
100–114	Allen Beechel
117	Sigrid R. Herd
119–128	Jerome Kuhl
131	W. Perry Conway
132	Franz J. Camenzind
134–142	Albert Miller
153	David S. Forman, Ante L. Padjen and George R. Siggins, National Institute of Mental Health
154	Alan D. Iselin
156	Mark H. Ellisman, University of California at San Diego
159	Alan D. Iselin
163	Bernard W. Agranoff, University of Michigan (*top*); Alan D. Iselin (*bottom*)
164	Annica Dahlström, University of Göteborg
165	Alan D. Iselin
166	Alan D. Iselin (*top*); James H. Schwartz, Columbia University College of Physicians and Surgeons (*bottom*)
168	Alan D. Iselin
173	A. G. Klein, University of Melbourne
174–176	Ben Rose

LETTERS

Sirs:

The article "The Ancestry of Corn," by George W. Beadle, in the January issue of *Scientific American* presents the best case that has so far been made for the theory that the ancestor of cultivated corn is its closest relative, teosinte. Because of recent developments, mentioned only in the bibliography, the article is already out of date.

The discovery by Hugh H. Iltis and his colleagues of a wild perennial teosinte that has the same chromosome number as corn and is cross-fertile with it has changed the dimensions of the problem rather drastically, and virtually all students of corn's ancestry have been compelled to modify their views. Of the several new hypotheses that have resulted from Iltis' discovery, I regard as the most plausible that of Garrison Wilkes, author of the book *Teosinte, the Closest Relative of Corn*. Wilkes postulates that the natural hybridization of the wild perennial teosinte with a corn in the early stages of domestication could have produced the annual teosinte that Beadle, Walton C. Galinat and others regard as corn's ancestor. According to this hypothesis, annual teosinte is a late stage in corn's evolution and is corn's progeny rather than its progenitor.

Bold as it may seem, and certain to be controversial, the Wilkes hypothesis is consistent with at least three series of significant facts:

1. There is no *firm* evidence of an early teosinte. At all archaeological sites where teosinte or evidence of teosinte influence is found, the teosinte appears only after corn is well established. An apparent exception to this finding is the two teosinte fruits Beadle mentions that are dated by associated remains as being about 7,000 years old. These specimens are virtually identical with fruits of a modern race of teosinte, Chalco, which is a common weed in the cornfields of the area of the archaeological site. Moreover, the site itself, although it is said to be undisturbed, does have rodent burrows in which modern teosinte fruits could readily have been introduced. Until the two fruits in question have been dated by carbon-14 or other techniques, they must be regarded as suspect.

2. There is apparently no evidence of any kind, archaeological, ethnological, historical, pictorial or folkloric, that teosinte was ever grown as a crop by the American Indians. On the contrary, teosinte is now and was prehistorically a weed in the cornfields.

3. Teosinte has never been used extensively as a food. Even when it is employed as a "hardship" food, it is used only as a supplement to corn.

The Wilkes hypothesis is not only plausible but also testable. I for one am testing it on an extensive scale. I have crossed the diploid perennial teosinte with a primitive Mexican popcorn race and now have plantings of the first-generation hybrids at two localities in southern Florida and two additional ones in Argentina. In both of the Florida plantings many of the F_1 plants resemble the teosinte parent in three of the principal botanical characteristics in which corn and teosinte differ: (1) two ranked "ears" v. many ranked ears, (2) solitary spikelets v. paired spikelets and (3) fragile rachises v. solid rachises. In their growth habit the plants are somewhat intermediate between annual and perennial but perhaps closer to the annual. As a plant breeder with some years of experience I am reasonably confident that plants having all the characteristics of an annual teosinte will occur in the second, or segregating, generation of this cross. If they do, the 19th-century theory that has been so effectively revived by Beadle, that annual teosinte is the ancestor of cultivated corn, may no longer be tenable.

PAUL C. MANGELSDORF

Harvard University
Cambridge, Mass.

University of North Carolina
at Chapel Hill
Chapel Hill

Sirs:

I appreciate the opportunity to respond to Professor Mangelsdorf's letter stating that my article on the ancestry of corn is outdated by the recent finding of diploid perennial teosinte populations that are fully fertile with both corn and annual teosintes. He is of course well aware that a tetraploid perennial teosinte was collected and described 69 years ago. It can be presumed to have had a diploid perennial ancestor. Finding it in *Zea diploperennis* is indeed significant and rewarding, but I see no way in which it contradicts the evidence presented in my article.

Mangelsdorf's postulated wild corn is purely hypothetical. Of all the many corn races and the thousands of examined segregant types of teosinte-corn hybrids, none other than those closely approximating the classical teosinte female spike is found capable of being able to survive continuously in the wild. All others lack an effective "seed"-dispersal capability.

There is a dominant gene in corn called Tunicate, well known to Mangelsdorf, that is readily transferable to teosintes. The result is a reduction and softening of fruit cases and outer glumes, thus allowing naked kernels to be threshed free of cases and glumes. I am now well along in genetically transferring this gene to *Z. diploperennis* teosinte, in the belief that particularly desirable phenotypes, which could then have been propagated asexually by man, might well have initiated the transition of teosinte to corn.

GEORGE W. BEADLE

University of Chicago
Chicago

Sirs:

Jerome A. Feldman, in his article "Programming Languages" [SCIENTIFIC AMERICAN, December, 1979], attributes to Isaac Newton an algorithm for finding the square root of an arbitrary number. Howard Eves and Carroll V. Newsom relate that the algorithm was included in Hero's *Metrica* (*An Introduction to the Foundations and Fundamental Concepts of Mathematics,* by Howard Eves and Carroll V. Newson, Holt, Rinehart & Winston, Inc., 1965). *Metrica* was found in Constantinople in 1896 by R. Schöne. Hero lived in Alexandria during the first century A.D.

A. D. BROCKMAN

San Francisco

Editorial correspondence should be addressed to The Editors, SCIENTIFIC AMERICAN, 415 Madison Avenue, New York, N.Y. 10017. Manuscripts are submitted at the author's risk and will not be returned unless accompanied by postage.

Advertising correspondence should be addressed to C. John Kirby, Advertising Director, SCIENTIFIC AMERICAN, 415 Madison Avenue, New York, N.Y. 10017.

Offprint correspondence and orders should be addressed to W. H. Freeman and Company, 660 Market Street, San Francisco, Calif. 94104. For each offprint ordered please enclose 40 cents.

Subscription correspondence should be addressed to Subscription Manager, SCIENTIFIC AMERICAN, 415 Madison Avenue, New York, N.Y. 10017. For change of address, notify us at least four weeks in advance. Send both old and new addresses and enclose an address imprint from a recent issue. (Date of last issue on your subscription is shown at upper right-hand corner of each month's mailing label.)

Name

New Address

Old Address

What's right for today?
A big car? Small car? Fast car? Safe car? Station wagon? Sedan? Economy car? Luxury car?
How about everything?

While common sense would seem to dictate the distinct improbability of such a phenomenal automotive accomplishment, there is a scattering of people around you who have in their possession powerful evidence to the contrary.

The evidence is the car they drive.

A Saab.

It's small but it's big.

The exterior of the Saab 900 is built on the scale of the Audi 4000 and 5000, the Volvo DL and GLE, the BMW 320i and 528i and the Mercedes 280E.

Inside, however, the Saab is bigger than all of them.

By EPA measurements, in fact, the Saab is a mid-sized car.

While the others are all compacts.

It stops. And it certainly goes.

From 60 to 0, in separate road tests conducted by *Road & Track* during '78 and '79, the Saab 900 Turbo stopped quicker than, among other cars, two Audis, two Jaguars, five BMWs, a Ferrari, a Maserati, a Mercedes and a Volvo.

And going was no less spectacular than stopping.

Through the standard *R&T* slalom course, the Saab 900 Turbo—a four-cylinder, front-wheel drive car, mind you—was timed faster than three Mercedes, four BMWs, two Ferraris, two Jaguars and a couple of Porsches, including the 928.

It's a sedan that also isn't.

The trunk in the Saab 900 is as big as those in the largest sedans being made.

Yet for those few times every year when you wish your sedan was a station wagon, the Saab accommodates you.

Fold the rear seat forward, lift the rear hatchback and the Saab presents a station wagon-like cargo space over six feet long and 53 cubic feet big.

Economy with the luxury of room.

The Saab 900 is not a tiny compact or subcompact that gets good gas mileage.

It's a comfortable *mid-sized* car that does.

The Saab 900 EMS, for example, gets (21) EPA estimated mpg and 30 estimated highway mpg.

(Remember, use estimated mpg for comparison only. Mileage varies with speed, trip length and weather. Actual highway mileage will probably be less.)

Is this the prestige car of the future?

Probably.

What could be more prestigious than buying a new car and, despite the times, getting everything you want?

SAAB

The most intelligent car ever built.

50 AND 100 YEARS AGO

SCIENTIFIC AMERICAN

APRIL, 1930: "The $1,000 prize of the American Association for the Advancement of Science has been awarded this year to A. J. Dempster for his 'noteworthy contribution to science' in proving that the proton has wave characteristics. In the words of Arthur H. Compton, winner of the Nobel prize in physics, 'the most important contribution of 20th-century physics is that the physical world can be reduced to three kinds of particles—protons, electrons and photons—and that each of these particles has also the characteristics of waves. The last stage is the proof that protons, the positively charged parts of matter, have wave characteristics. It is this completion of the great work of 20th-century physics that has been accomplished by Dr. Dempster.' In that Dr. Dempster's discovery demonstrates the dual nature—particle and wave—of the proton it is one vindication of the prediction of the French physicist Louis de Broglie. Following de Broglie's prediction C. J. Davisson and L. H. Germer of the Bell Telephone Laboratories proved the wave nature of the electron; Dempster's research does the same thing for the proton."

"For many centuries miners have been digging tortuous tunnels deep into the earth in search for coal. The development of open-pit mining on a large scale is a relatively new phase, but already it has become of great importance in the coal-mining industry. Of the numerous coal 'stripping' operations, perhaps the most interesting are those conducted on the Northern Pacific Railway Company properties at Colstrip, Mont. At this mine new operating equipment of the most advanced type has recently been installed. A new electrically driven machine operated by one man bites a hole in the ground large enough to serve as the cellar for a house and deposits the 15 tons of excavated material a full city block away, perhaps at a height equivalent to that of a 10-story building. Within one minute the operation is completed and the shovel is back for another 15-ton bite. Two or three men operating the new shovel can dig and load more coal in a shift than dozens of workers can in the average deep mine. Each worker in the pit averages 50 tons of coal per day, or 10 times the normal unit production of coal mines. Not more than 75 men will be needed at the Colstrip mine to produce 11,000,000 tons of coal recently contracted for by the Northern Pacific."

"There is no formula for determining which is the foremost physical laboratory, but the Ryerson Physical Laboratory of the University of Chicago has given the world so many famous physicists that the majority of those who are qualified to judge would perhaps so nominate it. How is such a choice as this arrived at? What makes a scientific institution a leader? That which is most likely to ensure advance is the strong inspiration and leadership of an outstanding personality, and it is therefore not a far cry to attribute Ryerson's supremacy to the leadership of the great physicist A. A. Michelson, who has been its head from 1892 until recently. Michelson, R. A. Millikan and Arthur H. Compton—what a trio this center of physical research can boast! H. G. Gale, whose name is linked with Michelson's in connection with ether-drift experiments; Samuel W. Stratton, president of the Massachusetts Institute of Technology; W. F. G. Swann, director of the Bartol Research Foundation; Frank B. Jewett, president of the Bell Telephone Laboratories; C. J. Davisson of the same laboratories, who proved the wave-atom theory—these and some 130 other physicists are all descendants of the Ryerson tradition. In a recent address Millikan, who is now at the California Institute of Technology, spoke of Michelson's economic value. He proved that Michelson was a greater asset than any billion-dollar corporation. This much can one man accomplish for the world by the right kind of leadership."

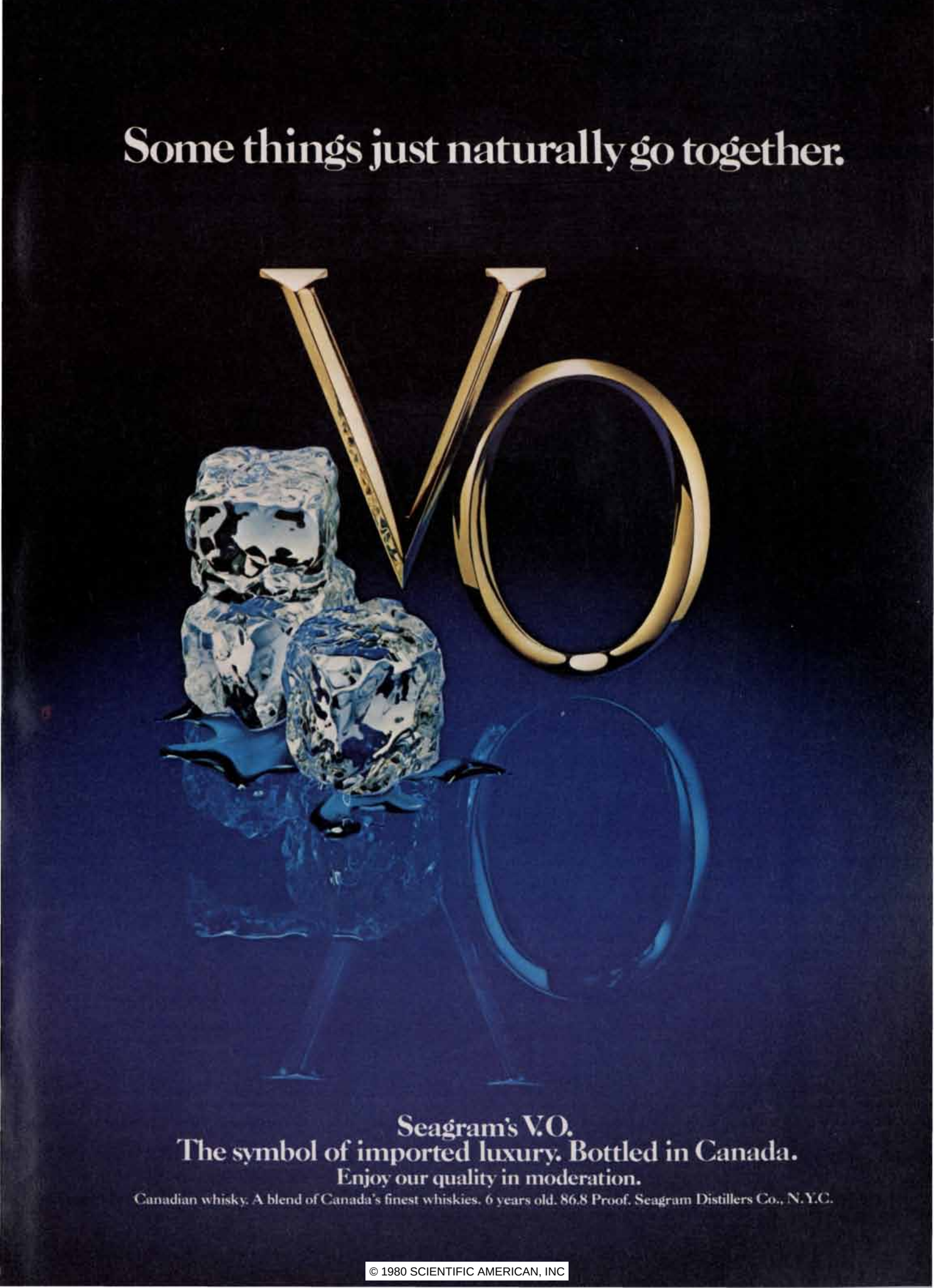
APRIL, 1880: "Last year Europe expended for military and naval purposes something near $800,000,000, even though there was no fighting. This profitless squandering of money is not the whole of the blood tax on Europe in times of peace. That which comes from withdrawing able-bodied men from productive labor is an item of scarcely less magnitude, for the standing armies of Europe foot up something over eight millions. The problem of industrial supremacy is therefore not hard to solve. The single advantage America enjoys in being free from the terrible war burdens of Europe even in times of peace cannot fail to maintain us in our position as the most prosperous people in the world. The annual tale of labor prevented, labor misapplied and labor driven away by the enormous armies and armaments of Europe finds no counterpart here. All our labor is productive, all tends to swell our national wealth and to increase our power to do and to enjoy. And the advantage of all of this must and does accrue mainly to the American producer, showing itself in lighter taxes, higher wages, a greater diffusion of wealth and a more generous style of living, all of which are everywhere recognizable by European tourists here as characteristic of the lives of American workers."

"Two successive years of severe visitation of yellow fever at New Orleans and Memphis each time drew general attention to the necessity of some action in the way of prevention, but with the disappearance of this dreadful disease it appears to have passed almost completely out of the public mind. Doctors are by no means agreed as to the best method for its treatment, or as to its original cause, and our knowledge of just how it is propagated, other than by contact with the developed disease or its germs, is very limited. The fact that stands out most prominently in connection with the subject is that the island of Cuba, and particularly the city of Havana, seem to be its chosen home, and in the latter the disease has been present in every month of the year for every year since 1850. It is quite plain that any protection we have from the constant visits of the disease must come from a more stringent regulation of our commercial intercourse with Cuba."

"Much has been written and said about Mr. Edison's new lamps, but there has been wonderfully little produced in the way of precise and reliable statement concerning the simple facts. Assuming that a Siemens or Brush machine is employed to generate the electric current, such a current would be obtained with a loss of about 40 per cent of the mechanical energy applied to the driving pulley of the machine. To operate 12 lamps, therefore, we should have to apply one horse power to the pulley. To produce one horse power in a steam engine about five pounds of coal must be burned. These five pounds of coal will yield 25 cubic feet of gas, which if burned in five gas burners will give 100 to 110 candles. The 12 Edison lamps will give 120 candles. This would show something in favor of the economy of the electric light, but when in fact everything in this regard is against the electric light, which demands more machinery, requires more skillful management and presents an utter lack of the storage capacity that secures efficiency and convenience for gas, we see that this trifling economy disappears."

"A locomotive on the Pennsylvania Railroad made the fastest run on record a few weeks ago. It was ordered from the round-house to the scene of an accident and ran 60 miles in 45 minutes eight seconds. This is at the rate of a trifle under 80 miles per hour and is a very remarkable performance."

Some things just naturally go together.



Seagram's V.O.
The symbol of imported luxury. Bottled in Canada.
Enjoy our quality in moderation.

Canadian whisky. A blend of Canada's finest whiskies. 6 years old. 86.8 Proof. Seagram Distillers Co., N.Y.C.

Making computers serve

Lockheed knows how.

Watching wheat from 560 miles up.

The world's vital breadbasket is the wheat field—it yields our most abundant and widely traded small grain. So wheat is worth keeping an eye on. And doing just that are a space satellite, an elaborate computer, and a crack, NASA-directed team of 300 Lockheed scientists and technicians.

From a satellite orbiting 560 miles high, the Lockheed analysts receive continual visible/infrared images of 5-by-6-mile segments of the world's eight major wheat-growing areas. Main concentration is on the United States, Canada, and the U.S.S.R. In a painstaking, high-precision process, they piece together the images and use weather, crop conditions, and farming practices to identify wheat. Then they feed the data into the computer, already programmed with yield models, to analyze wheat acreage.

The resulting forecasts—in bushels per country—are of critical value to American agriculture and, in particular, to export planning. This technology may soon cover all major world crops, but the first interest is wheat... because wheat fields supply a whopping one-fifth of the total calories consumed by mankind.

Handling the information explosion.

An answer to researchers' prayers is the Lockheed online reference retrieval system called Dialog.

Used by both specialized and public libraries, the computerized Dialog short-cuts the tedium of digging through printed indexes and tracking down cross-referenced sources.

Given a subject category or key words, Dialog can rapidly search any of its 100 massive databases that are pertinent. In minutes, it can return to the library's computer terminal a list culled from more than 30 million international document references.

Dialog databases range broadly from the professional and technical to a complete indexing of 370 popular American magazines and special periodicals.

Best of all, in view of the information gathered and the time saved, the cost-per-search is surprisingly small.

Helping a jetliner stretch its wings.

Computers on board modern aircraft are nothing new. They've been applied in automatic navigation, flight controls, automatic landing, and other functions for years.

But now Lockheed L-1011 TriStar engineers have put a computer to a new, timely use—namely, allowing wingspan to be added without the normal costly, time-consuming structural redesign.

What permits this 'stretching' of wings is an advanced, exclusive system of Active Control ailerons. Installed with the new wing extensions, these ailerons are precisely controlled by the computer to reduce added wing structure loads.

man in many ways.

And why this change? Because of big benefits. Longer wings translate into reduced drag, a smoother ride, and a healthy reduction in fuel consumption.

Preventing a floating traffic jam.

The last thing needed these days is oil spilled upon troubled waters. But in the Texas port complex of Houston/Galveston, third busiest in the nation, it was happening. Controlling the growing traffic of oil-carrying tankers and other big ships was a confounding problem.

So, to prevent spill-prone collisions and accidents, the U.S. Coast Guard sought a new way to 'oversee' that 50-mile-long lacework of interconnecting waterways and all the ships operating there. The answer was a Lockheed computerized system that enables the Coast Guard to stay aware of ship traffic and take quick action to block potential mishaps.

At six operator stations, Coast Guard personnel can now view graphic representations and listings of channel traffic. They can spot vessel meeting/overtaking situations fast.

New system monitors crowded traffic in Houston/Galveston port complex.

And with all important vessel data on call, they can make ship movement through the crowded, inland canal complex far easier, faster, and safer.

The computer techniques described here are only a few of Lockheed's current applications. In others, computers are being used to devise statistical maps, design aircraft, speed manufacturing and production processes, save fuel in flight, create and revise engineering drawings, control air traffic, cut energy costs in big buildings, and improve many other aspects of modern life.

When it comes to solving complex problems by using advanced technologies, Lockheed knows how.

Lockheed

THE AUTHORS

MATTHEW MESELSON and JULIAN PERRY ROBINSON ("Chemical Warfare and Chemical Disarmament") share a long-standing commitment to the prevention of chemical and biological warfare. Meselson is Thomas Dudley Cabot Professor of the Natural Sciences at Harvard University. A graduate of the University of Chicago, he obtained his Ph.D. in physical chemistry from the California Institute of Technology in 1957. In addition to his main scientific work in molecular genetics Meselson has devoted much of his time and energy over the years to the analysis of issues related to biological and chemical weapons. He is generally credited, for example, with having played a key role in the political process that led to the signing of the Biological Weapons Convention of 1972. Robinson, who is senior fellow with the Science Policy Research Unit of the University of Sussex, is a specialist on military technology and arms control. He was born in Jerusalem and was educated at the University of Oxford, where he received his B.A. and M.A. degrees in chemistry. Before joining the faculty at Sussex in 1971 he was head of the project on the limitation of biological and chemical arms at the Stockholm International Peace Research Institute (SIPRI).

FRANCIS VAN NOTEN, DANIEL CAHEN and LAWRENCE KEELEY ("A Paleolithic Campsite in Belgium") are archaeologists associated with the Royal Museum of Central Africa at Tervuren in Belgium. Van Noten, who is head of the prehistory-archaeology section of the museum, also lectures on paleoethnography at the Catholic University of Louvain. His degrees are from the University of Ghent (M.A., 1963; Ph.D., 1967). Since joining the museum's staff in 1965 he has done archaeological field work in both Africa and Belgium. Cahen is head of field work at the museum. He was educated at the University of Brussels (M.A., 1968; Ph.D., 1973). Before taking his present job he was a research fellow at the Belgian National Foundation for Scientific Research and taught at the University of Zaire and the University of Gabon. Keeley, a research associate of the museum, is also a visiting member of the faculty of the University of Illinois at Chicago Circle. He did his undergraduate work at San José State University and his graduate work at the University of Oxford, obtaining his D.Phil. from Oxford in 1977. His specialty is the functional analysis of stone tools.

RICHARD L. NAEYE ("Sudden Infant Death") is chairman of the department of pathology at the Pennsylvania State University College of Medicine. He received his A.B. at Colgate University in 1951 and his M.D. at the Columbia University College of Physicians and Surgeons in 1955. Before his appointment to the Penn State faculty in 1967, he was professor of pathology at the University of Vermont College of Medicine. The primary focus of Naeye's research has been on diseases of the fetus and the newborn infant. "I have a particular interest," he writes, "in environmental factors that influence specific antenatal disorders, such as the maternal use of tobacco, coitus, nutrition and so forth. I am deeply involved in large projects in two African countries attempting both to identify the disorders responsible for their excessive perinatal mortality rates and to find ways of preventing these disorders."

WALTER GILBERT and LYDIA VILLA-KOMAROFF ("Useful Proteins from Recombinant Bacteria") have collaborated on the development of techniques for the enzymatic manipulation of DNA molecules. Gilbert is American Cancer Society Professor of Molecular Biology at Harvard University. A Harvard graduate, he obtained his D.Phil. in mathematics from the University of Cambridge in 1957. He began his career as a theoretical physicist but switched to experimental work in molecular genetics about two decades ago. Gilbert is a founder of Biogen, SA, an applied-genetics company. Villa-Komaroff is assistant professor of microbiology at the University of Massachusetts Medical Center. She was graduated from Goucher College in 1970 and received her Ph.D. in cell biology from Harvard in 1975.

PRAVEEN CHAUDHARI, BILL C. GIESSEN and DAVID TURNBULL ("Metallic Glasses") are materials scientists. Chaudhari is a member of the research staff of the International Business Machines Corporation's Thomas J. Watson Research Center. A native of India, he got his undergraduate education at the Indian Institute of Technology in Kharagpur, earning a B.Tech. in 1961. He then came to the U.S. to continue his studies, obtaining his S.M. and Sc.D. from the Massachusetts Institute of Technology in 1963 and 1966 respectively. He has worked at IBM since 1966. Giessen is professor of chemistry at Northeastern University, where he also serves as associate director of the Institute of Chemical Analysis, Applications and Forensic Science. He was born in Pittsburgh but grew up in Germany, where he attended the University of Göttingen, receiving his Sc.D. in 1958. He was a research associate in metallurgy at M.I.T. from 1959 to 1968, when he joined the faculty at Northeastern. Turnbull is Gordon McKay Professor of Applied Physics at Harvard University. His Ph.D., in physical chemistry, is from the University of Illinois (1939). He joined the Harvard faculty in 1962.

JOHN D. BARROW and JOSEPH SILK ("The Structure of the Early Universe") are theoretical astrophysicists with a special interest in cosmology. Barrow is a research lecturer at the University of Oxford. He was born and raised in London, studied mathematics as an undergraduate at the University of Durham and obtained his doctorate in cosmology from Oxford in 1977. After spending a year as Lindemann fellow at the University of California at Berkeley he returned to Oxford to become a faculty member in the department of astrophysics. Silk is professor of astronomy at Berkeley. A native of England, he studied mathematics at the University of Cambridge, received his Ph.D. in astronomy from Harvard University and spent postdoctoral years at the Institute of Astronomy at Cambridge and at Princeton University. Silk is the author of a new book on cosmology, *The Big Bang: The Creation and Evolution of the Universe,* published by W. H. Freeman and Company.

MARC BEKOFF and MICHAEL C. WELLS ("The Social Ecology of Coyotes") are at the University of Colorado at Boulder. Bekoff, who has taught at Boulder since 1974, holds a bachelor's degree in anthropology and a doctorate in animal behavior, both from Washington University. In addition to his studies of canids, both in captivity and in the wild, he has investigated the behavior of Adélie penguins at the Cape Crozier rookery in Antarctica. Wells was graduated from Michigan State University and holds a master's degree and a Ph.D. from Colorado State University. His graduate work dealt with "perceptual processes in both waterfowl and coyotes." He has been studying coyotes for six years.

JAMES H. SCHWARTZ ("The Transport of Substances in Nerve Cells") is professor of physiology and neurology at the Columbia University College of Physicians and Surgeons. A graduate of Columbia College, he earned his M.D. in 1959 at the New York University School of Medicine and went on to obtain his Ph.D. in 1964 from Rockefeller University. He was a faculty member in the department of microbiology at N.Y.U. when he began his study of the biochemistry of nerve cells in 1968, joining a consortium of investigators to form the division of neurobiology and behavior. The division moved from N.Y.U. to Columbia in 1974.

Every Panasonic gives you a picture that's life-like. This Panasonic also gives you a picture that's life-size.

Panasonic brings you life in your choice of sizes. From our little 7" (meas diag) portable color TV with its brilliant color and realism right up to our biggest—the Panasonic Color Video Projection System—a super-real 5 ft. (meas diag) of picture so life-like you can't help feeling you're part of it!

Panasonic Projection TV, with a picture area nearly 10 times that of an ordinary 19" diagonal TV, transforms your living room into a screening room. A sports arena. A concert hall. You can even connect one of our Omnivision VI™ VHS™ six hour video recorders to it and replay great films. Favorite sports events. Or your own video tape masterpieces, wherever you made them!

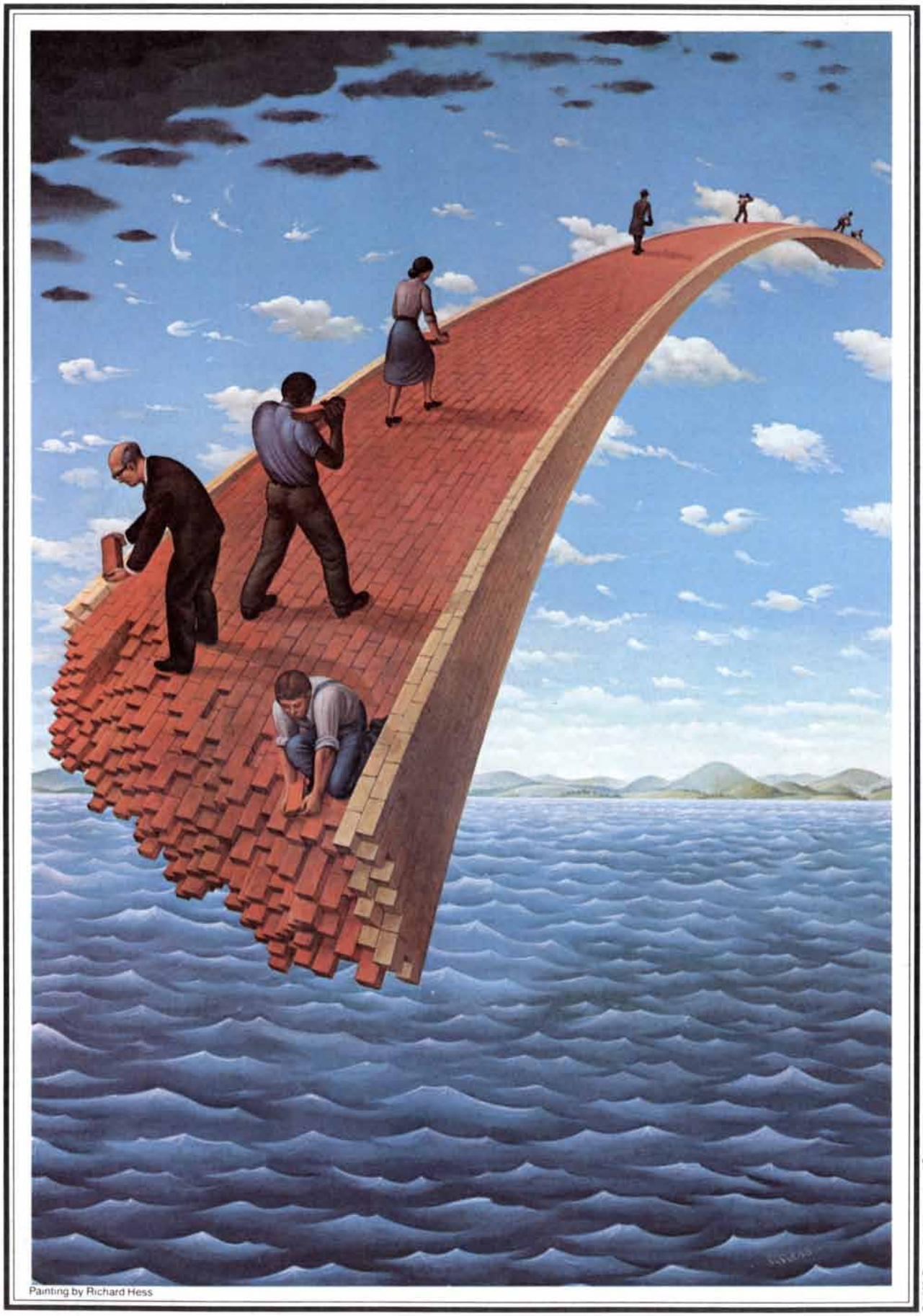
Yet the Panasonic Projection TV folds into a compact one-piece unit that's just 27 inches deep. And it comes with Panasonic remote control tuning, so you can relax in your favorite chair for an evening of brilliant television viewing.

To keep the viewing brilliant, this Projection TV, like many other Panasonic TV's, has two electronic color control systems. VIR, which "reads" color information transmitted by the TV station. And, when a VIR signal is not available, the Panasonic ColorPilot™ system takes over to maintain accurate, true-to-life color from program to program, from channel to channel—automatically.

Whether you choose a 7", 10", 12", 13", 19", 25", or 5-ft. Panasonic Color TV (all meas diag) you'll get a picture so life-like you'll feel like you're part of it. If you choose the 5-foot Projection TV, you'll get a picture so life-size, you may begin to feel it's part of you!

Cabinetry is simulated woodgrain.
TV picture simulated

Panasonic®
just slightly ahead of our time.



Painting by Richard Hess

There are some marvelous benefits ahead for mankind. But along with every benefit will come a whole new set of problems.

Champion is a forward-looking forest products company. We plant seeds for a living. Seeds that take from 25 to 50 years to become mature trees. Therefore, we think a lot about The Future of the forest. And, of the people who will be around to buy our products in the years to come.

So, during the coming year, in magazine ads like this, we will continue our program of discussing some of the potential cultural and sociological impacts of future technology and change—to help you make intelligent choices.

You might say, we're planting seeds of thought for tomorrow.

The Future is coming. But only you can decide where it's going.

Lord Kelvin, the eminent nineteenth century physicist, once predicted: "X-rays will prove to be a hoax"; "Aircraft flight is impossible"; and "Radio has no future."

Octave Chanute, an aviation pioneer said in 1904: "The [flying] machines will eventually be fast, they will be used in sport, but they are not to be thought of as commercial carriers."

Henry L. Ellsworth, U.S. Commissioner of Patents in 1844, a man who should have known better, said: "The advancement of the arts [of invention] from year to year...seems to presage the arrival of that period when further improvement must end."

In a comment on this kind of "technological pessimism," science writer Arthur C. Clarke, in *Profiles of the Future,* said: "When a distinguished but elderly scientist states that something is possible, he is almost certainly right. When he states that something is impossible, he is very probably wrong."

Obviously, we can't leave The Future *just* to the experts. As intelligent and well-informed as they are, they are not infallible.

Collectively, we all have to take responsibility for the future. It doesn't just *happen* to us. We must learn all we can from the past. And use it to help us in the years to come.

The human race is now making choices that may well determine our long-term future. No one knows the precise nature of these choices, but futurists agree that our actions today will reverberate throughout the years ahead.

As a company whose entire being is based on the tree, a renewable resource that takes from 25 to 50 years to mature, we have always been particularly concerned about the prospects of future generations of forests and of future generations of people.

So it seems only natural for us to consider some of the situations that futurists foresee for the coming generations. And to discuss some of the choices that will have to be made.

In magazine pages like this, we will continue to look at some of the major issues that can affect us all in the years to come.

If you have any doubts about The Future remember this: many of the supposedly "unsolvable" problems of past generations have been very successfully solved. For example, we now have insulin for diabetics, ships that fly to the moon and an effective polio vaccine.

If you agree that The Future consists of a variety of alternatives, that choice is unavoidable and that refusing to choose is itself a choice, you have taken the first step toward a more active role in your own future. You can learn more by sending for a free brochure about the critical issues we face in The Future and a bibliography for further reading. Write:
Champion International Corporation
Dept. 200A, P.O. Box 10140
Stamford, Connecticut 06921

**Champion—
a forest products company with its roots planted firmly in the future.**

We are in the forest products business. We plant trees, grow trees, harvest trees. And from trees we make wood building products. Plus fine paper for printing and business. And paper packaging for shipping and selling.

Because we make our living from the forest, our success depends, in one way or another, on the future. And we're planning—and planting—for it.

Champion
Champion International Corporation
Planting seeds for the future

THE 1980 FIAT SPIDER 2000. A RARE 14TH EDITION OF A CLASSIC.

ORIGIN OF A CLASSIC SPECIES:
OUR 1933 BALILLA SPIDER. ITS BODYWORK SET THE PATTERN FOR FIAT SPORTS CARS TO COME.

The sports car was born in Europe.

And Fiat has traditionally made some of Europe's most beautiful sports cars. Like our classic Spider designed by Pininfarina.

Introduced in 1966 and continually refined over the years, the Spider has been hailed by Road & Track as "the best of the vintage breed of roadsters."

And the 1980 Spider 2000 is even better.

SPIDER 2000. REFINED FROM ENGINE TO AERODYNAMICS.

The 1980 Fiat Spider 2000 has a DOHC 2-litre engine. Optional leather interiors, color-coordinated with its exteriors. An optional automatic transmission. And improved aerodynamics for optimal fuel efficiency. So unlike most sports cars today, it gets the kind of mileage you need today.

SPIDER 2000. FRUGAL, NOT FRIVOLOUS, WITH GAS.

Consider the Spider 2000's mileage. Remember: compare this estimate to the estimated MPG of other cars. You may get different mileage depending on speed, weather, and trip length. Actual highway mileage will probably be less and mileage varies in California.

22 EPA EST MPG / 32 EST HWY

But the most beautiful thing about the Spider 2000 is simply the exhilarating fun of driving one.

For name of nearest dealer or overseas delivery information, call (800) 447-4700 or in Illinois (800) 322-4400. Specifications subject to change without notice.

FIAT

MOTOR CARS IN THE GREAT EUROPEAN TRADITION.

MATHEMATICAL GAMES

Fun with eggs: uncooked, cooked and mathematical

by Martin Gardner

Not quite
spherical
White
Oddly closed
And without a lid
—MAY SWENSON

Thus begins "At Breakfast," eight whimsical stanzas about cracking and eating a soft-boiled egg in the Continental tradition. The poem continues: "A smooth miracle / here in my hand / Has it slid / from my sleeve? / The shape / of this box / keels me oval."

Is there any natural and simple sculpture that pleases the eye and the hand more than a chicken egg? One end of the object is more pointed than the other, and the delightful oval shape varies widely from egg to egg. The shape of a chicken egg can be simulated mathematically by a host of closed curves with different low-degree formulas. The simplest curve is the oval of Descartes, a family of egg-shaped ovals discovered by the 17th-century French mathematician and philosopher. Just as an ellipse can be constructed easily with two pins and a piece of thread, so can certain Cartesian ovals.

The illustration at the right shows how an ellipse is drawn by keeping taut a triangular loop of thread (nylon is best because it minimizes friction) as a pencil point traces the curve. Because the sum of *AP* and *BP* in the illustration cannot vary, the method ensures that the curve is the locus of all points the sum of whose distances from the two foci *A* and *B* is a constant.

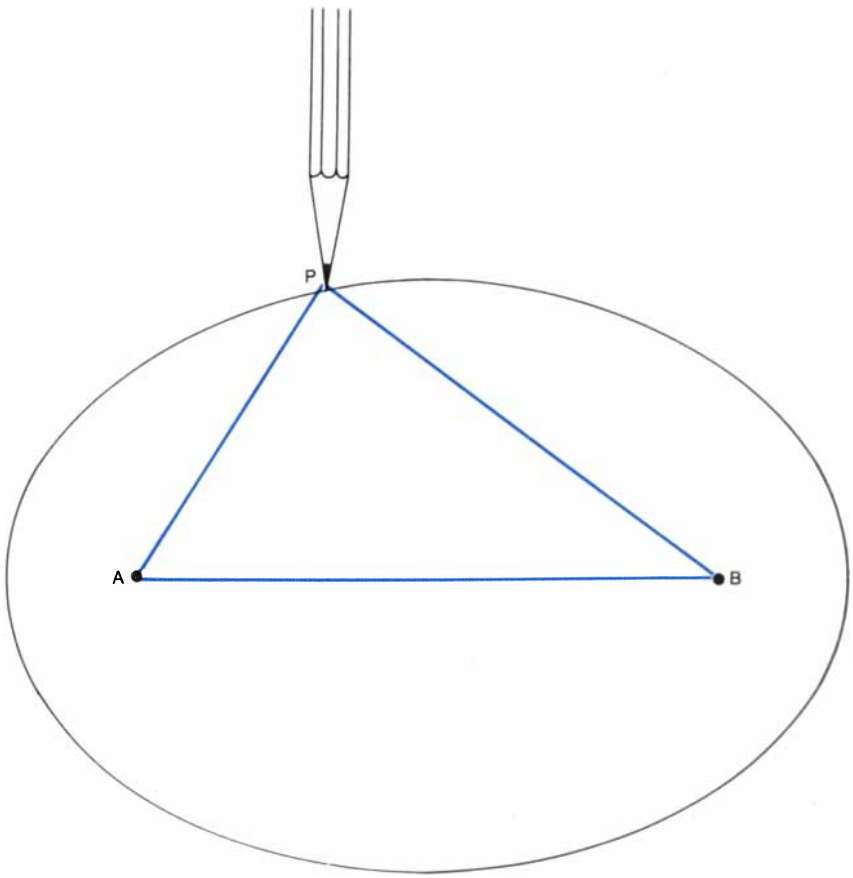
The top illustration on the next page shows how a Cartesian oval can be generated by a similar method. Here the thread is looped once around the pin at *B* and attached to the pencil point. By keeping the thread taut the upper half of the oval can be drawn. The lower half of the oval can be constructed by the same procedure with the thread arrangement inverted.

This method obviously generates a curve that is the locus of all points such that their distance from *A* added to twice their distance from *B* is a constant. Descartes generalized the curve by letting the constant be the sum of *m* times the distance from *A* and *n* times the distance from *B*, where *m* and *n* are real numbers. The ellipse and the circle are special cases of Cartesian ovals. In the ellipse *m* equals *n*, and *n* equals 1. The circle is an ellipse in which the distance between the foci is zero.

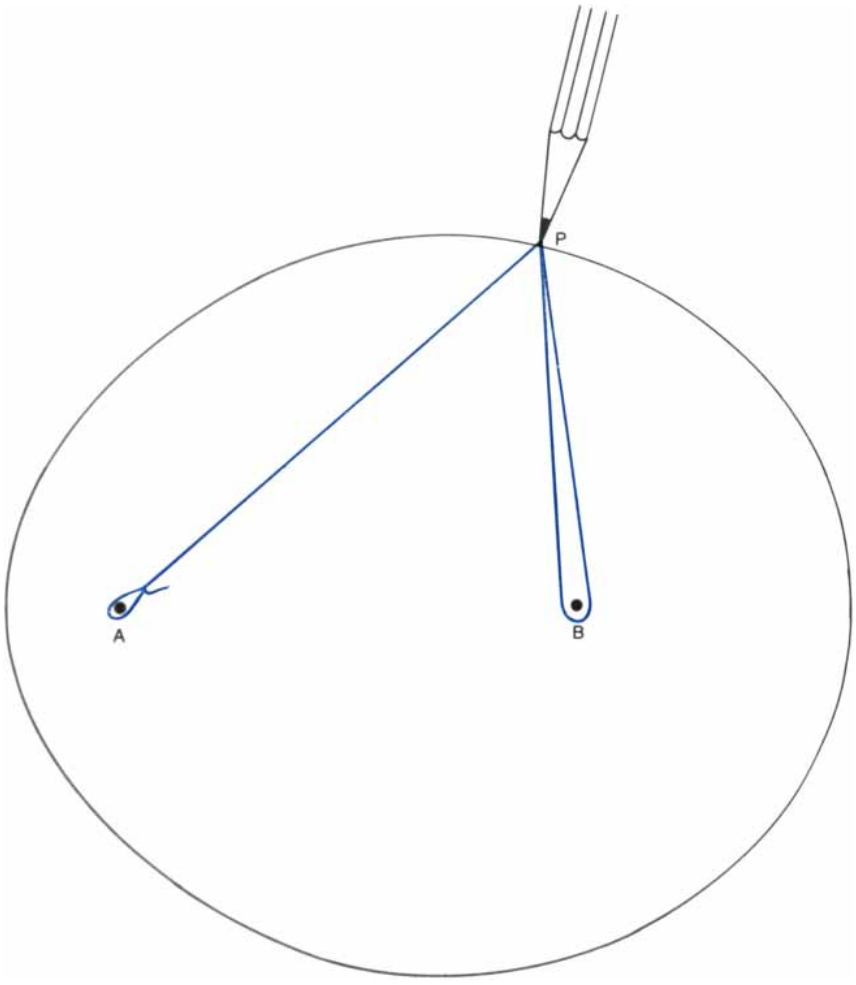
In the oval in the illustration *m* equals 1 and *n* equals 2. By varying the distance between the foci, by changing the length of the thread or by doing both, it is possible to draw an infinite number of Cartesian ovals all with multipliers in the ratio 1 : 2. The bottom illustration on the next page shows how to construct a family of Cartesian ovals with multipliers in the ratio 2 : 3. Here one focus lies outside the oval. Of course, the thread technique works only if *m* and *n* are positive integers and are small enough to ensure that the looping of the thread does not generate too much friction.

Many eminent physicists, including Christiaan Huygens, James Clerk Maxwell and Isaac Newton, were fascinated by Cartesian ovals because of their unusual optical properties of reflection and refraction. In 1846 the Royal Society of Edinburgh heard Maxwell's paper "On the Description of Oval Curves and Those Having a Plurality of Foci." The Scottish physicist had independently discovered the ovals of Descartes. He went further, however, in generalizing them to curves with more than two foci. Maxwell did not present the paper to the society himself because as he was only 15 he was considered too young to appear before such a distinguished audience! (Young Maxwell's paper is included in the Dover reprint *The Scientific Papers of James Clerk Maxwell.*)

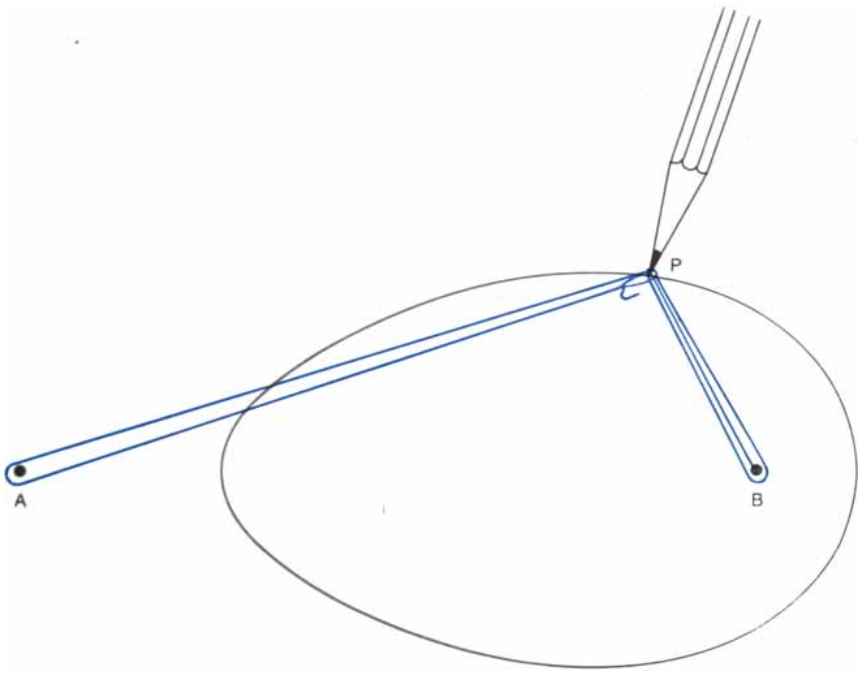
Among the many other ovals that resemble eggs, more rounded at one end than the other, are the well-known ovals of Cassini. A Cassini oval is the locus of all points the product of whose distances from two fixed points is a constant. Not all Cassini ovals are egg-shaped,



The ellipse: **AP + BP** *is constant*



Cartesian oval: $1(\mathbf{AP}) + 2(\mathbf{BP})$ *is constant*



Cartesian oval: $2(\mathbf{AP}) + 3(\mathbf{BP})$ *is constant*

but when they are, they come in pairs that point in opposite directions.

The physical properties of chicken eggs make possible a variety of entertaining parlor tricks. Because this is April, and Easter falls in April this year, eggs should now be uncommonly easy to find. If you try the following eggsperiments, you will find them both amusing and scientifically instructive.

Surely the oldest of all tricks with eggs is making a raw egg stand on end. Christopher Columbus is said to have done it by setting the egg down firmly enough to crush its bottom end slightly. A neater solution is to put a small quantity of salt on a white table top, balance the egg on the salt and then gently blow away all but the few invisible salt grains that keep the egg upright. (For details about Piet Hein's supereggs, solid forms that balance on end without any skulduggery, see Chapter 18 of my *Mathematical Carnival.*)

In fact, on an unsmooth surface such as a sidewalk or a tablecloth it is not difficult to balance a raw chicken egg on its broad end with the aid of only patience and a steady hand. Now and then the practice becomes a local mania. For example, the April 9, 1945, issue of *Life* described an egg-balancing craze that had hit Chungking. According to a folk belief in China, eggs balance more easily on Li Chun, the first day of spring in the Chinese calendar.

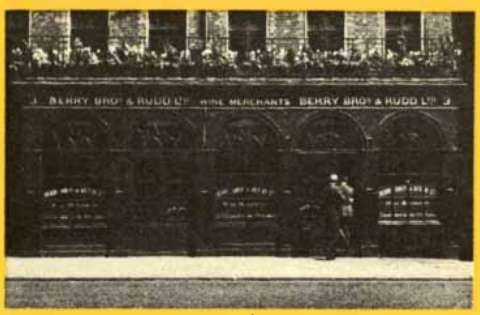
In the top illustration on page 22 there is a marvelous old egg-balancing stunt with a cork, a bottle and two forks. Hollow out one end of the cork so that it fits snugly on the egg. The forks should be long ones with heavy handles, and the rim of the bottle should be flat like that of most soft-drink bottles. Even so, it may take many minutes to make a stable structure. Because the egg may fall a few times before you balance it try a hard-boiled egg rather than a raw one. Once the precarious balance is achieved it will seem mysterious to anyone who is not familiar with physical laws about the center of gravity.

Egg balancing is the secret of winning an old puzzle game. The game calls for a large supply of nearly identical eggs. Two players take turns putting an egg on a circular or square table. The loser is the player who is unable to put down an egg without moving another one. The first player can always win by standing the first egg on its end at the center of the table. On his subsequent turns he puts an egg symmetrically opposite wherever his opponent puts one.

Because the inside of a raw egg is viscous the inertial drag of the liquid makes it difficult to spin the egg on its side and impossible to spin it on its end. This provides a quick way of distinguishing a raw egg from a hard-boiled

IT TOOK A WINE MERCHANT TO BLEND A SCOTCH THIS PLEASING TO THE PALATE.

Ever since the late 1600's, Berry Brothers & Rudd, Ltd. have affixed their personal label to some of the world's most expensive and pleasing potions. And their shop in London has attracted a parade of peers, poets and prime ministers to its door.



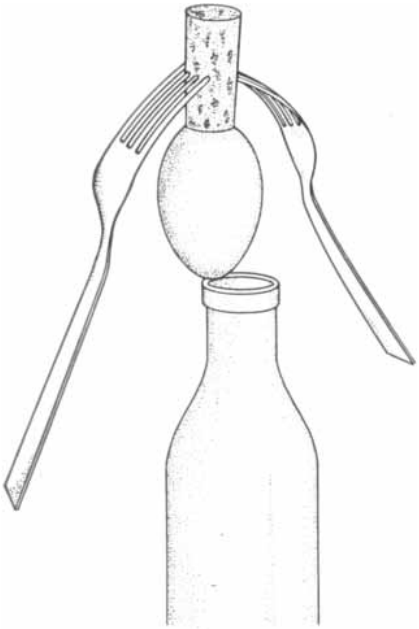
Lords tippled here.

Naturally, when Berry Brothers & Rudd created a Scotch Whisky, they blended it to meet the expectations of noble tastes. The result was Cutty Sark Scots Whisky. A Scotch of uncommon breeding and distinctive smoothness.

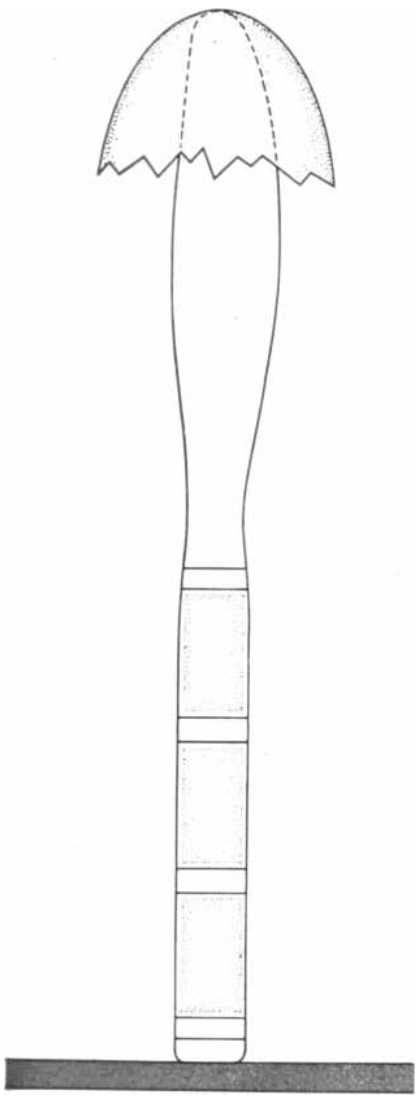
Today, you can obtain Cutty Sark from your neighborhood spirits merchant, secure in the knowledge that it will live up to its heritage. You'd expect no less from the people who provided Napoleon III with claret, Beau Brummel with chambertin, and Lord Byron with port.

CUTTY SARK

"CUTTY SARK" "CUTTY" THE CUTTY SARK LABEL AND THE CLIPPER SHIP DESIGN ARE REGISTERED TRADEMARKS OF BERRY BROS. & RUDD LTD. LONDON, ENGLAND
86 PROOF BLENDED SCOTCH WHISKY DISTILLED AND BOTTLED IN SCOTLAND. IMPORTED BY THE BUCKINGHAM CORPORATION, NEW YORK, N.Y.



How to balance an egg on a bottle



How to break an eggshell by a knife's inertia

one: only a hard-boiled egg can be spun on its end. The following stunt with a raw egg is less familiar. Spin the egg on its side as fast as you can, then make it come to a dead stop by pressing it with a fingertip. Quickly remove your finger. The inertia of the rotating interior will start the egg slowly turning again.

Charlie Miller, a magician friend of mine, likes to do a surprising trick with a hard-boiled egg. He explains that the egg can spin on its side (he spins it gently on its side) and also can spin on its end (he demonstrates that) but that only a magician can make it undergo both kinds of rotation in the course of a single maneuver. At that point he spins it vigorously on its side. Most eggs (particularly ones that were kept upright during boiling) will rotate for a while and then suddenly assume a vertical spinning position. (You will find this explained in the Dover reprint *Spinning Tops and Gyroscopic Motion: A Popular Exposition of Dynamics of Rotation,* by John Perry, and in "The Amateur Scientist," by Jearl Walker, SCIENTIFIC AMERICAN, October, 1979.)

The most remarkable of all egg-spinning tricks is hardly ever done, probably because it takes much practice and is easier to learn from someone who can do it than from printed instructions. You will need a dinner plate with a flat rim. From the shell of an opened egg break off a piece roughly the size of a half-dollar. It will be ragged at the edge and it should come from the egg's side, not its end.

Dip the plate in water, put the piece of shell on the edge of the flat rim and tip the plate at the angle shown in the illustration on page 24. The shell should start to rotate. If you now turn the plate in your hands while keeping it at the same angle, the shell will spin with surprising rapidity as it travels precariously around the wet rim. To get it right you may have to try different pieces of shell until you find one with the proper balance and convexity. Once you acquire the knack you will easily be able to demonstrate this amazing juggling feat whenever you want. Although the trick is described in old conjuring books, few magicians seem to know about it.

Inertia is the secret behind the following bet. Get a kitchen knife with a sharp point, hold it vertically and hang half an eggshell over the point as is shown in the bottom illustration at the left. Give the knife to someone and challenge him to puncture the shell by rapping the handle on a table or kitchen counter. Each time he tries the shell will bounce off unharmed, whereas you can crack it at will. The secret is to hold the blade loosely in your hand. Make it look as if you rap the handle on the counter when in fact you allow the knife to fall by its own weight so that it hits the counter and bounces. The imperceptible bounce sends the knife point through the shell.

The intact shell surrounding a raw egg is remarkably strong. Many people know that if you clasp your hands with an egg between them, each end touching the center of a palm, it is almost impossible to break the egg by squeezing. What is not so well known is the difficulty of smashing a raw egg by tossing it high into the air and letting it fall onto grass. The May 18, 1970, issue of *Time* described a flurry of such experiments that took place at Richmond in England after the headmaster of a school did it for his students. A local fireman dropped raw eggs onto grass from the top of a 70-foot ladder. Seven out of 10 survived. An officer in the Royal Air Force arranged for a helicopter to drop eggs from 150 feet onto the school's lawn. Only three out of 18 broke. *The Daily Express* hired a Piper Aztec to dive-bomb an airfield with five dozen eggs at 150 miles per hour. Three dozen of them were unharmed. When eggs were dropped into the Thames from Richmond Bridge, three-fourths of them shattered. That proved, said the school's science teacher, "that water is harder than grass but less hard than concrete."

The fragility of an egg when it falls onto a hard surface is the subject of the old nursery rhyme about Humpty-Dumpty and its retelling by Lewis Carroll in *Through the Looking-Glass.* It is also involved in the following practical joke. Bet someone a dime that he cannot put a thumb and finger through the crack of a door above the top hinge and hold a raw egg for 30 seconds on the other side of the crack. As soon as he firmly grasps the egg, put his hat on the floor directly below the egg, walk away and forget about him.

The best of all scientific tricks with an egg is the well-known one in which air pressure forces a peeled hard-boiled egg into a glass milk bottle and then forces it out again undamaged. The mouth of the bottle must be only slightly smaller than the egg, and so you must be careful not to use too large an egg or too small a bottle. It is impossible to push the egg into the bottle. To get the egg through the mouth you must heat the air in the bottle. That is best done by standing the bottle in boiling water for a few minutes. Put the egg upright on the mouth and take the bottle off the stove. As the air in the bottle cools it contracts, creating a partial vacuum that draws the peeled egg inside. To get the egg out again invert the bottle so that the egg falls into the neck. Place the opening of the bottle against your mouth and blow vigorously. This will compress the air in the bottle. When you stop blowing, the air expands, pushing the egg through the neck of the bottle and into your waiting hands.

Many old books suggest the following elaboration using a hard-boiled egg with its shell in place. Soak the egg for a few

IF YOU WEREN'T BLESSED
WITH A PERFECT MEMORY.

impromptu™

IMPROMPTU. The world's smallest, most convenient voice recorder. State-of-the-art technology in its most elegant expression. Ultra-thin, featherweight. Impromptu is the Norelco® recorder that's small enough to go wherever there's a big idea. For information, call 800-645-7290. In New York State, call 800-632-7522.

Norelco®

hours in heated vinegar until the shell becomes pliable. Put the egg into a bottle by the method described above and let it soak overnight in cold water. The shell will harden. Pour out the water and you have a curiosity with which to puzzle friends. It happens, however, that I have never been able to make this work. The shell does soften, but it also seems to become porous, which prevents a vacuum from forming. (I would be interested in hearing from any reader who can tell me how to get the vinegar-treated egg into the bottle.) Regardless of whether or not the feat works, the failure to perform it is central to one of Sherwood Anderson's funniest and finest short stories. It is called "The Egg." You will find it in his book *The Triumph of the Egg*.

The story is told by a boy. His parents, who formerly owned a miserable chicken farm, have bought a restaurant across the road from the railway station at Pickleville, a place not far from Bidwell, Ohio. The father fancies himself a showman. One rainy night the only customer in the restaurant is Joe Kane, a young man who is waiting for a late train. The father decides to amuse him by performing his favorite egg trick.

"I will heat this egg in this pan of vinegar," he says to Joe. "Then I will put it through the neck of a bottle without breaking the shell. When the egg is inside the bottle, it will resume its normal shape and the shell will become hard again. Then I will give the bottle with the egg in it to you. You can take it about with you wherever you go. People will want to know how you got the egg in the bottle. Don't tell them. Keep them guessing. That is the way to have fun with this trick."

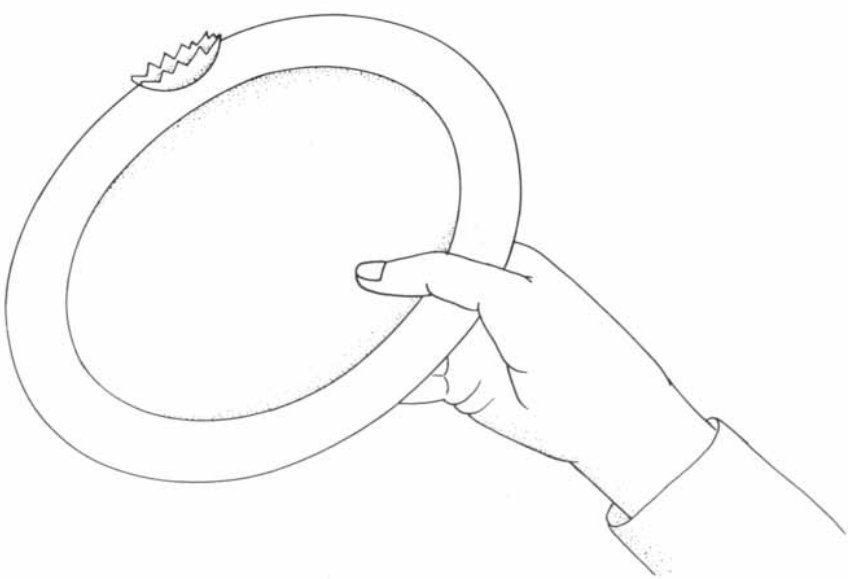
When the father grins and winks, Joe decides the man is crazy but harmless. The vinegar softens the egg's shell but the father forgets an essential part of the trick. He neglects to heat the bottle.

"For a long time he struggled, trying to get the egg to go through the neck of the bottle.... He worked and worked and a spirit of desperate determination took possession of him. When he thought that at last the trick was about to be consummated, the delayed train came in at the station and Joe Kane started to go nonchalantly out at the door. Father made a last desperate effort to conquer the egg and make it do the thing that would establish his reputation as one who knew how to entertain guests who came into his restaurant. He worried the egg. He attempted to be somewhat rough with it. He swore and the sweat stood out on his forehead. The egg broke under his hand. When the contents spurted over his clothes, Joe Kane, who had stopped at the door, turned and laughed."

Roaring with anger, the father grabs another egg and hurls it at Joe, just missing him. Then he closes the restaurant for the night and tramps upstairs, where his wife and son have been awakened by the noise. There is an egg in his hand and an insane gleam in his eyes. He gently puts the egg on the table by the bed and begins to cry. The boy, caught up in his father's grief, weeps with him.

Good stories have a way of turning into allegories. What does the egg represent? I think it is nature, the Orphic Egg, the vast world that is independent of our minds, under no obligation to conform to our desires. Understand its mathematical laws and you can control it to an incredible degree, as modern science and technology testify. Fail to understand its laws or forget them or ignore them and nature can be as malevolent as Moby Dick, the white whale, or the white egg in Anderson's tragedy.

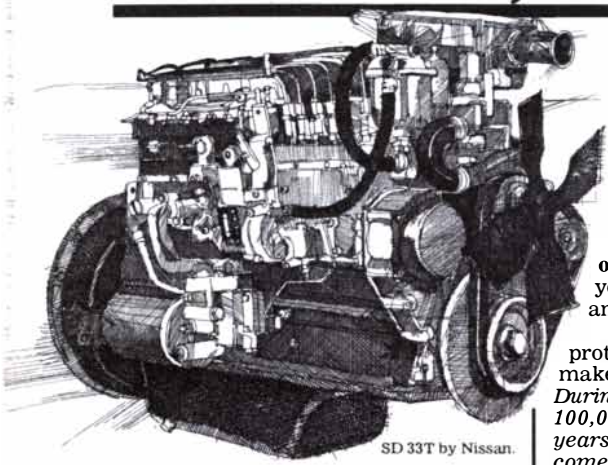
An egg is an egg is an egg. It is a small



How to spin an eggshell on the rim of a plate

FIGHT BACK AGAINST RISING GAS COSTS.

SCOUT® INTRODUCES THE WORLD'S FIRST TURBOCHARGED DIESEL WITH A 100,000 MILE WARRANTY.



SD 33T by Nissan.

The new International Scout Turbo-Diesel engine gives you all the economy and dependability of a diesel with startling acceleration. Power to pass. Extra power when you want it...and need it most.

Scout Turbo-Diesel fuel economy:

22 EPA EST MPG 24 EST HWY MPG

Remember use estimated mpg for comparison only. Mileage varies with speed, weather, trip length and your use of 4WD. Actual highway mileage will probably be less.

Diesel engines never need costly tune-ups, because they have no spark plugs or distributor points. Diesel dependability is unsurpassed. Many International Harvester truck engines getting 250,000 miles and more. Add turbocharging and you get the best mileage of any American 4-wheeler.

The warranty that separates our Turbo-Diesel from the Mercedes 300SD.

There's a promise that separates the Scout Turbo-Diesel not only from the Mercedes 300SD but from every other diesel car engine in the world. Our exclusive 100,000 mile engine warranty. *During the first 100,000 miles, or 5 years (whichever comes first), International® Scout will repair or replace without charge for parts or labor any part of the engine block and all internally-lubricated engine components which are defective.**

Every Scout engine is a 100,000 mile engine. From our 196 cubic-inch four cylinder to our 304 cubic-inch and 345 cubic-inch V-8's.

The anti-corrosion warranty that separates Scout from ordinary cars. Scout gives you five years with no-rust-through. Clean and simple.

Our extensive 4-step rust-protection process lets us make this promise: *During the first 100,000 miles, or 5 years (whichever comes first), International Scout will repair or replace any vehicle body component which suffers "perforation" due to corrosion without charge for parts or labor.**

Quality and security go hand-in-hand.

Our built-in quality will give you a sense of well-being you may never experience in an ordinary car. It's a secure feeling of sitting in a vehicle that surrounds you with protective steel.

In a Scout you sit higher than a car. A vantage point that lets you see the road ahead more clearly and avoid trouble more easily.

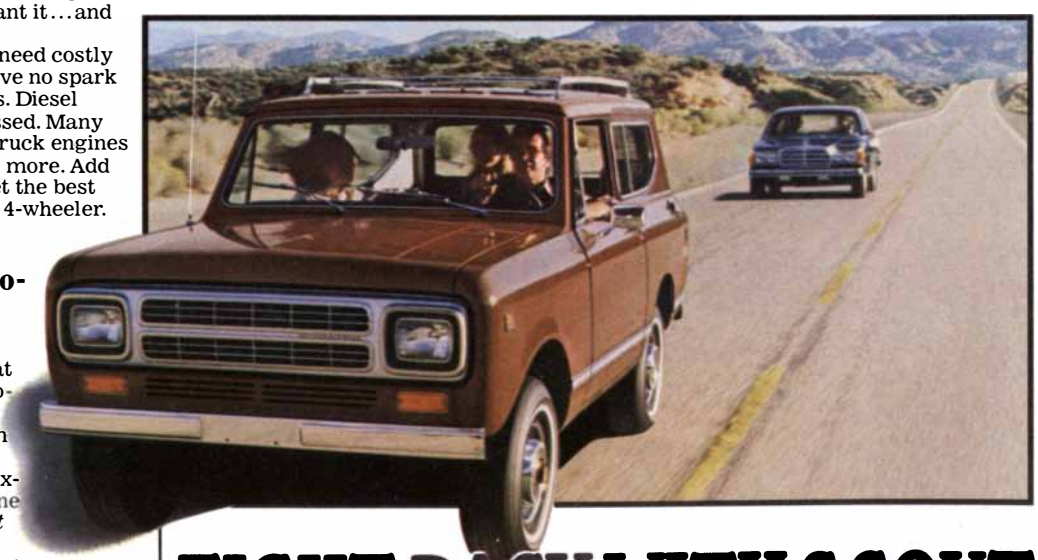
Then there's our selective 4-wheel drive. It gives you the option of easily shifting from economical 2-wheel drive to 4-wheel drive, for extra stability and traction when the road or the weather looks rough.

How to fight back.

Before you even consider buying an ordinary car, test drive a 1980 Scout. It's as easy as dialing 800-IH-SCOUT for your local Scout dealer.

Dial Toll-Free **800·IH·SCOUT**
Illinois Residents 800-322-0821

INTERNATIONAL HARVESTER



FIGHT BACK WITH SCOUT.

Anything less is just a car.

*Warranties are non-transferable, and assume customer's proper care and maintenance. See your dealer for details.

GRAND AWARD. THE ONLY 12 YEAR OLD CANADIAN WHISKY.

12 years. That's how long this Canadian whisky takes.

12 years to allow a blend of the finest whiskies to marry perfectly. To achieve an unrivaled smoothness. And an absolutely remarkable richness of taste.

Grand Award. No other Canadian whisky tastes like it.

No other is presented at 90.4 proof.

And in the tradition of items of rare and exceptional quality, *only a limited amount of Grand Award is available each year.*

physical thing with a beautiful geometrical surface. It is a microcosm that obeys all the laws of the universe. And at the same time it is something far more complex and mysterious than a white pebble. It is a strange lidless box that holds the secret of life itself.

Neatly
The knife scalps it
I scoop out
the braincap
Soft
Sweetly shuddering

Which is more important, the chicken or the egg? Is the hen, as Samuel Butler said, no more than an egg's way of making another egg? Or is it the other way around?

"I awoke at dawn," Anderson's narrator concludes his account of human failure, "and for a long time looked at the egg that lay on the table. I wondered why eggs had to be and why from the egg came the hen who again laid the egg. The question got into my blood. It has stayed there, I imagine, because I am the son of my father. At any rate, the problem remains unsolved in my mind. And that, I conclude, is but another evidence of the complete and final triumph of the egg—at least as far as my family is concerned."

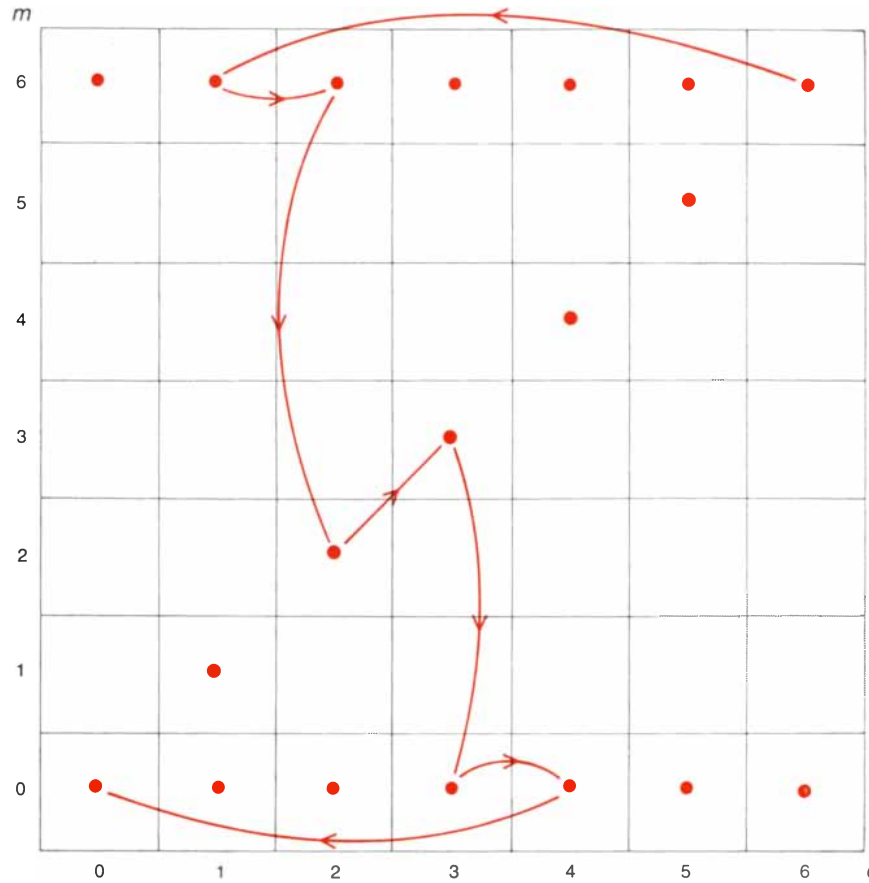
Here are the answers to last month's digraph problems:

The unique Hamiltonian circuit is found by starting at *A* and following a directed path that spells AMBIDEXTROUS. One more step joins *S* to *A*, honoring *Scientific American*.

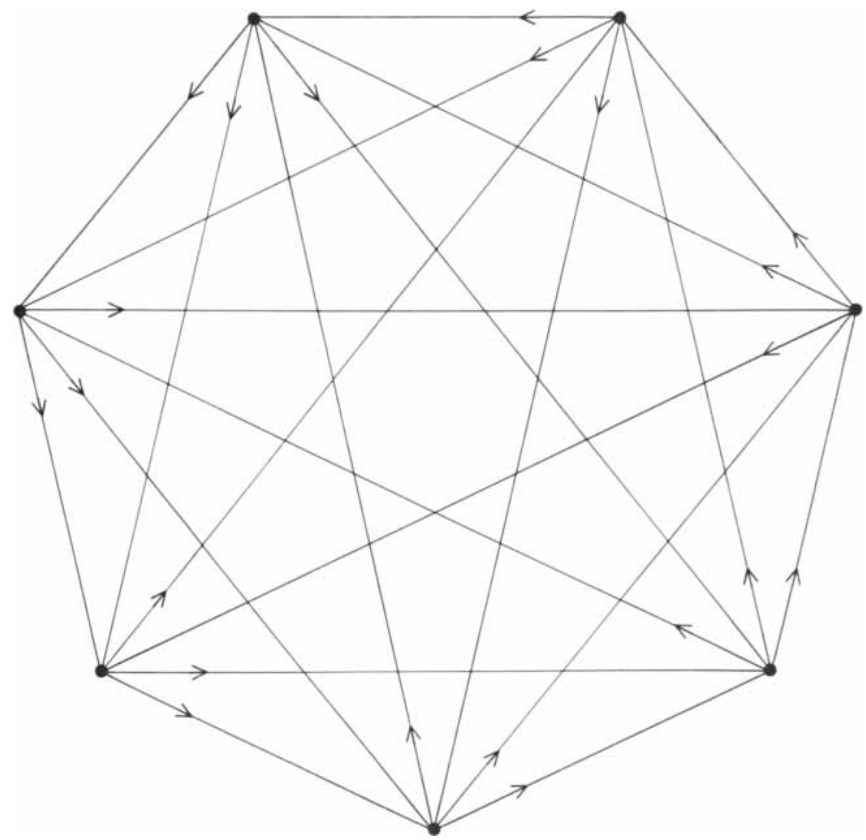
The top illustration at the right is a digraph for one of many seven-step solutions to the problem of six missionaries and six cannibals who want to cross a river safely in a boat that holds five.

The Paul Erdös problem is solved by placing arrows on the complete graph for seven points as is shown in the bottom illustration at the right. Of course, the points and their connecting lines can be permuted in any way to provide solutions that do not appear in this symmetrical form, but all such solutions are topologically the same. See "On a General Problem in Graph Theory," by Paul Erdös in *The Mathematical Gazette* (Vol. 47, No. 361, pages 220–223; October, 1963).

Benjamin L. Schwartz pointed out that the impossibility proof for the counter-jumping puzzle in the January column continues to hold even when the allowed moves are extended to include diagonal jumps or even a chess bishop's moves of any length. In last September's column I stated incorrectly that the run of seven 3's in the decimal expansion of pi begins with digit 710,150. Robert Baillie was the first to send the correct digit, 710,100, which was later confirmed by Harry Nelson.



A seven-step solution to last month's problem about missionaries and cannibals



The answer to Paul Erdös' third-town problem

BOOKS

Artificial gems, cave paintings, chemical contraceptives, coral and a Darwin reader

by Philip Morrison

MAN-MADE GEMSTONES, by D. Elwell. Halsted Press, a division of John Wiley & Sons ($44.95). GEMSTONES OF THE WORLD, by Walter Schumann. Translated by Evelyne Stern. Sterling Publishing Co. Inc. ($12.95). Unseen utilitarian single crystals of silicon grown by man, crystals in which the lattice is repeated virtually without interruption, are everywhere now in this world of digital electronic devices. But showy, hard, natural single crystals have for a very long time been prized, traded, laboriously worked, even sung. It was clear that the advancing human understanding of crystal growth would lead to a lively technology of man-made gemstones, precious stones fit for elegant faceting by the lapidary, not mere glassy visual simulations or other imitations but synthetic crystals, sharing the very atomic structure of the natural rarities.

From the beginning of the 19th century, when chemists came to understand the chemical nature of emerald and ruby, they tried to crystallize such gems out of solutions of high-melting-point alumina in lower-melting solvents: "fluxes" of various kinds. Small rubies were made first in 1837 by Marc Gaudin. By 1890 several efforts at emerald and ruby growth had succeeded, but none yielded crystals large enough to admire, or even to work economically for jeweled bearings. In about 1886 there appeared on the market a new type of ruby crystal, dubbed Geneva ruby; its precise origin remains a mystery. Tiny bubbles gave away the general method used; the rubies had been grown under a gas flame hot enough to fuse the material. In 1969 careful experiment proved that the Swiss producers had used a clever multitorch process, beginning with a fine powder. (There is a corroborating account collected in 1953 from a man who said he had grown Geneva rubies in his youth.)

Nowadays the dominant producer of flame-fusion corundum (one Japanese firm and the Russian bloc apart) is the Djeva company at Monthey in Switzerland. A photograph in Dennis Elwell's *Man-made Gemstones* shows the company's long lines of flame furnaces, which account for some 60 tons of corundum crystals per year, mostly for instruments but including a small fraction of gemstones in dozens of ruby and sapphire hues, carefully controlled by the right additive. The location on Lake Geneva offers cheap hydroelectric power for the economical production of oxygen and hydrogen for the flames. The company was founded by Hrand Djevahirdjian, himself once a maker of Geneva rubies in Paris as the past century turned. Star stones, their elegant asterisms the result of aligned needles of dissolved aluminum titanate, are made by adding rutile (titanium dioxide) to the aluminum powder under the torch. By careful periodic control of the flame temperature the star effect is made to occupy the entire width of the stone. ("Only rarely do natural star stones compare in sheer visual impact with their man-made counterparts.") The synthetic star stone is very popular in the U.S.; developed by the Linde Division of the Union Carbide Corporation just after World War II, the process was patented. Patents expired, and Linde left the star-stone trade, which is now probably also the province of Djeva.

Diamond is plainly the most desired of gems. A great burning glass destroyed adamant before the astonished eyes of the Florentine academy in 1694, and by the end of the 18th century Smithson Tennant had shown quantitatively that diamond was nothing but carbon, like so much weight of soot. Would-be diamond synthesizers abounded, but they did not succeed. Among them was James Hannay, who reported success in a dramatic paper to the Royal Society of London in 1880. His few tiny diamonds were skeptically received. An exhibit labeled "Hannay's diamonds" found much later in the British Museum turned out to be natural diamonds substituted for Hannay's products, by whose hand is not known. His sealed tubes of wrought iron in which hydrocarbons were heated with lithium, to allow crystallization from solution, could not have generated adequate pressure for diamond synthesis.

Henri Moissan (a Nobel-prize winner in 1906, but for the isolation of fluorine, not for his diamonds) tried the effect of pressures generated by the sudden quenching of a melt of carbon dissolved in molten iron. His tiny crystals also seem doubtful, although nothing of them remains, not even photographs. Sir William Crookes, working with explosives, and Sir Charles Parsons, the inventor of the steam turbine, firing a rifle against a graphite target within a heavy block, both announced success. Parsons' products were independently tested in 1928 and found wanting. It is easy to find small resistant mineral grains after any such complex preparation has been dissolved away. The pioneer of modern, rational high-pressure physics, Percy Bridgman of Harvard, tried his hand but failed like all the rest "to solve this glittering problem."

Success came in the middle 1950's. Both General Electric and the Swedish company ASEA succeeded by applying a pressure of 100,000 atmospheres, a temperature of about 2,000 degrees Kelvin and a catalyst, say molten iron, to dissolve the graphite. (You can start with almost any organic stuff, even peanut butter.) Today a worldwide industry synthesizes about half of all industrial diamond, some 10 tons per year. Such submillimeter stones grow in a couple of minutes at pressure. Gem diamonds can be made, but gem quality imposes slow growth rates. Gem size therefore requires a long time at pressure: some days. The cost is high and is said not to be competitive in the elaborately controlled market of the gem-diamond trade. The purest diamonds in the world are the General Electric stones given to the Smithsonian, the largest one about a carat.

Synthetic emeralds have been made for almost a century, by crystallizing them very slowly out of a solution of the constituent oxides of beryllium, aluminum and silicon (plus the essential greening impurity, one part in 1,000 of chromium). They were small. To grow a few large crystals instead of many small ones a long study produced what were called I.G.-meralds, developed at I. G. Farbenindustrie between the wars. The trick was to force a reaction within the dissolving flux, floating one constituent on the melt. Slow growth then feeds the few sites where the reaction first began. A good emerald may take a year.

The mix of innovative materials science and entrepreneurship in this conspicuous yet secretive industry nucleates heroes. Carroll C. Chatham of San Francisco, probably building on I. G. Farben, has made a success of synthetic emeralds for 30 years and more: his "single-handed research had cornered the world market." In the past decade or so his leadership has been shared by

HOW TO BUILD A BOEING.

Skillfull hands mold and shape the creations of modern-day flight.

Case in point: Glen Richer.

Glen was the sculptor of the earliest form given to a complex engineering idea — the 727.

He's also transferred the preliminary thoughts of the first 747, 737, and the new 757 and 767 into three-dimensional reality.

Glen is representative of a tradition of hand-crafting airplanes for airlines all over the world.

The number of parts, pieces, sub-assemblies and components totals well over one million in a single aircraft.

Therefore, it takes thousands of Boeing people to work with the individual metals, wires, plastics, electronics, fiber and synthetics needed to build a jetliner like the 727. For this is a custom business. And every Boeing is unique for every airline.

All of this work is a blend of a dozen complex technologies — engineering, metallurgy, chemistry, physics, cybernetics, anatomy, aerodynamics and a host of computer sciences.

And each phase is integrated by a logistical system that coordinates the work of hundreds of thousands of people in companies all over the world.

The result is a 95-ton machine that can fly near the speed of sound.

A 727 in service for 20 years will fly 25 million miles, make 45,000 takeoffs and landings, and carry 3.5 million passengers to destinations all over the world.

No other people machine can live up to such a lifetime performance record. No car. No truck. No train. No bus. Nothing else in the world.

THE BOEING FAMILY

Getting people together.

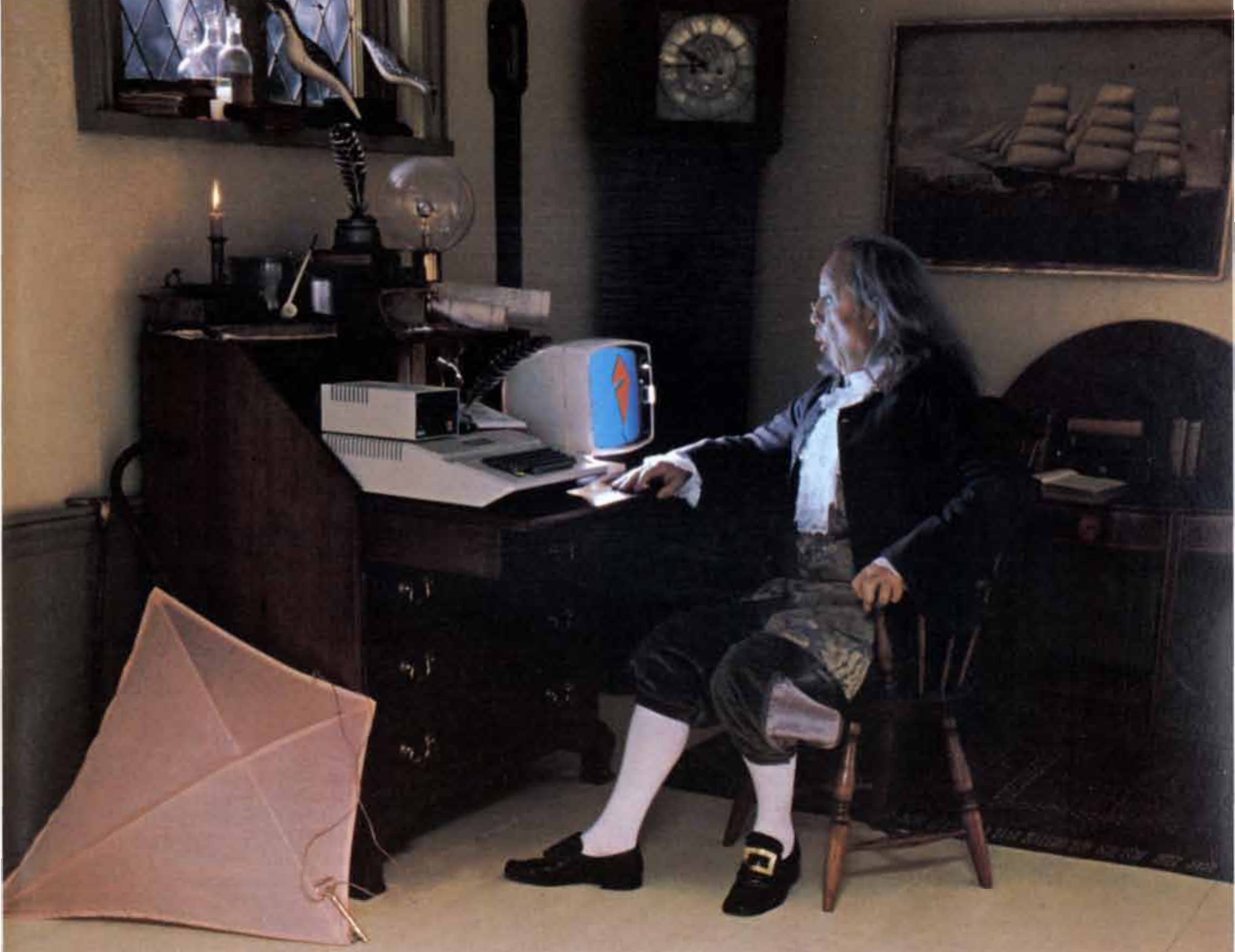
another authentic hero, Pierre Gilson. They have been joined by another producer lately; flux-grown emeralds have a firm place in the market, at about a tenth the cost of the scarce natural gem, and it cannot be doubted that they are genuinely beautiful.

Gilson has gone beyond rational improvement of the old flux-growing of emerald and ruby. He synthesizes opal, turquoise, coral, even the rock gem lapis lazuli. All his products are beautiful. The opal, once its cannonball packing of submicron spheres of silica was established by Australian investigators in the 1960's, was bound to yield to rational effort. Gilson has made fine opals since 1971; the colloidal spheres are not hard to make, probably by precipitation out of solution with careful control of size. It is uniformity of size and stacking that yields the wonderful colors (Bragg refraction scaled to the visible range). It is not easy to tell the best Gilson opals from natural stones of best quality by any secure test, although the fabricated opals sell by the carat at a cost lower by a factor of 10 to 20, a typical price for an excellent synthetic product in any gem. Gilson produces turquoises "in response to a challenge," and not chiefly for commercial gain, Elwell believes, as one demonstration of his mastery. Gilson's coral is in part meant as a measure toward conservation of the natural reefs.

What comes next? Flux-grown garnets, probably in the rare green hue, are a good guess, and perhaps a fine imperial jade. The fibrous texture of jade may daunt the synthesizers; the best-known imitation is a product of S. Iimori of Tokyo. He holds that the task of true synthesis is impossible. The strangely doped garnets of the electronics world may bring quite new gems in new colors to the market. Flux-grown alexandrites, the color-changing form of chrysoberyl (absorption spectra are offered to explain the effects), have been well made (and even patented in 1975) by a pair of Californians of the company Creative Crystals. Alexandrite is fashionable; the man-made stones sell for up to $500 a carat, because the natural sources are all but worked out.

Elwell is himself a renowned crystal grower, at work on the academic frontier of Silicon Valley. He does not forget to include an appendix on how to grow your own rubies, a hobby not to be undertaken lightly. He opts for flux growth. The entire book is admirable, including its many color plates, but its price, more than 23 cents per modest-sized page, is certainly appropriate to the subject.

In the style of a field guide—compact, comprehensive and thoroughly illustrated with about 90 evocative color plates—Walter Schumann's *Gemstones of*



What kind of man owns his own computer?

Rather revolutionary, the whole idea of owning your own computer? Not if you're a diplomat, printer, scientist, inventor... or a kite designer, too. Today there's Apple Computer. It's designed to be a *personal* computer. To uncomplicate your life. And make you more effective.

It's a wise man who owns an Apple.

If your time means money, Apple can help you make more of it. In an age of specialists, the most successful specialists stay away from uncreative drudgery. That's where Apple comes in.

Apple is a real computer, right to the core. So just like big computers, it manages data, crunches numbers, keeps records, processes your information and prints reports. You concentrate on what you do best. And let Apple do the rest. Apple makes that easy with three programming languages—including Pascal—that let you be your own software expert.

Apple, the computer worth not waiting for.

Time waiting for access to your company's big mainframe is time wasted. What you need in your department—on *your* desk—is a computer that answers only to you... Apple Computer. It's less expensive than timesharing. More dependable than distributed processing. Far more flexible than centralized EDP. And, at less than $2500 (as shown), downright affordable.

Visit your local computer store.

You can join the personal computer revolution by visiting the Apple dealer in your neighborhood. We'll give you his name when you call our toll free number **(800) 538-9696**. In California, **(800) 662-9238**.

Apple Computer, 10260 Bandley Drive, Cupertino, CA 95014.

apple® computer

the World (one page is devoted to synthetics) is knowing and attractive. Schumann is a Munich expert; the translation is clear, and the German printers have done very well at a bargain.

SECRETS OF THE ICE AGE: THE WORLD OF THE CAVE ARTISTS, by Evan Hadingham. Walker and Company ($14.95). It is just a century since modern eyes first looked at the painted bisons of Altamira, a decade since the magnificent compilation and effort at analysis of cave art was published by André Leroi-Gourhan, and the archaeologists do not rest. Our attention was drawn within that decade to the value of microscopic study of the engravings, and here in the U.S. we know a little of the remarkable finds that have been made by Soviet workers from the Ukraine to Lake Baikal. This personally written, judicious and well-illustrated volume surveys the topic as a whole in the light of reason rather than iconoclastically. Above all it brings a general reader up to date with the novelties that have emerged in the decade just past.

Evan Hadingham is a young British writer-scholar who has himself worked in the caves of Europe. The 15 chapters take a reader past the time of our very distant forebears, the hominids of the Rift and their kin, to the Mousterians with the Neanderthal label, and then for most of the volume into the Upper Paleolithic. Careful discussion of the ecological and economic issues, comparisons with ethnographic realities today, the details of cave art, painting, sculpture and engraving, and the final fade-out as the forests came back to Europe follow; this is the story of a few hundred centuries. It is Hadingham's special and readable style to put the issues in the form of a struggle among interpretations held by one or another worker in the field, so that the reader emerges with a sense that in prehistory too each generation rewrites the facts to suit the needs of the day, always with a few new documents and a few new ideas.

Most valuable perhaps is the wealth of new material from the French, German and Soviet workers that even the attentive reader of this magazine may have missed. Some taste of that treasure can be given by a quick account of a few new findings. There is a photograph of a model of a hut of the mammoth hunters, dated to about 20,000 years ago, found at Mezherich near Kiev. It was a round hut framed in mammoth bones, the foundation a ring of interlocking jaws. The arching roof supports three dozen tusks, some even joined by an ivory sleeve. Caves are scarce in eastern Europe but mammoths were plentiful. In western Europe the pollen students have made plain the remarkable local diversity of climate even in the time of the ice. In one French site the settlement holds many reindeer bones, but the simultaneous pollen record shows lime trees and hazels, which require temperate conditions. A German site of similar age looked out on a Rhine valley forested in pine, although the plateau above the valley was devoid of trees except for a few birches.

Europe was then a mosaic, not like the unrelieved flat tundra of the present Eskimos or the Siberians. Reindeer were the main source of food for the artists, although the animals are rare in their art. A fascinating discussion develops around the issue of semidomestication, because the long settlement assumed for the painted-cave regions does not fit with the migratory caribou over today's tundra. The answer is not fully in; the most plausible new work, by Derek Sturdy of Cambridge, shows that the reindeer-hunting sites now found, sometimes 500 kilometers apart, can be interpreted as paired summer or winter camps at each end of a long seasonal migration. The scheme is alive in Greenland today: it is "the discreet practice of herd-following, always one step behind the animals, which left them to their own devices as much as possible" but did not lose sight of them for an entire season, thereafter to return or not unpredictably, as the tundra hunters always fear.

In the 1960's there arose a widespread view of the hunters' life as an idyll, free of work and want. It seems more accurate to bear in mind that the key point is apt to be the unusual or even seasonal lean periods, not the seasons of abundance. Even the easygoing !Kung of the Kalahari turn out to be chronically underweight: the dry spring is a hungry season, without their staple food the mongongo nut. The Magdalenians had to work to survive, as far as we can tell; a fine-tuned steady balance is after all not the only rhythm possible for cultures long persistent. Some groups could not have had it easy; the evidence tends to suggest that the handprints of the Gargas cave, with so many missing finger joints, were not the result of curled-up fingers or of retouching. The casts of finger holes found in cave clay also show scarred stumps of fingers. There are various medical causes postulated; none is certain.

Nearly 500 human figurines are now known throughout ice-age Europe. They are not uniform in style, and most of those in western Europe are sexless, hardly support for the view of a universal cult of a pregnant Mother Goddess such as the famous little Venus of Willendorf.

The rock-shelter at La Marche has yielded 1,500 limestone slabs, brought into the shelter from farther up the valley. They are covered with superimposed hairline scratches, which turn out after years of ingenious decipherment by a team led by Léon Pales, published in 1976, to include more than 100 human heads and bodies, "well over a quarter of all the human figures known in Paleolithic art." They are fully human, individualized, caricatured, by no means masterful. A few show sexual intercourse, conventionally, even reticently, rendered. Five sites are now known to hold one or another such "intense and peculiar artistic activity, concentrated on small pieces of stone." In one site the slates used are broken and dispersed, reused "without concern for problems of space and composition." Were they perhaps drawn and redrawn at significant times? Some of the sites lie far from other decorated caves and show mediocre designs.

The slow enrichment of the data has not fulfilled any of the simpler hypotheses. We are looking at a diverse world, its landscapes complex, its cultures differentiated, shifting, by no means isolated from one another. We see 10,000 years illuminated by haphazard flashes that offer snapshot detail for a few days and then darkness again. No wonder our ideas, like the images themselves, are superimposed and tangled. Finally the strong art faded into the striped pebbles and the warring stick figures of the world after the ice. Almost the last of it is found in the cave of Addaura in Sicily, dated to some 11,000 years ago, where an engraved panel outlines a dozen well-drawn, lively human forms, clearly participants in some strange and vividly composed scene.

By 5500 B.C. at the latest the farmers of eastern Europe were working their land, and before 4000 B.C. their way had spread to the Irish Sea. We have grown in number four-hundredfold since the dwindling of the ice. We look back here to a time when human beings were manifestly as subtle as ourselves, albeit few on the face of ice-fringed Europe.

THE POLITICS OF CONTRACEPTION, by Carl Djerassi. With photographs and drawings. W. W. Norton & Co., Inc. ($10.95). At the edge of Silicon Valley are the Steroid Hills, where the pharmaceutical company Syntex has its headquarters, attracted to Palo Alto by the present academic employment of Carl Djerassi. Once he was Syntex' most significant innovator and then its chief of research. Little Syntex S.A., "the small Mexican upstart," rose from the early 1950's to today's big multinational, with a half-billion-dollar-a-year gross. A brilliant group of young chemists there, freely publishing their results to earn a reputation before earning a market, found syntheses first for cortisone and then for a series of increasingly active and orally effective variants on the fe-

More sports: optional 4-wheel power disc brakes—power front disc/rear drum system is all Celica offers.

More luxury: power steering standard. $165 extra on Celica.

More luxury: dual electric remote-control racing mirrors, not available on Celica.

(21) EPA est. MPG/32 highway MPG
When equipped with 5-speed manual transmission. Use the circled EPA estimate for comparison to other cars. Your mileage may vary depending on speed, distance and weather. Actual highway mileage will probably be less. Calif. ests. lower.

Even more sports: bigger radial tires, 195mm of tread vs. 185mm.

More coupe: more overall passenger room, by EPA Interior Roominess Index.

Even more luxury: Sapporo's unique overhead console. A more convenient cluster of digital clock, additional gauges, swivel map light.

Plymouth Sapporo: built by Mitsubishi for Chrysler-Plymouth. The top of the line which in total is Japan's most technologically advanced fleet of passenger cars.

More sports: Sapporo's 2600cc MCA-JET engine. Sportier performance than Celica's 2200cc. Clean air and terrific mileage, too, because a unique jet valve maximizes combustion.

Sports and luxury: Silent Shaft, another Mitsubishi exclusive. Counterbalancing shafts reduce engine vibration for a smooth ride.

PLYMOUTH SAPPORO IS A LUXURY SPORTS COUPE FROM JAPAN, JUST LIKE CELICA EXCEPT SAPPORO HAS MORE LUXURY, MORE SPORTS AND MORE COUPE.

CHRYSLER
Plymouth

Plymouth imports by Mitsubishi. Japan's most technologically advanced passenger cars.

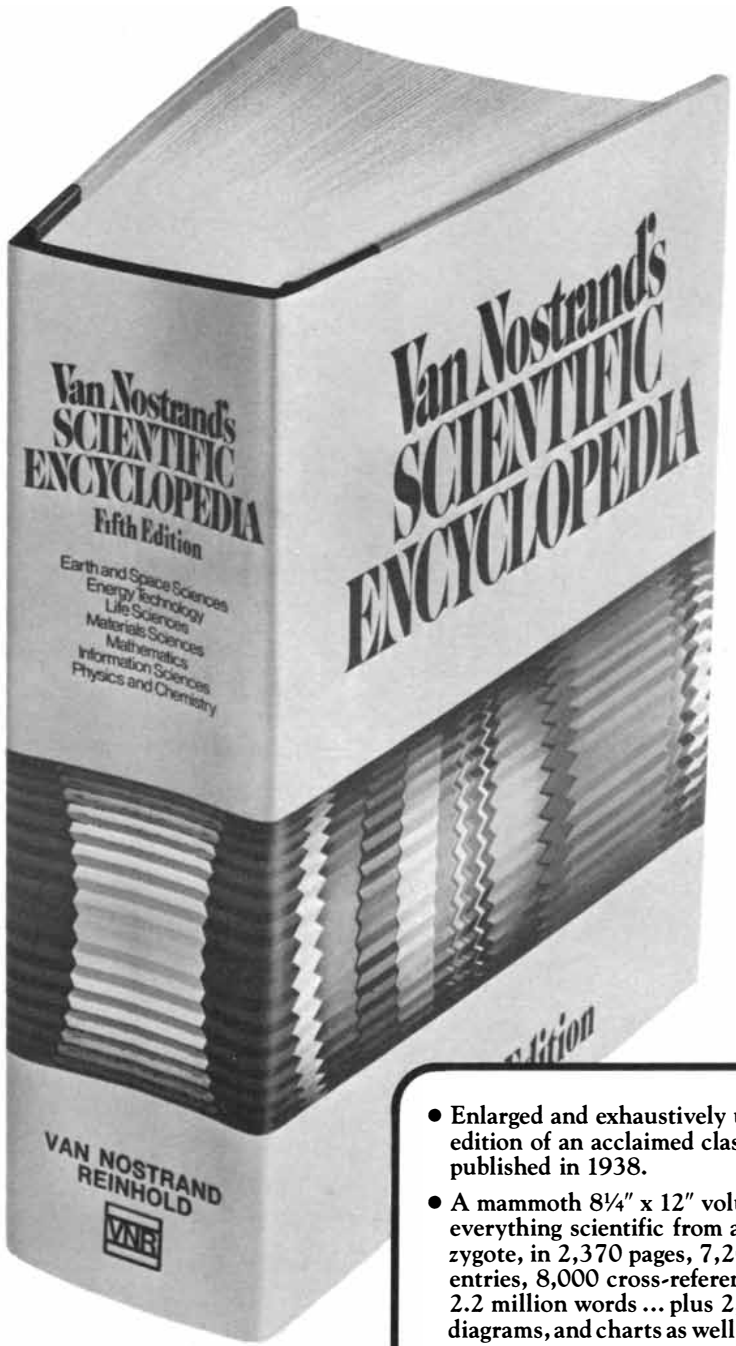
male progestational hormone, derived from a molecular precursor in Mexican jungle yams. Their best product, the first oral-contraceptive chemical, they tradenamed Norlutin. It remains the leading compound for oral contraceptives today worldwide, used by about 30 million women.

The patent has expired, and the author now reports "I was pleasantly amused" to find that the Chinese generic name for their most widely used oral contraceptive is norlutin. (Here are the labels to prove it.) Pill No. 1 is its trade name in China, one "of unsurpassed simplicity." With its use, amid an arsenal of software and hardware techniques, the People's Republic of China had by 1979 reduced the population growth rate to less than 1 percent in a long list of cities and even entire provinces and had announced the goal of bringing about the same outcome nationally by 1980. In the largest country in the world, to be sure "a disciplined people living in a disciplined society," the forebodings of the Reverend Thomas Malthus have been belied again, at least while the economic growth of the country can overmatch that small rate of increase.

The politics signaled in Djerassi's title is on the whole less momentous than what we have just examined. He devotes a few of his lively chapters to old battles of his own: the history of Congressional investigation touching the regulation of pharmaceutical innovation, "the road from laboratory to consumer," and even the response of some constituencies to the social and ethical defects they saw in the Pill, chiefly those flowing from the fact that its side effects, by no means unimportant, fall fully on the female member of a partnership. These confrontations sting our urbane and expert guide, who is of course a singularly successful entrepreneur in the generally oligopolistic world of the big drug companies. He would despair of any innovation such as that of the 1950's, much of it his own work, in the American regulatory and critical climate that can be expected in the 1980's.

The matter seems less than grave; all private reproduction research at the flood cost about $20 million per year (in harder 1969 dollars, to be sure), a volume that one or another form of subvention in the complex grants economy of this big country could well replace. The companies are in fact out of the picture pretty much now, and Government support is flowing, although not always effectively. ("We can expect the taxpayers will spend more and more... and have less and less to show for it.") The in-house Government research effort is inhibited by various constraints of politics, and the contracts let do not add up to a winning strategy. The

The most comprehensive and authoritative scientific reference in the world.



Van Nostrand's Scientific Encyclopedia

a $69.50 value

Yours for only **$2.97**

when you join the Natural Science Book Club for a trial period and agree to take 3 more books—at handsome discounts—over the next 12 months.

Find the answers to virtually *all* your scientific questions, in the new, thoroughly updated and expanded fifth edition of Van Nostrand's SCIENTIFIC ENCYCLOPEDIA. It has been hailed by *The New York Times* as "an amazing job of editing for both the general and scientific reader."

Thousands of photos, diagrams, graphs and charts completely illuminate the ENCYCLOPEDIA's clear and thorough coverage of every scientific field—including archaeology, astronomy, general science, biology, medicine, physics, ethology and meteorology. Whether you're looking for a basic explanation of earthquakes or a comprehensive analysis of nuclear reactors—you'll find it all in Van Nostrand's SCIENTIFIC ENCYCLOPEDIA.

Just as surely, you'll find exactly what you want in the Natural Science Book Club. From the life story of early man to the death of a solar system... from the largest mammals to the invisible kingdom of microscopic organisms... all the wonders of our natural world are revealed.

Begin enjoying the Club's benefits by accepting Van Nostrand's SCIENTIFIC ENCYCLOPEDIA. It's the perfect guide to the marvels of nature... and it's a great bargain, too!

- **Enlarged and exhaustively updated edition of an acclaimed classic, first published in 1938.**
- **A mammoth 8¼" x 12" volume covering everything scientific from abacus to zygote, in 2,370 pages, 7,200 editorial entries, 8,000 cross-references and 2.2 million words ... plus 2,450 photos, diagrams, and charts as well as 550 tables.**
- **Authoritatively compiled by over 180 internationally respected scientific experts.**

If reply card has been removed, please write:
Natural Science Book Club - Dept. 4-AD9, Riverside, N.J. 08370
to obtain membership information and application.

The Chivas Regal of Liqueurs.

Chivas Brothers make the world's finest Scotch. And the same renowned Chivas quality and tradition goes into its equally-regal Lochan Ora Liqueur. With a unique taste all its own. Lochan Ora is to be lingered over—sipped slowly, savored fully. It's expensive but, then, good taste invariably is.

Lochan Ora.

The Imported Liqueur from Chivas Brothers.

recent Chinese announcement of a safe and effective pill for males, based on gossypol, an active principle (a derivative of binaphthalene) obtained from cottonseed oil, offers a case in point. ("The speed with which the Chinese progressed from initial animal toxicology to human experiments is truly remarkable.") It will take longer here, if it can go at all.

Data gathered by the World Health Organization suggest that all hardware aids to fertility control worldwide serve a total of a couple of hundred million users, of whom perhaps a third are on the Pill. In the U.S. the Pill's side effects, a genuine albeit not a large risk, are cutting steadily into its popularity. Declining some 5 percent per year, it nonetheless remains the leading procedure.

The most striking piece of biology in this review is the contraceptive effect of prolonged lactation. Not fully understood, this natural feedback method, which involves neural endocrine stimulation through the suckling stimulus, prevents more births than any other method of contraception. Breast-feeding both reduces infant mortality and increases the interval between births. Its decline under many influences (including the milk-substitute marketplace) is an unhappy phenomenon, particularly in the Third World. One striking observation taken from the studies of Kalahari hunter-gatherers is that a !Kung San woman can expect in her lifetime only about 48 menstrual cycles, together with four years of pregnancy. The rest is a time of lactational amenorrhea. The average modern woman passes through more than 400 menstrual cycles. Such a protracted monthly rhythm is not "normal" in the biological sense, if the African data are to be trusted as reflecting biological antiquity. The coupling of the Pill with the monthly cycle is not a necessity but a cultural practice; it provides, of course, a frequent reassurance against pregnancy. There are certainly other ways to gain the same end that are perhaps closer to the natural state of our species.

Djerassi writes clearly and personally. His career and character are extraordinary: he has written some 900 papers and was for a long period the most cited chemist in the world. He is a devoted teacher and a successful entrepreneur-magnate; his life, he says, is "like having two cakes and eating them both." The very readable book is ornamented with photographs of figurines from his fine collection of pre-Columbian art. The book is a first-class review, at once a work of information and of advocacy, that will educate many a general reader. The least our Congress can do is remit to the World Health Organization for its reproduction research the couple of million a year WHO spends here for contract work. Might we not be more generous? Say by each year adding "a fourth of the cost of a single sophisticated fighter plane"? Time is what we all have to gain, and "in birth control time is *the* most expensive commodity."

LIVING CORALS, by Douglas Faulkner and Richard Chesher. Clarkson N. Potter, Inc., distributed by Crown Publishers, Inc. ($45). A few hundred miles east of one of the deepest ocean trenches the southern Philippine Sea shallows up to a ridge, on the tip of which is the island of Peleliu, a bitter battleground a generation ago. The coral reefs around this island ridge, called Belau (still Palau in the atlases), some within sight of Peleliu, are the locus of most of the remarkable photographs that fill this book with strikingly colorful pattern. Douglas Faulkner has spent 16 years in underwater photography from Australia to the Red Sea. Four photographs in five here come from Belau. ("Nowhere have I encountered quite so rich a coral world in so wondrous a setting.") These were made in natural light, down on the reef a few tens of meters below the surface. With some impressive long-shot exceptions, the elegant color plates display life-size labyrinthine texture or a field of delicate polyp blossoms on a stony but brilliant ground. The plates satisfy visually; "this book is not a catalog for fabric designers, though they may see it as such," writes the author-photographer disarmingly.

Actually it is a work of some scientific novelty, comparable in purpose and content to the great field guides to wildflowers, although the rocky slopes Faulkner has devotedly and watchfully studied and imaged can be visited only by the amphibian variant of our species. He has presented nearly 200 examples of corals arranged taxonomically, carefully identified (a few are species new to science) by his scientific consultants, Frederick Bayer of the Smithsonian and John Wells of Cornell. Thirty-one coral families are presented in their taxonomic order, most of them viewed for their textural identity, some seen at longer range. The student of corals working in the museum with only the hard skeletons of these wonderful assemblages will find this a guide to life without parallel, and the general reader will enjoy a display of color and design vivified by the personal notes that accompany each glimpse of the living coral. The corals often fluoresce; the glow is "more noticeable on overcast days," when the direct light is muted. Faulkner has given his specimens common names, like those of wildflowers but all his own, because the folklore of the coral reef is only at its beginning. The protection of coral against the greedy or careless human collector, and the safeguarding of the reef habitat as a whole, are urgent, again reminding the reader of rare wildflowers.

A valuable essay by Richard Chesher offers a compact introduction to the biology of coral, still a frontier for exploration. The colors of coral owe much to the pigments of their inherited symbiotic algae, whose photosynthetic prowess enables the coral to flourish in watery sunshine, there below to build the crowded and massively stony reef. Corals are by weight "more plant than animal (sometimes as much as 3 to 1)," packed with their zooxanthellae. The sea surface sets a sharp upper limit on coral growth, and one photograph here eloquently shows the reef at the lowest of annual ebb tides, a flat field of coral spines at the margin of their tolerance. There is "only one really successful coral predator," the crown-of-thorns starfish, which can spread its stomach like a blanket over the polyps, to digest the tissues "right in their little coral cups." Life is slow in this world, but it is ancient, tenacious and complex. Chesher remarks: "What other animal could have survived, as did Bikini, 21 megaexplosions, direct hits with powerful thermonuclear weapons?"

THE VOYAGE OF CHARLES DARWIN, by Charles Darwin. Autobiographical writings, selected and arranged by Christopher Ralling. Mayflower Books ($9.95). "Surprisingly, for such a reticent and private man, Charles Darwin wrote a great deal about himself." This small, attractive volume is the first in which the three records of his memories—his private *Beagle* diary, his public journal of the voyage and the wonderful autobiography he wrote late in life—are pieced together in part in chronological order to recount one continued adventure and its meaning. It deserves wide attention, the more since it is the reader's bounty from the British Broadcasting Corporation and Time-Life film series of last year, shown on the Public Broadcasting Service network in the U.S. early this year. Ralling is the talented producer of the circumnavigating television series, and his own salty jacket photograph of the reconstructed *Beagle* under way off Tierra del Fuego introduces an enchanting 180 pages of Darwin, lightly annotated. The photographs, including rain forest and pampas, the Galápagos and the view of Aconcagua, are altogether fine. "It is most disgusting to feel soft wingless insects, about an inch long, crawling over one's body.... Afterwards they become round and bloated with blood." So we meet—and see in the act—the great black bug of the pampas, the infectious, bloodsucking Benchuca, just about the only insect for which Darwin ever had an unfriendly word.

Established 1845 SCIENTIFIC AMERICAN April 1980 Volume 242 Number 4

Chemical Warfare and Chemical Disarmament

Unless the current negotiations in Geneva succeed in prohibiting the development, production and stockpiling of chemical weapons, a new and more dangerous phase of the arms race may be in store

by Matthew Meselson and Julian Perry Robinson

The use in war of poison gas and other chemical weapons is prohibited by the Geneva Protocol of 1925, to which all major nations are now parties. Some nations accept the Geneva Protocol as an absolute prohibition; others, including the U.S., Britain, France, the U.S.S.R. and China, view it as a no-first-use agreement, having formally reserved the right to retaliate in kind if the Protocol is violated by an adversary. Of the member states of the North Atlantic Treaty Organization (NATO) only the U.S. and France have militarily significant stocks of chemical weapons. The continued existence of these weapons is based on their possible retaliatory role in the event of a chemical attack by the U.S.S.R.

Starting in 1976, the U.S. and the U.S.S.R. have been engaged in a series of bilateral technical discussions and negotiations in Geneva aimed at bringing about chemical disarmament, including a ban on the development, production and stockpiling of chemical weapons. (The Biological Weapons Convention of 1972 already embodies such prohibitions against biological agents, but it does not apply to chemical weapons.) The bilateral talks have achieved considerable agreement on what is to be prohibited and also on the general principle of incorporating both national and international arrangements for verifying compliance. Little progress has yet been made, however, in reaching agreement on specific verification measures.

As talks continue between the U.S. and the U.S.S.R., and concurrently within the multilateral Committee on Disarmament, which also meets in Geneva, the U.S. and its allies in NATO have embarked on a major program to enhance and modernize the protection of their forces against chemical attack. These defensive measures have found widespread support within NATO governments, which view them not only as important precautions in the present situation but also as a safeguard to be retained even if a chemical-weapons ban comes into being.

Although antichemical protection is being improved, the U.S. has not added to its stocks of the weapons themselves since 1969. The American stockpile, although substantial, is positioned mainly within the U.S. Its utility for retaliation is limited by the sizable logistic effort that would be required to deploy it to Europe under wartime conditions and by a reluctance within NATO to integrate chemical weapons into the force structures and defense planning of the alliance. Requests by the U.S. Army for funds to build production facilities for a new generation of poison-gas artillery projectiles, called binary munitions, have been rejected by Congress and the Administration partly on the ground that such action could impede negotiations for a chemical-arms-limitation treaty. Moreover, there is debate about the military value of a retaliatory chemical capability and about its possible interactions with nuclear deterrence.

In sum, the policy of the U.S. regarding chemical weapons appears to be nearing a crossroads. If a satisfactory treaty is obtained, there will be chemical disarmament. Otherwise the U.S. may decide to go ahead with the production of new chemical weapons and to make a determined effort to persuade NATO to integrate them into its defense planning. In this article we shall describe some of the technical, military and political considerations that bear most directly on the choices facing the U.S. and its NATO allies. In the wider international context there are related questions that may be no less important, but we shall not address them here.

Modern lethal chemical weapons are based on organophosphorus compounds known as nerve gases or nerve agents. They are chemically related to

NERVE GAS IS STORED as a liquid in metal containers at the Tooele Army Depot in Utah. The containers hold a total of about a million gallons of agent GB, or sarin, a high-

certain pesticides but are much more toxic. The first of these compounds, called tabun, was discovered in Germany in 1936 in the course of research on insecticides. Its military possibilities were soon recognized by the German government, which proceeded secretly to produce it and to develop production methods for a related agent found in 1938, called sarin. Although chemical weapons were used extensively in World War I, the European belligerents in World War II refrained from chemical warfare. Nerve gases in particular have never been used in combat.

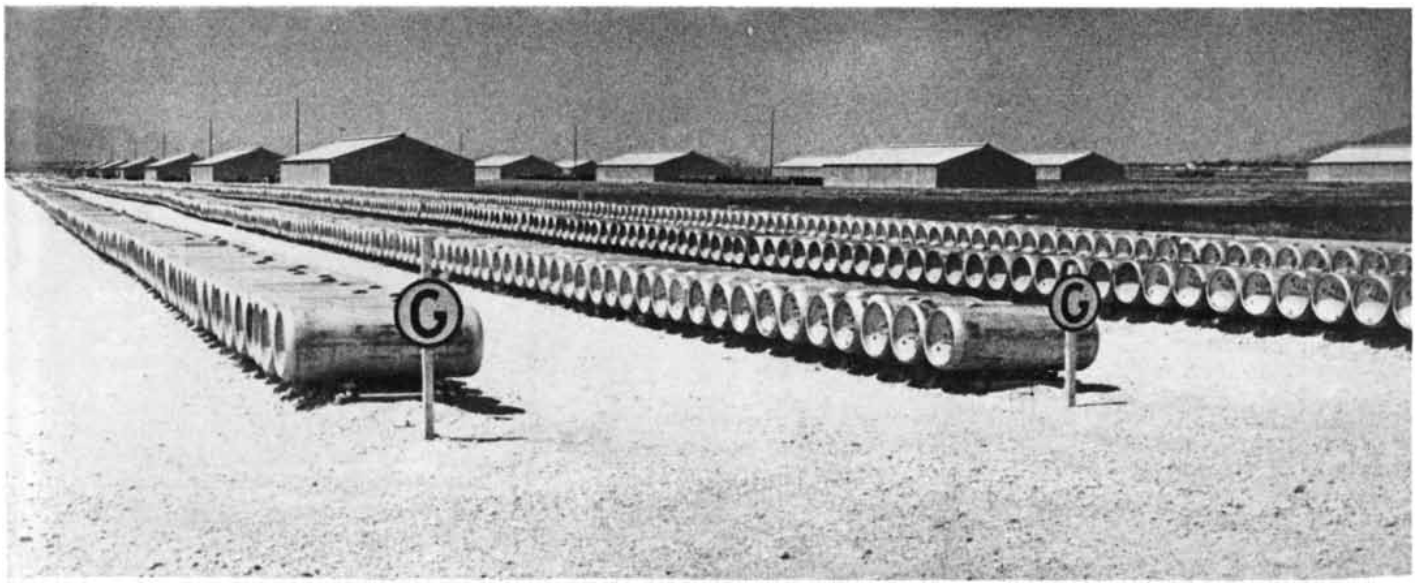
Nerve gases are stored as liquids. Depending on the volatility of the particular agent, they can be released from munitions as a cloud of vapor or as a spray of liquid droplets dispersed by explosive, mechanical or thermal means. They can enter the body by inhalation or by absorption through the skin. The nerve gas then exerts its lethal effect by binding to the enzyme acetylcholinesterase, thereby inactivating it. Blocking the enzyme causes a rapid accumulation of the synaptic transmitter substance acetylcholine, which normally is decomposed by acetylcholinesterase within milliseconds after being released at nerve endings. The buildup of acetylcholine at autonomic ganglia and effectors, at skeletal neuromuscular junctions and at synapses in the central nervous system causes a wide array of symptoms: intense sweating, filling of the bronchial passages with mucus, bronchial constriction, dimming of vision, uncontrollable vomiting and defecation, convulsions and finally paralysis and respiratory failure. Death from acute nerve-gas poisoning is caused by asphyxia, which generally will occur within a few minutes. If the dose is only marginally lethal or if it is received through the skin, however, it may take up to several hours for the victim to die. There is evidence that long-lasting neurological and psychiatric disorders can develop after sublethal exposure. Natural detoxification of nerve-gas poisoning is slow, so that the lethal dose is approximately the same whether it is received all at once or over a period of hours. Antidotes of limited effectiveness are available, but a far more effective defense against nerve gases (and indeed against all chemical-warfare agents) is provided by a gas mask and, for agents that attack or penetrate the skin, by protective clothing.

Of the hundreds of organophosphorus anticholinesterases that have been considered for use in weapons three have dominated attention: their chemical names are O-isopropyl methylphosphonofluoridate (otherwise known as agent GB, or sarin), O-1,2,2-trimethylpropyl methylphosphonofluoridate (agent GD, or soman) and O-ethyl *S*-2-diisopropylaminoethyl methylphosphonothiolate (agent VX). It is estimated that about one milligram of sarin or .4 milligram of VX is the median lethal dose for man, with the lethality of soman being in between. Sarin is nearly as volatile as water and would be used primarily as an air contaminant. VX, with a volatility close to that of heavy lubricating oil, would be disseminated in sprays as a direct contact hazard or as an indirect one, through contamination of the ground or other surfaces with which people might later come in contact. VX applied at about 300 kilograms per square kilometer would create a deadly skin-contact hazard that would persist for a period of days or weeks, depending on the weather. The hazard from sarin, being primarily an airborne one, is of much shorter duration and is highly dependent on vertical and horizontal air movements and on the ambient temperature; under most conditions the amount needed to create a lethal respiratory dosage would be between 100 and 3,000 kilograms per square kilometer.

Sarin and VX are the two standard U.S. nerve gases. Soman, first prepared in Germany in 1944, is believed by Western officials to be the standard Russian nerve gas. The volatility of soman approaches that of sarin, but greater persistency can be obtained by thickening it with synthetic polymers. What the Russians are reported to call VR-55 is thought to be a stockpiled formulation of this type. Tabun (O-ethyl N,N-dimethylphosphoroamidocyanidate, also known as GA), the original but now superseded nerve gas, was said at one time to figure prominently in the chemical arsenal of the U.S.S.R.; if that is true, the stocks could still exist.

For use in regular battlefield munitions no other poisons match the nerve gases. Their toxicity and rapidity of action, their effectiveness through the skin as well as the lungs, their easy disseminability, their fairly low cost and their stability set them apart from all other chemical-warfare agents. The older agents can now be considered obsolete for the industrialized countries, although some must still be taken seriously, chiefly because substantial supplies remain available. Hydrogen cyanide is one example; *bis*(2-chloroethyl) sulfide, also known as mustard gas, is another.

The nerve gases also overshadow the



ly toxic organophosphorus compound chemically related to certain pesticides. The lethal dose of sarin for an adult human being is about a milligram. The buildings in the distance contain additional nerve-gas supplies in the form of filled munitions. The objects stacked between the warehouses are 160-gallon aircraft spray tanks, filled with another nerve gas, agent VX. Approximately 40 percent of the total U.S. stockpile of poison gas, which includes both nerve gas and mustard gas, is stored at this site and others at the Tooele depot.

category of incapacitating agents, substances intended to put soldiers out of action for a period of several hours or days but with a low probability of death or lasting ill effects. Although many candidate incapacitants have been screened, none has proved satisfactory. The anticholinergic psychotropic drug known as agent BZ (3-quinuclidinyl benzilate) was for a time stocked in standard U.S. incapacitating munitions, but its many military shortcomings, including its unpredictable tendency to elicit maniacal behavior, led to its abandonment. The only nonlethal antipersonnel weapons now in the chemical-weapons inventory of the U.S. are those employing the irritant agents CS (orthochlorobenzylidene malononitrile) and CR (dibenz[*b*,*f*][1,4]oxazepine). Also used by domestic police, they are classified as riot-control agents. Although the U.S. made extensive use of CS munitions in the Vietnam war and interprets the Geneva Protocol as not applying to riot-control agents, they are essentially irrelevant to combat between modern military forces because of the brevity of their effects and the protection afforded by gas masks.

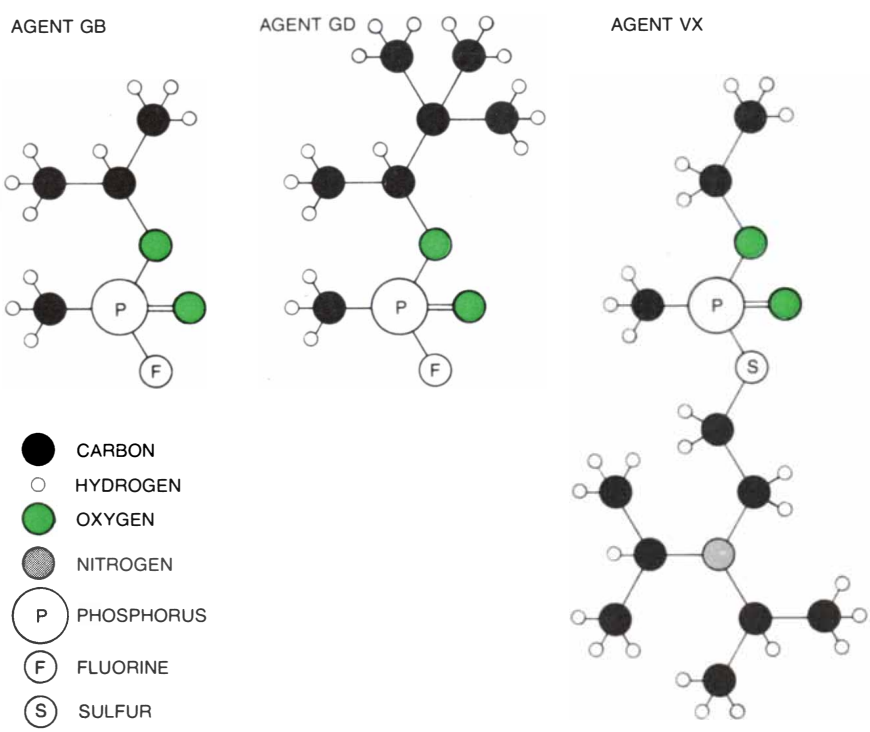
The size of the U.S. stockpile of lethal chemical munitions is classified information, but estimates can be made from open sources. Approximately 15,000 tons of sarin were produced during the period between 1953 and 1957, and some 5,000 tons of VX were made between 1961 and 1967. About 5,000 tons of nerve gas, mostly sarin, are accounted for by the destruction of obsolete munitions and surplus stocks. Of the remainder about a fourth is held in bulk-storage containers and three-fourths in munitions. Approximately 30 different types of nerve-gas munition have been approved for the operational inventories of U.S. armed forces over the past three decades, half of them having been produced in quantity. Some are now obsolete and have been or are being discarded. Remaining in the stockpile are about three million artillery projectiles (105-millimeter GB shells, 155-millimeter GB and VX shells and eight-inch GB and VX shells), several thousand 500- and 750-pound GB aerial bombs, hundreds of thousands of two-gallon VX land mines and about 1,500 160-gallon VX aircraft spray tanks. Supplies of mustard gas dating from World War II are also maintained, both in munitions and in bulk stock, the total quantity of the agent being about the same as that of nerve gas. U.S. stocks of lethal chemical munitions total approximately 150,000 tons, referring to the weight of the munitions themselves, not just the chemical agent they contain. Nerve-gas munitions comprise about two-thirds of this total.

Overall the weight of the U.S. stockpile of lethal chemical munitions equals about a fourth of the weight of the conventional (high-explosive) munitions the U.S. Army currently has on hand in Europe. Only a small fraction of this chemical-weapons stockpile, however, has been positioned abroad: on Johnston Island in the mid-Pacific and in West Germany. The stocks in West Germany, which are under exclusive U.S. control, are mostly ground munitions; it is said they would suffice for no more than two weeks of widespread battlefield chemical operations in Europe.

If Administration and Congressional authorization is given, the next addition to the U.S. chemical-weapons stockpile probably would be the 155-millimeter GB artillery projectile. Instead of containing actual nerve gas, it contains two nerve-gas precursors held in separate canisters. When the projectile is fired, the canisters burst and their contents react to form the nerve gas while the munition is in flight. One of the canisters could be stored and shipped separately, to be loaded into the projectile at the gun site. This built-in safety feature of binary-nerve-gas munitions is intended to provide greater operational flexibility in the storage, shipment and deployment of chemical weapons, in part by alleviating public concern about the possible unintended release of poison gas.

Little seems to be known outside the U.S.S.R. about the chemical weapons of that nation, either quantitatively or qualitatively. The Russians themselves have said nothing on the subject in public. Estimates of the size of the Russian stockpile that have appeared are based more on appraisals of assumed Russian military requirements than on solid evidence. U.S. defense officials have stated that little confidence can be placed in current estimates of the total size of the Russian stockpile, but that a considerable amount of it is deployed both in European forward areas and near the Chinese frontier. Part is believed to consist of nerve-gas munitions, the remainder being mostly mustard gas and hydrogen cyanide.

Whether the Russians consider their stocks to be solely retaliatory, as the Americans consider theirs, is of course not known. A buildup in Russian supplies, both of chemical weapons and of protective equipment, is said to have taken place in the late 1960's. If that is the case, the instigating decisions would have been made during the last high point of U.S. chemical-weapons procurement. According to the 1979 military-posture statement by the Chairman of the U.S. Joint Chiefs of Staff, initial-release authority for the use of chemical weapons by the Russian forces lies at the level of the Politburo: the highest council of the Soviet state.

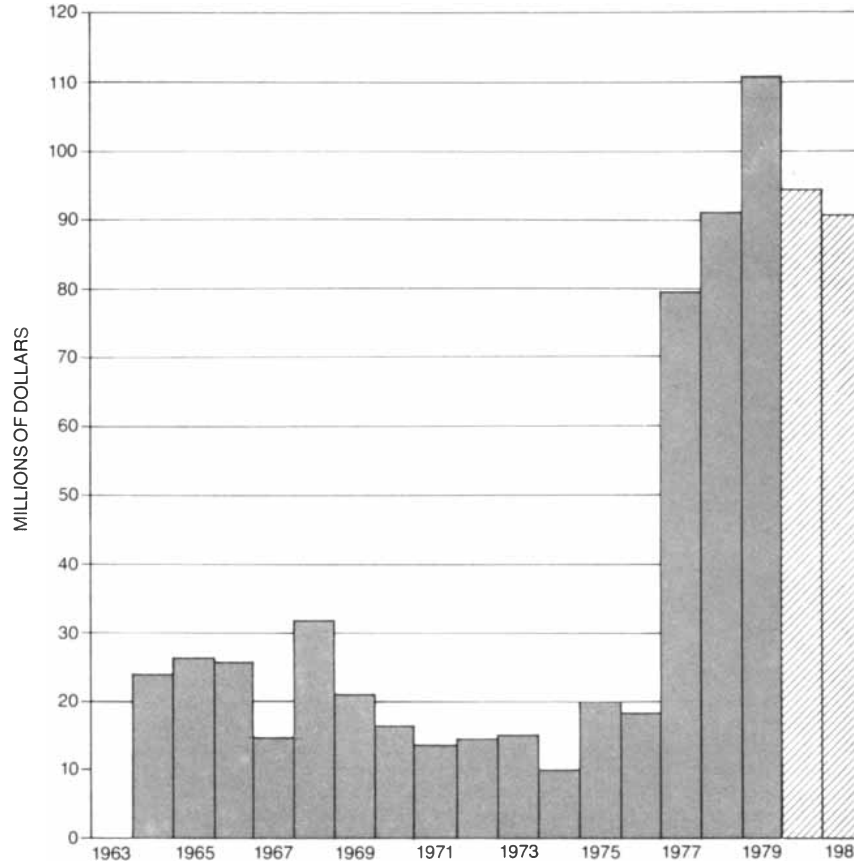


CHEMICAL STRUCTURES of three organophosphorus anticholinesterases, or nerve gases, currently in the arsenals of the U.S. and the U.S.S.R. are given in these molecular diagrams. Reading from left to right, the compounds are O-isopropyl methylphosphonofluoridate (agent GB), O-1,2,2-trimethylpropyl methylphosphonofluoridate (agent GD, or soman) and O-ethyl *S*-2-diisopropylaminoethyl methylphosphonothiolate (agent VX). Agents GB and VX are the two standard U.S. nerve gases. Agent GD is thought to be the standard Russian nerve gas.

To a degree not approached by other categories of weapons, it is possible to protect people from the effects of chemical weapons without at the same time preventing them from engaging in

most of their normal activities. Important and distinctive aspects of policymaking with regard to chemical weapons stem largely from this feature. The first and most important line of defense against chemical-warfare agents (also needed in part against radioactive fallout) is the physical protection that respirators, special clothing and air filters for collective shelters can provide. Properly fitted gas masks are capable of reducing the concentration of chemical-warfare agents in inspired air by a factor of at least 100,000. The filters contain activated charcoal for vapor adsorption and paper or some similar material for retaining particulates. To increase protection against small-molecule agents such as hydrogen cyanide, the charcoal is impregnated with copper compounds or other reactants. Gas masks currently deployed by NATO can be donned in less than 10 seconds and worn thereafter for long periods, even in sleep. The physiological stresses imposed are minor, and the psychological ones can be mitigated by training and practice. The new American mask, currently in an advanced stage of development, incorporates several refinements over the existing one. It is lighter and is designed to interface better with optical and audio equipment. The current Russian mask, although effective, is harder to don quickly than the principal NATO masks and is heavier and less comfortable.

All U.S. Army forces in Europe are equipped either with the British Mark 3 protective suit or with its more recently issued American counterpart. Each suit is a disposable two-piece overgarment, which for full protection is worn with butyl-rubber gloves and overboots. The American suit weighs four pounds and is water-repellent and permeable to air. The outer layer of its two layers of fabric is wear-resistant and treated to be rapidly wettable by droplets of nerve gas in order to accelerate their evaporation. Penetrating vapor is adsorbed by activated carbon bonded to the unexposed surface of the inner layer. Because the material can "breathe" and pass perspiration, it interferes little more than ordinary clothing with the ability of its wearer to shed heat. At temperatures usually encountered in central Europe the degradation of combat performance in full protective gear attributable to heat stress is minimal. At temperatures higher than 75 or 80 degrees Fahrenheit, however, any periods of heavy exertion must be limited to about an hour or else protection must be partly relaxed, for example by removing the gloves and unzipping the front of the protective jacket. Current Russian protective garments are made of air-impermeable rubberized fabric. At 60 degrees F. they can be worn for about four hours before heat stress builds up to casualty levels; above 70 degrees F. the tolerance time is less than half an hour. The Russians are said to be working on an improved suit.

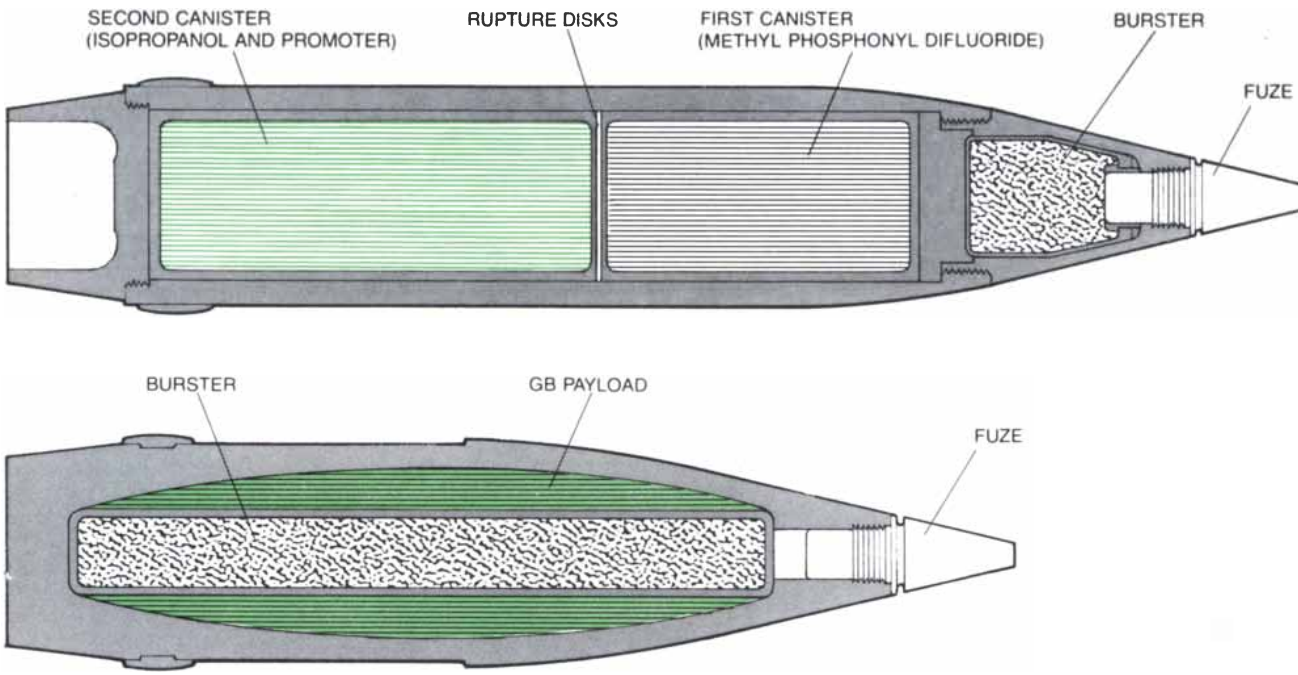


U.S. EXPENDITURES for protective equipment against chemical attack have increased sharply in recent years as this country and its allies in the North Atlantic Treaty Organization have sought to improve the anti-chemical-warfare capability of their forces in Europe. Bars are based on constant 1973 dollars. Hatched bars indicate approximate planned levels of spending.

For armored fighting vehicles collective rather than individual protection can be provided. The latest Russian and European NATO tanks have seals and positive-pressure filtered-air supplies so that their crews are fully protected without having to wear masks. The Russian forces appear to be relying increasingly on this method for the armored personnel carriers and combat vehicles in which their infantrymen would move during battle. The American preference is to provide armored vehicles with a central pressurized supply of filtered air to which individual respirators can be connected, making it possible to operate with the hatches open and allowing soldiers to enter and leave the vehicle; full collective protection is limited to vehicles such as "command, control and communications" vans and certain mobile missile units. Collective protection is also available on both sides for fixed installations, including command posts and temporary shelters through which front-line units can be rotated for medical care and rest.

NATO troops are trained to put on their masks and other protective equipment in response to commanders' orders, warnings given by chemical-agent-detection personnel or individual detection by a variety of means, including the sensing of characteristic symptoms such as a runny nose, dimming vision and tightness in the chest. The capacity for determining the proper degree of protection is being enhanced by the deployment of sensitive automatic field alarms for nerve gases. Such alarms are important because nerve-gas contamination at casualty-threatening levels may be undetectable by the unaided human senses. One of the latest alarms to enter service is a 30-pound British device that monitors the voltage across an electrochemical cell in which covalently immobilized cholinesterase is continuously irrigated with a solution of butyrylthiocholine substrate; nerve gas in the sampled air inhibits the enzyme, just as it would in the human body, resulting in a drop in the thiocholine level, which triggers the alarm.

Gas masks and protective clothing can provide effective protection against nerve gas. If they should be circumvented, a second line of defense—the self-administration of antidotes—is available to the individual. Antidotes would come into play when protective equipment had not been donned promptly enough or when it had become



ARTILLERY SHELLS designed to deliver the nerve gas GB in different ways are shown in these cutaway drawings. The 155-millimeter projectile at the top is the newer binary-type munition now ready but not yet authorized for production; the one at the bottom is its stockpiled nonbinary equivalent. In the binary version one of the two canisters containing the ingredients to form GB can be stored and shipped separately, to be loaded at the gun site. When the projectile is fired, the contents of the two canisters mix and react to produce the lethal agent. The binary feature provides greater insurance against unintended release of nerve gas and facilitates possible disposal. The heavier casing and central burster of the nonbinary round provide substantial fragmentation effects. Although the binary shell holds more chemical, only about 70 percent of its payload ends up as GB; the other main product of the chemical reaction is hydrogen fluoride.

damaged. They would also be necessary in the more remote eventuality that the sorptive capacity of respirator filters or protective suits had become saturated under circumstances not allowing immediate replacement. The most widely available antidote is atropine, which blocks acetylcholine at autonomic receptors, used in conjunction with an oxime compound that can displace bound nerve gas from inhibited acetylcholinesterase. Compact autoinjectors are issued to be self-administered as soon as the symptoms of nerve-gas poisoning begin to be felt. The formulation used in current American and Russian autoinjectors, referred to as TAB, consists of trimedoxime, atropine and a second antagonist of acetylcholine, benactyzine. This antidote can save the lives of people receiving somewhat more than the median lethal dose of nerve gas, and it can reduce the severity of symptoms due to sublethal doses.

Severer intoxication, up to several median lethal doses, can be countered only if positive-pressure artificial respiration is also applied. Prophylactic use of oximes or reversible inhibitors of acetylcholinesterase such as pyridostigmine (administered by means of pills swallowed a short time before nerve-gas exposure) may improve the prognosis. Notwithstanding the advances in therapy and prophylaxis that now seem possible, however, it is doubtful whether these medical defenses would significantly reduce casualties in the sense of soldiers put out of action, although they could certainly save lives and bolster morale.

The third principal component of antichemical protection consists of equipment and procedures for decontamination. Soldiers are provided with kits for decontaminating their skin and personal equipment. The other main requirement is a capacity for ensuring that crucial combat and support equipment remains usable. The contamination that must be countered is that which because of its density or location would otherwise overstress the protection of the operators or be transferable to critical clean

	NONCHEMICAL SHELLS		NERVE-GAS SHELL (GB)			
	FRAGMENTATION SUBMUNITION SHELL	AIRBURST HIGH-EXPLOSIVE SHELL	TARGET PERSONNEL UNPROTECTED	TARGET PERSONNEL CARRYING BUT NOT WEARING GAS MASKS AT START OF ATTACK	TARGET PERSONNEL WEARING GAS MASKS BUT NOT PROTECTIVE CLOTHING	TARGET PERSONNEL WEARING GAS MASKS AND PROTECTIVE CLOTHING
TARGET PERSONNEL ON THE ATTACK	1	4	1	2	74	(CASUALTY LEVEL EXCEEDING A FEW PERCENT WOULD BE UNATTAINABLE)
TARGET PERSONNEL ON THE DEFENSIVE	4	51	1	66	74	

NUMBERS OF VOLLEYS of different projectiles that would have to be fired by a battalion of 18 155-millimeter howitzers in order to inflict casualties of about 30 percent on a platoon-size target (with a radius of 150 meters) in open terrain at a distance of 10 kilometers are estimated in this table. The figures take into account the differences between attackers and defenders with respect to their posture, breathing rate and time required to don their gas masks once the shells have started to fall. The fragmentation submunition shell, one of a family of new munitions called Improved Conventional Munitions (ICM) by the Army, detonates at a height of about 50 meters, releasing a cluster of 88 small antipersonnel bombs. For the nerve-gas shells the number of volleys required would vary over at least an order of magnitude depending on the weather. The figures given here are midrange ones: for a cool, dry, overcast day with a gentle breeze.

areas. This task can be accomplished with portable dispensers and scrubbers, which can apply decontaminating agents to door handles, gunsights, machine controls, entryways and the like. Effective decontaminants are available in the form of oxidizing agents, such as bleaching powder. Also available, although perhaps less critical, is large-scale decontamination equipment for use in logistical centers and staging areas. The Warsaw Pact nations have deployed large numbers of vehicles for chemical and radiological decontamination, including the TMS-65 turbojet-powered large-volume dispenser, first observed in the 1960's, which is said to be capable, when it is used in pairs, of decontaminating the outer surfaces of a tank in less than three minutes.

The new protective items now being deployed by NATO in Europe are greatly increasing the capacity of the NATO forces for operating effectively on contaminated battlefields and for preserving support and resupply functions. Equipment, however, is only a part of what is needed. An adequate defense must also embody a detailed and widely diffused understanding of the problems involved, thorough training and exercising of personnel, and an organization efficient enough to operate smoothly under the chaotic conditions of war, which large-scale chemical operations would undoubtedly aggravate.

All the major NATO and Warsaw Pact armies provide training for antichemical protection at the individual level, but there are many tasks that must be done by groups requiring special equipment and expertise. These requirements overlap those for biological and radiological defense, and all three tasks (nuclear, biological and chemical) are generally organized together under the abbreviation NBC. The American practice is to assign such tasks to teams under local field command, down to and including the company level, with key personnel in each team receiving more specialized NBC training. A typical U.S. Army company of between 100 and 130 men includes an NBC Defense Team to which 15 or more men are assigned, most of whom usually have other duties as well. The team includes separate groups assigned to chemical detection, radiological monitoring and decontamination. In addition there are career chemical-specialty troops attached to brigades and higher command levels, such as the NBC Defense Companies authorized for each U.S. combat division and corps support command. The Russian organization, which resembles that of the West German army, places much more emphasis on career NBC troops organized as a separate branch, of whom there are estimated to be approximately 80,000.

Antichemical defense procedures are

PROTECTIVE GEAR designed to defend soldiers against a chemical attack is modeled by a U.S. infantryman in this photograph released recently by the Army. The gas mask, a new style now in an advanced stage of development, incorporates filters made of activated charcoal for vapor adsorption and glass fiber for particle retention. The protective suit, a disposable two-piece, multilayered overgarment, is lightweight, water-repellent and permeable to air. The outer layer of fabric is chemically treated to be rapidly wettable by droplets of nerve gas in order to accelerate their evaporation; penetrating vapor is adsorbed by a layer of activated charcoal bonded to the inner fabric layer. For full protection the suit is worn with butyl-rubber gloves and overboots. Adhesive-backed strips of detection paper are placed on the arm, wrist and ankle. All U.S. troops in Europe are equipped with gas masks and protective clothing.

routinely practiced during Warsaw Pact maneuvers. Evidence of such close attention to protection has been available to NATO since the 1950's, not least in the pages of Russian military journals. Russian-supplied protective equipment of many kinds was found among Israeli-captured Arab materiel after the Six-Day War of 1967, indicating that the equipment was standard Russian issue. Similar NBC materiel was captured during the October War of 1973. In neither case were any chemical munitions found.

In 1974, citing the October War findings, the U.S. Army announced that it was assigning a high priority to antichemical preparedness, and it is now engaged in a $1.5-billion program intended to provide by the mid-1980's a greatly improved capability for withstanding chemical attack and for conducting operations in a toxic environment. Battle-training exercises are routinely held in full protective gear. Similarly, the Air Force has begun a program, estimated to cost $234 million and due for completion by 1984, to improve the chemical defenses of its European air bases. These programs are rapidly bringing the quality of the antichemical protection of U.S. forces in Europe up to or beyond that of those allied forces that have long given it priority, particularly the British, Canadian, French and German forces. NATO itself has embarked on an alliance-wide program to smooth out disparities and upgrade overall antichemical defenses.

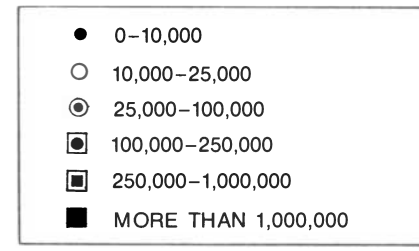
Even with the advanced methods of chemical protection now available, a sufficiently determined chemical attack would still make an impact, not only in casualties among troops caught off guard or with defective or improperly used protective equipment but also in the degradation of mission performance imposed by the protective measures themselves. The better the protective posture of a fighting unit is, however, the less economical would the use of chemical weapons against it become in comparison with other weapons. For causing casualties the principal non-nuclear competitors with nonpersistent agents such as sarin are flame-producing munitions and airburst high-explosive or fragmentation munitions against troops in the open and fuel-air explosives against dug-in troops; competitive with persistent agents such as VX for "area denial" are the many varieties of scatterable mine, including those deliverable by artillery. Although side-by-side comparisons of these different munitions have apparently not been undertaken in any great detail, the existing munitions-expenditure tables for each one provide a rough guide. For unprotected or unprepared troops the casualty effects of chemical weapons can be competitive with those of conventional weapons, but this is not the case for an attack on prepared troops with good antichemical protection, particularly when the comparison is with the much more effective newer types of conventional antipersonnel weapons now being deployed. Soldiers wearing antichemical protective equipment are far more vulnerable to conventional attack than they are to attack with chemicals. Moreover, it must also be taken into account that, at least for NATO, resources devoted to chemical weapons contribute nothing to firepower unless the other side chooses to use chemicals first.

Much more difficult to assess than the casualty effects of chemical weapons is the degree to which antichemical protection degrades mission performance. Large-scale controlled tests adequately designed to provide the necessary data have only recently begun in the U.S. There is bound to be some degradation, and for some missions it would be worse than it would be for others. Current estimates range from near zero, as in a recent British exercise at an air base in Germany measuring tactical aircraft turnaround times with the air and ground crews fully protected, to more than 30 percent for some unspecified types of front-line mission cited in the testimony of Department of Defense officials before Congress.

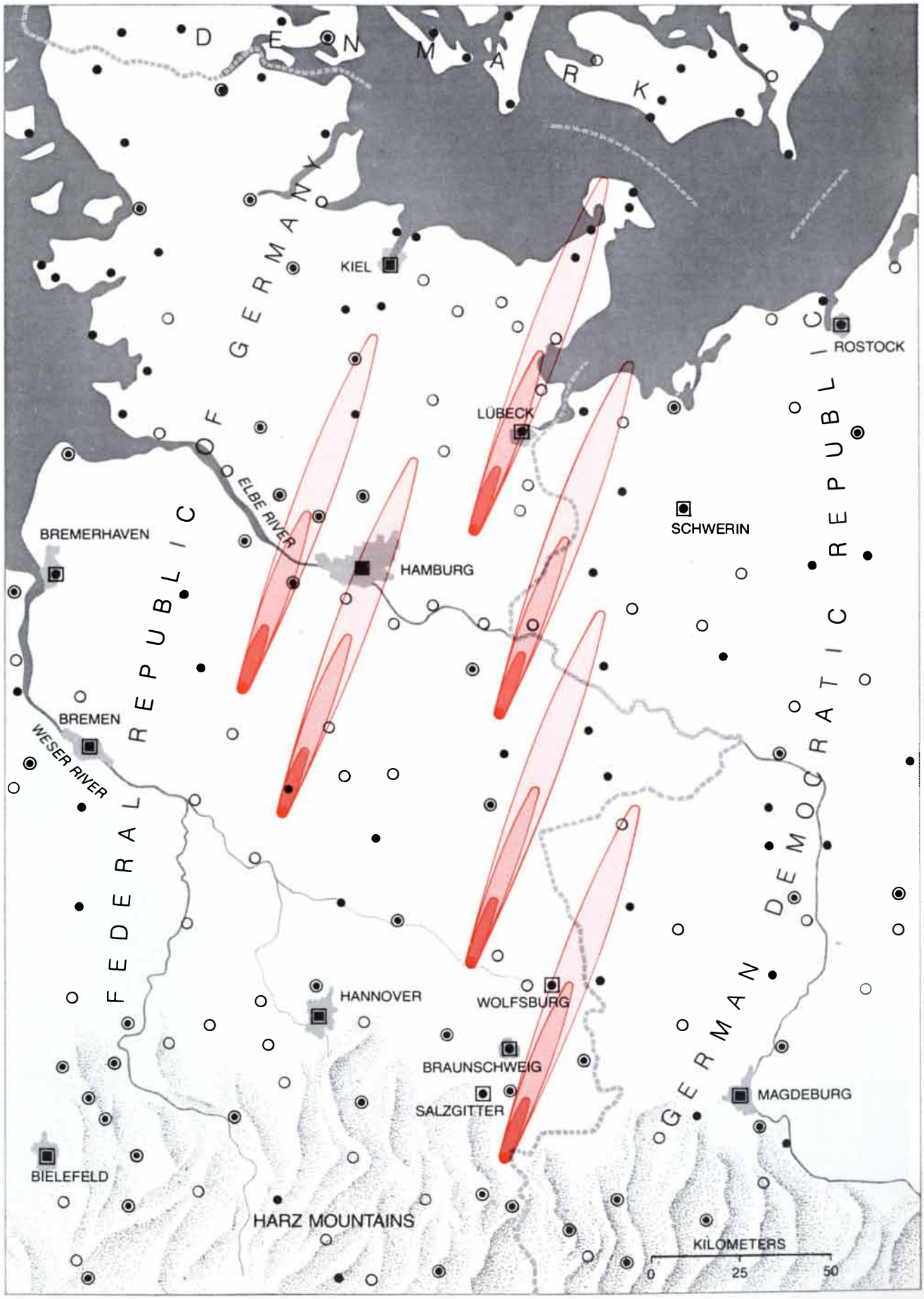
Since civilians are unlikely to be provided with protective equipment and trained in its use to the same extent as combat units, noncombatants stand to suffer more severely from the effects of chemical attack. Existing chemical weapons are not designed for strategic purposes, and military doctrine does not envision intentional chemical attacks on civilians. Clouds of nerve-gas vapor could drift long distances downwind of a battlefield before becoming harmless, however, and terrain contaminated by nerve gases may remain hazardous long after fighting in the region has ended. Battlefield chemical weapons thus carry with them an immense potential for causing civilian casualties. It can be estimated that on-target sarin contamination intended to cause 20 percent casualties among soldiers carrying respirators but not at first wearing them could, under weather conditions frequent in central Germany, kill unprotected people 20 kilometers or more downwind and seriously incapacitate people out to about twice that distance. Civilian casualties on the order of millions could result from battlefield chemical warfare in Europe.

Quite apart from the purely military factors determining the utility of chemical weapons there are within NATO major political considerations limiting their deployment and use. The U.S. and France are alone among the NATO allies in possessing them. Italy (like Bulgaria, Hungary and Romania in the Warsaw Pact) is under international treaty constraints limiting the acquisition of chemical weapons. West Germany, also limited by treaty, has renounced them altogether in perpetuity and, as the sole European repository of U.S. stocks, is a reluctant host. In an official White Paper the West German armed forces have disavowed any intention either now or in the future of seeking access to the stocks or of training combat units in the use of chemical weapons.

The arguments advanced for NATO's maintaining a chemical retaliatory capability vary, according to whether it is supposed the Russians employ chemicals in an otherwise conventional war or whether instead nuclear weapons are also in use. In the event of a major Russian conventional attack on Europe a NATO capability for retaliating in kind is seen as an important, yet minimally escalatory, deterrent against a Russian initiation of chemical warfare. It is considered that NATO retaliation would be seen by the Russians as substantially offsetting any gain from their use of chemi-



POTENTIAL CIVILIAN CASUALTIES resulting from a hypothetical chemical attack on a battlefield in north-central Europe are suggested by the equal-dosage contours of this map. The solid colored dots represent battalion-size targets (a square kilometer or less in area), each attacked with GB bombs releasing a total of six tons of nerve gas per target, a quantity intended to inflict about 20 percent casualties on troops carrying but not at first wearing gas masks. The weather is assumed to be cool, dry and overcast with a gentle southwesterly breeze. Most people within the light-color areas would be poisoned, although not fatally; their vision would be affected, and they would suffer protracted eye pain, headache and difficulty breathing. Within the medium-color areas unprotected people would be incapacitated for a period of days. The innermost, dark-color areas are those in which people would be severely poisoned; only young adults near the outer fringes of each area would have a good chance of surviving, and many of them would be brought to the brink of death, collapsed and in convulsions. Under more stable atmospheric conditions, for example at night with clear or partially clear skies, all the areas would be several times larger; under less stable conditions, for example in warm, sunny weather, they would be smaller. Normally there would be wind fluctuations over the 10-hour period considered here, altering the shape of the equal-dosage contours. The six attacks illustrated would release only a fraction of a percent of the total amount of nerve gas that could be expended in a large-scale chemical war in Europe.



cals. Moreover, since such a NATO response would be only a continuation of what the other side had started, the NATO retaliatory threat would be credible where the much more escalatory threat of nuclear retaliation might be less so. It is further argued that if deterrence fails, NATO forces can discourage escalation of the extent and intensity of the use of chemicals and possibly end it by being able to use their chemicals to match the effect of chemical strikes at each level, both on the battlefield and in rear support areas.

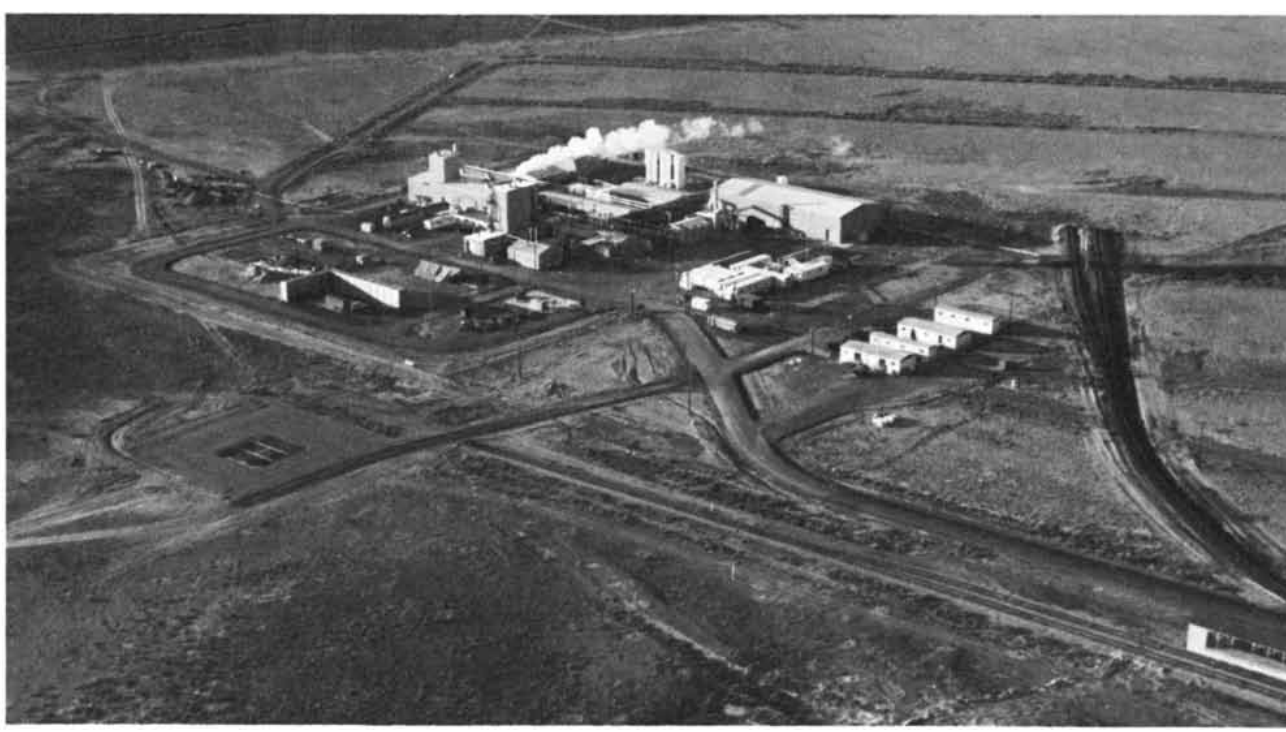
U.S. doctrine on chemical weapons promulgates these ideas in current field manuals as follows: "The objective of U.S. policy is to deter the use of chemical weapons by other nations. If this deterrence fails, and the use of chemical weapons is authorized by national command authorities, the primary objective is to achieve early termination of chemical-warfare operations at the lowest level of intensity."

Under the different assumption that nuclear weapons are already in use, the antiescalation benefits seen for a chemical retaliatory capability largely disappear. The utility of chemical retaliation would then hinge on its battlefield effectiveness in inflicting casualties and imposing delays on enemy military units.

The deterrent value and the de-escalating potential of NATO's chemical weapons have been questioned both in terms of immediate military effectiveness and in relation to broader strategic considerations. If the Russians were to use chemical weapons in support of a conventional offensive, NATO retaliation in kind at the same level would compel the Russian forces to adopt more stringent antichemical precautions than their own chemical attack had necessitated. This effect might or might not have some significance in determining the overall outcome, but its possibility, it is argued, would hardly be likely to be seen by the Russians as offsetting the immediate gains that recourse to chemicals could promise. An initial chemical strike, in contrast to a retaliatory one, might have a substantial probability of catching opposing forces at a low level of antichemical protection and would hold out a correspondingly greater prospect of major tactical impact. It is therefore maintained that NATO's chemical weapons would add little to the deterrence of chemical warfare unless the retaliation threatened were highly escalatory: heavy enough to overwhelm Russian front-line protection or deep enough to reach targets in the Russian rear.

Serious liabilities for NATO would, it is argued, be attached to such a response, however, thereby reducing its credibility. The extension or intensification of the battlefield use of chemical weapons could slow NATO counteroffensives and greatly increase civilian casualties. Longer-range chemical attacks, with effects intrinsically difficult to predict or control, would carry a serious risk of precipitating nuclear or other escalatory responses that NATO might prefer to avoid or to preserve as its own initiative. The retaliatory options available in a chemical-warfare capability of this kind would, in terms of potential target effects, overlap those afforded at present by NATO's nuclear weapons, so that the deployment of chemical weapons could be perceived by the Russians as a sign of diminished resolve to use nuclear weapons. Increased reliance on chemical retaliation to deter a Russian chemical attack could then carry a cost of reduced capacity for deterring war itself.

As it happens, the latter considerations are for the present largely academic since the chemical weapons NATO has available in Europe are sufficient only for rather limited retaliation. The leading NATO allies have made it clear that they are unwilling to countenance any expansion of the stocks, whether through procurement actions of their own or by expanding the chemical-depot facilities available to the U.S. Domestic political considerations have been influential, but it is also recognized that the resources needed to expand and modernize the NATO stocks, possibly by deploying binary munitions, would represent a substantial drain on other NATO programs, such as the present upgrading of conventional military ca-



DISPOSAL FACILITY for the destruction of chemical weapons that have become unserviceable was built recently at the Tooele Army Depot. Agent GB is decomposed here by hydrolysis in alkaline solution, agent VX is decomposed by chlorination and mustard gas is destroyed by incineration. The disposal of unserviceable stocks of lethal chemical weapons currently under way is expected to take seven years and to consume a few percent of the U.S. stockpile. The facility serves as a prototype of the installations that would be needed for the larger-scale elimination of chemical-weapons stockpiles in the event that a chemical-disarmament treaty comes into being.

pabilities. There is also fear that if an expanded chemical retaliatory capability were ever to be used, the consequence would be a stalemate on the battlefield, as in World War I, with attendant greatly increased casualties and destruction in Europe.

Maintaining a chemical retaliatory capability and entering into an agreement to limit chemical arms are alternative approaches to the same objective: the minimizing of the threat presented by the chemical weapons of one's adversary. Only arms limitation, however, seeks to remove the opponent's weapons and to reverse the usual cycle whereby the military programs of one side act to drive those of the other. Moreover, only arms limitation addresses the problem of the possible proliferation of chemical weapons to conflicts and confrontations between parties other than the NATO and Warsaw Pact countries. Both approaches entail risks. Maintaining chemical weapons perpetuates the already existing threat and may augment it. Entering into an arms-limitation agreement may in the worst case expose NATO to an undiminished threat while denying NATO a chemical capability of its own. Both approaches are subject to important political constraints, quite apart from the constraints imposed by the purely military strengths and weaknesses of the weapons themselves. On the one hand there are political limits to the measures attainable for verification of compliance with an agreement. On the other there are political constraints on the nature and effectiveness of the chemical retaliatory force NATO can maintain. These constraints are rooted not only in public opinion but also in the national-defense policy of key NATO allies, such as West Germany.

Nevertheless, there are two essential factors that give NATO considerable flexibility in shaping its policy for chemical weapons. One of these factors is the greatly improved chemical-protective posture now coming into being in Europe. This factor limits the threat to NATO forces created by Warsaw Pact chemical weapons, both in the present situation and in the environment of an arms-limitation agreement, should the other side retain or produce chemical weapons in violation of the agreement. The other factor allowing flexibility in NATO policymaking is the wide range of modern conventional weapons and nuclear weapons, which overlap and overshadow the capabilities of chemical weapons, both for deterrence and for combat. These considerations help to set the boundary conditions within which the current bilateral talks between the U.S. and the U.S.S.R. on chemical disarmament proceed.

At the Moscow summit meeting of July, 1974, President Nixon and Secretary Brezhnev declared they had agreed to consider a joint initiative on the prohibition of chemical weapons. This agreement was reaffirmed by President Ford and Brezhnev at Vladivostok that November, and it led in August, 1976, to the start of the current bilateral negotiations in Geneva. By the end of the 10th round of the talks, in August, 1979, agreement had been reached that both lethal chemical weapons and incapacitating ones should be included within the scope of a chemical-weapons convention, and that highly toxic chemicals (and precursors) of types and in quantities having no justification for purposes other than chemical warfare should also be prohibited, subject to certain additional criteria intended to facilitate verification. It is also agreed that on ratifying the convention states should declare their chemical-weapons stockpiles and means of production, and that verification of their elimination within a specified period should be based on a combination of national and international measures, including a provision for requesting on-site inspection to investigate suspected violations. Although these agreements represent substantial progress, critical negotiations still lie ahead, since little accord has yet been reached on the particular information to be provided in the required declarations or on the pivotal issue of the specific methods to be used for verifying the destruction of chemical weapons and the elimination of production facilities.

Existing means of surveillance, including a variety of procedures for intelligence gathering and evaluation, have an important if limited ability to detect chemical-warfare activities in the Warsaw Pact region. Such national verification procedures by themselves are considered by the U.S. and other NATO countries to be inadequate for monitoring compliance with a chemical-disarmament treaty. It is not necessary, however, that a verification system be able to detect all the activities and facilities that go into creating or maintaining a chemical-warfare establishment. What is required is a high likelihood of detecting chemical-warfare preparations on a scale large enough to constitute a major military threat. It is important to note in this regard that the effectiveness of verification measures is enhanced by a high level of chemical defense. Good defense greatly raises the scale of chemical-warfare preparation needed to constitute a major military threat, making concealment more difficult and intrusive inspection less necessary.

Although historically there is wide divergence between the approaches of the U.S. and the U.S.S.R. to problems of verification, the agreed concepts of declaring chemical weapons and means of production and of using a combination of national and international measures to verify their elimination may provide the basis of a convention acceptable to both sides. One approach for reliably verifying the destruction of declared weapons and chemicals would be to transport them to a site or a few sites chosen by the possessor where the destruction would be carried out under international observation. Even with automated disposal techniques this process would require several years, during which the participants might take various measures to assure themselves that the agreement was being implemented as expected. The elimination of declared production facilities could be monitored by satellite reconnaissance, following limited on-site visits to ascertain that the facilities were of the types declared. These procedures would guarantee the elimination of large quantities of chemical weapons and sizable production facilities. The problem of verifying the absence of undeclared stocks or facilities could be addressed by carefully designed measures based on the already agreed right to request on-site inspection where other means had indicated questionable activities.

The search for political accommodation within these possibilities and the various others that can be conceived for a chemical-arms-limitation agreement has developed a pace of its own, albeit one that is governed by changes in the broader course of international relations. If the U.S. and the U.S.S.R. are able to come to terms on chemical warfare, the next step would be to present a proposal for a multilateral agreement to the Geneva disarmament conference. The exploratory negotiations and technical study that have been continuing there for the past 11 years could then finally result in a chemical-weapons treaty with wide international support, but it will clearly be some time before the ultimate success or failure of these endeavors becomes apparent. Meanwhile there is a danger that the existing constraints against chemical warfare will weaken and that additional countries will move to acquire chemical weapons, as is emphasized by the recent unconfirmed but troubling allegations of the use of poison gas in Afghanistan and Southeast Asia.

What is at stake in the negotiations goes beyond the problem of dealing with the threats chemical weapons currently present to the security of nations. Mankind has entered a period of rapid and accelerating understanding of the fundamental biochemical and cellular processes of life. As this knowledge expands, so too will the range of its possible applications for good and ill. In the long run the existence of a chemical-disarmament treaty in addition to the present biological one could help to establish the principle that the increasingly profound knowledge of life processes be directed solely to beneficial purposes.

A Paleolithic Campsite in Belgium

In which bits of stone scattered in sand are analyzed to reconstruct human activities of some 9,000 years ago. In one method of analysis flint tools are refitted into the piece from which they were struck

by Francis Van Noten, Daniel Cahen and Lawrence Keeley

New methods of analysis are beginning to provide information on a period in the prehistory of Europe about which little has been known. This is the time, beginning some 9,000 years ago, when the cold climate associated with the last ice age had given way to moderate conditions roughly comparable to those of northern Europe today. Parklike tundra had been replaced by forests of birch and pine. Where the tundra was populated by mammoth, woolly rhinoceros and reindeer, the forests sheltered various kinds of deer, moose, wild cattle and boar. The human population, hunters and gatherers who had formerly pursued the animals of the ice age, adopted new strategies better suited to the habits of the less gregarious and more widely dispersed postglacial animals.

In this period the hunters and gatherers of northwestern Europe seem to have preferred to camp on sandy soils. Indeed, this preference is why we know so little about them. Those soils are generally acidic, so that few organic remains such as animal bones have survived. The chief evidence of human activity is the flint artifacts the hunters and gatherers made, used and left behind at their campsites. It is our intention here to describe one such campsite in Belgium and to show what could be learned from almost the only evidence of human presence at the site: the flint artifacts made and used by its occupants of nine millenniums ago.

Meer is a village near the border between Belgium and the Netherlands, some 35 kilometers northeast of Antwerp. Not far from the village, along the line of an ancient wind-built dune, commercial digging for sand in the mid-1960's exposed evidence of prehistoric occupation half a meter below the surface. Investigators from the Royal Museum of Central Africa at Tervuren in Belgium eventually located four sites in the area; the last of them is still being excavated. All four are campsites on what was then a low dune overlooking shallow valleys that must have been marshy. The valleys are now drained and under cultivation, but apart from that the environment of the campsites was probably not very different from what it is today.

The second of the sites, Meer II, is the one we shall discuss. It was systematically excavated between 1967 and 1969 by one of us (Van Noten). Analysis of the findings generated intriguing hypotheses about the site, and excavation was resumed in 1975. This second campaign was completed in 1976.

Apart from stone artifacts the various Meer II excavations yielded only a few eroded pieces of unidentifiable bone, some concentrations of small scraps of charcoal (a few of them probably representing hearths) and some bits of ocher (the red iron oxide hematite). The stone artifacts, however, were quite numerous. They included hammerstones made of quartzite and schist and grindstones made of sandstone. Other sandstone fragments appear to be the remains of slabs cracked by fire; they were probably hearthstones. Of some 16,000 stone artifacts uncovered during the excavations, however, 98 percent were flint.

The source of these materials is problematical. For example, the fine-grained quartzite of a few of the artifacts evidently came from an area 75 kilometers south-southeast of Meer. There are, however, no apparent surface sources of flint anywhere in the vicinity of the site today. Did such a source exist 9,000 years ago? Possibly so. At that time the level of the North Sea was many meters lower than it is now, hence the river channels in the area may have been deeper and could easily have exposed gravel deposits containing an abundance of flint. Nodules of flint might therefore have been had for the gathering in the postglacial period. That such was the case is suggested by the fact that many of the flint artifacts at the Meer II site appear to have been made from flint nodules worn by water.

The stone artifacts at Meer II were not all encountered at a single level. Although somewhat more than half were concentrated in a zone that measures only nine centimeters from top to bottom, the vertical distance separating the artifacts buried the deepest from those nearest the surface was in places five times greater. Now, it is axiomatic in archaeology, as it is in geology, that apart from certain obvious exceptions a buried stratum is older than a stratum lying above it. Thus the broad vertical distribution of the Meer II artifacts raised a serious question. Did the finds represent an assemblage, accumulated during a single occupation of the site, that had later been dispersed vertically by natural processes, such as the tunneling of rodents and the growth of roots? Or was the position of the tools, as principle would suggest, evidence of several successive occupations? The question could not be answered solely on the basis of field observations. It was here that one of the new analytical methods, known as refitting, came into play.

Before explaining the refitting technique and the conclusions to be drawn from its application at Meer II it will be helpful to describe the kinds of artifacts unearthed at the site. Putting aside great quantities of waste from the manufacture of flint tools (more than 80 percent of the material at the site), the most numerous artifacts were tools of the kind known as burins. They made up more than 1.5 percent of the total inventory, 264 in all. Next most numerous were scrapers (a total of 170) and projectile points (87). Most of the projectile points were of the kind known as Tjonger points; they are named after a site that is one of a group of late-glacial sites in this part of Europe, the Federmesser group.

Next in order of their abundance were 81 notched pieces, 63 truncated pieces, 59 microliths and 45 backed blades, several of them fragmentary. Fine and coarse borers made up most of the balance, along with a few "composite" tools, suitable for more than one kind of work. A substantial number of flint-tool "blanks" that showed some signs

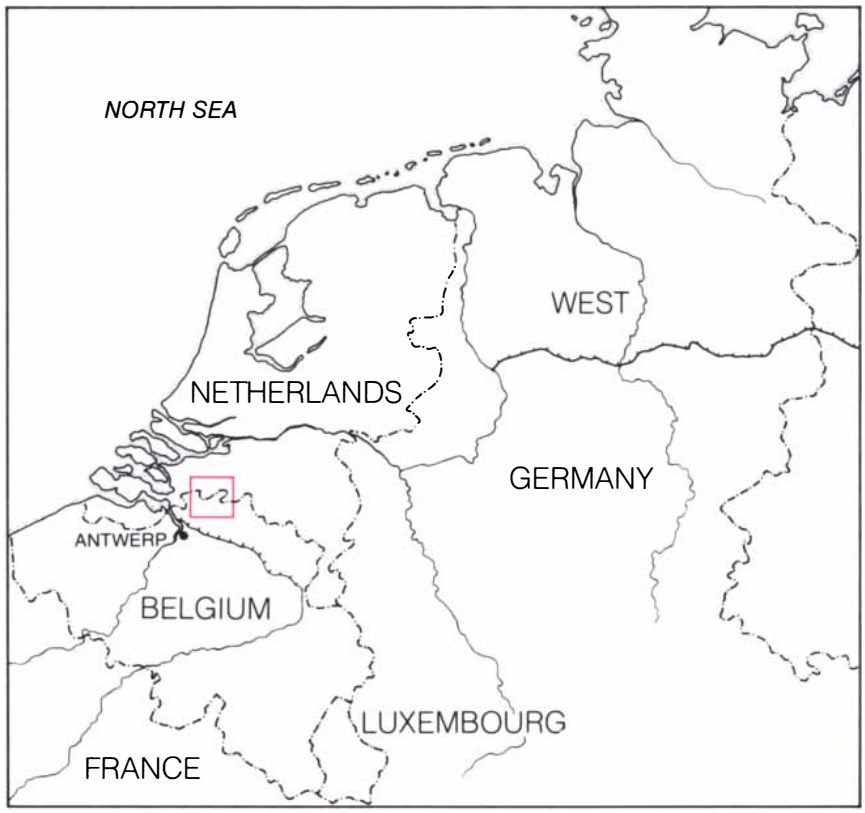
of retouching, 231 in all, could not be assigned to any of the foregoing standard categories.

Even though the Meer II inventory included Tjonger points and other tools comparable to artifacts of the Federmesser group of flint industries, the Meer II tool assemblage is not what one would call classic late glacial in character. Some of the tools are well made and fit neatly into established classic categories, but a large proportion of them do not and are therefore difficult to classify. Furthermore, carbon-14 analysis of charcoal samples collected from Meer I and Meer II indicated that the age of the sites is somewhere between 8,740 and 8,950 years. This is about at the threshold between the postglacial periods known as the Pre-Boreal and the Boreal.

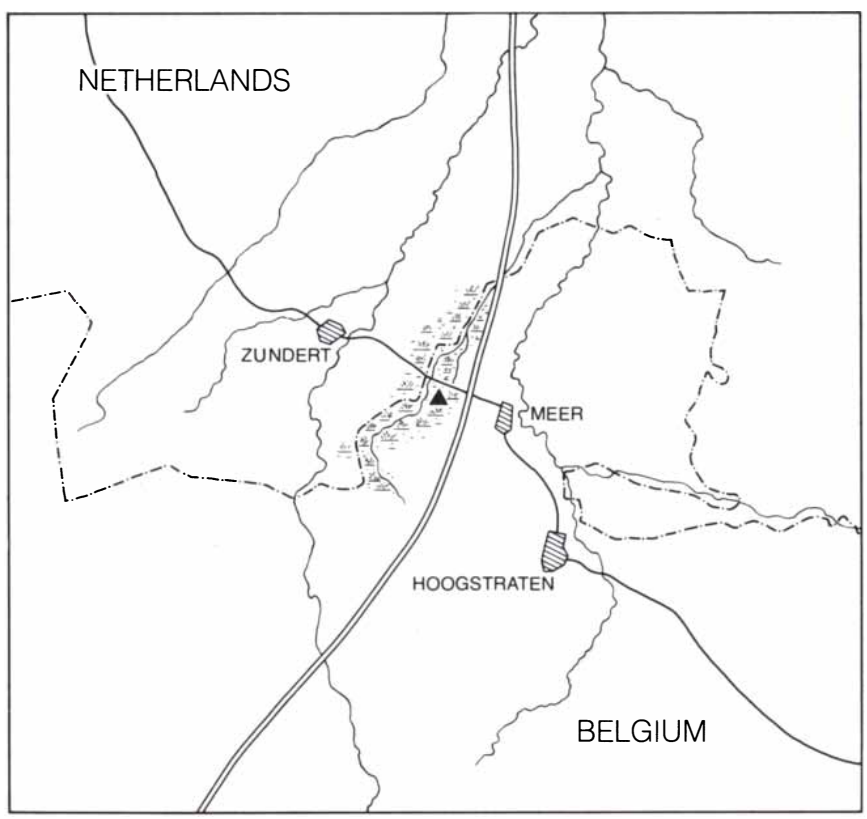
Such a date is rather late for a stone-tool industry related to the Federmesser ones; the Federmesser sites are usually reckoned to be between 10,000 and 11,000 years old. Nevertheless, there are exceptions to this chronological position, and in view of the fact that the Meer II artifacts were not in any event classic we did not find an age of about 9,000 years for the site either unexpected or troubling.

A plot was made of the horizontal density of the Meer II artifacts based on the excavation grid, which was divided into one-meter squares. The plot revealed large variations; the richer squares contained as many as 500 artifacts and the poorer contained few artifacts or none at all. It also became

TECHNIQUE OF REFITTING has put together most of a single nodule of flint that a hunting band had made into tools early in the postglacial period of northwestern Europe. The central "core" and some surface parts of the nodule were not recovered. Seen here are waste flakes and chips and four of the nine tools made from the nodule. Borers, gravers and burins, they were used to make bone artifacts at the Belgian site named Meer II. This refitted group was called the white-line bloc because the nodule had light-colored streaks in it.



CAMPSITES are near the border between Belgium and the Netherlands some 35 kilometers northeast of Antwerp (*area in box*). The locale is shown in more detail in the illustration below.



ANCIENT DUNE near the village of Meer (*triangle*), now covered by mixed forest, is where commercial digging for sand in the 1960's exposed signs of prehistoric human activities. Investigators located four sites along the dune; authors' work was done at the second site, Meer II.

evident that there were four separate concentrations of artifacts. They differed in size and density as follows.

Concentration *A,* an elliptical area about seven meters long and three and a half meters wide, was in the northwest corner of the site. Within the area was a relative abundance of tools of all types; they numbered about a third of the total inventory. Immediately to the east, in a satellite area designated *A*-1, a number of small pieces of flint could be identified as burin spalls: fragments knocked off in the process of making or resharpening burins. The spalls suggest that such work was concentrated in the area. A second satellite area along the northwest perimeter of the main concentration, designated *A*-2, yielded a large number of scrapers, suggesting the presence of some specialized activity in this area too. At the western edge of the concentration five projectile points were found in a group, as if a quiverful of arrows had been left there.

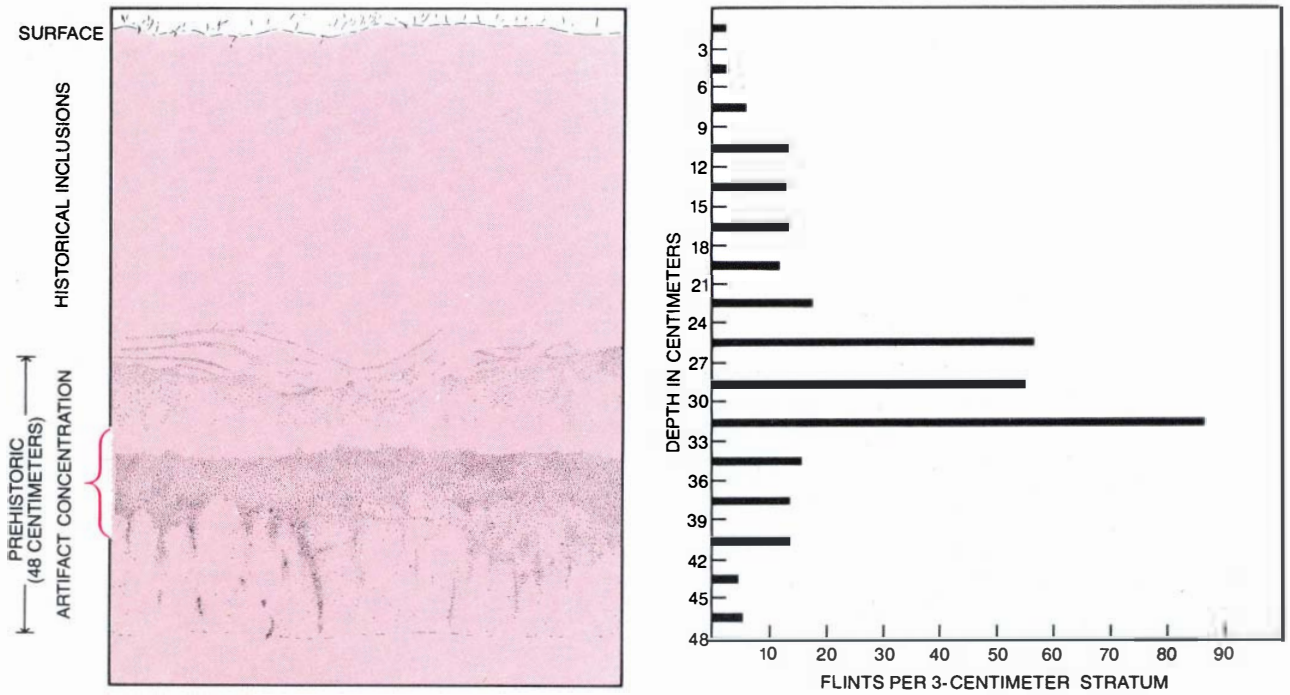
In addition to the stone tools and waste flint Concentration *A* held three hearths and a few small and unidentifiable bits of bone. It is impossible to tell whether the bone fragments represent kitchen debris, the waste from making bone implements or even the sole surviving remains of a human burial.

Concentration *B,* less clearly defined in shape but roughly three meters in diameter, was in the southwest corner of the site. It contained no hearth but did contain relatively large quantities of ocher. Angular flint fragments, other bits of flint that had been burned, probably by accident, some flint blades and a few projectile points complete the inventory at this concentration.

Concentration *C,* quite small and nearly circular with a diameter of about 1.5 meters, was close to the center of the site. Three "cores," the larger pieces of flint from which the tool-manufacturing blanks had been struck, were found here, along with a large amount of flint waste but no other artifacts. It seems likely that the concentration was a primary tool-production area.

Concentration *D,* smaller than Concentration *A* but somewhat similar to it in shape and orientation, was at the eastern end of the site. Large numbers of very small flint flakes, evidently the waste from the making and resharpening of tools, were found here. As for tools, however, there were only a few end scrapers, burins, borers and notched pieces.

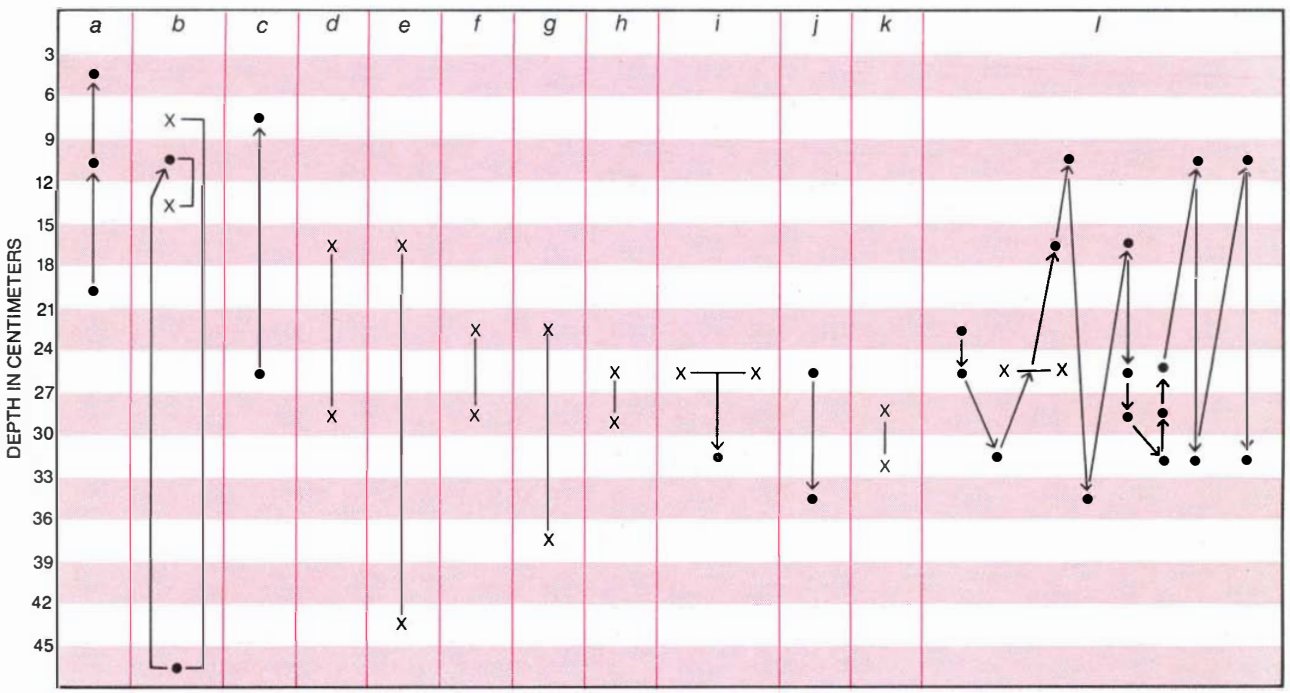
Such was the picture at Meer II, derived by conventional archaeological methods, that left the excavators with a number of unanswered questions. What additional interpretations were possible that might transform this static picture into a dynamic one? Consider the questions that called for answers. First, although the various carbon-14



PREHISTORIC REMAINS at Meer II, consisting almost entirely of waste flint and tools, lay in a zone half a meter deep (*cross section at left*). The bar chart at the right indicates the number of artifacts found per three-centimeter level in one excavation trench. Most were found in a zone three levels deep but many lay above and below it. This at first raised doubts about how often the site had been visited.

dates were consistent with one another, the artifacts at the site were sometimes separated vertically by distances as great as 45 centimeters. Second, analysis of the horizontal distribution of artifacts showed the existence of four concentrations that differed in character. Were these concentrations the result of a single occupation of the ancient dune? Or were they the result of successive unrelated visits to the place? We had no basis for preferring one conclusion over the other.

The organic material at Meer II was so impoverished that no help in interpretation could be expected from its analysis. The stone artifacts were basically all we had to work with. If we were not to give up and leave the questions unanswered, this body of evidence would have to provide the answers. To find



SINGLE OCCUPATION of Meer II was demonstrated by the refitting studies. The graph shows the considerable vertical distances separating related artifacts. Arrows, usually connecting dots, indicate refits between flakes struck successively from the same core; lines, usually connecting crosses, indicate refits between fragments of the same broken blank or tool. Each stripe represents one three-centimeter level. Evidently the old soils had been churned by natural forces such as root growth, which separated the related artifacts.

these answers we had to turn to and improve on two novel methods of investigation: refitting and microwear analysis.

One of us (Cahen) conducted the refitting study. Refitting means exactly that: solving a series of three-dimensional jigsaw puzzles in stone. For example, the investigator may begin with a discarded flint core and seek out the individual tool blanks that were successively struck from it and were then either discarded or made into tools of various kinds. Or he may start with a tool and search for the various fragments of flint that were removed from it in the process of either forming it into a tool or resharpening the tool after it was dulled by use. Or, sorting through fragments, he may reassemble all the parts of a single broken tool.

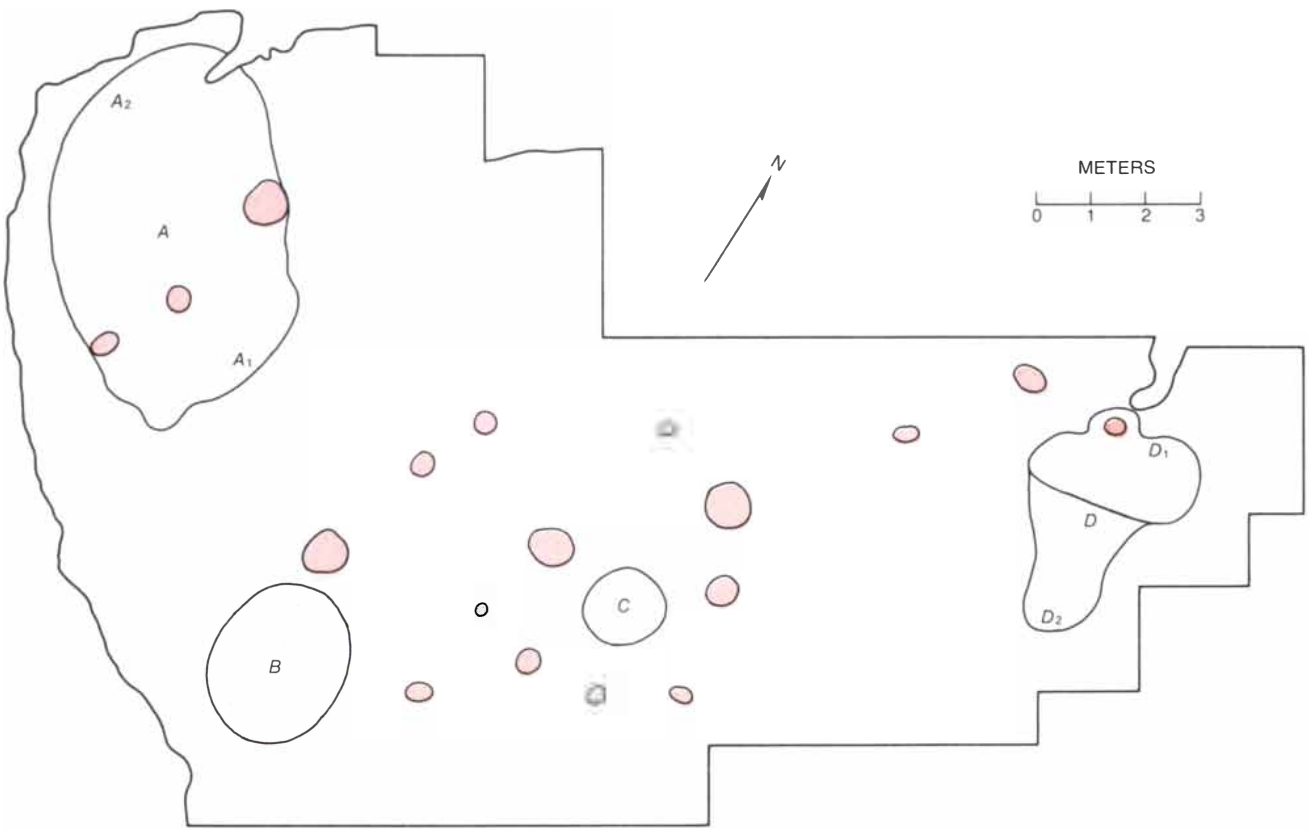
The refitting process is clearly a demanding one. Nevertheless, when the Meer II refitting program came to an end, 18 percent of the artifacts in the collection were shown to be interrelated. Moreover, the horizontal distribution of the related flints proved that all four concentrations at the site were linked. Equally important, it was demonstrated that the vertical distribution of the artifacts was not stratigraphically significant.

For example, the vertical distribution of the flint artifacts in one Meer II trench ranged from fewer than five in the top three-centimeter section to more than 80 per section at a depth of between 30 and 33 centimeters. The number then fell away to fewer than 10 per section just before the bottom of the artifact-bearing deposit was reached. It was found that parts of the same broken tool could be separated by vertical distances ranging from three to 30 centimeters.

Two examples of the vertical displacement are particularly striking. In the first one a flint flake found at a depth of 45 centimeters was refitted to another flake found at a depth of about 12 centimeters. A fittable fragment from the second flake lay a few centimeters lower in the trench and a fittable fragment from the first flake was found only three centimeters below the top section. In the second example a total of 17 flints could be refitted; three came from depths of less than 12 centimeters and five were found at depths of more than 30 centimeters [*see bottom illustration on preceding page*]. The complexity of these refitting sequences, together with the fact that in many instances the refitted pieces were small, unusable fragments, disposes of a possibility, namely that the matches are the result of later visitors' scavenging and reworking flints left behind by earlier occupants of the site.

Hence the refitting analysis eliminates any concern that the vertical distribution of the Meer II artifacts might be due to events occurring over an extended period of time. What about the horizontal distribution? Let us answer by describing what has been learned from refitting a group of tools and waste materials that all came from a single nodule of flint. Because the nodule had light-colored areas the group is known as the white-line bloc. Although the waste core and a few flakes from the surface of the nodule are missing, the rest of it has been pieced together [*see illustration on page 49*].

The refitting study shows that all the blanks removed from the white-line core for toolmaking purposes were struck off in Concentration *D*. Several of the blanks were made into tools, used and discarded in that area, but five of them were brought from Concentration *D* to *A*-1, the satellite area adjacent to Concentration *A*, either in the form of



EXCAVATION AT MEER II covered an area measuring a maximum of 24 meters on the long axis and a maximum of 15 meters on the short axis; the long axis was oriented northeast-southwest. The irregular boundary of the southwestern end of the excavation is the edge of the commercial sand-digging operations. A horizontal survey of the distribution of the artifacts revealed two major concentrations, *A* and *D*, one at each end of the excavated area, and two smaller concentrations, *B* and *C*, to the south of the long axis. Concentration *A*, the largest, included two satellite areas, *A*-1 on the southeast perimeter and *A*-2 on the northwest perimeter; it also included three hearths (*color*). Further evidences of fire (*color*) were uncovered elsewhere in the excavation, but the only other hearth was in Concentration *D*.

blanks or already made into tools. For example, one flint fragment knocked off in the resharpening of a burin was found in Concentration *D*. The fragment showed traces of wear. Refitting matched it to a burin found in the satellite area *A*-1. The burin had been used there and resharpened.

The artifacts of the white-line bloc evidently represent a set of tools manufactured in a single episode that began at Concentration *D* and was later completed in the satellite area, *A*-1. The horizontal distribution of the white-line components demonstrates that the two places of work were linked and therefore were contemporaneous. It should be added that refitting has assembled several similar sets of tools, most of them found in Concentration *D*.

A summary of what can be concluded from the refitting analyses can be presented for each of the concentrations as follows.

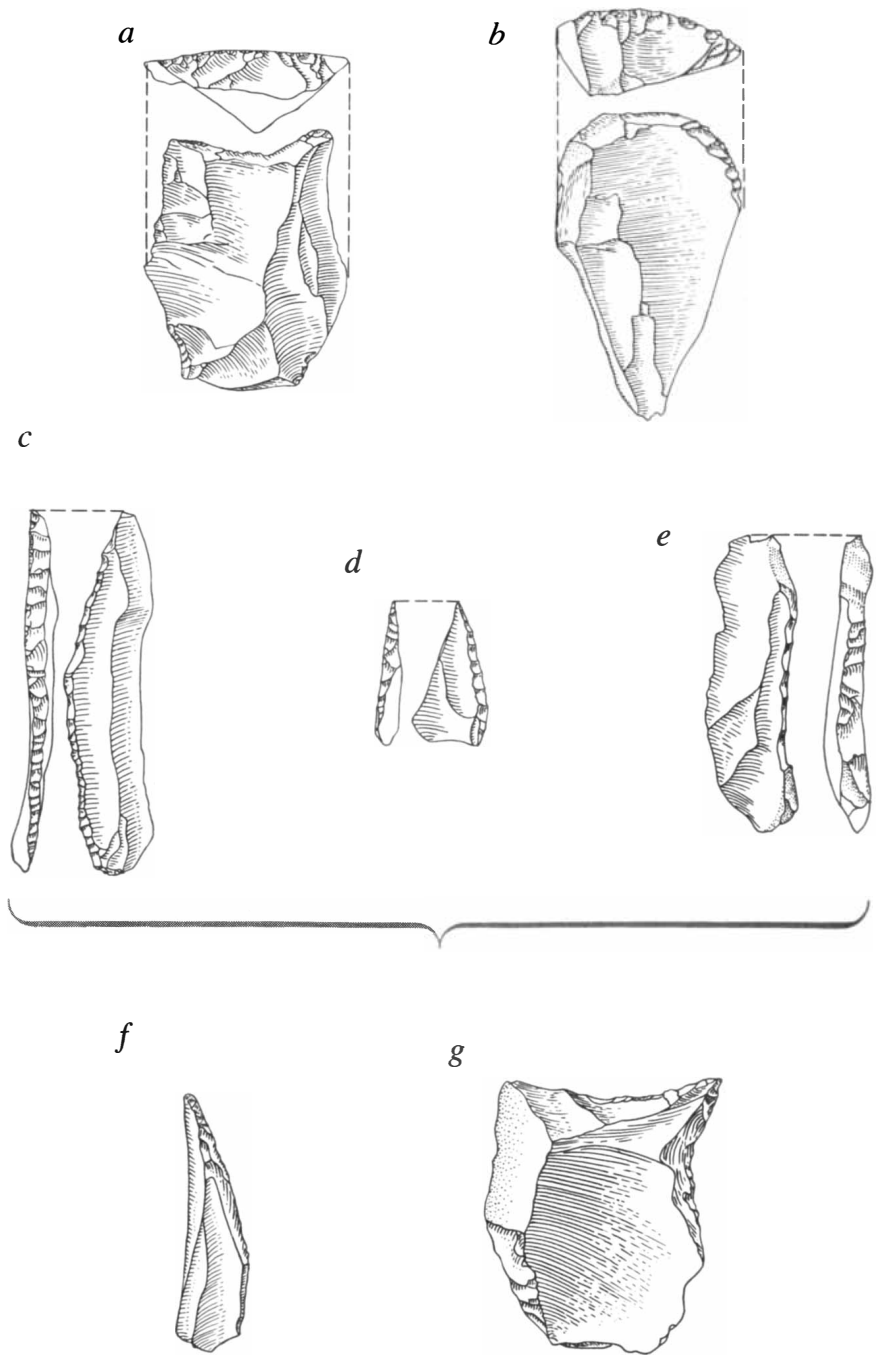
Concentration *D*. Of a total of 1,464 artifacts found here nearly a third have been refitted. The fraction is much higher than it is in the other three concentrations, where on the average fewer than a fifth of the artifacts have been refitted. The greater success of the refitting can be attributed mainly to the special character of the activities in Concentration *D*, where many tools were made, used and abandoned in the same place.

In any event, of the 104 tools in Concentration *D* that showed signs of modification or resharpening, 93 have been refitted. In many instances the refitting only involved finding small retouching flakes and replacing them on the tool. In other instances, however, it has been possible to fit together the tools themselves and sometimes to fit groups of tools to the core from which they were struck. The majority of these instances indicate not only that the tools were fashioned in Concentration *D* but also that the blank from which the tool was made had been struck off its core there.

This point may not seem to be important, but it rules out any argument that Concentration *D* was merely a rubbish dump where worn-out tools, unused blanks and waste flint were discarded. For example, it would be difficult to explain how the tools, the waste from their preparation and even the tiniest of flint flakes detached in the course of retouching and resharpening were found together unless Concentration *D* had been a working area where the tools were prepared and used.

Concentration *A*. This large area and its satellite area, *A*-1, appear to have had a preferential relation to Concentration *D*. For example, blanks and tools prepared in Concentration *D*, including the artifacts of the white-line bloc, were carried to the satellite area. The numerous associations between the two concentrations and the similarity of the activities in them even imply that the same craftsmen worked in both locations.

Another aspect of the activities in Concentration *A* combines conventional archaeological typology with refitting analysis. The inventory of tools in Concentration *A* includes Tjonger projectile points, microliths and backed blades. The last two can also be classified as projectile points differing from Tjonger points. Most of the refitting done here consisted in associating resharpening flakes with various resharpened tools; few tools have been refitted with one another and few groups of tools have been refitted with cores. Moreover, although most of the projectile points are fragmentary, an intensive search for



KINDS OF FLINT TOOLS found at Meer II are arrayed in the order of their relative abundance. The commonest was the kind known as a burin (*a*); 264 were found. Next commonest was the end scraper (*b*); 170 were found. Projectile points followed; they were of three types: Tjonger points (*c*), microliths (*d*) and backed blades (*e*). Although other kinds of tools were also found, these and two others, small borers (*f*) and heavy-duty borers (*g*), make up the majority.

the missing parts has been unsuccessful even though fits between fragments of the same tool are among the easiest to recognize.

The refitting studies nonetheless indicate that projectile points were manufactured in Concentration *A*. This leads to the conclusion that one activity here was the mounting of new points on projectile shafts whose old points had been damaged. The discarded fragmentary points evidently lack matching fragments because these fragments had been left in the field when the points were broken during the hunt.

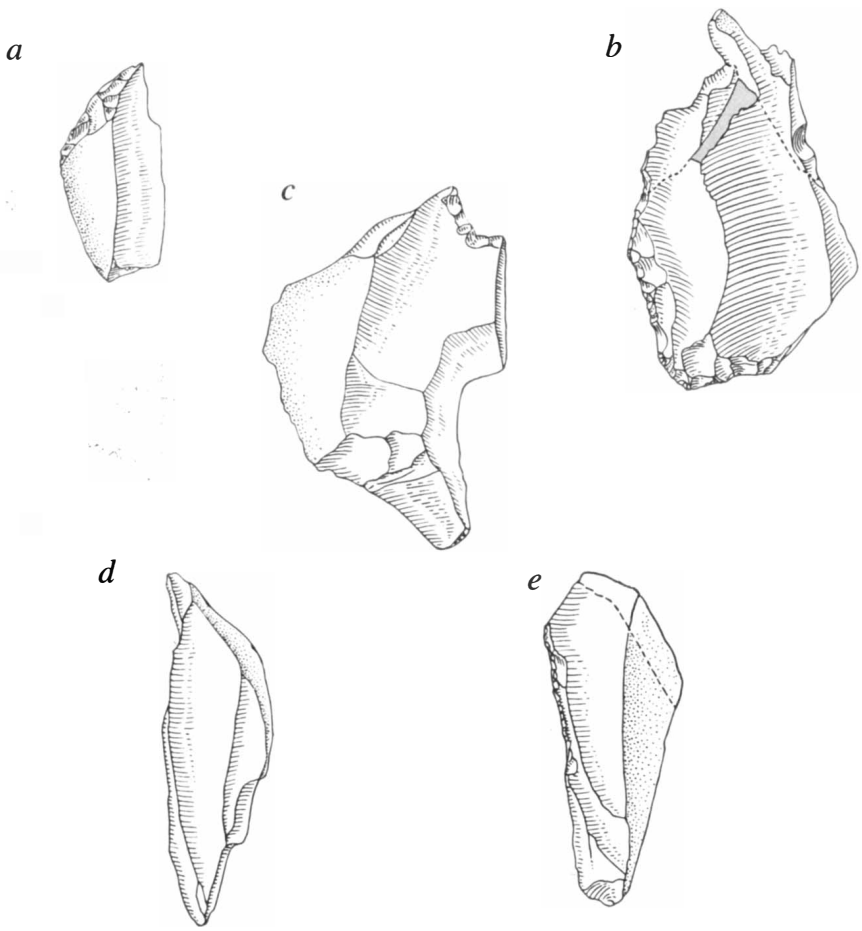
Concentration *C*. The pattern here is more complex and difficult to interpret than the pattern of Concentration *D*. Some links with other concentrations, however, are evident. First, worn-out tools and one depleted core that had been utilized in Concentration *D* were found here. Second, cores depleted by the manufacture of blanks in Concentration *C* were found in Concentration *A* and its satellite area, *A*-1. If Concentration *C* was an area of specialized activity, the work done there was probably the production of flint blanks for manufacture into tools somewhere else. The refitting study suggests that the somewhere else was outside the excavated area of Meer II.

Concentration *B*. In some respects this concentration presents a much clearer pattern than the one in Concentration *C*, because here hardly any relations can be established with the other three concentrations. The refitting study disclosed only three instances. One burin, first used in Concentration *A*, where a fragment was left behind, was used later near Concentration *C*, where one more fragment was found. The worn remnant of this burin was found in Concentration *B*. The second interrelation involves a fragment of a burned flint flake from Concentration *D;* a similar burned fragment from Concentration *B* fits it. Still another flint flake from Concentration *B* fits a flake found in Concentration *A*. Because Concentration *B* also lies away from the main axis of Meer II and contains no hearth but does contain a great deal of burned flint, one is led to the conclusion that it was a dump area, related not to the other Meer II concentrations but to areas to the west that have now disappeared as a result of commercial sand digging.

The refitting analysis shows how dangerously static a picture of a site and its activities can be given by a standard typological inventory of artifacts. The analysis proved not only that many of the Meer II tools were made in one place and then used and often resharpened somewhere else but also that they might eventually end up in still a third place. Furthermore, during its useful life one flint artifact could evolve from one type into another. Only a study of the dynamics of a stone-tool industry can lead to an accurate interpretation of the activities at a site.

A unique contribution to these interpretations at Meer II was made by the second new research method: microwear analysis. This analytical technique requires examination of the working edges and points of the flint tools at high magnification. Laboratory tests have shown that flint tools develop different characteristic polishes when they are used to work different materials such as wood, hide, bone and antler [see "The Functions of Paleolithic Flint Tools," by Lawrence H. Keeley; SCIENTIFIC AMERICAN, November, 1977].

An example of what microwear studies can accomplish is related to the remarkable refitting from Concentration *D:* the artifacts of the white-line bloc. As one of us (Keeley) found, all but one of the 10 tools and tool fragments belonging to the white-line bloc were used to engrave or to bore bone. (The exception is an end scraper, and it was used to scrape bone.) Moreover, the white-line tools used at Concentration *D* were mainly heavy-duty ones, possibly devoted to roughing out bone tools for finer work. For example, one of the borers was used to drill holes as large as 10 millimeters in diameter and depth, and one of the burins was used to cut grooves some five millimeters wide and five millimeters deep. The end scraper had also seen vigorous service. In contrast, the white-line tools that were carried from Concentration *D* to Concentration *A* were largely used for fine work. Three burins served for cutting grooves no more than two millimeters deep and the single borer served for drilling holes of similar dimensions.

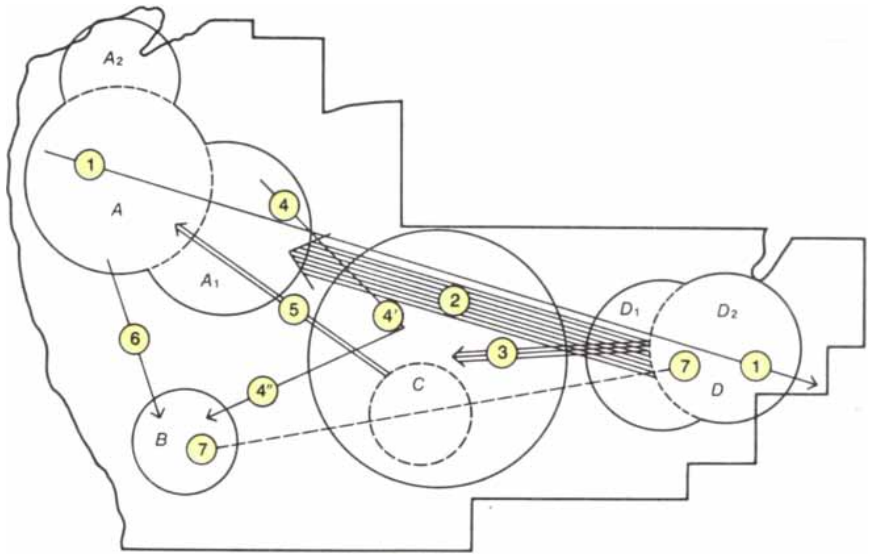


TOOLS OF THE WHITE-LINE BLOC include these five, four of which can be seen in the photograph on page 49. Tool *a* is a burin found in Concentration *D;* in the photograph it is at the far right, bearing the specimen number XXIII 672. Tool *b* is a burin used for fine bone engraving, found in Area *A*-1; in the photograph it is at the right edge of the group at the left, marked XXV 233. Of the two flakes refitted here (*top*) the one at the center was found in Concentration *D* and the one at the left was found in Area *A*-1. This shows that the burin was made and used in Concentration *D* and later brought to Area *A*-1, where it was used, resharpened and finally abandoned. Tool *c* is a borer used for delicate work on bone, found in Area *A*-1; in the photograph it is near the center of the group at the right, marked XXV 173. Tool *d* is another borer for delicate work on bone, found in Concentration *D;* in the photograph it is at the lower left of the group at the right, with the specimen number XXIII 669 only partly visible. Tool *e* from the white-line bloc is not visible in the photograph. It is a graver used for delicate work on bone, found in Area *A*-1. The refitted flake (*top*) was also found in Area *A*-1.

Such fine tolerances suggest that the work on bone being done with these tools was finishing and decorating.

As we have seen, other tools from Concentration *D* have been refitted. Most of them are burins and borers, and microwear analysis shows that they served almost exclusively for work on bone or antler. One such group included three bone borers. All of them had done their work while being twisted in a counterclockwise direction. Almost all the other Meer II borers were turned clockwise. It can therefore be concluded that more than one craftsman worked in Concentration *D* and that one of them was probably left-handed.

A total of 29 end scrapers were found in the satellite area *A*-2, and more than half of them have been refitted. We found that nine of the scrapers were made from blanks struck from a single core. Microwear analysis shows that all 29 of these tools were used to scrape dry hide. This part of Concentration *A* can therefore be identified without doubt as an area used largely, although not exclusively, for hide preparation. Wear analysis of other tools here and elsewhere in Concentration *A* indicates a wide range of activities: working bone, antler and wood, splitting canes and cutting meat and soft plant materials.



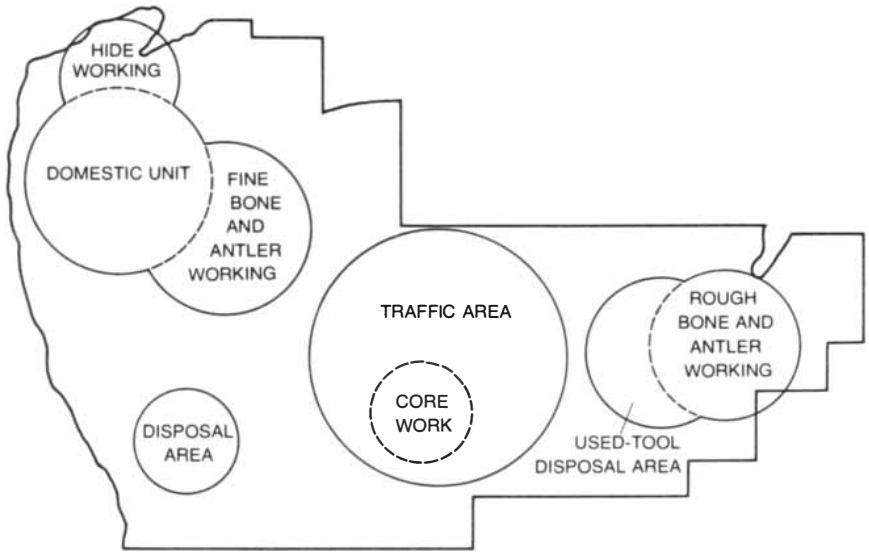
REFITTING STUDY demonstrated relations among the four concentrations of artifacts at Meer II. Diagrammed here are seven such relations (*colored numerals*). First, at the far left, a core was produced in Concentration *A*, transported to the periphery of Concentration *D*, at the far right, and then discarded. Second, eight artifacts (a core, three blanks and four tools) were transported from Concentration *D* to Concentration *A*. Third, four artifacts (a core and three rejected tools) that had been used in Concentration *D* were discarded in the vicinity of Concentration *C*; they may have been thrown there by a worker in Concentration *D*. Fourth, one tool moved in two steps, traced by the bent arrow. One flake from the tool was found in the satellite area *A*-1; a part of an intermediate stage in the manufacture of the tool was found on the periphery of Concentration *C*; the tool in its final form was found in Concentration *B*. Fifth, two cores that had been used to produce flint blanks in Concentration *C* were transported to Concentration *A*. Sixth, a blank from a core in Concentration *A* was found in Concentration *B*. Seventh, parts of the same artifact were found in Concentration *B* and Concentration *D*.

To sum up, our analyses show that Meer II holds the remains of a single period of occupation and that the occupation dates back about 8,900 years. Concentration *D* was an area where flint tools were prepared for work on bone and antler. At least two craftsmen worked there, and one of them was probably left-handed. Another of the craftsmen, who was probably right-handed, carried tools and blanks from Concentration *D* to the satellite area *A*-1 in Concentration *A*. There the flints from Concentration *D* were used primarily for fine work on bone.

Concentration *C* was at least in part an area where flint blanks were struck from cores. Very few of the blanks were retouched into tools in the area, but that work may have been done elsewhere. Concentration *B* is eccentric in many respects. It appears to be a refuse area related to a part of the Meer II site that was destroyed by modern sand digging.

Concentration *A* and its satellites *A*-1 and *A*-2 correspond in every respect to a domestic unit or habitation. One may cite in support of this conclusion the variety of the flint artifacts found here, the wide range of activities indicated by microwear analysis and the specialized tasks undertaken, such as hide preparation in Area *A*-2 and fine work in bone in Area *A*-1. Finally, Concentration *A* is the hub of the network of refitted pieces at Meer II and holds the largest and densest assemblage of artifacts.

The reader might now recall that Meer II was a featureless site, that the very few organic remains found there were uninformative and that the archaeological record consisted essentially of a diffuse scattering of pieces of flint. By careful excavation, refitting analysis and microwear analysis we have nonetheless been able to extract a substantial amount of information from the site. The results from Meer II make it clear that even a site that is poor in terms of the traditional kind of archaeological evidence has much potential for yielding information about human activities in the distant past.



MICROWEAR STUDY of Meer II tools demonstrated that different activities were pursued at different locations. For example, the patterns of wear on some tools found in Concentration *D* indicate that preliminary work on bone and antler was done in that area, and the patterns of wear on some burins and borers in the satellite area *A*-1 indicate that finishing work on the same materials was done there. Wear patterns of 29 end scrapers found in the satellite area *A*-2 indicate all were used to scrape dry hides. The wear patterns of other tools in Concentration *A* show they were used to work wood, to split cane and to cut meat and soft plant materials.

Sudden Infant Death

For many years this phenomenon, in which an apparently healthy baby dies quite unexpectedly, was mystifying to physicians. New evidence points in a majority of the cases to abnormalities in respiratory control

by Richard L. Naeye

One of the most devastating things that can happen to parents is to lose a baby to the "sudden-infant-death syndrome," where an infant who had seemed to be in good health is found dead in its crib. The phenomenon, which is also known by its initials SIDS (pronounced as letters rather than as a word), is defined clinically as the sudden, unexpected death of an apparently healthy infant for whom a routine autopsy fails to identify the cause of death. It is often called crib death or cot death, since it usually happens while the baby is sleeping. In the U.S. it kills about 7,000 infants per year, or about one out of every 500 babies born, making it the most frequent cause of death between the ages of one month and one year. It is also a common cause of death in many other countries. For years it has been almost totally mystifying to physicians. Now, however, as a result of an intense interdisciplinary effort over the past eight years, several promising clues to the syndrome have been obtained. They hold out the hope that potential victims can eventually be identified and that steps can be taken to save them.

Ideas about the causes of the deaths are abundant. Most of them have assumed that death is due to a sudden, catastrophic event affecting an otherwise normal infant. Until 1972 the most widely held hypothesis attributed the deaths to an abrupt closure of the upper airway that occurred without preliminary symptoms. Three types of evidence were cited to support the argument. Inflammation and ulcerations found on the vocal cords of some victims were taken as evidence that the cords had suddenly closed, cutting off the flow of air to the lungs. (In recent years such signs have been found to be as frequent in babies who die of known causes as in victims of the sudden-death syndrome.) Petechiae, or small hemorrhages, have long been noted on the surfaces of the lungs and other organs in the chest of more than half of the victims of the syndrome. (Before 1972 the petechiae were assumed to be the result of strong negative intrathoracic pressure developed when the infant strained to overcome an obstruction of the airway. Recent studies by Warren G. Guntheroth of the University of Washington School of Medicine have shown that an obstruction of the airway will not by itself produce petechiae.) The third abnormality commonly recognized before 1972 was fluid in the pulmonary air spaces. (This finding is of uncertain significance because it is not specific for sudden infant death; moreover, it can develop after death if there is a long interval between death and autopsy.)

For many years the sudden-infant-death syndrome aroused little interest in the medical community. Research on the syndrome had a minimal appeal for investigators because the diagnosis could be made only after death, a situation that rendered useless many of the tools of modern medical investigation requiring living subjects. In addition most investigators had never seen the syndrome or its consequences because the cases were handled by the police, coroners and medical examiners.

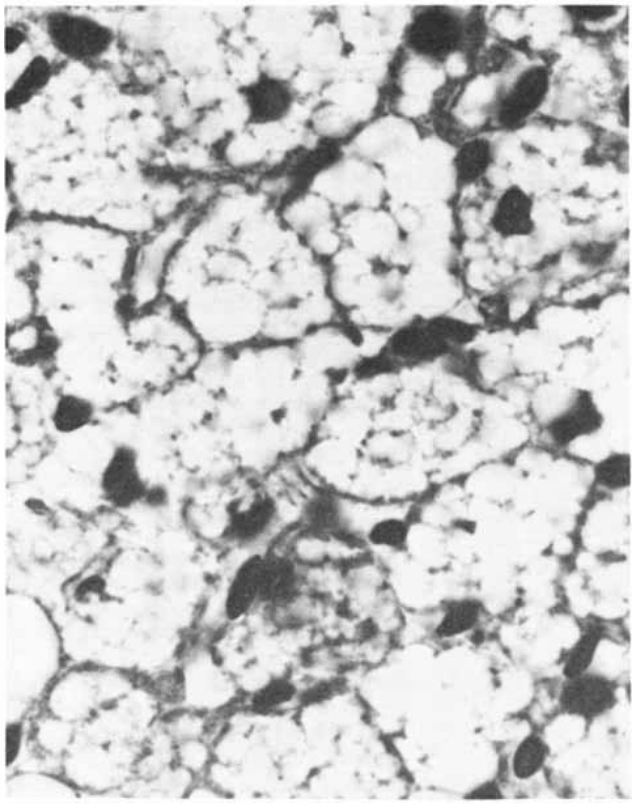
The period of neglect ended when two nationally organized groups of parents who had lost babies to the syndrome brought pressure on the U.S. Public Health Service (through Congress) to encourage research on the phenomenon. In 1972 Eileen G. Hasselmeyer of the National Institute of Child Health and Human Development organized seminars aimed at recruiting workers from several disciplines to investigate the syndrome. As a result physiologists, pediatricians, behavioral scientists, immunologists, biochemists and pathologists who had shown no previous interest in sudden infant death were stimulated to begin work on the syndrome.

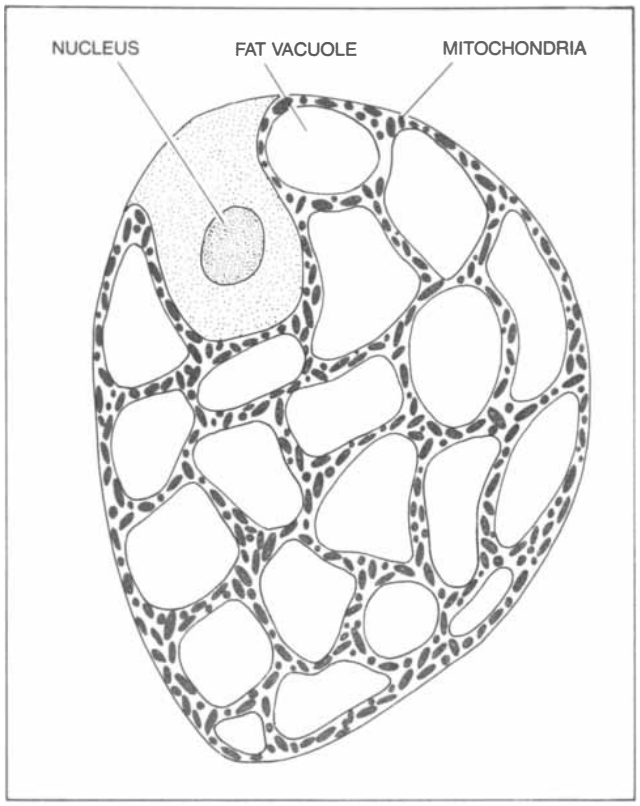
Epidemiological investigations made before 1972 had revealed some unusual features of the syndrome that are not easily explained by a sudden closure of the airway or by most of the other notions about sudden infant death that were entertained before 1972. The deaths have a distinctive age distribution. They do not take place in the period shortly after birth, appearing first among babies who are two or three weeks old, reaching a peak at three months of age and then decreasing in frequency until they become rare after the first year of life. Most of the hypotheses advanced before 1972 also failed to explain why most of the victims die while they are asleep.

Several of the workers who were recruited in 1972 raised the possibility that the deaths were the result of an abnormality in the mechanism controlling some life-sustaining system. Attention promptly turned to respiration because Alfred Steinschneider, working at the Upstate Medical Center of the State University of New York at Syracuse, had just reported prolonged periods of apnea (arrested breathing) during sleep in several infants who became victims of the syndrome. He postulated that the babies had died during an apneic episode. His idea was promptly named the apnea hypothesis.

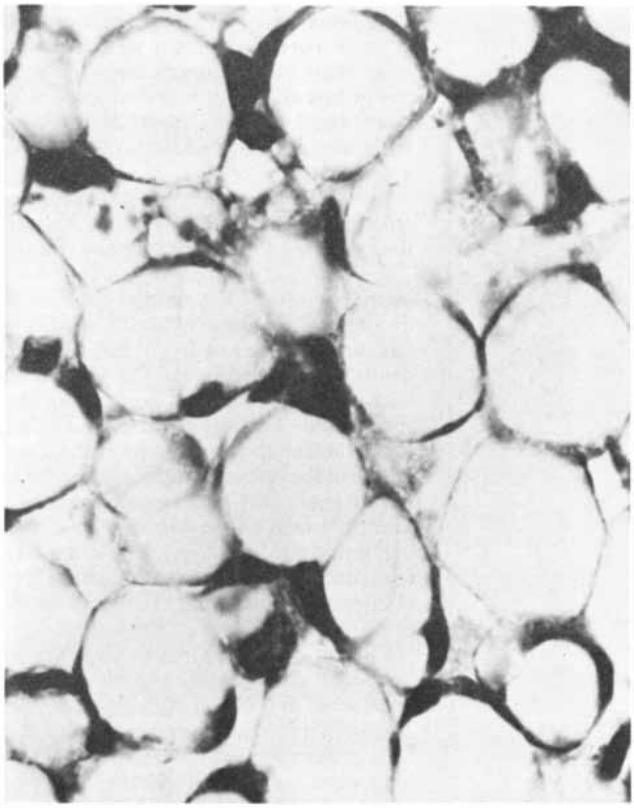
Elliot D. Weitzman of Montefiore Hospital and Medical Center in New York and others pointed out that the apnea of sleep described by Steinschneider resembles a condition in adults who have chronic abnormalities in the control of respiration. Such adults characteristically underventilate their lungs during sleep. It seemed possible that victims of sudden infant death might do the same.

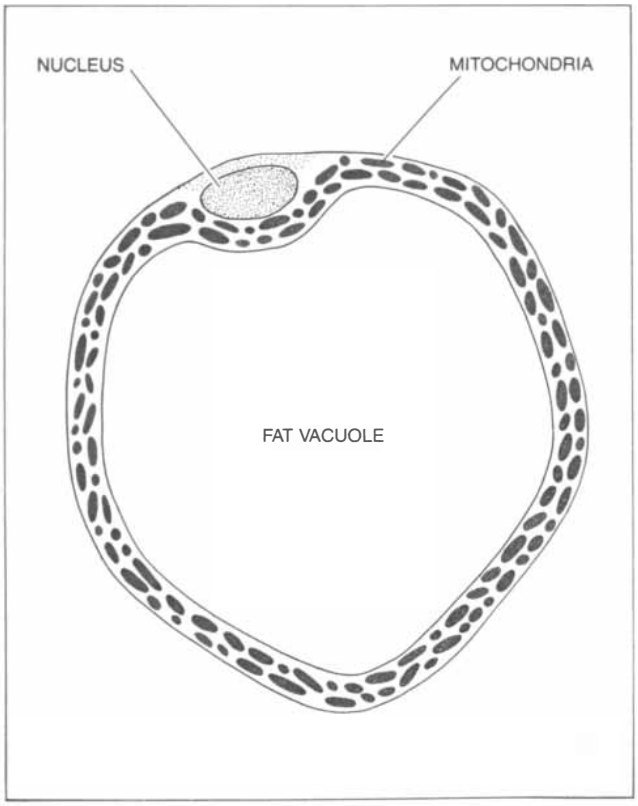
Working at the Milton S. Hershey Medical Center of Pennsylvania State University, I recognized that underventilation of this kind would leave anatomical markers. With the aid of Russell S. Fisher, the chief medical examiner of Maryland, an investigation was begun to see whether the victims of sudden infant death have such markers. We soon found that about 60 percent of the victims have an abnormal increase of muscle in the small pulmonary arteries. We postulated that the increase is caused by a chronic underventilation of the lungs. Underventilation reduces the level of



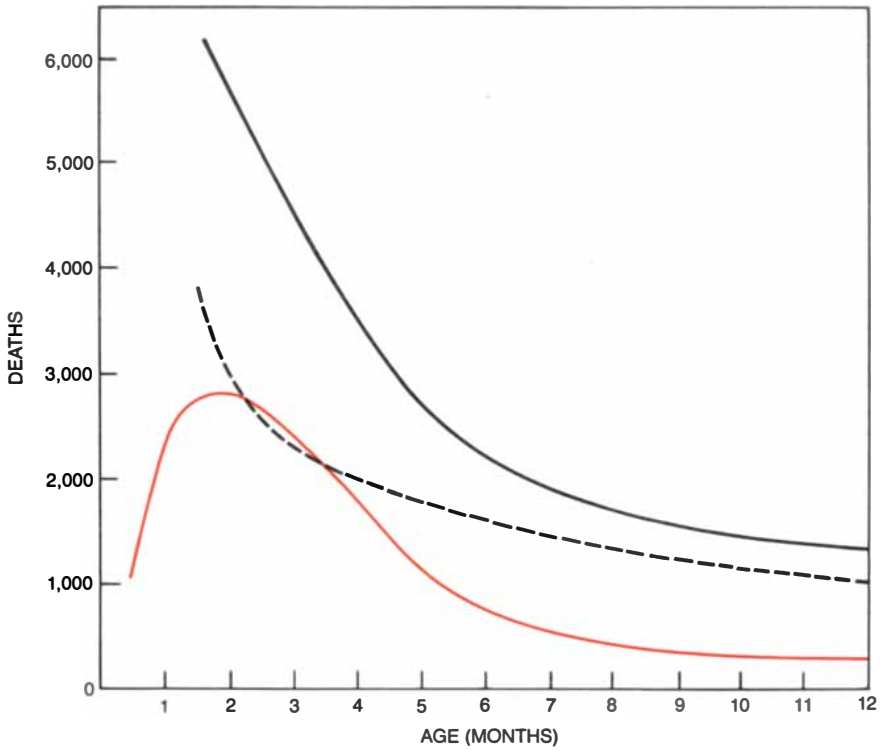


BROWN FAT is retained for an abnormally long time in many babies who die of the sudden-infant-death syndrome. At the left is a micrograph (enlarged 1,500 diameters) of cells from a baby who died of the syndrome at the age of four months. The round cells contain webs of mitochondria surrounding small vacuoles of fat, as diagrammed at the right. The mitochondria give brown fat its typical appearance.

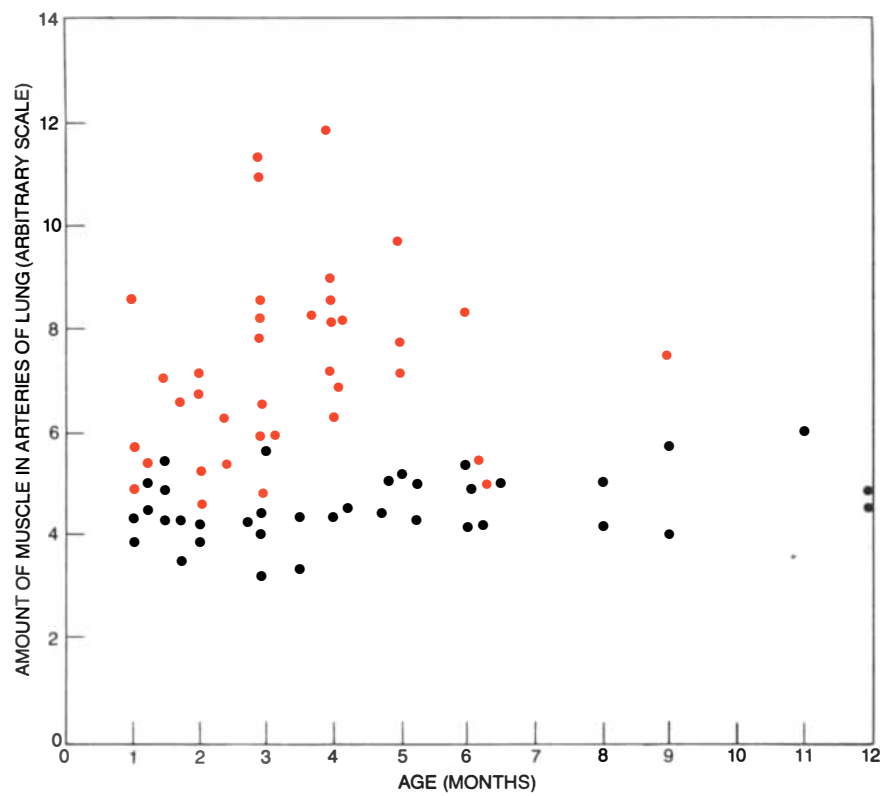




NORMAL FAT CELLS appear in the micrograph at the left and are diagrammed at the right. The cells in the micrograph are from a baby who died in an accident at the age of four months. Most of the mitochondria have disappeared. Their retention in many sudden-death babies is thought to be caused by hypoxemia (insufficient oxygen in the blood), a result of chronic underventilation of the lungs in sleep.



INFANT DEATHS in the U.S. from the sudden-infant-death syndrome (*colored curve*) and all other causes (*broken black curve*) are charted. Solid black curve shows total number of deaths between the ages of 10 weeks and 12 months. The syndrome is the most frequent cause of death between the ages of one month and one year, and at one age it exceeds all other causes.



MUSCLE INCREASE in the pulmonary arteries is a frequent postmortem finding in victims of the sudden-death syndrome. The abnormality is reflected in this chart showing the amount of pulmonary-artery muscle in several sudden-death infants (*color*) and in controls (*black*), infants who had died of other causes. The increase is thought to be caused by a chronic underventilation of the lungs, which makes the arteries constrict chronically and develop extra muscle.

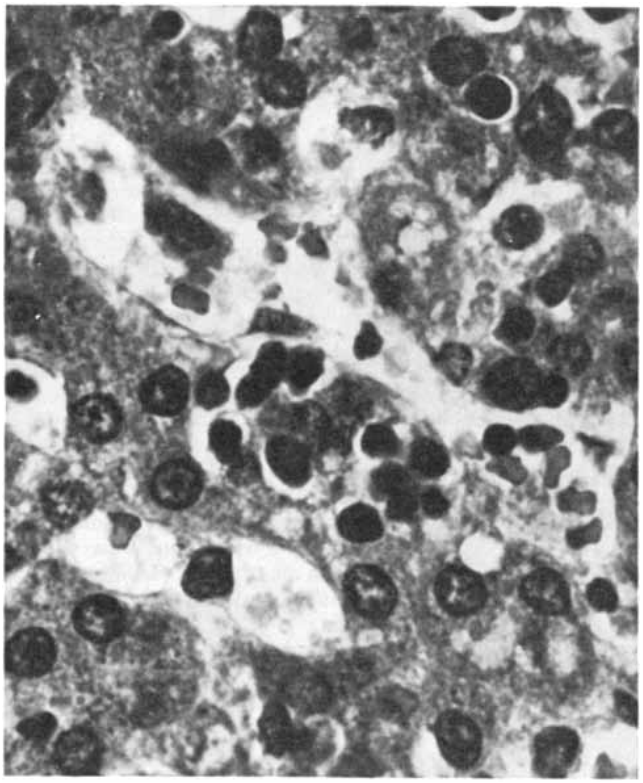
oxygen in the air spaces of the lungs, causing nearby arteries to constrict. When a chronic underventilation prolongs the constriction, the number of muscle cells in the walls of the arteries increases (the condition known as hyperplasia). Hyperplasia increases the resistance of the vascular system to the flow of blood through the lungs, which in turn forces the pressure to rise in the right ventricle of the heart. The heart responds like the pulmonary arteries by increasing the amount of muscle in the right ventricular wall. The abnormalities of both the pulmonary arteries and the heart were overlooked in cases of sudden infant death for many years because the quantitative studies required to recognize them are not part of routine postmortem examinations.

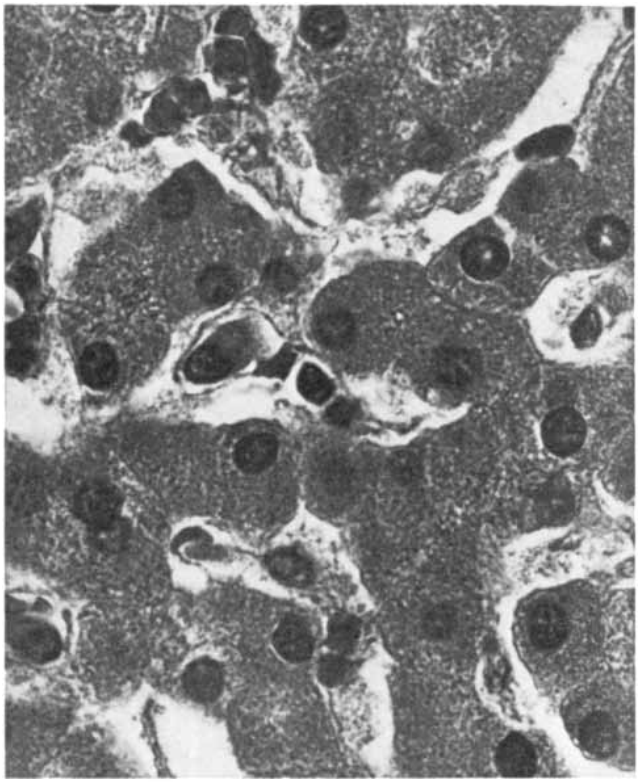
The underventilation that reduces the level of oxygen in the pulmonary air spaces also lowers the level of oxygen in the arterial blood that circulates through the rest of the body. This deficiency of oxygen in the blood is termed hypoxemia. Its consequences are found in more than half of the victims of the sudden-infant-death syndrome.

The first of the consequences to be discovered was an abnormal retention of brown fat. Brown fat surrounds certain vital internal organs at birth and is specially adapted for the generation of heat. What gives brown fat its characteristic appearance under the microscope is an abundance in the fat cells of the intracellular particles known as mitochondria. Most of the mitochondria are normally lost during the first year of life, after which the cells lose their brown color and their distinctive microscopic appearance.

In infants who are chronically hypoxemic after birth these fat cells retain their mitochondria and brown color. The condition is present in about half of the victims of the sudden-death syndrome, which suggests that the babies had long periods of hypoxemia before death. Most victims of the syndrome also have an abnormal increase in the specialized adrenal-gland tissue that makes adrenalin (epinephrine). An increase in the release of epinephrine from the adrenal gland may explain the retention of brown fat in babies who die of the syndrome, since brown fat usually reappears in adults who have a high level of epinephrine in the blood as a result of an adrenal tumor.

Further signs of chronic hypoxemia in sudden-death babies include the production of red blood cells by the liver and an increase in the production of red cells in the bone marrow. (Normally the liver does not make red cells after the first week of life.) These effects presumably arise because hypoxemia causes the kidneys to release the hormone erythropoietin, which stimulates the manufacture of red cells.





ANOMALY OF RED-BLOOD-CELL PRODUCTION appears in some babies who die suddenly and unexpectedly. The elliptical area slightly to the left of center in the micrograph at the left shows precursors of red blood cells in the liver of a four-month-old victim of the sudden-death syndrome. Normally the liver does not make red blood cells after the first week of life. The micrograph at the right shows a section of the liver of a child of the same age who died of other causes. The liver shows no precursors of red blood cells. The bone marrow also increases its production of red blood cells in many sudden-death babies. The abnormalities probably arise because the deficiency of oxygen in the blood causes the kidneys to release the hormone erythropoietin, which stimulates the manufacture of red cells.

The victims of the sudden-death syndrome are not abnormally small at birth, but they often lag in growth after birth. The growth pattern of their organs resembles the one seen in experimental animals that are maintained in a low-oxygen environment after birth. It does not at all resemble the growth pattern resulting from undernutrition. Still another sign of hypoxemia in about half of the babies is an increased level of the adrenal hormone cortisol; the level normally rises in response to hypoxemia and other forms of stress.

With so many signs of underventilation before death in these babies, one is moved to look for a reason. There is evidence to indicate that the underventilation is the result of abnormalities in the mechanisms that control respiration. Prolonged episodes of apnea during sleep in babies that later fell victim to the sudden-death syndrome have been observed not only by Steinschneider but also by Daniel C. Shannon and Dorothy H. Kelly of Children's Hospital in Boston, who also observed chronic underventilation and blunted respiratory responses to increased levels of inhaled carbon dioxide in the infants. This evidence suggests that the babies had abnormalities in the control centers of the brain stem that normally respond to accumulations of carbon dioxide by increasing the frequency and depth of breathing.

Reasons have recently been found for the sudden-death phenomenon's being more frequent in the first months of life. David Read in Sydney, Australia, and Charles Bryan and Elliott A. Phillipson of the University of Toronto School of Medicine have shown that in the first months certain mechanisms of respiratory control operate differently from the way they do later in life. In babies who are from one month to six months old the lungs partly collapse in the phase of sleep when the eyes move rapidly under the eyelids, because in this phase the intercostal muscles that move the chest stop functioning. If the diaphragm also stops moving so that respiration is interrupted during rapid-eye-movement sleep, little residual air remains in the lungs to continue the normal exchange of oxygen and carbon dioxide. The result is hypoxemia within a few seconds. An adult, in contrast, can stop breathing for from 30 to 40 seconds without developing severe hypoxemia.

When breathing slows down or stops, the reflexes that augment it or restart it in older children are notably less active in young infants. The survival of these infants therefore depends on a reflex arousal out of rapid-eye-movement sleep and a switching on of the brainstem mechanisms that restart breathing. The carotid body, a small organ in the neck, has an important role in both functions. Our group found in 1976 that more than half of the victims of the sudden-infant-death syndrome had an underdeveloped carotid body. If this organ is not functioning normally, the infant may not be able to restart its breathing during a prolonged episode of apnea. Sudden-death babies who have these underdeveloped carotid bodies also show at postmortem examination the signs of chronic underventilation and hypoxemia I have described.

Why is the carotid body underdeveloped in so many victims of the syndrome? One possibility is a lack of stimulation by nerve impulses coming to the carotid from the respiratory-control centers in the brain stem. It might then be asked if those centers are structurally normal. Detailed anatomical studies of them have not yet been made because the centers are both structurally complex and closely associated with other centers that control other vital functions. Any abnormalities that may eventually be found in the respiratory-control centers are likely to be subtle, because an infant with severe abnormalities there would not survive after birth.

Our group at the Hershey Center

found in 1976 that about half of the sudden-death infants have an abnormal proliferation of astroglial fibers in the lateral reticular formation of the brain stem. This formation is a key center for respiratory control, so that it would be tempting to interpret the astroglial proliferation as evidence of damage to respiratory-control mechanisms. The interpretation would be inappropriate because many other areas of the brain stem also exhibit the condition in victims of the syndrome. Moreover, the condition can be produced by chronic hypoxemia. Sachio Takashima and his associates at the Hospital for Sick Children in Toronto have recently found that astroglial proliferation is greatest in sudden-death babies in the areas of the brain where the blood supply is the poorest. The finding strengthens the view that the astroglial proliferation is the result of hypoxemic injury.

John Emery and his associates in Sheffield, England, have observed that about half of the sudden-death victims they have investigated have scavenger cells laden with fat in the spinal fluid. The fat appears to be derived from broken-down brain tissue. Hypoxemia may be the cause of this breakdown.

John Olsson in our laboratory recently found that the brain-stem area controlling the tongue has a significant deficiency of neurons, or nerve cells, in many sudden-death infants. Among adults there is a syndrome, characterized by apnea, in which the tongue falls back and obstructs the upper airway during sleep. It remains to be seen whether the tongue participates in the obstruction of the airway that develops at the end of occasional apneic episodes in a few infants who are prone to apnea.

The brain-stem centers that control respiration are very close to structures that control other body functions, and so any defect impairing the respiratory-control mechanisms might also affect those other functions. Nonrespiratory impairments are found in some of the babies who die of the sudden-death syndrome. The impairments include abnormalities in temperature regulation, feeding, muscle tone and neurological reflexes starting soon after birth. Some parents of sudden-death babies have reported that their infant had an abnormal cry from the time of birth. Recordings of several such cries confirm their abnormal character. Apart from Olsson's work little effort has been made to correlate the various nonrespiratory findings in sudden-death infants with specific lesions of the brain.

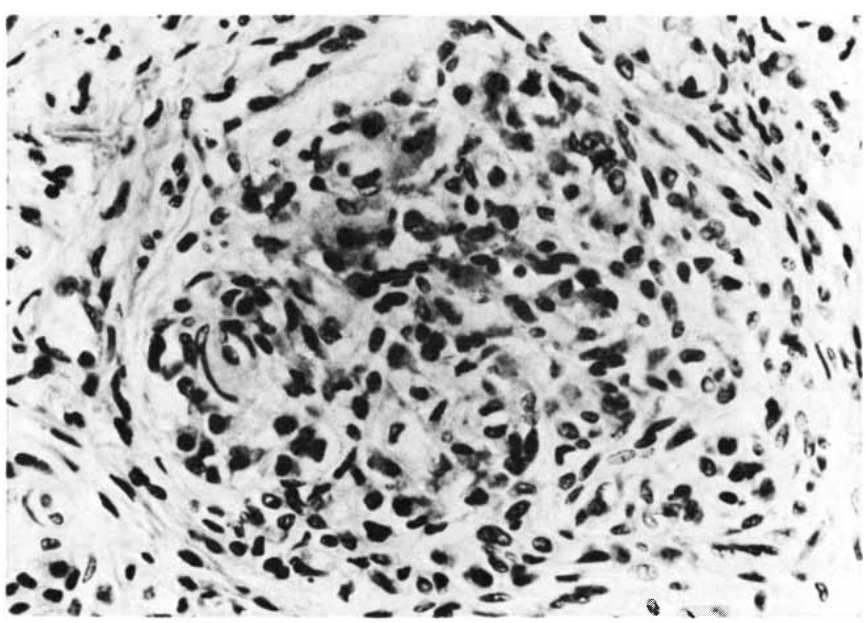
From interviews we have had with parents it seems that the majority of sudden-death babies had less intense reactions to various environmental stimuli than their surviving siblings had at the same age. These behavioral characteristics were most evident in the sudden-death victims who had an abnormal increase of muscle in the pulmonary arteries and the other postmortem signs of chronic pulmonary underventilation and hypoxemia. The finding raises the possibility that the behavioral pattern is the result of subtle brain damage caused by hypoxemia. Evidence for such damage has emerged from a preliminary study in our laboratory that found a delay in the myelination of two areas of the brain stem in sudden-death victims. Myelin is the fatty insulation that enables electrical impulses to travel along nerve fibers. Any delay in myelination might delay the maturation of certain brain functions.

Several investigators have suggested that the behavioral pattern might be due to a deficiency in the levels of the neurotransmitters mediating the conduction of impulses from one neuron to another. John D. Connor, a pharmacologist at our institution, has measured the levels of the neurotransmitters norepinephrine, serotonin and dopamine in various areas of the brain of sudden-death babies. No deficiencies were found when those levels were compared with the levels in infants who had died in accidents.

If the primary abnormalities responsible for sudden infant death are often in the brain stem or the carotid body, when are those organs first damaged? Some of the dysfunctions observed in babies who die of the syndrome are recognized in the period shortly after birth. The primary injury or defects could therefore be genetic or they could result from damage sustained during pregnancy, labor or delivery. The data we have collected in a large survey show no evidence that sudden-death babies had more oxygen deprivation, damage from anesthetic agents or trauma before or during delivery than babies who did not die. The finding raises the possibility that some of the abnormalities of the brain in victims of the syndrome are genetic in origin or that the primary damage occurs in the fetal period. The sudden-infant-death syndrome rarely runs in families, however, and published investigations have failed to find abnormal ventilatory control in the families of the victims.

One can cite other evidence that the syndrome is usually an acquired rather than a genetic disorder. Donald R. Peterson of the University of Washington School of Medicine has found that the rate of incidence of sudden infant death among first cousins is no higher than it is in the community as a whole. He also reports that if one twin dies of the syndrome, the chance that the other will die of it is only from 5 to 8 percent, regardless of whether the twins are identical or fraternal. The low rate of concordance means that a genetic origin for most cases of the syndrome is quite unlikely.

Although the concordance rate among twins is much too low to support a genetic hypothesis, it is many times higher than the incidence of the syndrome in the population as a whole. It may therefore be that if both twins die, they perhaps shared a predisposing environment. With data from our survey we recently identified six factors that appear to have an independent relation to sudden infant death. One factor has a genetic character and four are related to pregnancy. The genetic factor is infant blood type *B*. The factors related to pregnancy are (1) a bacterial infection of the amni-



UNDERDEVELOPED CAROTID BODY is another common finding in sudden-death infants. Such a body, the roughly circular structure that takes up most of this micrograph, is shown enlarged 420 diameters. A normal carotid body pictured at the same scale would be much larger. Carotid bodies, one on each side of the neck, are involved in control of breathing.

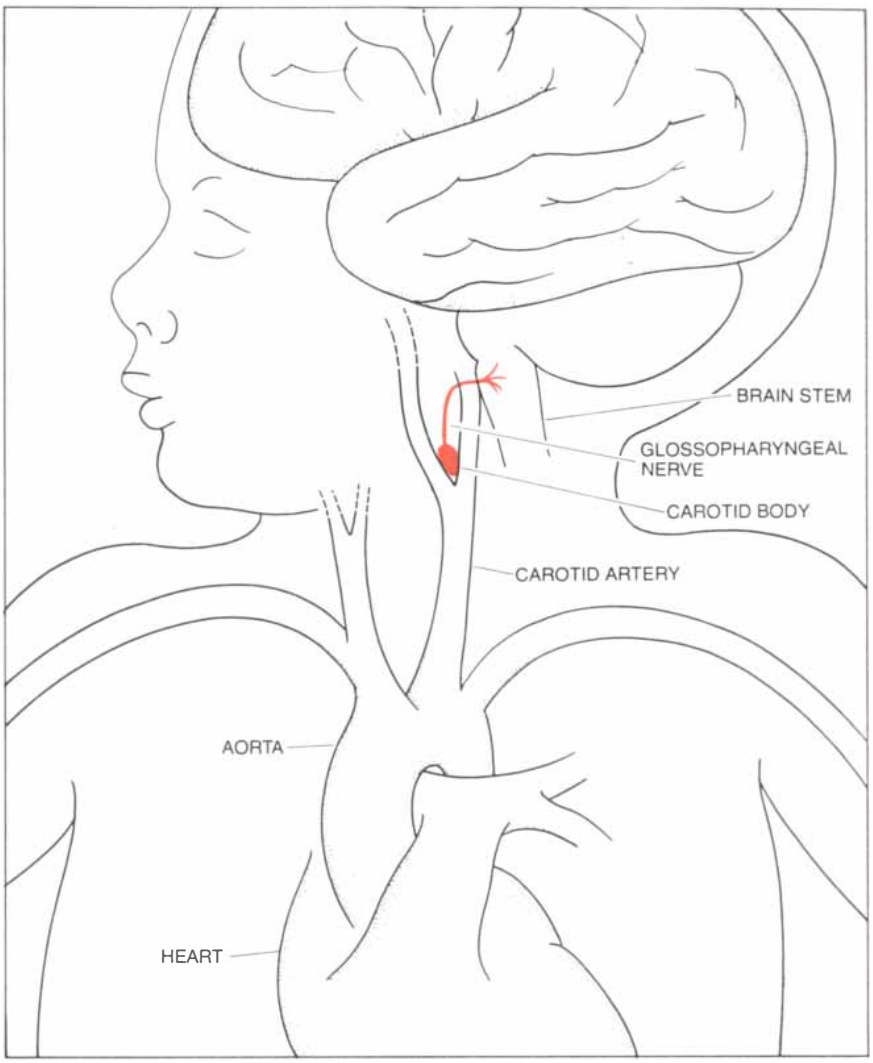
otic fluid, (2) anemia in the mother and (3) the use by the mother of cigarettes or (4) barbiturates. The sixth factor is crowded housing.

Four of the six factors have been shown to either damage the fetus or place it at increased risk of damage. Infections of the amniotic fluid directly or indirectly cause brain damage in some infants. Smoking by the mother reduces the flow of blood to the placenta and retards the growth of the fetus. Barbiturates are known to selectively retard the growth of the brain in newborn rats. Severe anemia in the mother during her pregnancy is associated with excessive deaths among fetuses and newborn infants. Infant blood group *B* is a high-risk factor for stillbirth and for death shortly after birth in a number of disorders unrelated to the sudden-infant-death syndrome. Peterson has found that the syndrome has a particularly high frequency in the offspring of mothers who have had more than one pregnancy. The specific environmental factor that is responsible remains to be determined.

Many other factors associated with the syndrome appear to lose their high risk in the absence of an infection of the amniotic fluid. They include preterm delivery, the fact that the infant is male or nonwhite, low family income and situations where the mother is poorly educated, makes few visits for prenatal care or has a history of losing fetuses.

In our study all the excess sudden deaths related to crowded housing were babies who were shown at autopsy to have had a mild infection of the respiratory tract. Several studies have found that infections of the respiratory tract increase the frequency and duration of apneic spells in infants who are prone to apnea.

Even if all six of the factors we have identified contribute to the genesis of sudden infant death, they explain only about a third of the deaths. Their greatest significance may be their indication that fetal life is a fruitful area in which to continue the search for the origins of the syndrome. It is worth noting that the brain stem is a particularly vulnerable target for damage during fetal life because it has a higher metabolic rate than other areas of the brain have. Specifically, the brain stem is vulnerable to damage by low levels of both oxygen and glucose in the blood.



ANATOMICAL SETTING OF CAROTID BODIES is represented schematically. The carotid abnormality often found in sudden-death babies has led to efforts to see if the respiratory-control centers in the brain are structurally abnormal. The efforts have been impeded by the fact that the centers are closely associated with other centers controlling other functions.

Although Steinschneider's apnea hypothesis has a substantial amount of supporting evidence, it will not easily explain all the sudden infant deaths. At least a third of the victims have none of the postmortem signs that suggest underventilation of the lungs or chronic hypoxemia before death. Hundreds of hypotheses have been offered to explain these remaining deaths, often with no supporting data or with only fragmentary evidence and no follow-up studies. In spite of the confusion clues have been found for several nonrespiratory mechanisms in sudden infant deaths. Bradycardia (an abnormally low heart rate) and serious disturbances of the heart rhythm have occasionally been observed during episodes of apnea in sleeping infants. The findings have encouraged speculation that sudden cardiac arrhythmia, with or without apnea, may cause death in some cases. The hypothesis is plausible, but the investigators working on it have been greatly handicapped by their inability to study the victims before death. Searches for cardiac abnormalities in the families of sudden-death babies have been inconclusive.

From 5 to 10 percent of the deaths attributed to the syndrome without corroboration by autopsy are in fact due to other identifiable causes, including meningitis, other fulminating infections, homicide and accidental strangulation in an improperly designed crib. Manufacturers have changed their crib designs, so that deaths caused by accidental strangulation should eventually disappear. Various studies have shown that even newborn infants remove blankets loosely placed over their face, so that suffocation from bedding is not a plausible cause of a sudden infant death even though anguished parents often think it may have been.

Sudden infant death appears to be more frequent when the mother has received methadone in the course of treatment for addiction to heroin. These deaths could be caused by other risk factors for sudden infant death, such as an infection of the amniotic fluid, but it is possible that methadone itself plays a role. After a single dose of methadone the mother underventilates her lungs for as long as 24 hours, and babies born to such mothers have a subnormal response to stimuli that normally increase ventilation.

In some young experimental animals the stimulation of the larynx and the areas around it by various fluids leads to

an interruption of the heartbeat and of breathing. It is therefore possible that a regurgitation of fluid from the stomach or an inhaling of fluid into the larynx might be responsible for some sudden infant deaths. At present it is impossible to study this mechanism safely in human beings, and so its relevance to the syndrome will probably remain uncertain for some time.

Stephen Arnon and his colleagues at the California Department of Health have identified a small number of syndrome victims who died of an infectious form of botulism. The bacterium (*Clostridium botulinum*) can grow in an infant's intestines and manufacture enough toxin to cause sudden death. The source of the infection has usually been found to be the ingestion of bacterial spores contained in honey. The toxin acts by binding irreversibly to nerve terminals and preventing the release of the neurotransmitter acetylcholine. In time the muscles required for breathing become paralyzed.

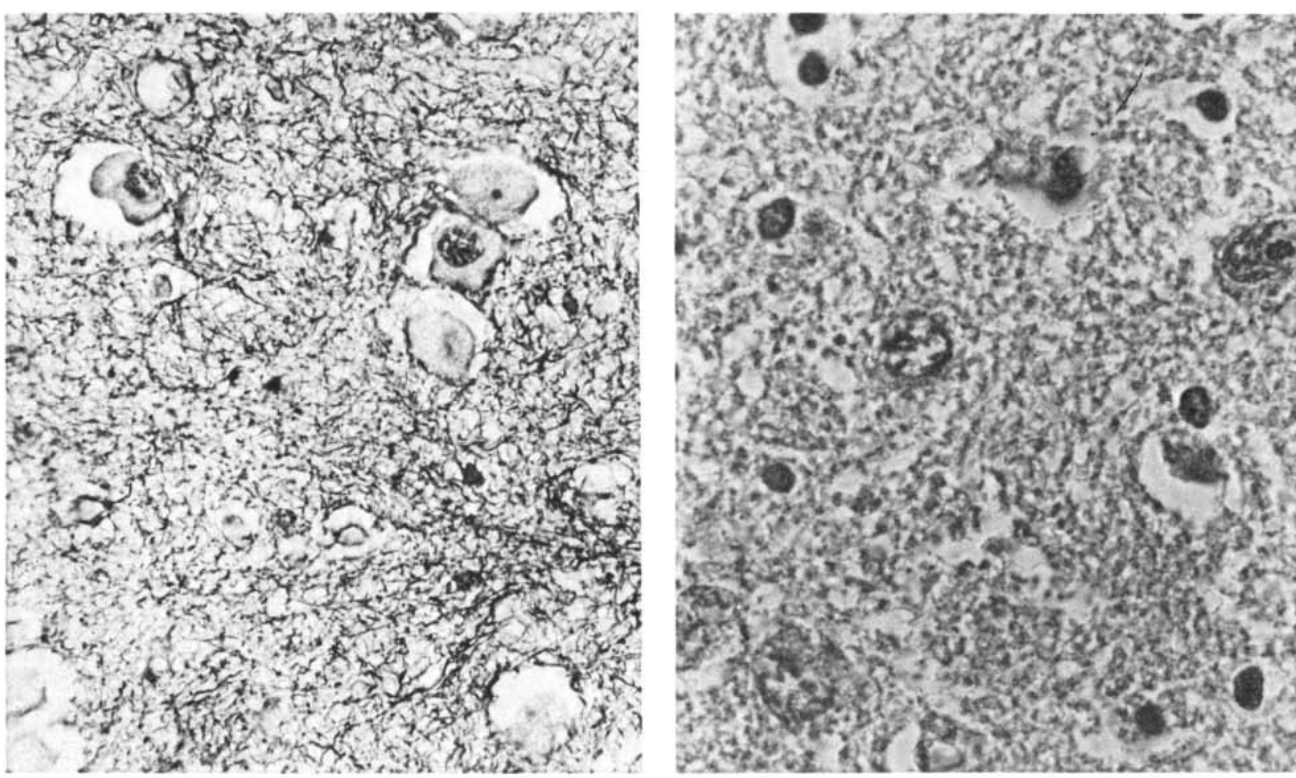
The impact of sudden infant death on the affected families and on society is severer than the number of cases would suggest. Parents usually react with shock, disbelief and anger. Until recently most sudden infant deaths were unexplained, and so blame was often placed by one parent on the other or on the person who was taking care of the infant at the time of death. The grief of the parents, tinged with guilt, sometimes persists for many years. Such parents often become overly anxious about surviving and subsequent children and unduly protective of them. Police, neighbors and relatives sometimes harbor suspicions of parental abuse or neglect in sudden-death cases, which can lead to harsh contacts with investigative authorities and to painful interactions with relatives and friends. Many of these disagreeable consequences should disappear when the cause of every sudden infant death can be determined.

The long-term prospect for preventing sudden infant deaths is promising. Once the damaging prenatal events that predispose an infant to sudden death have been identified, it may be possible to prevent the damage and so prevent the deaths. Extensive investigations are now in progress to determine whether abnormalities can be detected in newborn babies that will identify infants who are at high risk of sudden death.

One of the more promising methods is to record the electrical activity of neurons in the brain stem in response to visual, auditory and tactile stimuli in order to evaluate the integrity of the brain stem. James Orlowsky and his associates at the Cleveland Clinic recently reported that such recordings (showing responses to auditory stimuli) were abnormal in 10 infants who had life-threatening spells of apnea but were normal in infants who went through prolonged hypoxemia from other causes. If these efforts and others succeed in identifying infants who are at high risk of sudden death, it may be possible to prevent some of the deaths by employing monitors to warn of respiratory or cardiac arrest. The monitors of this kind that are available now for use in the home are inadequate, but one can expect improvements.

Several drugs that stimulate the respiratory-control centers might serve to prevent apneic episodes in susceptible infants. Unfortunately they are too toxic to be administered at home, but there is always hope that the pharmaceutical industry will develop safer and more selective compounds. Whatever means are eventually brought to bear, an infant will need them for only a few months, since the prolonged apneic spells that appear to identify many high-risk infants usually disappear between the ages of eight and 12 months.

If measures to prevent sudden infant death are eventually found, might the survivors show evidence of a handicap such as brain damage? Clearly such a handicap is not likely if the processes that predispose a baby to sudden death are forestalled. If a baby is resuscitated after prolonged apnea or cardiac arrest, however, the long-term outlook is less certain. A few babies who have survived such an episode have handicaps of various degrees, but most of the survivors show no impairment.



PROLIFERATION OF ASTROGLIAL FIBERS is found in about half of the victims of the sudden-death syndrome. The fibers appear in many areas of the brain stem, including the lateral reticular formation, which is a center for the control of respiration. They provide further evidence of prolonged hypoxemia in many sudden-death infants. The micrograph at the left shows a section of the brain stem of such a baby; the many thin black lines are astroglial fibers. They are absent in the normal brain stem shown in the micrograph at the right.

Delighted to have been of service

If we are going to be thumping our chest in exultation over our centennial, let's try to do it in a useful way instead of belaboring the obvious. Certainly it is not obvious to outsiders, aware of gene-splicing and genetic engineering only as hot topics, that the literature the insiders write and read should mention our name over and over.

The talky ad shown below appeared when we were only 82 years old. The ad had more scientific than business impact. The illustration shows macromolecules separated in acrylamide gel by difference of mobility in an electric field. It advertised the idea. Readers were invited to send for the theory and the working details. Not that *we* had created anything. The authors were two bioscientists who didn't work for us but accepted our offer to submit their method swiftly in full detail for the scientific community to try out. They called it disc electrophoresis. We justified our small part in the hope it would sell Eastman organic chemicals for preparing and working with the gel.

This unconventional form of scientific communication by paid advertising —prepublication we called it—accomplished in full measure all we had hoped. It has turned out that:

1 Though the cylindrical form still offers some advantage, most gel electrophoresis today is done in rectangular slabs where two dimensions of migration are available and the thickness dimension is subsequently used for spraying betas from radionuclide-labeled spots onto film in contact for autoradiography.

2 The way molecular biology is moving today, those spots often as not represent individual gene products that some living cells have been fooled into manufacturing through the use of restriction enzymes in recombinant experiments that either approach fundamental problems of biology as exercises in code-breaking or else seek slicker ways of manufacturing valuable molecules than are described in organic chemical textbooks.

3 When the labeled products are still so scanty as to be flirting with the detection limits for direct autoradiography, incorporation of fluors into the gel causes light to take over the job of exposing the film, which helps greatly.

4 What proves equally necessary in using the feeble betas from tritiated material is to expose at around -78° so that the first atom or two of silver at a sensitivity speck on a silver halide crystal does not diffuse away before more arrive—the cause of reciprocity failure.

5 An earlier contribution from photographic science has also helped. The sigmoid shape of the plot of optical density *vs* log exposure has correctly predicted that preflashing the film to get above the toe of the curve would gain sensitivity and linearity.

6 From the view at the lab bench, our most appreciated contribution to the work has proven to be some very high-grade x-ray films we make for the world's medical centers. Meanwhile one recent paper *(Analytical Biochemistry 93,* 189-195 [1979]) shifts attention to Kodak Ektacolor or Vericolor film for experiments using multiple isotopes and using color on a single sheet of film to see where they each end up. Films and their processing are what get us mentioned so often in the current literature of the subject.

If contemplating a jump onto the capacious bandwagon of recombinant studies, you may wish to ask E. J. Hahn, Health Sciences Markets Division, Kodak, Rochester, N.Y. 14650, phone 716—724-4633, for the latest edition of his product guide and bibliography entitled "Autoradiography of Large-Area Specimens."

1880 Kodak 1980

A 100-year start on tomorrow

(1962)

Kodak reports on:

what to do till the flying-spot scanner comes... light-sensitive liquids for less-than-juicy volume... why there are several spectrochemical emulsions

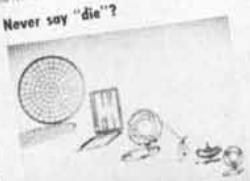
Disc electrophoresis

Each of the dark discs in this little tube of gel represents a different protein in a 3-microliter sample of normal human serum. The separation was effected in 30 minutes. The pattern tells a detailed story to the practiced eye. The equipment can be jerry-built in the laboratory for a materials outlay of about $12.* The chemicals we recommend are

Mount Sinai Hospital Cell Research Laboratory in New York City have extended electrophoresis in the directions of 1) more simplified equipment that gets you into the technique easily; 2) more sophisticated equipment that speeds and refines results once you have found the technique indispensable; 3) a clear (albeit concentrated and mathematical) exposition of the physical chemistry at work.

We propose a little experiment in casting bread upon the waters. We shall count how many will accept an offer hereby made by Distillation Products Industries, Rochester 3, N. Y. (Division of Eastman Kodak Company), to send a free preprint of a fully illustrated set of directions by Dr. Dimitri Ostrenko on the theory and a fully by Dr. Ostrenko on how to proceed. Then we shall wait and count how many orders come in for the above-named Eastman Organic Chemicals. The results of this experiment you will never know.

Never say "die"?



These metal parts are not stampings, nor were they cut out by knife, scissors, do it for hire. The method uses either *Kodak Photo Resist* or *Kodak Metal-Etch Resist*, depending on the metal to be worked. Both are light-sensitive liquids. The object is drawn to enlarged scale and photographed. The metal is coated with *KPR* or *KMER* and exposed to light through the negative. Where the negative protects from the light, the resist will subsequently flush away; where light-struck, it becomes resistant to an etchant. Etchants leave no burrs. The thinner the metal the closer an etchant can work within tolerance. Designers can keep changing their minds, fancy-free, with less peril to their budgets, if any.

Eastman Kodak Company, Graphic Reproduction Division, Rochester 4, N. Y., can provide all sorts of information about photo-etching. We even hold seminars on the subject.

The grateful but cautious spectrographer

A small pamphlet has been issued under the title "Spectrum Analysis with Kodak Materials." The words it contains may prove less useful than its graphs and numbers, though the words devoted to a warning against taking the graphs and numbers too seriously must be taken seriously. That's life.

Life lived with the photographic emulsion as a measuring instrument for radiation intensity must be filled with gratitude for its simplicity, versatility, and economy and filled with caution against glib assumptions. Those who live that life have learned that. 11 *Kodak Spectroscopic Plates and* Type 1(4) work fast, capture

SCIENCE AND THE CITIZEN

Let Only Two Children Bloom

The most populous nation in the world is out to attain zero population growth. Having already achieved a remarkable decline in fertility in less than a decade, the leadership of the People's Republic of China, convinced that "rapid population increase obstructs economic development," is adopting legal, economic and institutional reforms whose essential objective is to keep parents from having more than two children and to encourage them to have only one child. Detailed statistics reflecting the success to date of China's birth-planning efforts were presented, along with the official rationale for a policy of population control and a description of steps to be taken in the future, in a newspaper article by Chen Muhua, the vice-premier in charge of birth planning. An annotated translation by Pi-chao Chen of Wayne State University has now been published in *Family Planning Perspectives.*

In 1978 the population of mainland China was 960 million. It had been about 540 million in 1949, and the net increase of 420 million in 30 years reflects an average annual growth rate of 2 percent. At its peak in the 1960's the crude birthrate was as high as 40 per 1,000 of population (about the same as India's). With the initiation of a vigorous birth-planning campaign after the "cultural revolution" the birthrate began a precipitous decline in 1971, reaching 18.34 in 1978. The rate of natural increase was reduced from 2.3 percent in 1971 to 1.2 percent in 1978. In her article Vice-Premier Chen called for a two-stage campaign to reduce the rate of natural increase first to about .5 percent by 1985 and then to zero by the year 2000.

She insisted that population control not only is essential for economic development but also "is dictated and demanded by the socialist mode of production." Admitting that "in our previous critiques of the Malthusian theory of population we one-sidedly stressed man's role as producer, even going so far as to assert that the more people the better," she maintained that "we neglected the other side, namely that man, having a mouth, is also a consumer." In addition to retarding improvement in the standard of living, she argued, rapid population growth interferes with the accumulation of capital and makes it more difficult to educate and train young people and provide jobs for them.

The first objective, according to the vice-premier, is to "reduce and then altogether eliminate the phenomenon of multiparity," or the practice of having more than two children. This is to be accomplished by imposing a "multi-child tax" on those who have a third child (except as the result of a multiple birth at the second confinement) and making third children ineligible for various medical and other benefits. Third and higher-parity births now account for some 30 percent of all births, or about 5.2 million in 1978. Eliminating almost all such births by 1985 would reduce the birthrate to about 13 per 1,000 and the natural-increase rate to less than .7 percent; the hope is to reach the .5 percent goal by increasing the proportion of one-child families. Promoting the practice of having one child is also "the primary method whereby we can bring the natural-increase rate down to zero."

A number of economic and institutional measures are proposed to encourage people to have only one child, even if that child is a girl. These include annual bonuses, housing priorities and higher pensions for people who have one child and priority in schooling and employment for single children. To deal with the traditional Chinese attitude characterized by Vice-Premier Chen as "Don't call it quits until a boy baby comes along," the government will "insist on the principle of equal pay for equal work regardless of sex," will encourage "matrilocal" marriages (in which the couple live with the wife's parents if the parents have no son, thereby helping to support them in their old age) and will improve facilities for childless old people. "Once the economic problems are solved the question of more v. fewer children and of male v. female offspring will be more than halfway solved." These various negative and positive incentives are to be supported by expanded birth-control programs, all "putting the stress on prevention" to reduce the incidence of abortion.

Fish Find

A vast fishery resource, until now not fully recognized because of the limited and primitive fishing industry in the area, has come to light in the North Arabian Sea through a survey made under the auspices of the United Nations Development Programme, the Food and Agriculture Organization of the UN and the government of Norway. The resource includes fishes that are pelagic (in the open sea), mesopelagic (in depths of from 600 to 3,000 feet, or about 180 to 900 meters) and demersal (bottom-dwelling). "Assuming a potential extraction rate of 40 percent for coastal pelagics and 20 percent for demersals," the sponsors say, "and an average landed value of $75 per [metric] ton of coastal pelagics and $500 per ton for demersals, the four major countries concerned—Pakistan, Somalia, Oman and the People's Democratic Republic of Yemen—could gain $92.1 million in income from those resources each year. Potential annual production could be 742,000 tons."

These figures, however, do not include the mesopelagic fishes. The study estimated the mesopelagic stock to be 102 million metric tons. (The UN has estimated that the total catch of fish in the world in 1977 was 73.5 million tons.) "The species tend to be short-lived, and it is therefore reasonable to postulate that the extraction rate has a theoretical upper limit of from 40 to 50 percent. Since nothing is known about the economics of harvest, however, it is unrealistic to assume that level of harvest in the foreseeable future. A more realistic appraisal [is] that a 10 percent extraction rate would increase world marine annual protein supplies by about 13 percent and a 20 percent extraction rate would increase [them] by 27 percent." At 10 percent the harvest would be 10.2 million tons a year with a landed value of $765 million based on $75 per ton.

Hydro and Geo

The General Accounting Office, the Congressional watchdog of Executive Branch operations, has summarized a five-year record of efforts by the Executive Branch to promote two alternative sources of electric power: water turbines and geothermal-steam turbines. Given substantially streamlined procedures, the GAO finds, Federal support would allow new hydroelectric plants to make a significant additional contribution to the nation's power grids. Efficient geothermal power generation, however, is possible in so few parts of the U.S. that the technology must be ranked among the least attractive alternative power sources even after five years and $500 million of Federal aid.

Hydroelectricity has long been an important source of power in the U.S. Some 40 years ago water turbines furnished 40 percent of the nation's electricity. Today less than 15 percent of U.S. electric power is so generated (compared with 35 percent in France). The Federal Government is now the nation's largest producer of hydroelectricity, providing nearly half of a total 60,000-megawatt capacity. Of this total, facilities controlled by the Department of Defense provide more than half, or 16,500 megawatts. Facilities controlled by the Department of the Interior have a capacity of 9,400 megawatts. The capacity of the Tennessee Valley Authority is 3,300 megawatts.

The Federal dominance in hydroelectricity is directly related to Federal dam

It may be the most sophisticated production car on earth.

From lessons learned in outer space comes the 1980 Eldorado by Cadillac . . . very possibly the most advanced, most sophisticated production car on earth. In fact, a considerable number of Eldorado innovations can be traced directly to GM's extensive developmental work in guidance control.

Even adjusts to changes in altitude. Perhaps most dramatic is Eldorado's standard new Digital Electronic-Fuel-Injected Engine. As you travel coast-to-coast, it automatically adjusts to changes in altitude . . . to barometric pressure . . . to temperature . . . even to eventual wearing of parts. There was a time when such things as high-altitude packages were required for Eldorado. Not with this car. For California, 5.7 liter EFI engine is standard. Eldorados are equipped with GM-built engines produced by various divisions. See your Cadillac dealer for details.

To help take guesswork out of servicing . . . Almost as remarkable is Eldorado's on-board computer diagnostics to help take the guesswork out of servicing. This system, again a Cadillac exclusive, enables a Cadillac service technician to find a number of possible problem areas quickly . . . with a push of buttons in the car and a code book. And then to verify and correct. It's standard with Digital EFI.

Going from 69°F to 70°F. Another spaceage feature is Electronic Climate Control with digital accuracy. Change temperature settings as precise as one degree with a touch of a button.

To be a more efficient driver. And to help make you a more efficient driver there's Cadillac's MPG Sentinel—standard with Digital EFI. It displays your instantaneous miles per gallon and your average mpg for a trip.

On at dusk . . . off at dawn. Add to that an unprecedented combination of driving features. Including front-wheel drive for traction and roominess—plus almost every advanced electronic convenience known. All standard. Including Twilight Sentinel that turns your headlights and taillights on at dusk and off at dawn . . . automatically.

To take command of your own Eldorado, visit your Cadillac dealer. Tomorrow wouldn't be too soon . . . to buy or lease one of the best-engineered cars in the world.

GM
MARK OF EXCELLENCE

construction and maintenance. Within the Department of Defense it is the Army Corps of Engineers, with its responsibility for river navigability, that has developed a hydroelectric sideline. Within the Department of the Interior the Bureau of Reclamation, which provides irrigation water to 15 western states, and to a lesser extent the Bureau of Indian Affairs and the National Park Service generate hydroelectricity for various power grids.

As far as utilizing the nation's total hydroelectric potential is concerned, only 3 percent of the 49,000 dams in the U.S. have power-generating facilities. If the most suitable of the unused 97 percent were to be similarly harnessed, one Department of Energy study suggests, the nation's hydroelectric capacity could be increased by an additional 110,000 megawatts, or the equivalent of more than four million barrels of oil per day. Even more intensive exploitation of existing dams and the construction of power dams on suitable streams that are now undammed would add to the increase.

Meanwhile, the GAO notes, obstacles abound. Any new hydroelectric plant must be approved by Federal authorities that separately administer 13 public laws controlling activities that range from Federal land management to the protection of endangered species. The GAO further notes that the Department of Energy has taken more than three years to authorize a total of eight hydroelectric demonstration projects. Moreover, seven of the projects, with a combined generating capacity of some 20 megawatts, were not authorized until last year.

As for the geothermal generation of electricity, only three fields (one in northern California, one in Italy and one in New Zealand) provide the kind of dry steam that is naturally suitable for driving turbines. The California field was first tapped in 1960; by last year it was producing 665 megawatts. A 150-megawatt geothermal plant, powered by hot water rather than steam, is in Mexico just south of the California border. The source of the hot water is a thermal zone that extends northward under the Imperial Valley and the Salton Sea. This area of southern California appears to be the only other one in the U.S. with a potential for the geothermal generation of electricity. According to the GAO, the usefulness of numerous other thermal zones appears to be limited to local heating applications that might lower the consumption of conventional fuels for the same purpose.

Medical Execution

"I will use treatment to help the sick according to my ability and judgment, but never with a view to injury and wrongdoing. Neither will I administer a poison to anyone when asked to do so nor will I suggest such a course."

The language of the Hippocratic oath would seem to leave the physician little room for ethical maneuvering. In at least some parts of the U.S., however, Hippocrates is apparently still taken with a grain of salt.

Within the past few years four states—Idaho, New Mexico, Oklahoma and Texas—have passed laws adopting death by drug injection as the prescribed method of executing condemned prisoners. In Oklahoma, for example, the law now provides that the death sentence be carried out by "continuous intravenous administration of a lethal quantity of an ultra-short-acting barbiturate in combination with a chemical paralytic agent until death is pronounced by a licensed physician." Several other states are considering similar legislation.

The active involvement of physicians in this new form of capital punishment has been criticized by two members of the faculty at the Harvard Medical School. Writing in *The New England Journal of Medicine,* William J. Curran, a professor of legal medicine, and Ward Casscells, a physician, state that "the growing adoption of these programs raises serious ethical issues for American physicians about their continued and expanded participation in state-ordered execution of human beings for crimes." They call on the medical profession in the U.S. to "examine seriously the issues presented by this new method of capital punishment," arguing that "unlike any other methods, this procedure requires the direct application of biomedical knowledge and skills in a corruption and exploitation of the healing profession's role in society." Their own conclusion is that the medical profession should "formally condemn all forms of medical participation" in the new practices.

According to Curran and Casscells, the objectives of the new laws "are clear enough. It is expected, first of all, that the method will be considered less painful and thus more humane to the condemned prisoner. Secondly, it is hoped that the new method will encourage more juries to vote the death penalty.... A third objective is constitutional: it is hoped that statutes providing for execution by this method will be less apt to be struck down by the courts as 'cruel and unusual punishment.' A fourth objective is economic: the method is considerably less expensive than death by electrocution or lethal gas."

Curran and Casscells contend that regardless of the motives of the state the physician has a special obligation not to use his medical skills to help take a life. They base their position not only on the Hippocratic oath but also on the pronouncements of various international medical bodies, including the World Medical Association. The ethical principles enunciated by such bodies concerning the involvement of medical doctors in torture and other forms of cruel, inhuman or degrading treatment or punishment should, they believe, "be interpreted to unconditionally condemn medical participation" in the practice of execution by drug injection. Such participation, they say, can involve a variety of roles, ranging "from ordering the substance and preparing it for injection, to injecting the substance or ordering and supervising the injection by other medical personnel, to monitoring the administration and observing the prisoner throughout the continuous injection of the drug, and, lastly, to examining the prisoner and pronouncing his death."

The "continuous intravenous administration" referred to in the Oklahoma statute, Curran and Casscells write, "ends only when the monitoring physician pronounces the condemned prisoner dead. The physician then becomes the instrument, the order, to stop the lethal action itself. There is no other way to describe this physician's role but as that of an active participant, a key human participant, in the execution."

The total number of condemned prisoners potentially subject to physician-assisted execution in the U.S. "is by no means small," Curran and Casscells point out. Texas, which already has such a capital-punishment law on the books, currently ranks second in the nation, with 119 on death row. Florida, which is said to be on the verge of enacting a similar law, is first with 140 (139 men and one woman).

Undogmatic Toad

The "central dogma" of modern biology states that in every living cell coded instructions for the synthesis of protein are transcribed from DNA to RNA. A gene therefore is a length of DNA that specifies a product molecule. Although the means of transcription—the code and the transcription machinery—have been held to be virtually universal in all forms of life, it was recently reported that the cell organelles known as mitochondria use a slightly aberrant code (see "Science and the Citizen," SCIENTIFIC AMERICAN, February). Now a difference is reported with regard to the machinery. It suggests that in animals a control is placed on transcription that does not exist in bacteria.

The difference is as follows. In the genes of the bacterium *Escherichia coli* the transcription of RNA on a template strand of DNA typically begins with the binding of an enzyme (the molecule that engineers the transcription) to a promoter, a part of the DNA that is at the end of the template and is not itself transcribed. In the clawed toad *Xenopus laevis* the details of enzymatic binding are uncertain, but the transcription of a par-

THE TASTE BEYOND 12-YEAR-OLD PREMIUM SCOTCH

Discover more.

Let your mature taste lead you from the finest premium Scotch on up to the most expensive 12-year-old Scotch in the world. The Glenlivet. The ultimate in Scotch.

Most premium Scotch is blended and depends on several whiskies for taste and smoothness.

Yet the unblended character of The Glenlivet is noble enough to stand alone. In this distinctive Scotch whisky you'll experience an exceptional smoothness and full-bodied richness, unmatched in all other premium Scotch.

Try the taste beyond premium Scotch.

The Glenlivet
Unchanged since 1824.

ticular type of RNA from DNA is directed by a region not at the end of the template but in the middle. This means that in *Xenopus* a part of a gene acts both as code that is transcribed and as control of the transcription.

The experiments revealing the difference were conducted in the Department of Embryology of the Carnegie Institution of Washington by Daniel F. Bogenhagen, Shigeru Sakonju and Donald D. Brown. They report their findings in a recent issue of the journal *Cell*. The gene they worked with is designated 5*S* DNA. It is present on nearly all the chromosomes in *Xenopus,* in hundreds of duplicate copies. It is transcribed into 5*S* RNA, which is assembled into ribosomes, the intracellular organelles on which proteins are synthesized. The region that is transcribed consists of 120 of the nitrogenous bases whose sequence embodies the genetic code in both DNA and RNA. It is flanked on each side by "spacer DNA" whose function is not known. The spacer DNA is not transcribed.

The experiments proceeded in stages. First enzymes were used to prune bases from one end or the other of a strand of DNA comprising the 5*S* DNA and the flanking spacer DNA. Then the shortened strand was spliced into a plasmid: a self-replicating circular strand of bacterial DNA. Once inserted into a bacterium the plasmid clones itself. Hence the bacterium and its progeny are a source of countless copies of a bacterial DNA that includes *Xenopus* DNA with an experimental truncation. The DNA is purified and introduced into an extract made from the nuclei of frog oocytes (precursors of egg cells). The extract contains the intracellular machinery that will enable the truncated DNA from *Xenopus* to express itself if it can.

The results are described by the Carnegie workers as a series of surprises. First, the removal of spacer DNA turns out not to matter: the 5*S* DNA is transcribed anyway. The spacer does not include a promoter. Second, the removal of up to 50 bases from one end of the 5*S* DNA (designated the 5′ end) turns out to matter less than was expected: the gene continues to serve as a template for the synthesis of RNA. The RNA, however, consists of hybrid molecules including in only part of their length the sequence of bases of a 5*S* RNA. The remaining sequence of bases is transcribed from the bacterial DNA that lies at the splice in the plasmid. The crucial point is the length of the RNA's. They are from 116 to 121 bases long: the length of 5*S* RNA. With more than 54 bases removed little or no such synthesis occurs.

Pruning bases from the other end of the 5*S* DNA (the end designated 3′) entailed more difficult experiments because deletions from this end remove the region of DNA that codes for the

termination of the transcription. (In *Xenopus* 5*S* DNA that region is a sequence of four thymine bases at positions 119 through 122.) Hence the experimenters could no longer simply assay the oocyte extract for RNA of 5*S* length to determine whether the gene functioned. The RNA might be any length. The Carnegie workers devised an alternative assay by adding to the oocyte extract a modified constituent of RNA: a base that if incorporated into the transcription will prevent the acceptance of other bases. The addition of this substance in a known concentration entails a size distribution of synthesized RNA strands. Each ends with a modified base. From the distribution can be deduced the position on the DNA template at which transcription began.

The result is that if the enzymatic pruning of bases from the 3′ end of 5*S* DNA leaves intact at least the first 83 bases, then RNA is synthesized. If the pruning goes beyond base 80, synthesis no longer occurs. In sum, a site on *Xenopus* 5*S* DNA that is bounded "upstream" between bases 50 and 55 and "downstream" between bases 80 and 83 somehow governs the expression of the gene. That site is roughly the middle fourth of the gene.

The Carnegie workers have no direct evidence that an enzyme binds to the site. Therefore they prefer to call their discovery a control region rather than a promoter. Still, the investigators hypothesize that an enzyme interacts with the control region and is induced by the interaction to reach some 50 bases upstream and begin transcribing a template. An analysis of the bacterial DNA placed upstream from the control region by its splice into a plasmid suggests that the enzyme is best suited to reach out to a guanine base and begin transcribing there.

Ringside Seat

Serving once more as a pathfinder for the two much larger Voyager spacecraft, as it had in surveying Jupiter in late 1974, *Pioneer 11* dipped under Saturn's rings last September 1, swerved sharply and sailed off on a trajectory that will carry it on a limitless voyage beyond the solar system. It will thus follow its sister ship, *Pioneer 10,* which acquired solar escape velocity through its encounter with Jupiter late in 1973. Saturn, whose orbit lies 9.54 astronomical units (A.U.) from the sun, is now the remotest planet visited by a spacecraft. (One A.U. is the mean distance from the earth to the sun.) When *Pioneer 11* passed to within 43,000 kilometers of Jupiter more than five years ago, it acquired enough energy from Jupiter's gravitational pull to take a swift shortcut across the solar system on a trajectory that carried it 15 degrees above the plane of the earth's orbit and more than

1.5 A.U. inside the orbit of Jupiter to keep its rendezvous with Saturn.

What *Pioneer 11* (since renamed *Pioneer Saturn*) reported back about the sun's sixth planet is summarized in a recent issue of *Science*. *Pioneer Saturn* is a much smaller craft (weighing 250 kilograms) than the two Voyagers (each weighing 2,080 kilograms), and so its photoimaging equipment is much more primitive: a single imaging photopolarimeter, a pointable telescope with an aperture of 2.5 centimeters (one inch) that uses the spin motion of the spacecraft to scan an object. Nevertheless, *Pioneer Saturn* returned 440 pictures of Saturn, of which 40 exceed in resolution the best photographs made from the earth. The images made from the closest range have a resolution of 90 kilometers, compared with about 1,200 kilometers for the images made from the earth. The largest of Saturn's nine previously known moons, Titan, was photographed at a resolution of 180 kilometers.

The most significant pictorial results were the finding of a small new moon and a narrow new ring just beyond the three prominent and previously well-established rings. The new moon, designated 1979 *S* 1, signifying that it was the first Saturn satellite discovered in 1979, is between 100 and 200 kilometers in diameter and at one point came within 2,500 kilometers of colliding with the spacecraft. The new ring, designated *F*, is only about 800 kilometers wide and is separated from the next-innermost ring, the *A* ring, by a narrow gap that has been named the Pioneer division in honor of the mission that discovered it.

Pioneer Saturn viewed the rings in an unusual light: from below, illuminated from above, and hence in scattered light rather than reflected light, which is the usual view from the earth. In addition to the three well-known rings (*C*, *B* and *A*, in order of their distance from the planet) there had been evidence in studies made from the earth for a faint *D* ring inside the *C* ring and for a broad, tenuous *E* ring beyond the *A* ring. *Pioneer Saturn* found no evidence at all for the *D* ring and no photographic evidence for the *E* ring. In flying through the region occupied by the putative *E* ring, however, the craft registered two hits on its micrometeoroid detectors. There is also some evidence for the *E* ring in the data returned by its charged-particle detectors. (In January astronomers at the University of Arizona confirmed the existence of the *E* ring in images made with a 1.5-meter telescope.)

Several of the *Pioneer Saturn* instruments provided the first direct evidence that the planet has a magnetosphere and therefore an intrinsic magnetic field. The field at the equator is from three to five times weaker than had been predicted by theoretical models: .2 gauss (compared with .5 gauss for the earth's

Faculty Positions Open

Al-Fatah University
Faculty of Nuclear and Electronic Engineering

Tripoli, Socialist Peoples Libyan Arab Jamahiriya

Medium of Education is English. Duties involve teaching undergraduate courses as well as assisting in planning of new laboratories and research projects in this recently established faculty.

Attractive salaries and fringe benefits are offered. Applicants with Ph.D. and several years of experience in teaching and/or industry are preferred. Those interested are requested to apply preferably by cable, to the Dean of the faculty, for application forms and information concerning terms and conditions of the contract.

Cable Address

Dr. Fathi Nuh
Al-Fatah University

People's Bureau of
The Socialist People's
Libyan Arab Jamahiriya
Cultural Section
Post Office Box 19125
Washington, D.C. 20036

Applications are invited for the academic positions available in this faculty, beginning with the academic year 1980/1981, in one of the following departments with the indicated areas of specialization:

1. Department of Electronics & Computer Science

A) Integrated Circuits Design and Fabrication
B) Digital Electronics and Instrumentation
C) Industrial Process Control
D) Data Communications
E) Mini-micro Computer Systems
F) Data-base engineering
G) Systems Modelling and Simulation
H) Computer-aided Design
I) Computer-aided Instructions
J) Programming Languages
K) Systems Programming
L) Numerical Analysis
M) Artificial Intelligence
N) Computer Networks & Distributed Processing

2. Department of Materials Science & Engineering:

A) Crystal Structure and Diffraction
B) Electric, Magnetic and Optical Properties
C) Physical Metallurgy
D) Processing Metallurgy
E) Ceramic
F) Corrosion
G) Non Destructive Testing
H) Materials Shaping and Treatment
I) Materials Selection and Failure Analysis

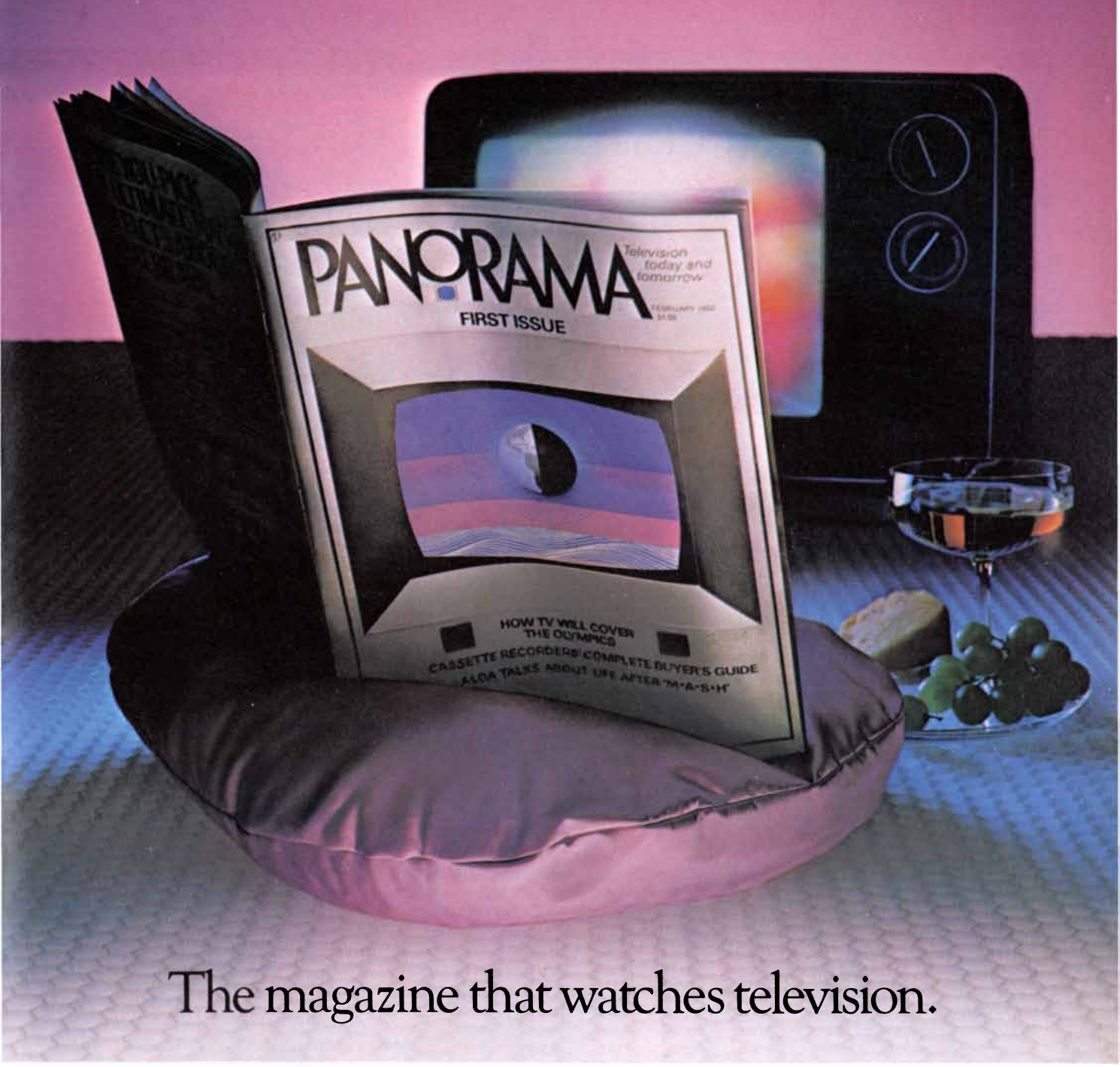
3. Department of Nuclear Engineering and Technology:

A) Nuclear Safety
B) Thermal Hydraulics
C) Chemical Aspects of Reactor Technology
D) Material Aspects of Reactor Technology
E) Fuel Cycles Analysis
F) Nuclear Data

field). An unexpected feature of Saturn's magnetic field is that the dipole axis deviates from the planet's rotation axis by less than one degree. On the earth, Mercury and Jupiter the dipole axis is tilted about 10 degrees from the rotation axis. Prevailing theories of planetary magnetic fields have assumed that the internal dynamo generating the field must be tilted by 10 degrees or more from the spin axis. Saturn shows that such a tilt is not required. As on Jupiter, the polarity of Saturn's magnetic field is opposite to the earth's; in other words, Jupiter's and Saturn's north geographic pole is their south magnetic pole.

Additional evidence on Saturn's rings and inner satellites was provided by the *Pioneer Saturn* charged-particle detectors. The rings and satellites tend to sweep charged particles out of the magnetosphere. Sharp dips in the counting rate suggest that the spacecraft crossed the orbit of the new satellite 1979 *S* 1 16 hours after the satellite was recorded photographically. Another sharp dip some 11 minutes later on the inbound leg of the flyby is evidence for another new satellite. Indeed, the charged-particle detectors suggest the presence of as many as five previously unknown satellites. The authors of the report in *Science* propose the recognition of "a new technique (particle-beam astronomy) for discovering previously unknown satellites and rings and for confirming or contradicting reports of such objects based on optical evidence."

Saturn's temperature and heat balance were determined by an infrared radiometer. The planet's average temperature is 94.4 ± 3 degrees Kelvin (degrees Celsius above absolute zero), a value similar to estimates made from the earth. The ratio of total planetary heat emission to solar input, however, is significantly higher than had been expected from models of the planet's cooling history. The total emission is about 2.2 times greater than the absorbed sunlight. Although about the same excess ratio was found for Jupiter, Jupiter's excess can be accounted for by heat left over from the planet's formation. In the case of Saturn another internal source of heat seems necessary. Evidently much of the planet's interior consists of liquid hydrogen containing a small amount of dissolved helium. It has been suggested that as the interior cools, some of the helium comes out of solution and appears as insoluble droplets, which, being heavier than liquid hydrogen, fall toward the planet's center. The falling helium releases kinetic energy that ultimately reaches the surface as heat. The fruitful reconnaissance of *Pioneer Saturn* paves the way for the much more intensive examination of the Saturn system planned when *Voyager 1* arrives this November, followed by *Voyager 2* in August of next year.



The magazine that watches television.

Practically everybody watches television. And practically everybody wants to know more about it.

Luckily there's a magazine that also watches television. And can tell you more about it.

Panorama, created by the publishers of TV Guide.

It doesn't just watch what's going on "on" television. It also watches what's going on "in" television. From the people to the programs. From the news to the arts. From the sports arena to the political arena.

If you're really interested in television, tune in to Panorama.

Pick up a copy at your newsstand. Buy a subscription by calling toll-free 800-523-7601. (Pennsylvania residents call 800-662-5180.) Or fill in the coupon on the right.

PANORAMA Television today and tomorrow
The magazine to watch.

If I'm not delighted by my first issue, I may cancel at once and owe nothing. (Merely write "cancel" across the bill you receive or write for refund of any payment made.)

☐ Please bill me ☐ Payment enclosed ☐ Master Charge ☐ Visa

Interbank no. (Master Charge only)_____

Card no._____ Exp. Date_____

Signature_____

Name_____

Address_____

City_____ State_____ Zip_____

19283A6

Mail to PANORAMA, Box 650, Radnor, PA 19088. Offer expires May 31, 1980. Please allow 30 to 65 days for delivery of initial issue. Subscription price for U.S. only $12. Canada and Mexico $18. All other countries $24.

Useful Proteins from Recombinant Bacteria

Bacteria into which nonbacterial genes have been introduced are able to manufacture nonbacterial proteins. Among the proteins made by recombinant-DNA methods are insulin and interferon

by Walter Gilbert and Lydia Villa-Komaroff

A living cell is a protein factory. It synthesizes the enzymes and other proteins that maintain its own integrity and physiological processes, and (in multicelled organisms) it often synthesizes and secretes other proteins that perform some specialized function contributing to the life of the organism as a whole. Different kinds of cells make different proteins, following instructions encoded in the DNA of their genes. Recent advances in molecular biology make it possible to alter those instructions in bacterial cells, thereby designing bacteria that can synthesize nonbacterial proteins. The bacteria are "recombinants." They contain, along with their own genes, part or all of a gene from a human cell or other animal cell. If the inserted gene is one for a protein with an important biomedical application, a culture of the recombinant bacteria, which can be grown easily and at low cost, will serve as an efficient factory for producing that protein.

Many laboratories in universities and in an emerging "applied genetics" industry are working to design bacteria able to synthesize such nonbacterial proteins. A growing tool kit of "genetic engineering" techniques makes it possible to isolate one of the million-odd genes of an animal cell, to fuse that gene with part of a bacterial gene and to insert the combination into bacteria. As those bacteria multiply they make millions of copies of their own genes and of the animal gene inserted among them. If the animal gene is fused to a bacterial gene in such a way that a bacterium can treat the gene as one of its own, the bacteria will produce the protein specified by the animal gene. New ways of rapidly and easily determining the exact sequence of the chemical groups that constitute a molecule of DNA make it possible to learn the detailed structure of such "cloned" genes. After the structure is known it can be manipulated to produce DNA structures that function more efficiently in the bacterial cell.

In this article we shall first describe some of these techniques in a general way and then tell how we and our colleagues Argiris Efstratiadis, Stephanie Broome, Peter Lomedico and Richard Tizard applied them in our laboratory at Harvard University to copy a rat gene that specifies the hormone insulin, to insert the gene into bacteria and to get the bacteria to manufacture a precursor of insulin. In an exciting application of this technology Charles Weissmann and his colleagues at the University of Zurich recently constructed bacteria that produce human interferon, a potentially useful antiviral protein.

DNA, RNA and Proteins

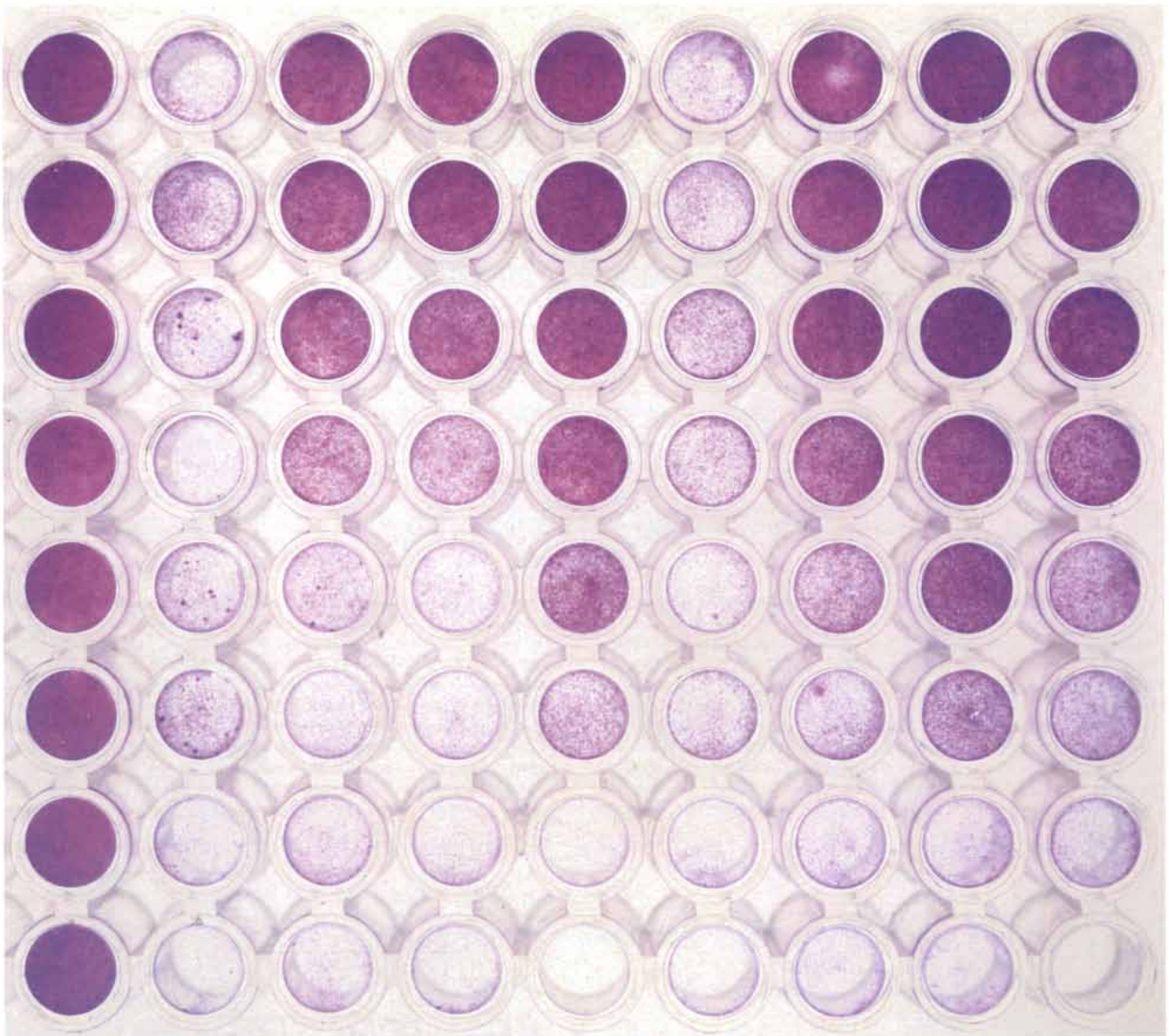
Cells make proteins by translating a set of commands arrayed along a strand of DNA. This hereditary information is held in the order of four chemical groups along the DNA: the bases adenine, thymine, guanine and cytosine. In sets of threes along DNA these bases specify which amino acids, the fundamental building blocks of proteins, are to be used in putting the protein together; the correspondence between specific base triplets and particular amino acids is called the genetic code. The part of a DNA molecule that incorporates the information to specify the structure of a protein is called a structural gene.

To act on this information the cell copies the sequence of bases from its genetic storehouse in DNA into another molecule: messenger RNA. A strand of DNA serves as a template for the assembly of a complementary strand of RNA according to base-pairing rules: adenine always pairs with uracil (which in RNA replaces DNA's thymine) and guanine pairs with cytosine. In animal cells transcription takes place in the nucleus of the cell. The messenger-RNA molecules carry the information out of the nucleus into the cytoplasm, where a complex molecular machine translates it into protein by linking together the appropriate amino acids. In bacteria, which have no nucleus, transcription and translation take place concurrently. The messenger RNA serves as a temporary set of instructions. Which proteins the cell makes depends on which messengers it contains at any given time; to make a different protein the cell makes a new messenger from the appropriate structural gene. The DNA in each cell contains all the information required at any time by any cell of the organism, but each cell "expresses," or translates into protein, only a specific small portion of that information. How does the cell know which structural genes to express?

Along with the structural information, a DNA molecule carries a series of regulatory commands, also written out as a sequence of bases. The simplest of these commands say in effect "Start here" or "Stop here" both for the transcription and for the translation steps. More complicated commands say when and in which type of cell a specific gene should be used. The genetic code is the same in all cell nuclei, a given structural sequence specifying the same protein in every organism, but the special commands are not the same in bacteria and in animal cells. One of the most surprising differences was discovered only in the past two years. The information for a bacterial protein is carried on a contiguous stretch of DNA, but in more complicated organisms, such as pigs and people, the structural information is broken up into segments, which are separated along the gene by long stretches of other DNA called intervening DNA or "introns." In such a cell a long region (often 10 times more than might be needed) is transcribed into RNA. The cell then processes this long RNA molecule, removing the sequence of bases that does not code for the protein and splicing together the rest to make a messenger-RNA molecule that carries essentially just the "start," the structural sequence and the "stop" needed for translation.

To persuade a bacterium to make a nonbacterial protein one must put into bacteria a DNA molecule that has a sequence of bases specifying the protein's amino acids as well as the bacterial commands for transcription and translation. Moreover, the inserted DNA must be treated by the bacterium as its own so that it will be duplicated as the bacterium divides. The problem thus breaks down into three parts: to find the right structural sequence (insulin's, for example), to place it in bacteria in such a way that it will be maintained as the bacteria grow and then to manipulate the surrounding information, modifying the regulatory commands so that the structural sequence is expressed as protein. Once the protein is made, still further changes in its gene or modifications of the bacterium may be needed to obtain the protein in large enough amounts to be useful.

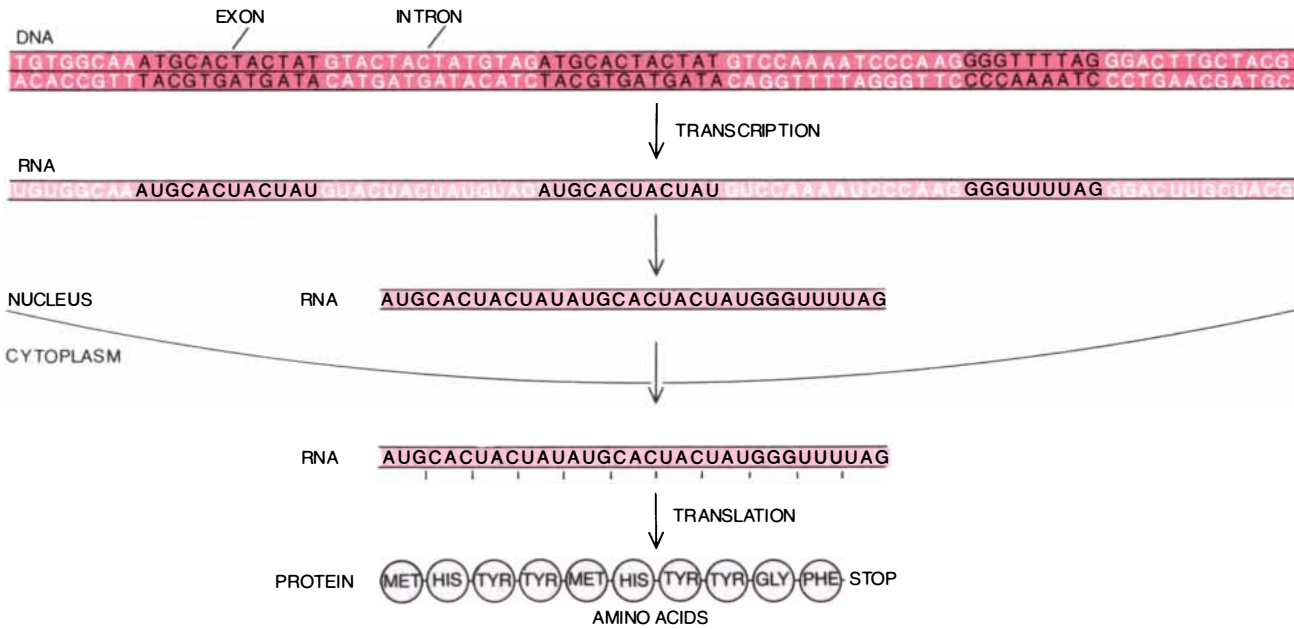
The constellation of recombinant-



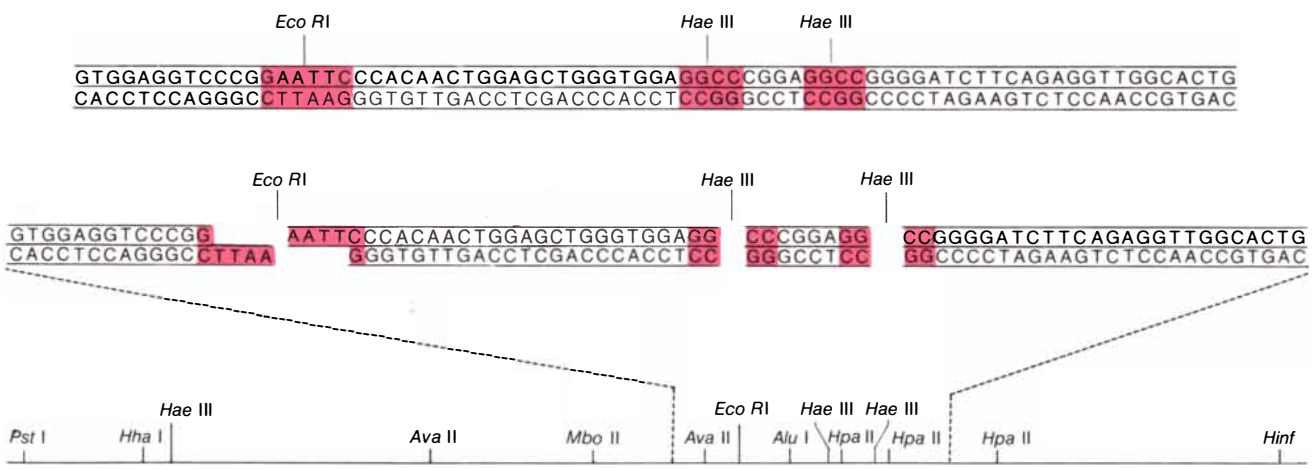
HUMAN INTERFERON synthesized in bacteria demonstrates its ability to block a viral infection in this biological assay. The structural information for making the protein interferon was obtained from human white blood cells in the form of messenger-RNA molecules; the RNA then served as a template for the synthesis of double-strand molecules of copy DNA, and the DNA in turn was inserted by recombinant-DNA techniques into a laboratory strain of the bacterium *Escherichia coli*, which synthesized the protein. For the assay dilutions of an extract of the bacteria were placed in some of the wells of a clear plastic tray; the other wells served as controls. (The wells are seen through the bottom of the tray in this photograph.) Human cells were added to the wells and were grown to form a layer of cells covering the bottom of each well. A virus preparation was then added to the cells. Twenty-four hours later the cell layer was stained. Where interferon in the extracts protected the cells against the virus the cells survived and were stained. Where there was no interferon the virus killed the cells and the dead cells did not pick up the stain. The control wells in the first column at the left contain a layer of cells that were never exposed to the virus; they accordingly appear stained. The control wells in the second column contain cells that have been killed by the virus; they look gray or clear. The control wells in the third column contain dilutions of a standard laboratory sample of interferon obtained directly from human cells; the top well has the most interferon and each succeeding well has a third as much interferon as the well above it. The wells in the next six columns hold dilutions of bacterial extracts from six different colonies of *E. coli* in which interferon DNA was present. Five of the six columns containing the bacterial extracts show evidence of interferon activity. The third extract tested (Column 6) had no detectable interferon; it apparently did not have a complete interferon gene. The synthesis of human interferon by the recombinant-DNA method was achieved by Charles Weissmann and his colleagues at the University of Zurich in collaboration with Kari Cantell of the Finnish Red Cross. The work was supported by Biogen, SA. Interferon is synthesized by many animal cells, but it is species-specific: only human interferon works for human beings, and it has been too scarce even for satisfactory experimentation.

DNA techniques for placing and maintaining a new gene in bacteria is called cloning, which in this sense means the isolation of a specific new DNA sequence in a single organism that proliferates to form a population of identical descendants: a clone. There are two convenient ways of doing this. In one method a small circular piece of DNA called a plasmid is the vehicle for introducing the new DNA into the bacterium. Plasmids carry only a few genes of their own and are maintained in several copies inside the bacterium by the bacterium's own gene functions; they remain separate from the main set of bacterial genes carried on a circle of DNA about 1,000 times larger. Alternatively the vehicle could be a virus that grows in bacteria. Such viruses normally have some 10 to 50 genes of their own (a bacterium has several thousand genes) and can often carry other new DNA segments in place of some of their own. All the techniques we shall describe apply to both plasmids and viruses.

A molecule of DNA resembles a very



PROTEINS ARE MADE in a living cell according to instructions encoded in the cell's genes, which consist of specific sequences of chemical groups (bases) strung out along a double-strand molecule of DNA in the cell's nucleus. The genetic code is "written" in the four letters *A, T, G* and *C,* which stand respectively for the four bases adenine, thymine, guanine and cytosine. The code is "read" in the three-letter sets called codons, which specify the amino acids linked together in the protein chain. The order of the bases can also convey regulatory commands. In multicelled organisms the structural sequence, or gene, encoding a particular protein is usually broken into fragments separated by long stretches of other DNA; in this diagram the gene fragments, called exons, are represented by the black letters and the intervening sequences, known as introns, by the white letters. The genetic information is translated into protein indirectly. First the entire sequence of bases is transcribed inside the nucleus from the DNA to a single-strand molecule of RNA. According to the base-pairing rules governing transcription, adenine always pairs with uracil (*U*) and guanine always pairs with cytosine. Next the RNA copies of the introns are excised from the message and the remaining RNA copies of the exons are joined together end to end. The reassembled strand of messenger RNA then moves from the nucleus to the cytoplasm, where the actual protein-manufacturing process takes place.



DNA CAN BE CUT into comparatively short lengths with the aid of restriction endonucleases, special enzymes that recognize specific base sequences at which they cause the molecule to come apart. For example, *Eco R*I, the first such enzyme discovered, recognizes a certain six-base sequence and cuts the molecule wherever this sequence appears, whereas *Hae* III, another restriction enzyme, operates at a certain four-base sequence. Since the probability of finding a particular four-base sequence is greater than that of finding a particular six-base sequence, one would expect *Hae* III to cut DNA more often than *Eco R*I. Accordingly one *Eco R*I site and two *Hae* III sites are represented in the DNA segment at the top, which corresponds to part of the gene coding for insulin in rat cells. The same DNA contains recognition sites for a number of other restriction enzymes, as is shown in the line diagram of a larger gene fragment at the bottom.

What's the right wine for candlelight and Saturday night?

Almadén.

Vintage-dating makes it right. As you come to appreciate fine wines, you learn that there are subtle differences from one vintage year to the next. So at Almadén, we vintage-date our fine varietal wines to enhance your appreciation and enjoyment of these differences. We take great care to use only the best of each year's harvest. This assures you of superior vintage wines year after year.

Almadén makes it right.

BMW. THE CAR COMPANY THAT HASN'T BEEN LEGISLATED INTO MEDIOCRITY.

The challenge that faces the automaker of the 1980's lies not in meeting tougher pollution standards, nor in coping with ever more restrictive safety regulations—not even in accommodating the petroleum shortages that are fast becoming a regular summer occurrence.

No indeed. The challenge lies in meeting the myriad of societal demands and still building automobiles that are worth driving.

Pessimists darkly predict that it cannot be done and point to the depressing number of uninspired automobiles on the market as incontrovertible proof.

Yet, fortunately, these gloomy predictions do not take into account the inventive genius and the obsessive determination of the engineers at BMW in Munich, Germany to build extraordinary automobiles.

Against all odds the BMW not only meets the demands of

society, it also provides the sort of exhilarating driving experience that automotive enthusiasts have all but given up for lost.

A SEEMINGLY INCONGRUOUS COMBINATION OF LUXURY, PERFORMANCE AND EFFICIENCY.

Conventional automotive wisdom has it that, inevitably, one must choose between luxury, performance and fuel efficiency. A sufficiency in any one necessitating a corresponding insufficiency in another.

And in the face of this, the BMW seems all the more remarkable for requiring no compromise whatsoever.

Round a particularly sticky curve and the legendary BMW suspension system—independent on all four wheels—flexes with an uncanny resiliency that makes one feel as if the car were built into the roadway. A sensation that results from highly advanced suspension technology and the virtually perfect integration of man and machine.

The BMW power plant—whether 4 or 6 cylinder—has long been a model for modern design. Press the accelerator and the fuel-injected, overhead cam engine responds in a manner that can only be described as exhilarating.

Yet, the 320i (with 5-speed standard transmission) delivers an impressive 25 EPA estimated mpg, 36 estimated highway mileage and, based on these figures, an estimated mpg range of 383 miles and a highway range of 551 miles.

(Naturally our fuel efficiency figures are for comparison purposes only. Your actual mileage and range may vary, depending on speed, weather and trip length. Your actual highway mileage and highway range will most likely be lower.)

And, while the BMW provides as long a list of luxury items as one could sanely require, its luxury is purposefully engineered to help prevent driver fatigue.

Vital controls are within easy reach; the tachometer, speedometer and ancillary instruments are well-marked and easy to read.

Its front seats are designed to hold their occupants firmly in place, and are so thoroughly adjustable that it is all but a mathematical impossibility not to find a comfortable seating position.

SAFETY BEYOND STURDY BUMPERS.

At BMW, automotive safety was of primary concern long before the first bumper law was written.

The passenger compartment is encased in a solid steel "cage." So strong is this construction that the car could be dropped on its nose from the fourth floor of a building without significant damage to the compartment itself.

Yet with all its sheer strength—its computer-programmed "crush zones," its double-braking systems—the BMW features a safety device even more estimable.

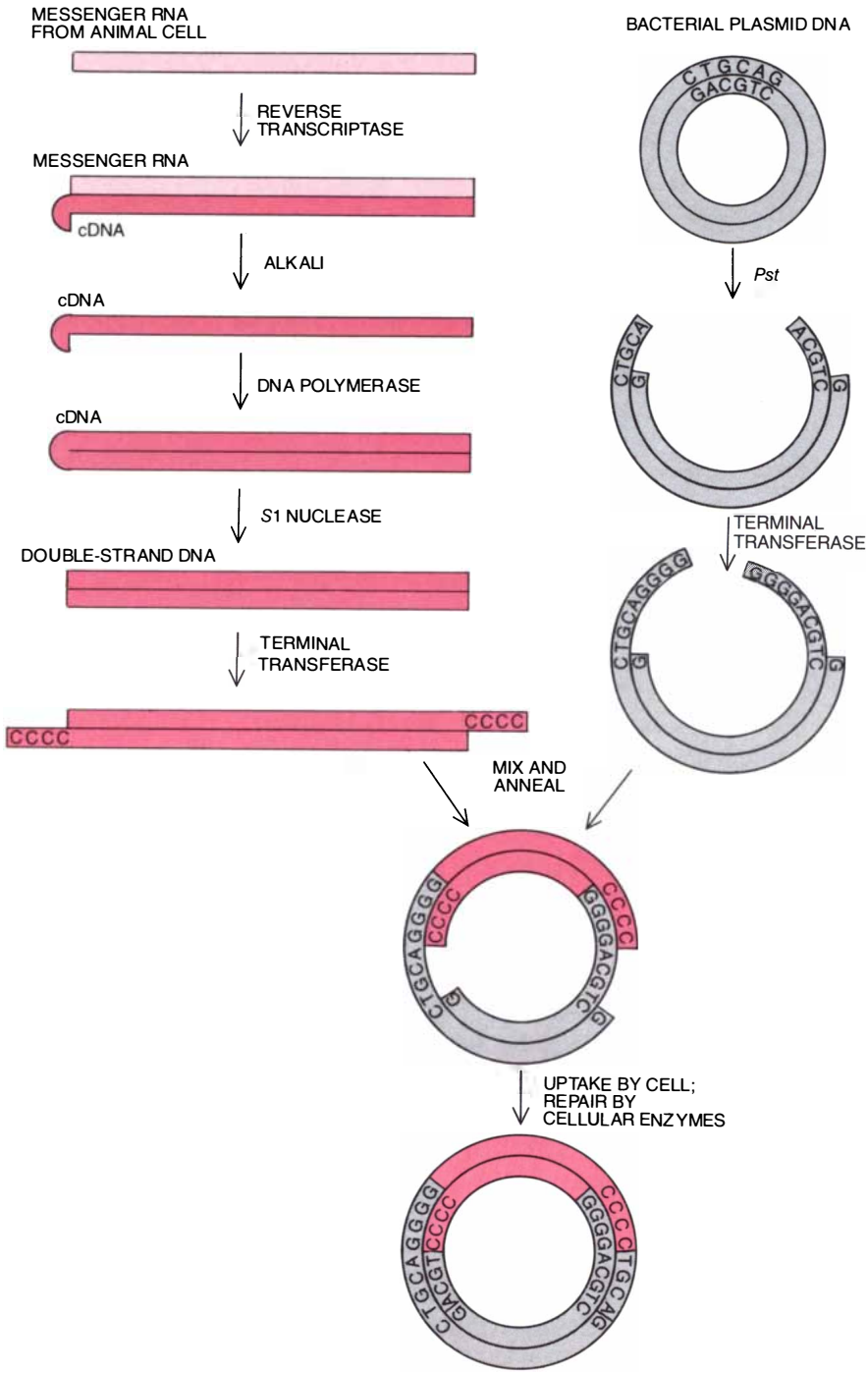
Its exceptional responsiveness and handling characteristics give it the ability to avoid accidents as well as merely survive them.

All in all, in a time of lowered automotive expectations, amidst increasing mediocrity, the engineers at BMW have actually improved the BMW.

If you'd care to judge for yourself, telephone your nearest BMW dealer to arrange a thorough test drive at your convenience.

THE ULTIMATE DRIVING MACHINE.

BMW, MUNICH, GERMANY



RECOMBINANT-DNA TECHNIQUE for making a protein in bacteria calls for the insertion of a fragment of animal DNA that encodes the protein into a plasmid, a small circular piece of bacterial DNA, which in turn serves as the vehicle for introducing the DNA into the bacterium. The plasmid DNA is cleaved with the appropriate restriction enzyme and the new DNA sequence is inserted into the opening by means of a variety of enzymatic manipulations that connect the new DNA's ends to those of the broken plasmid circle. In the procedure illustrated here, for example, a special enzyme, reverse transcriptase, is first used to copy the genetic information from a single-strand molecule of messenger RNA into a single strand of copy DNA. The RNA template is then destroyed, and a second strand of DNA is made with another enzyme, DNA polymerase. Still another enzyme, *S*1 nuclease, serves to break the covalent linkage between the two DNA strands. In the next step the double-strand DNA is joined to the plasmid by first using the enzyme terminal transferase to extend the ends of the DNA with a short sequence of identical bases (in this case four cytosines) and then annealing the DNA to the plasmid DNA, to which a complementary sequence of bases (four guanines) has been added. Bacterial enzymes eventually fill the gaps in the regenerated circular DNA molecule and seal the connection between the inserted DNA and the plasmid DNA. The particular plasmid used by the authors to make rat proinsulin in bacteria, designated *pBR*322, incorporates two genes that confer resistance to two antibiotics: penicillin and tetracycline. The plasmid is cleaved by the restriction enzyme *Pst* at a recognition site that lies in the midst of the gene encoding penicillinase (the enzyme that breaks down penicillin). The added DNA destroys this enzymatic activity, but the tetracycline resistance remains and is used to identify bacteria containing the plasmid.

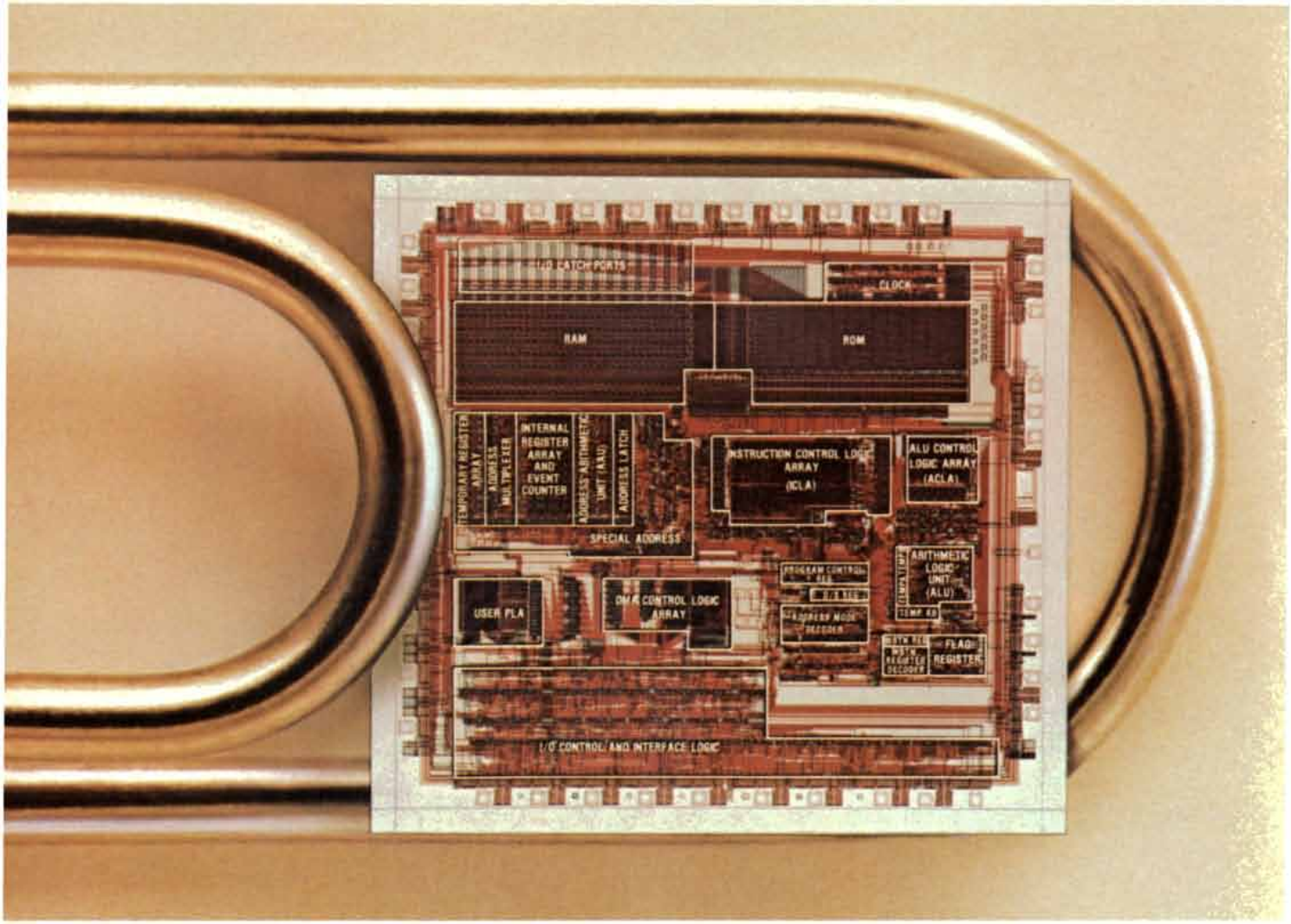
long, twisted thread. A bacterium has one millimeter of DNA in a continuous string of some three million bases folded back and forth several thousand times into a space less than a micron (a thousandth of a millimeter) across. In human cells the DNA is packed into 46 chromosomes, each one containing about four centimeters in a single piece, the total amount corresponding to about three billion bases. How can one find and work with a single gene only a few thousand bases long? Fortunately nature has devised certain enzymes (proteins that carry out chemical reactions) that solve part of the problem. These special enzymes, called restriction endonucleases, have the ability to scan the long thread of DNA and to recognize particular short sequences as landmarks at which to cut the molecule apart. Some 40 or 50 of these enzymes are known, each of which recognizes different landmarks; each restriction enzyme therefore breaks up any given DNA reproducibly into a characteristic set of short pieces, from a few hundred to a few thousand bases long, which one can isolate by length.

One can clone such DNA pieces in bacteria. As a first step one purifies the circle of plasmid DNA. The sequences of the plasmids are such that one of the restriction enzymes will recognize a unique site on the plasmid and cut the circle open there. One can insert a chosen DNA fragment into the opening by using a variety of enzymatic techniques that connect its ends to those of the circle. Ordinarily this recombinant-DNA molecule could not pass through the bacterial cell wall. A dilute solution of calcium chloride renders the bacteria permeable, however; in a mixture of treated cells and DNA a few bacteria will take up the hybrid plasmid. These cells can be found among all those that did not take up the DNA if a gene on the plasmid provides a property the bacterium must have to survive, such as antibiotic resistance. Then any bacterium carrying the plasmid will be resistant to the antibiotic, whereas all the others will be killed by it. When one spreads the mixture of bacteria out on an agar plate containing nutrients and the antibiotic, each single bacterium with a plasmid will grow into a separate colony of about 100 million cells. A single colony can be chosen and grown further to yield billions of cells, each of which contains identical copies of the new DNA sequence in a recombinant plasmid.

The Sequencing of DNA

The procedures we have outlined so far are followed in "shotgun" cloning experiments. One breaks up the DNA of an animal cell into millions of pieces and inserts each piece into a different bacterium. In this way a number of collections of all the fragments of human,

The one-chip computer: offspring of the transistor



The MAC-4 one-chip computer, developed for a variety of telecommunications applications, is compared to a standard-sized paper clip. The chip's numerous functional areas are labeled.

One of the transistor's latest descendants is the Bell System's 30,000-element MAC-4 "computer-on-a-chip." It's another in a long line of microelectronic developments that have come from Bell Laboratories.

The MAC-4 is so efficient that a program written on it takes 25 percent less storage space than that required by most other microcomputers. Its assembler language, C, also developed at Bell Labs, has features that make MAC-4 easier to program, debug and maintain. And the MAC-4 can handle anything from nibbles to bytes to words with its 4-, 8-, 12-, and 16-bit operations capacity.

Like other one-chip computers, the MAC-4 has sufficient memory to support its varied tasks—3000 nibbles of read-only memory and 200 nibbles of random access memory coupled to 34 input/output ports.

Fabricated with the latest CMOS technology, the MAC-4 needs little power. Thus it is well matched to a variety of telecommunications applications.

It started with the transistor

MAC-4 is just one current example of the many microelectronic devices to come from Bell Labs since we started the solid-state revolution with the invention of the transistor in 1947.

Over the past three decades, our advances in materials, processing, and devices have been vital to solid-state technology. These include:

- The Junction Transistor
- Crystal Pulling
- Zone Refining
- Field-Effect Transistor
- Diffusion
- Solar Cell
- Oxide Masking
- Thermocompression Bonding
- Photolithography
- Epitaxial Film Process
- Magnetic Bubble Memory
- Charge-Coupled Device
- Semiconductor Heterostructure Laser Used in Lightwave Communications
- Electron-Beam Exposure System

Today and tomorrow

Today, we continue to make important contributions to solid-state technology. For example, we've developed a rugged 65,536-bit RAM that can tolerate processing faults. Corrections can be made on the chip itself, so we can get more usable chips out of each manufacturing batch—and thus lower unit costs.

In materials processing, we've developed a technique for precisely controlling the growth of successive atomic layers of single crystal materials. This "molecular beam epitaxy" process is finding increasing use within Bell Labs and elsewhere in the electronics industry. We've used it to fabricate a device that permits us to double the speed of electrons by channeling them into crystal layers where they meet less resistance.

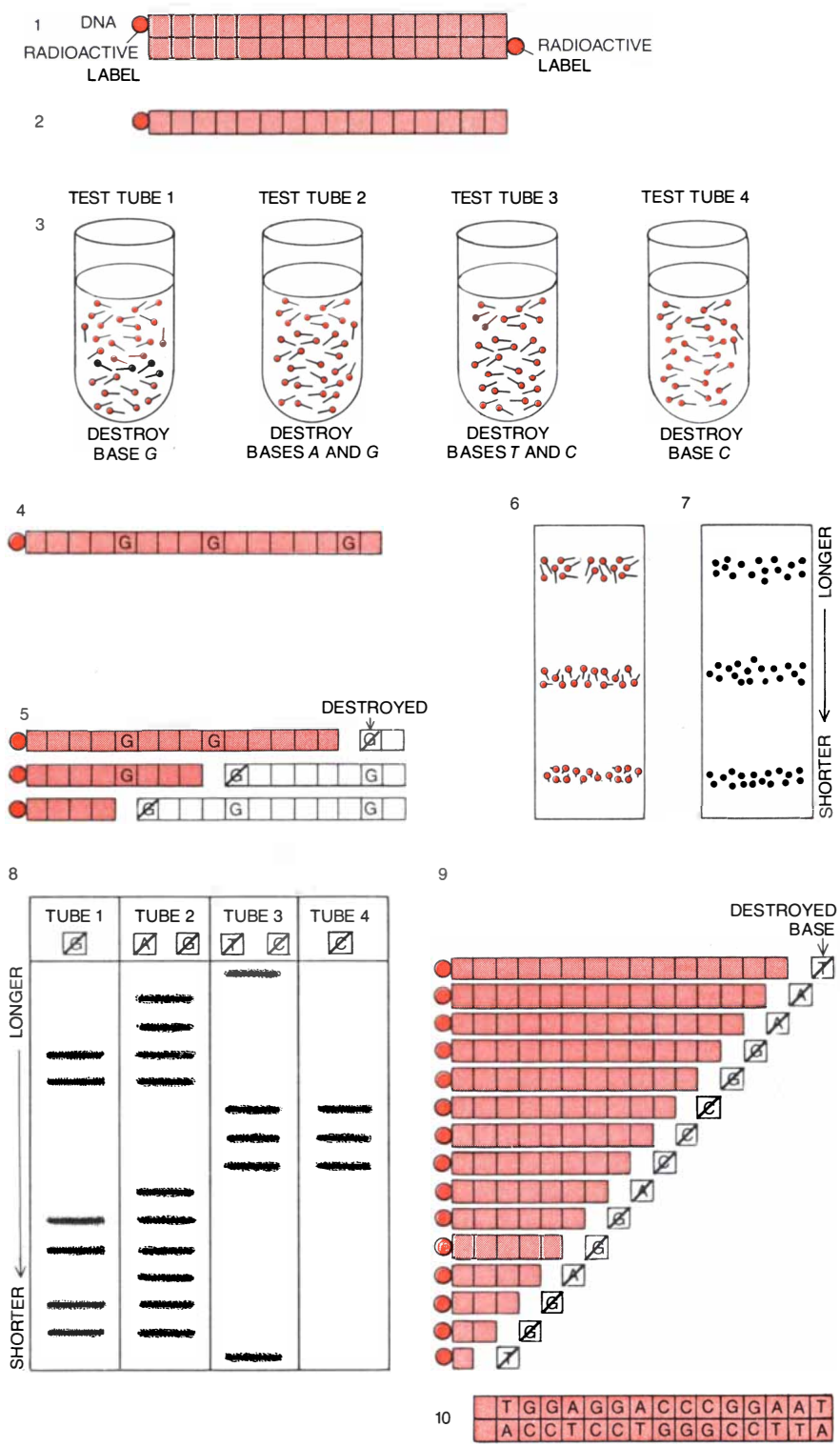
Other advances, in X-ray lithography and new resist materials, for example, promise to help place more elements on microelectronic devices and thus enhance their ability to perform important tasks.

As the solid-state revolution continues, these and other developments from Bell Labs will play an important part in it. What's important to us is the promise these advances offer for new telecommunications products and services. Like the transistor, MAC-4 and its solid-state relatives will find more and more applications in the nationwide telecommunications network.

For information about employment, write:
Bell Laboratories, Room 3C-303,
600 Mountain Avenue,
Murray Hill, N.J. 07974.
Please include a résumé.
An equal opportunity employer.

Bell Laboratories

From Science: Service



SEQUENCING OF DNA, in the method devised by one of the authors (Gilbert) and Allan M. Maxam, begins with the attachment of a radioactive label to one end of each strand of double-strand DNA (*1*). The strands of trillions of molecules are separated (*2*) and a preparation of one of the two kinds of strands is divided among four test tubes (*3*). Each tube contains a chemical agent that selectively destroys one or two of the four bases *A, T, G* and *C*, thereby cleaving the strand at the site of those bases; the reaction is controlled so that only some of the strands are cleaved at each of the sites where a given base appears, generating a set of fragments of different sizes. A strand containing three *G*'s (*4*), for example, would produce a mixture of three radioactively labeled molecules (*5*). The reactions break DNA at the *G*'s alone, at the *G*'s and the *A*'s, at the *T*'s and the *C*'s, and at the *C*'s alone. The molecules are separated according to size by electrophoresis on a gel; the shorter the molecule, the farther it migrates down the gel (*6*). The radioactive label produces an image of each group of molecules on an X-ray film (*7*). When four films are placed side by side (*8*), the ladderlike array of bands represents all the successively shorter fragments of the original strand of DNA (*9*). Knowing what base or pair of bases was destroyed to produce each of the fragments, one can start at the bottom and read off a left-to-right sequence of bases (*10*), which in turn yields the sequence of the second strand.

mouse, rat and fly DNA have been made. One can determine the structure of any one of these cloned DNA's by breaking up the hybrid plasmid with a restriction enzyme, separating the resulting DNA fragments, determining the base sequence of each of the fragments and then putting the sequences together to deduce the entire structure of the cloned DNA.

There are two methods for sequencing DNA. Both exploit reference points created by restriction-enzyme cleavage of the DNA at a specific short sequence and then work out the rest of the sequence by measuring the distance of each base from that cut. They do this by creating a set of radioactively labeled molecules, each of which extends from the common point to one of the occurrences of a specific base. When these molecules are separated by size and detected by their radioactivity, the length of the smallest one shows the position of the first occurrence of that base; longer molecules correspond to later occurrences. The pattern created by the analysis of these molecules looks like a ladder. From the positions of the rungs one reads off the lengths. By comparing four such patterns one reads off a sequence.

One technique, devised by Allan M. Maxam and one of us (Gilbert), makes use of chemical reagents that detect the different chemical properties of the bases and break the DNA there. To generate the set of fragments the reactions are done for a short time, so that the molecule is broken only occasionally instead of everywhere the base occurs; different molecules will be broken at different places. Four different sets of reagents are used to generate the four patterns. The radioactive label is attached directly to the end of the particular restriction fragment one wants to sequence, so that only the molecules stretching from the labeled end to the break are detected by their radioactivity.

The other sequencing method, devised by Frederick Sanger of the British Medical Research Council Laboratory of Molecular Biology in Cambridge, makes a DNA copy with an enzyme and stops the sequential synthesis, and hence the elongation of the copy, by blocking the movement of the enzyme at a specific base. Here the radioactive label is incorporated into the newly synthesized molecule in four different reactions. Both methods can provide the sequence of from 200 to 300 bases in a single experiment. One of the small plasmids involved in our cloning experiments was sequenced in a year by Gregory Sutcliffe, who worked out the order of the 4,357 bases on one strand and checked them by working out the complementary strand.

Any DNA region carried on a plasmid can be isolated and sequenced. The difficulty is not in determining the sequence but in obtaining the specific

DNA fragments needed. The recombinant-DNA technique serves almost as a microscope to isolate and to magnify, by making many copies, a DNA region, but one does not want to look through a million bacteria to find a specific gene. The fundamental problem, which has no general solution, is to place only the desired DNA sequence—the desired structural gene—in a bacterium.

Getting the Right Gene

One straightforward approach is suitable for very small proteins. The amino acid sequence and the genetic code will predict a sequence of bases that can specify those amino acids. One can then chemically synthesize a corresponding DNA molecule. Exactly this was done by Keiichi Itakura and his co-workers at the City of Hope National Medical Center in Duarte, Calif., who constructed a DNA sequence 42 bases long that dictates the structure of somatostatin, a small hormone consisting of 14 amino acids. The longer the stretch of DNA, however, the harder it is to make; the synthesis of a stretch of DNA 100 bases long is extremely difficult. Many small hormones consist of from 50 to 100 amino acids, and enzymes and other proteins range from 200 to several thousand amino acids in length. Furthermore, one does not know the amino acid sequence of many interesting proteins. (Indeed, the amino acid sequence of some of these proteins has become available only through the sequencing of cloned DNA.)

The desired structural gene is present, of course, somewhere on the DNA of the animal cell. The problem is to find it, but even if that were possible, the structural information would be broken up (as we mentioned above) by long stretches of other DNA. The information does exist in a continuous form, however, on the messenger RNA. Moreover, different cells specialize in the synthesis of different proteins, so that the appropriate tissue will contain the desired messenger RNA along with other messengers for the common proteins made by all cells. Insulin, for example, is made by the beta cells of the pancreas; those cells contain insulin messenger RNA and other cells do not, even though the insulin gene is present in the DNA of every cell.

The task is then to convert the desired structural information from the cell's messenger RNA into DNA, which can be cloned. For this one takes advantage of a special enzyme, reverse transcriptase, that can copy a single strand of RNA to make a complementary strand of DNA. (The enzyme is found in certain RNA viruses that reverse the normal DNA-to-RNA transcription. Such viruses depend on RNA rather than DNA to carry their information from one cell to another and convert the RNA

back into DNA with the help of reverse transcriptase after they infect a new cell.) One takes this strand of complementary DNA, called copy DNA, and makes a second strand of DNA with the more usual DNA-copying enzyme. The resulting double-strand cDNA fragments are more or less complete copies not only of the desired messenger RNA but also of all the other messenger RNA's that were present in the tissue. At best, however, only a few of the DNA fragments contain all the wanted structural information. Even in those fragments the regulatory signals that surround the structural sequences refer to translation in the animal cell, not in bacteria, and (since the DNA was made from RNA) there will be no transcriptional commands. Although the cDNA can be cloned, two problems remain: to detect any clones containing the sought-after structural DNA fragment and to provide the appropriate signals.

Finding the Right Clone

It is simple to find the right clone if the experiment began with a pure messenger RNA. One can detect matching sequences by the process called hybridization. The two strands of a DNA molecule can be separated by heating, which breaks the weak bonds that hold the two strands together without breaking the strong chemical bonds between bases along the chain. When a mixture of such strands is cooled, those sequences that match will find each other. The first step of this process is called denaturation, the second step reannealing. The same process serves to identify sequence matches between RNA and DNA.

One grows bacterial colonies on a disk of cellulose nitrate paper, breaks open the bacterial cells where they lie and fixes the released DNA to the paper. When the DNA is denatured and reannealed to radioactive RNA, only the remains of those colonies that contained a plasmid whose sequence matches the messenger become radioactive. Since one keeps a replica (a living duplicate set of the colonies), one can obtain bacteria containing the desired DNA. One grows these bacteria to provide material to identify, in further hybridization tests, other clones that contain the same sequence in different surroundings and may turn out to be more effective in producing the wanted protein.

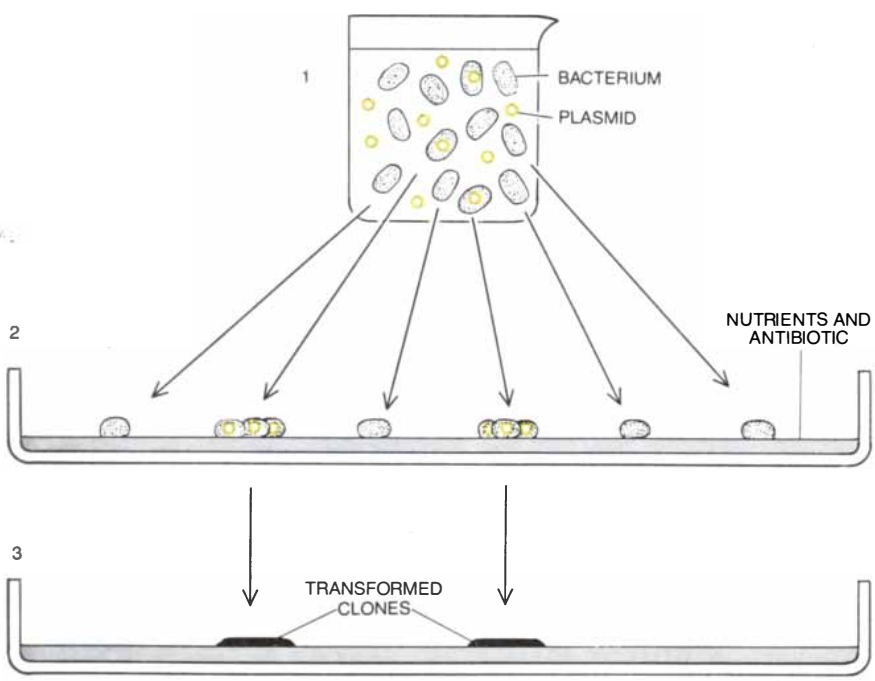
If one cannot purify the messenger RNA because the specific messenger is a small fraction of all the messengers in a cell, there are other ways to search for the DNA sequence. One useful property is the detailed shape of the corresponding protein molecule. Those shapes that are most different and distinctive can be recognized by the protein molecules called antibodies. Animals make antibodies as part of their protective response to foreign substances. If one injects human insulin into a guinea pig, for example, the guinea pig will make antibodies that bind to human insulin. These antibodies will not bind to guinea pig insulin because they "see" only the shapes that make the human protein different. A purified antibody, then, can serve as a reagent to detect a particular protein. (This is the way vaccines work. If an animal is injected with an inactivated virus, it is stimulated to make antibodies against the viral proteins. Thereafter the antibodies will protect the animal against infection by that virus by binding to the virus particle and signaling other cells to remove the invader. Without the earlier stimulation the antibody response to the invading virus is too slow to block the infection.)

Even without purifying a specific messenger RNA one can make the RNA molecules function in the test tube by adding the machinery needed to translate the messengers (obtained from the cytoplasm of broken cells) along with radioactive amino acids. Among the small amounts of radioactive proteins that are synthesized one can recognize the protein of interest with antibodies. This provides a means of detecting the presence of a specific messenger. If one takes a recombinant plasmid and hybridizes it to the mixture of RNA's, only the RNA that matches a sequence in the plasmid will anneal to it and therefore no longer function in translation; the plasmid of interest is detected by its ability to block the synthesis of the desired protein. This identification can be verified because the RNA bound to the DNA can be separated from all the other RNA's and then released from the DNA, whereupon it will function to direct the synthesis of the protein.

Regulatory Signals

With these techniques one can clone and identify DNA fragments carrying the information that dictates the structure of a protein. Will the information work in bacteria?

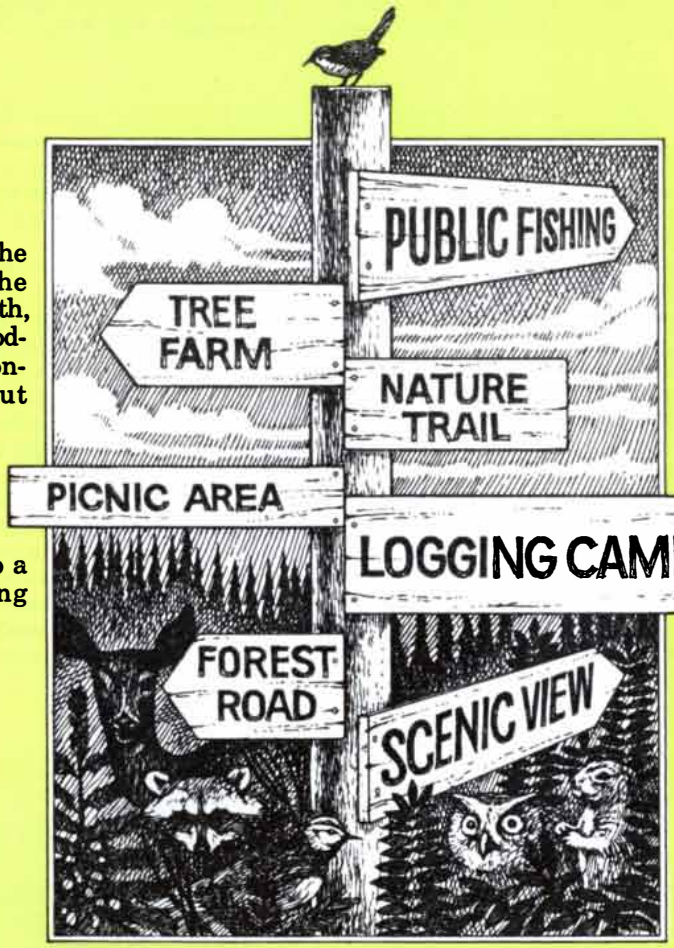
One must provide regulatory signals the bacterium can use. One of them is the signal to start the synthesis of a messenger RNA; in bacteria it is a region of DNA immediately in front of the segment of DNA that will be transcribed into RNA. The second important signal functions as part of the messenger RNA, telling the bacterial translation machine to "Start here." All bacterial genes have these two kinds of start signals (some of which work better than others). They also have two stop signals, one for translation and one for transcription. A simple way to make the new protein sequence is to cut a bacterial gene open in its middle with a restriction enzyme and to insert the new DNA there. This results in a hybrid protein that starts out as some bacterial protein and then continues as the string of amino acids one wants. That is how the chemically synthesized gene for somatostatin was made to work in bacteria. The DNA for those 14 amino acids, followed by a stop signal, was inserted near the end of a 1,000-amino-acid protein. After the bacterium made the hybrid protein the



RECOMBINANT PLASMIDS (*color*) bearing the inserted animal-protein genes and genes for resistance to tetracycline are mixed with bacteria (*1*). Some cells take up the plasmid. The mixture of cells is spread on a culture medium containing the antibiotic (*2*), which kills all the cells that do not have the plasmid. The cells that have taken up the plasmid are antibiotic-resistant; they live, and each of them gives rise to a clone, a colony of genetically identical cells (*3*).

A report on the great American forest.

The all-purpose forest has something for everyone.



The forest is one of the most useful resources the planet has been blessed with, providing thousands of products that are not only convenient and pleasant but essential: lumber and building materials, paper products, packaging, chemicals, fuel.

But the surprising, bountiful forest is also a source of other enduring benefits:

Fishing streams, for example.

Nature trails.

Swimming holes.

A place for Sunday drives.

Grazing land.

Board and room for wildlife.

Pure water.

And escape.

Sharing the benefits

All these can and do coexist in the working commercial forests of America. (*Commercial forest,* as defined by the U.S. Forest Service, is *all* forestland — whether owned by individuals, government or the forest industry — that is capable of, and potentially available for, growing repeated crops of trees for harvest. It includes land in National Forests but not in National Parks or Wilderness areas.)

But demands on the commercial forest are growing at an alarming rate. An expanding population is placing new pressures on the forest for recreation. Thousands of acres are withdrawn every year for homes, shopping centers and additions to Wilderness. And of even more concern, America's consumption of wood and paper products is expected to double in the next 50 years.

Can the commercial forest keep on providing these multiple benefits indefinitely?

The big if

There is reason for cautious optimism *if* the techniques used by industry to grow more trees, faster, can be applied on *all* our commercial forestland.

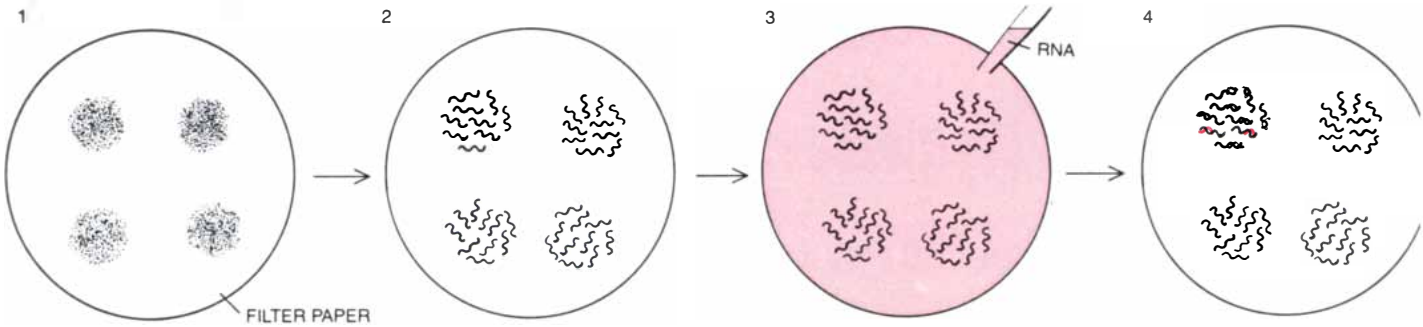
Unfortunately, trees are not growing fast enough in all commercial forests. Productivity is less on privately owned land than on industry's and is seriously lagging in National Forests.

So there is a long road ahead if America is to continue to receive multiple benefits from the forest.

If you'd like to be better informed on how important it is to keep America's forests productive, write American Forest Institute, P.O. Box 873, Springfield, VA 22150 for a free booklet, "The Great American Forest."

The great American forest. Trees for tomorrow. And tomorrow. And all the tomorrows after that.

Trees. America's renewable resource.



CLONE CONTAINING DESIRED DNA can be found among all the successfully transformed clones (*1*) by means of RNA-DNA hybridization if one has a pure messenger-RNA probe for the desired sequence. The cells are broken open and their DNA is denatured and fixed to filter paper (*2*). The RNA probe (RNA molecules labeled with a radioactive isotope) is added (*3*). The RNA (*color*) will anneal to any DNA whose sequence it matches, forming RNA-DNA hybrids (*4*); the remainder of the RNA is washed away. The presence of the hy-

somatostatin part was cleaved off chemically and purified.

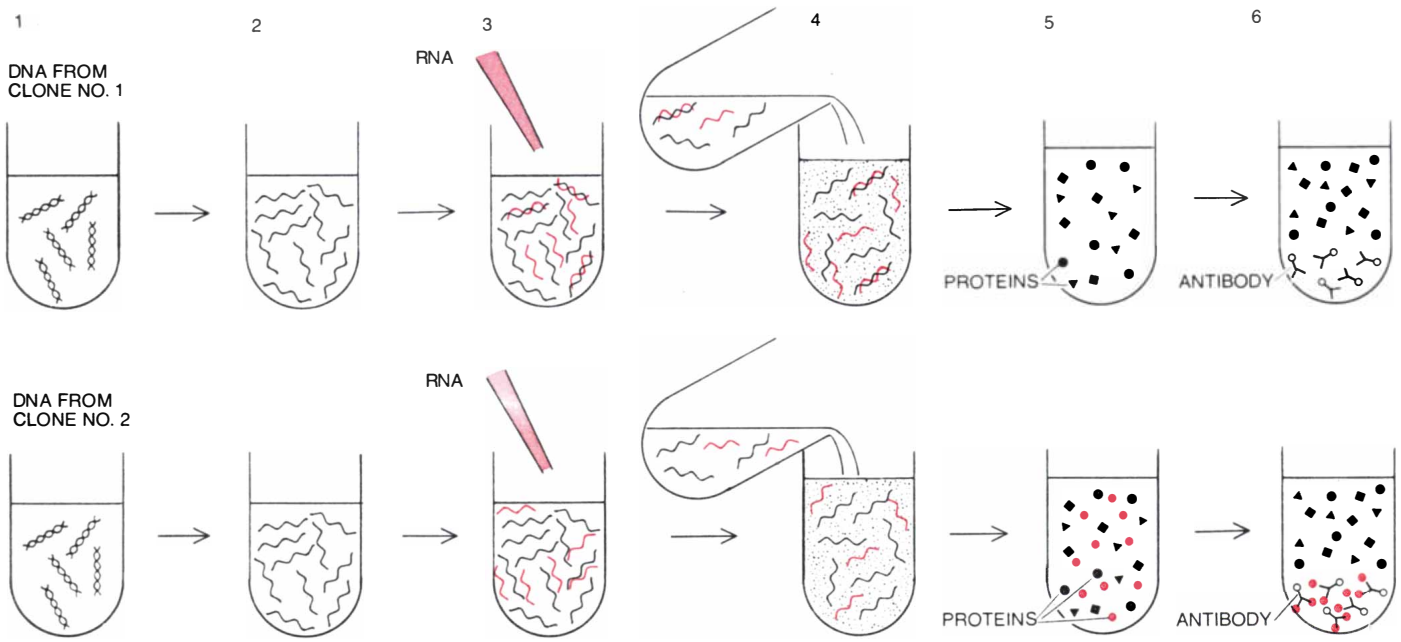
Not only can the bacterial gene serve to provide the regulatory signals but also it may endow the hybrid protein with further useful properties. For example, a few bacterial proteins are secreted through the membrane that surrounds the cell. If one inserts the animal DNA into the gene for such a protein, the bacterial part of the hybrid protein will serve as a carrier to move the new protein through the membrane so that it is more easily observed and purified.

We exploited all the techniques described above to obtain a copy of the insulin gene and to insert it into bacteria to make proinsulin. Insulin is a small hormone made up of two short chains, one chain 20 amino acids long and the other 30 amino acids long. These two chains are initially part of a longer chain of 109 amino acids, called preproinsulin. As preproinsulin is synthesized in the beta cells of the pancreas, the first 23 amino acids of the chain serve as a signal to direct the passage of the molecule through a cell membrane. As this happens those amino acids are cleaved off, leaving a chain of 86 amino acids: proinsulin. The proinsulin chain folds up to bring the first and last segments of the chain together, and the central portion is cut out by enzymes to leave insulin. The role of the central portion is to align the two chains comprising insulin correctly. If the two chains are taken apart later, they do not reassemble easily or efficiently. (In spite of these difficulties Itakura and his co-workers synthesized two DNA fragments corresponding to the two chains of human insulin and attached them separately, like somatostatin, to the same large bacterial gene in order to synthesize two separate hybrid proteins in two different bacteria. Then they cut off the two short pieces, purified them and put them together to form insulin.)

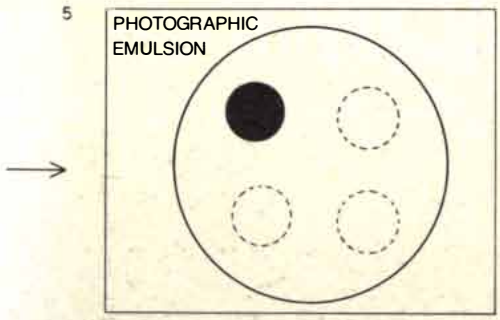
The Proinsulin Experiment

In our experiments we started with a tumor of the insulin-producing beta cells of the rat. (We worked with rat insulin because at the time we began our experiments the guidelines established by the National Institutes of Health for recombinant-DNA investigations would not allow us to insert the human insulin gene into bacteria; that prohibition has since been removed.)

We made DNA copies of the beta-cell messenger RNA and put them into a plasmid, in the middle of a gene for a bacterial protein, penicillinase, that



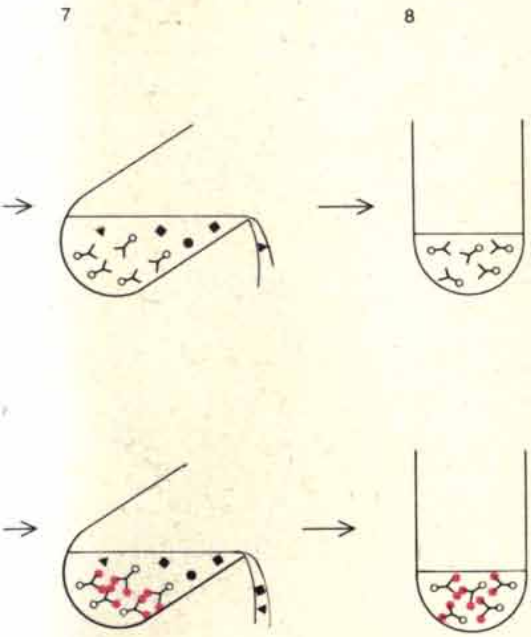
HYBRID-ARRESTED TRANSLATION, a technique developed by Bryan Roberts of the Harvard Medical School, identifies a clone (*top*) containing the desired DNA even in the absence of a purified RNA probe. DNA from clones being tested (*1*) is denatured (*2*). Unpurified RNA (the same RNA used to make the inserted DNA) is added (*3*); it anneals to any matching DNA. Placed in a "translation system" containing radioactively labeled amino acids (*4*), the unhybridized RNA directs the synthesis of radioactive proteins, but the hybridized RNA cannot be translated; the specific protein (*color*) encoded by the desired DNA is not synthesized in the presence of the clone containing that DNA (*5*). The presence or absence of that protein is determined by an antibody test. Antibody to the protein, fixed to plastic beads,



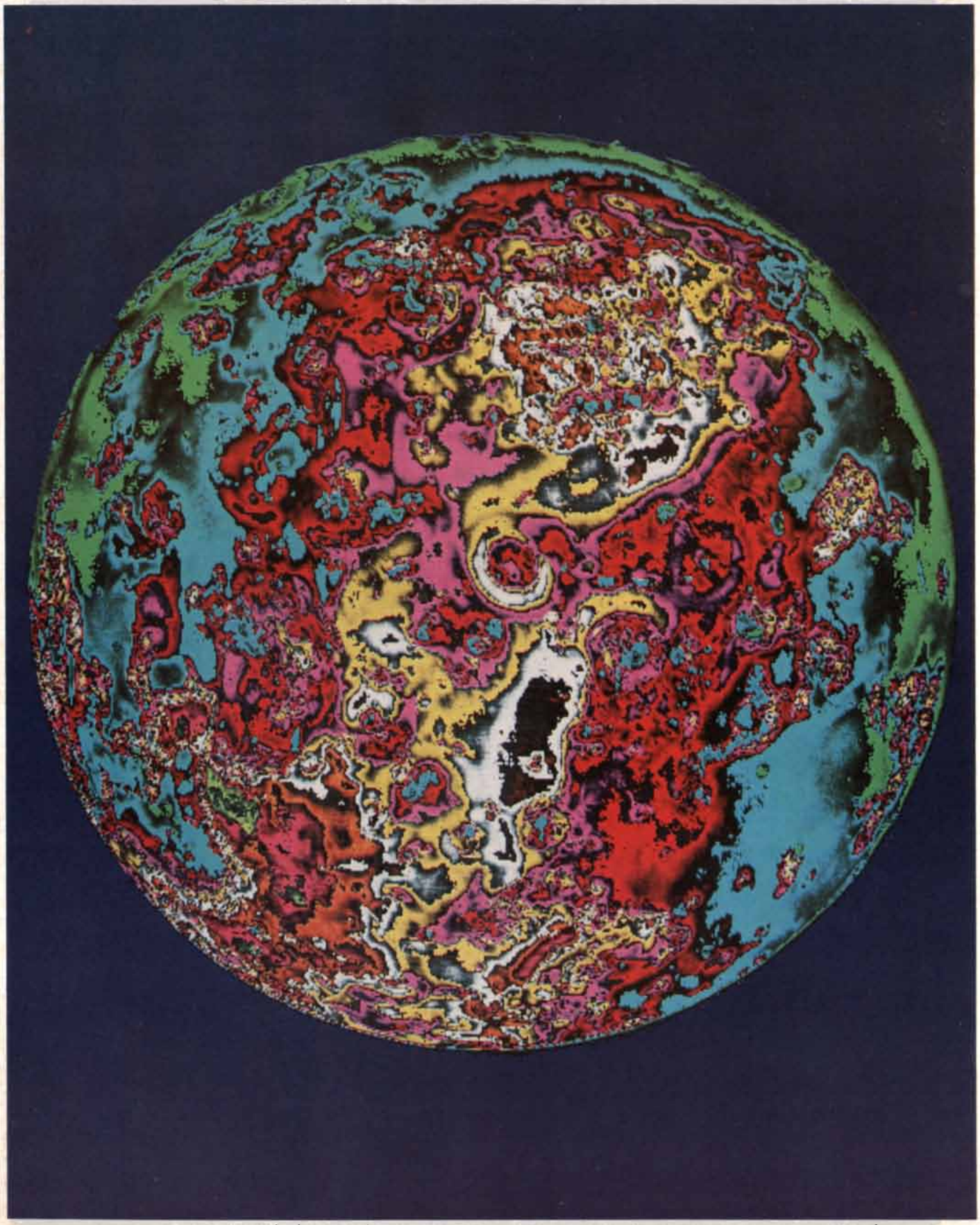
brids is revealed by autoradiography: a photographic emulsion is placed on the filter paper and after exposure the clone containing the desired DNA is identified as a dark spot (*5*).

would be secreted through the membrane of the bacterial cell. We looked among the bacterial colonies by hybridization, we proved that we had the right hybrid plasmid by blocking the synthesis of insulin in a test tube as we described above and we sequenced the DNA to see exactly what part of the insulin gene we had. Once we had found one hybrid plasmid, we used it to find 48 more by repeating the hybridization test. These 48 clones represented 2 percent of all the clones we had made.

Would any of those clones actually synthesize insulin? We looked among the clones containing insulin DNA for any that were synthesizing a hybrid protein part of which was proinsulin. For this we relied on a sensitive radioactive-antibody test. We coated plastic disks with antibody directed against either insulin or penicillinase and exposed them



is added and binds the protein, precipitating the protein out of the solution (*6*), which is poured off (*7*). Measurement of the precipitates' radioactivity (*8*) shows that one clone (*top*) contains the desired DNA, because it blocked the synthesis of the specific protein.



Actual-size reproduction of a Polacolor 8 x 10 hardcopy of Io, moon of Jupiter, taken by Voyager satellite. An example of remote sensing. Photo courtesy of JPL/NASA.
All photographs taken with a Dunn Instruments 631 color camera.

Now, direct from your computer-big instant pictures.

Now your computer can immediately deliver sharp pictures in brilliant colors on Polaroid 8 x 10 Land film.

This is an ideal form of hardcopy. It adds impact to your graphic data by presenting it in a large, easily readable form. And it serves a wide variety of informational needs in business graphics and image processing—with applications in mapping, earth studies from satellites, medical diagnosis, computer-aided design and animation.

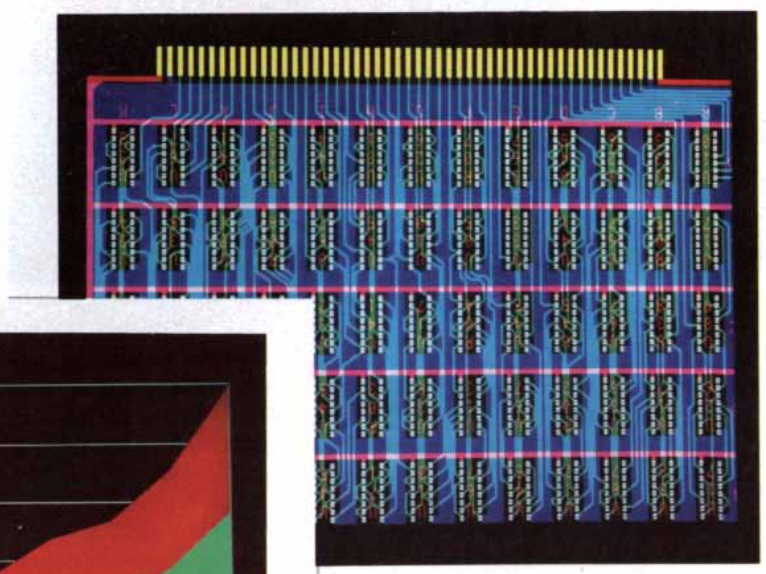
The pictures shown here were made by new computer peripherals—color cameras. They are manufactured by Dunn Instruments and Matrix Corp. Since the cameras use standard video (RS 170) signals, you can conveniently interface them with computers or color-raster based terminals.

The Polaroid 8 x 10 print produced by the camera is the highest-quality instant record available. Since you receive your hardcopy immediately, you can be sure you're getting exactly the record you want, exactly the way you've seen it displayed on your monitor. And you can distribute it at once if the data is urgently needed. The pictures are distortion-free, and their bright, saturated colors yield superb results.

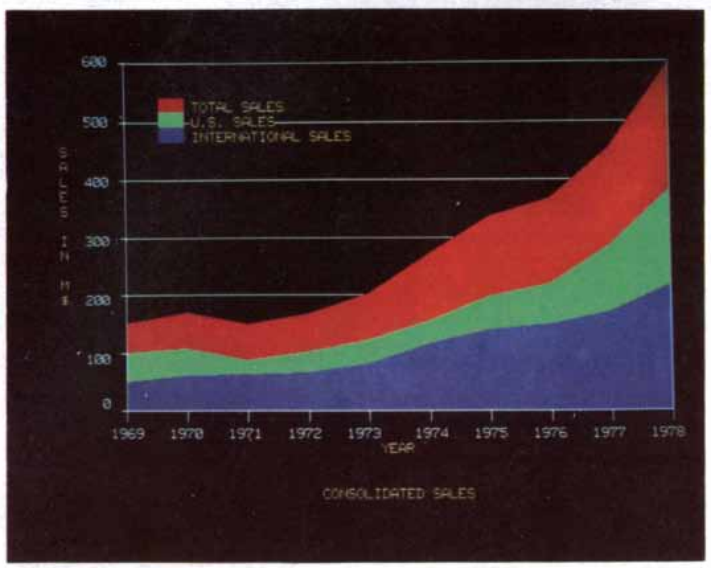
The print can also record continuous-tone images from digital color TV signals in such applications as remote sensing, animation and geological sounding. Its resolution surpasses the resolution of present color digital TV systems. As the technology of digital TV advances, these large Polaroid prints will be able to record even greater detail and more information.

The film's colors are stable, so the picture stays fresh and bright. The photo can be used as original art for high-quality printing. And because of its 8 x 10 size, it can be inserted as a complete page in a report.

For more information or a demonstration, write to: Polaroid Corporation, Dept. A428, 575 Technology Square, Cambridge, Mass. 02139. Or call toll-free from anywhere within the Continental U.S.: 800-225-1618. (In Massachusetts call collect: 617-547-5177.)



Computer-aided design of IC chip from Ramtek color terminal. (Reduced from Polacolor 8 x 10 print.)



Typical management information graphic from Tektronix color terminal. (Reduced from Polacolor 8 x 10 print.)

Polaroid
Instant 8x10 color film

AFTER YOU COMPARE IT FOR MILES PER GALLON, COMPARE IT FOR COMFORT PER MILE.

Load up Renault Le Car, and take advantage of more luggage space than you'll find in either a Ford Fiesta or Honda Civic.†

Settle into the anatomically-contoured seats, and luxuriate in more passenger room than either a Civic or a Datsun 210.†

Pick out a really rough road, and watch Le Car's four-wheel independent suspension and standard steel-belted Michelin radials soak up jolts and bumps so well, they give you a smooth, level ride *Motor Trend* says "would do credit to far larger, more expensive cars."

Just visit one of the hundreds of Renault dealers from coast to coast, and take Le Car for a test-drive.

When you read the mileage estimates, you'll know how much a car costs to drive. But only after you test it on the road will you know whether or not it's worth driving.

*Remember: Compare these 1980 EPA estimates to estimated mpg for other cars. Your mileage may vary due to speed, trip length or weather. Your highway mileage will probably be lower. California excluded. †Based on 1980 EPA data.

RENAULT LE CAR

WE BUILD MORE INTO ECONOMY CARS THAN JUST ECONOMY.

to the contents of cells from each clone. Any insulin (or penicillinase) present in the cells binds to the antibody and is thereby fixed to the plastic disks. Then we applied radioactively labeled anti-insulin antibody to detect the presence of proteins with insulin shapes. One clone gave positive responses, both on disks coated with anti-insulin and on those coated with antipenicillinase, to radioactive antibody to insulin, thereby demonstrating the presence of a penicillinase-insulin hybrid protein.

To see if the bacteria were secreting the hybrid protein we grew the clone in liquid culture and tried to extract the protein by a method that does not burst the bacterial cell membrane. The test showed the fused protein to be present outside the membrane: it was secreted, as we had hoped it would be.

Sequencing the DNA showed that the DNA fragment and the details of the fusion were such that the structural information in the clone was only for proinsulin and did not contain the "pre" region. In order to make insulin we removed most of the bacterial protein and the middle segment of the proinsulin with the digestive enzyme trypsin. Would the insulin made from the bacteria be an active hormone? Stephen P. Naber and William L. Chick of the Elliot P. Joslin Research Laboratory in Boston tested the molecule by showing that it affected the metabolism of sugar by fat cells, as it should.

Improving the Yield

The amount of proinsulin made by the original clone was very small; we are currently engaged in various manipulations to improve the yield. Regulatory signals must be not only efficient but also optimally placed. One need not be satisfied with the signals that happen to surround preexisting bacterial genes. With restriction enzymes one can clip out small DNA fragments that carry only the regulatory signals and tie them together with a DNA-linking enzyme to make new combinations. One can trim back the ends of these fragments by nibbling off bases with still other enzymes before reconnecting them. This will alter the spacings between the signals and the structural sequence. Although each of these manipulations generates only a small number of correct molecules, by cloning after each step one can make large amounts of the DNA and work out its sequence, and then continue the tinkering.

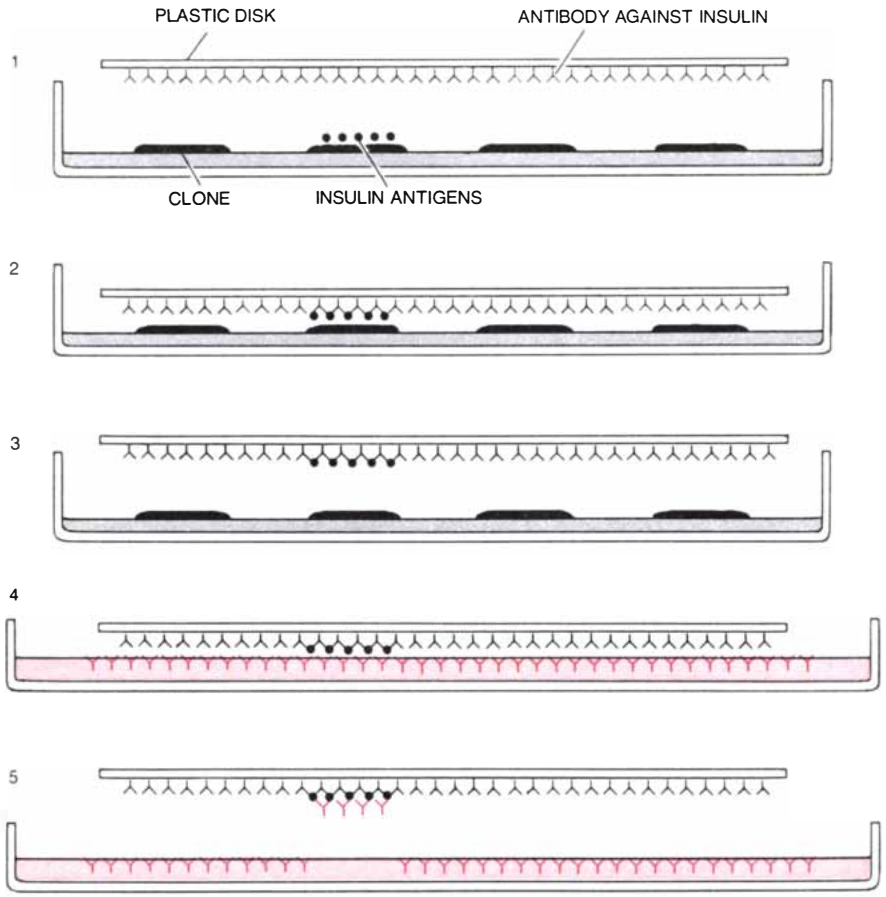
Moreover, one can synthesize short desired DNA sequences and tie them to other fragments. For example, David V. Goeddel and his co-workers at Genentech, Inc., took a piece of DNA containing the structural information for human growth hormone (168 amino acids), connected it to a synthetic piece of DNA containing part of the translational start signal and attached that combination in turn to a fragment containing the rest of the regulatory signals. When this DNA construction was cloned, the bacteria made a protein of the shape (as recognized by antibodies) and size of growth hormone (although not yet with demonstrated hormone activity).

Although we do not yet know the optimal combinations of the DNA elements for making insulin in bacteria, finding them is only a matter of time. There are other problems to be considered. Often the new animal proteins are broken down in the bacterial cell because their structure is such that enzymes normally present in the bacteria can digest them. Ways have to be found to stabilize the proteins either by removing these enzymes, by embedding the new protein in a hybrid protein to protect it or by secreting it from the cell. Messenger-RNA molecules themselves are often unstable within the cell; modifications in their structure and in the cell itself can make them more effective and lead to increased protein synthesis. And if the number of copies of the plasmid carrying the gene in each cell can be increased, more of the product will be made.

While we work to improve the yield of rat proinsulin and to purify it we expect to apply the same methods to the bacterial synthesis of human insulin. Investigators in other laboratories are also working on the problem, and one can hope that eventually the manufacture of human insulin by bacteria will be cheaper than the purification of insulin from pigs and cattle, the present sources of the hormone. Clearly other human hormones can also be prepared by these procedures. What other therapeutic proteins might be made in bacteria? In general any human protein that cannot be obtained in useful form from animals is an excellent prospect.

Other Proteins from Bacteria

Many genetic diseases are caused by the lack of a single protein. Replacement therapy may be possible if such proteins can be made in bacteria. Vaccines against viral or parasitic infections are a further wide class of possibilities. Today in order to make a vaccine one



RADIOACTIVE-ANTIBODY TEST, developed by Stephanie Broome and one of the authors (Gilbert), is used to search among the bacterial clones containing insulin DNA for signs that insulin is indeed being synthesized. A plastic disk coated with an anti-insulin antibody is first exposed to the contents of cells from each clone (*1*). Any insulin present in the cells is bound to the antibody (*2*) and thereby fixed to the plastic disk (*3*). Radioactively labeled antibody (*color*) to insulin is then applied to the disk in order to detect the presence of the protein (*4, 5*). When the test is repeated with a plastic disk coated with an antipenicillinase antibody, only a hybrid protein, part penicillinase and part insulin, will bind the labeled antibody.

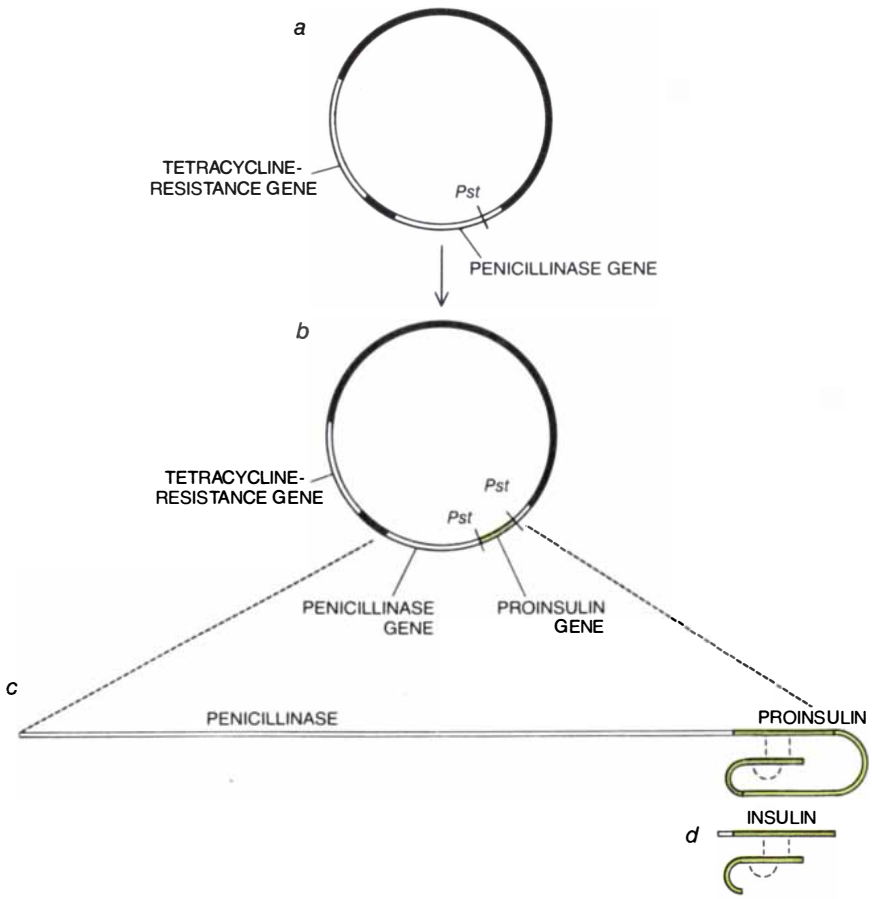
must be able to grow the disease organism in large amounts; often this is impossible or dangerous. Furthermore, the vaccine must be rendered harmless before it is administered, which can be difficult. The new technology offers the chance to make in bacteria only the protein against which the antibody response needs to be directed. This would eliminate any need to work with the intact disease organism. For example, the hepatitis *B* virus, which causes serum hepatitis, cannot be grown outside the body. The only source of this small DNA virus is the blood of infected human beings. The DNA of the virus has now been cloned in several laboratories and its complete sequence has been worked out, revealing the structure of the viral proteins; now the proteins are being made in bacteria. A flood of new information has resulted from this work.

A particularly promising candidate is interferon, a protein cells make to block viral infections quickly. (The antibody response is much slower.) Interferon appears to be the body's first line of defense against viruses. It may also have a therapeutic effect in some cancers. Interferon has never been available in sufficiently large amounts, however, to determine how effective it might really be in protecting against disease. The ability to test the activities of human interferon will soon be a reality because the protein has now been made in bacteria. Weissmann, with his colleagues Shigekazu Nagata, Hideharu Taira, Alan Hall, Lorraine Johnsrud, Michel Streuli, Josef Ecsödi and Werner Boll, along with Kari Cantell of the Finnish Red Cross, applied many of the techniques we have described to clone and to express this protein. The problem they faced was that the messenger RNA for interferon is far rarer than the one for insulin, even in white blood cells that have been stimulated by infection with a virus to make interferon. They took messenger RNA from these white blood cells (17 liters at a time), made double-strand cDNA and cloned it by the procedures we have described.

They looked through some 20,000 clones (in batches) by hybridizing the plasmid DNA from the clones to the messenger RNA of the white blood cells, isolating the RNA that annealed and checking the RNA to see if it was able to direct the synthesis of interferon (not in the test tube but by injecting the RNA into a particularly large cell, a frog's egg). Fortunately interferon is a remarkably potent substance, and so the amount synthesized in the frog's egg could be detected by its ability to protect cells against viruses.

Once Weissmann and his colleagues had found a batch of clones that could hybridize to interferon messenger RNA they tested progressively smaller groups of those clones to find the correct one. Then, with that clone as a probe, they found other clones by means of hybridization testing. Finally they tested extracts of the bacteria carrying the interferon DNA (inserted into the penicillinase gene) directly to see if any of the bacterial clones made biologically active interferon. A number of clones did, confirming that the interferon structural DNA had been correctly identified. The sequencing of the DNA of those clones will determine the structure of interferon, which is still not known.

The amount of interferon made in the bacteria was extremely small: only one or two molecules per cell. (Bacterial proteins are usually made in from 1,000 to 100,000 copies per cell.) We are confident that the methods we have described will solve this problem and lead to the production of enough interferon for clinical tests.



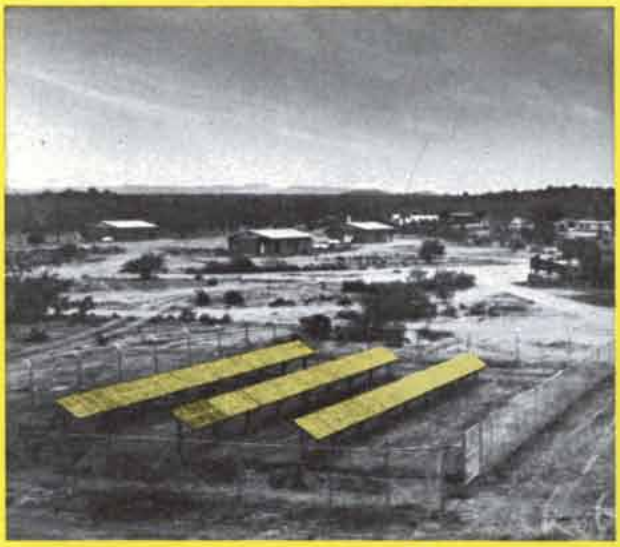
RAT INSULIN WAS OBTAINED by the authors from a hybrid protein composed of part of the bacterial penicillinase molecule and a molecule of proinsulin, an insulin precursor. The map of the plasmid that served as a vehicle, *pBR*322 (*a*), shows the location of the genes for the two enzymes conferring antibiotic resistance and the site of cleavage by the restriction enzyme *Pst*. The next map (*b*) shows the structure, as determined by DNA sequencing, of the recombinant plasmid in the bacterial clone that synthesized proinsulin. The proinsulin sequence (*color*) lies between two *Pst* sites that were regenerated in the insertion process. The hybrid protein synthesized by the clone (*c*) comprises most of the penicillinase and also the proinsulin molecule (*color*); broken lines represent disulfide bonds. The authors cut away most of the penicillinase and the middle segment of the proinsulin (*light color*) to make biologically active insulin (*d*).

The Recombinant-DNA Debate

The development of the genetic-engineering techniques described in this article was greeted, over the past decade, with both excitement and alarm. The possible benefits of the techniques were obvious, but some people felt there was reason for concern. Biologists called for an evaluation of the possible hazards of this research; the result was an unprecedented national and international effort in which the public, governments and the scientific community joined to monitor research activities. New knowledge about the properties of genes and the behavior of the bacteria used in this work (usually *Escherichia coli*) has led to a steady lessening of these concerns and to a relaxation of the guidelines that once restricted such experiments. In retrospect, with the advantage of hindsight, the concerns about hypothetical hazards seem to have been unwarranted. We know of no adverse effects from this research. The great potential of the new techniques, both in promoting the growth of basic knowledge and in making possible the synthesis of products of direct benefit to society, is much closer to realization than seemed likely only a few years ago.

The World's First Solar-Electric Community

This Indian village is Sun-Powered with the help of LEAD



The Papago Indian village of Schuchuli, Arizona gets all of its electricity directly from the sun and stores the excess in a huge lead-acid battery.

The upper left photo shows the village's solar cell array field which has 192 photovoltaic power modules that convert sunlight directly into electricity. This gives Schuchuli's 96 residents more than enough power for 15 refrigerators, a community washing machine, sewing machine and 5,000 gallon-per-day water pump, plus lighting for the village's 15 homes, church, feast house and domestic services building.

The excess electrical energy is stored in a battery system, having 53 lead-acid cells in series, which supplies power when the sun isn't shining. The upper right photo shows David Santos, Village Chairman, flanked by the battery system which was specially designed by C & D Batteries Div. of Eltra Co. for this purpose.

The Schuchuli Photovoltaic Village Power Project was funded primarily by the Department of Energy and managed by the NASA Lewis Research Center. The U.S. Public Health Service administered local portions of the project. The power system was installed by the Papago Construction Company and the pole-line distribution system was erected by the Papago Tribal Utility Authority.

Lead is a vital material for today and for the future.

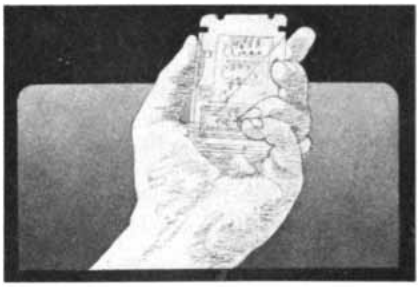
ST.JOE
LEAD COMPANY
Division of St Joe Minerals Corporation
7733 Forsyth Blvd., Clayton, Mo. 63105 (314) 726-9500
A BASIC SOURCE

A plane that makes peace with its neighbors.

The jetliner streaks down the runway and soars skyward. Below, babies nap on, outdoor conversations continue, undisturbed by the muffled hush of the jet's engines.

This is the new DC-9 Super 80. On takeoff and landing, its engines are only half as loud as those on comparable aircraft. The high-noise area around the airport for a Super 80 is shrunk to one-fifth the size of that produced by other narrow-body jetliners.

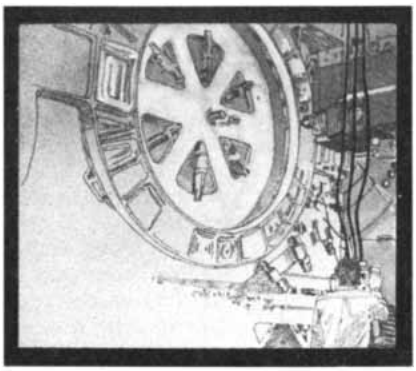
The Super 80 brings welcome peace to airport neighborhoods; and to airlines, the lowest fuel cost per seat mile of any jetliner, up to its maximum range. Watch for the new Super 80, entering service later this year.



Find out what's bugging you—fast.

In the hospital medical lab, where minutes count in detecting and identifying disease, doctors have a powerful new ally. Our Vitek Automicrobic® System pinpoints infectious microbes 50 to 80 percent faster than conventional testing. The system also suggests the most effective antibiotic.

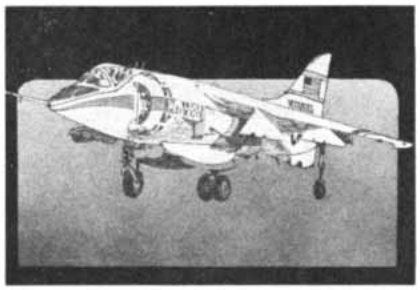
Quick, accurate diagnosis for you at a lower cost to the hospital. That's something we can all feel good about.



Carve metal with a computer.

Countless products of America's manufacturers take form from shapeless slabs of metal. Our Actrion® III guides the cutting bits of a machine tool with accuracy, reliability, and economy of operation that's unmatched by any other machine control.

If you're shaping new products for market, ask us to help.



A plane that hides just yards from the action.

The AV-8B is built to deliver quick, effective close-air support to Marines on the ground. It can wait in a clearing—it needs no runway—literally yards behind the lines. When the call comes, it rises straight up to streak off and strike with up to 9000 pounds of munitions. Then returns to its hiding place to await another call.

The AV-8B. Be glad it's on our side.

At McDonnell Douglas, ours is a world of ideas. In flight, health care, manufacturing, energy, data processing, communications, and a dozen other fields. To learn more about our ideas at work for you, write McDonnell Douglas, Box 14526, St. Louis, MO 63178.

MCDONNELL DOUGLAS

A JOB? LET'S SWAP RESUMES. SEND YOURS, WE'LL SEND OURS AN EQUAL OPPORTUNITY EMPLOYER. WRITE: BOX 14526, ST LOUIS, MO 63178

Metallic Glasses

In composition they are metallic, but they have the noncrystalline atomic structure typical of a glass. Such a material can be prepared by cooling a molten alloy at a rate of a million degrees per second

by Praveen Chaudhari, Bill C. Giessen and David Turnbull

A glass is a solid that can be regarded as a stop-action photograph of a liquid. In general when a liquid freezes, the atoms or molecules come to rest only after taking up positions in an orderly array: a crystal. As a result the configuration of the atoms in the solid is much different from that in the liquid, and extensive rearrangement must take place during solidification. In the formation of a glass, on the other hand, the atoms of the liquid essentially stop in their tracks. Thus it is not only the material itself that is frozen in a glass but also the very configuration of the atoms. Unlike the crystalline solid, the glass has no discernible long-range order; it is amorphous.

The familiar glasses are silicates, or compounds of silicon and oxygen. It was long thought that most other substances, notably the metals, could not be made to solidify in the glassy state but would invariably assume a crystalline form. There is now abundant evidence to the contrary: dozens of metallic alloys have been prepared as glasses. On casual inspection they have little resemblance to ordinary glass; for example, most of them are not brittle, and they are not transparent to visible light. In their microscopic structure, however, they are unmistakably amorphous. Over distances of more than a few atomic spacings there is no regularity or periodicity in the positions of the atoms. Determining how best to describe this microscopic structure is one of the most active areas of investigation in the study of the new materials.

If the metallic glasses are not much like silicate glasses, they also differ in significant ways from crystalline metals. Some of the glassy alloys may have distinctive chemical or mechanical properties, such as resistance to corrosion or high strength combined with ductility. Also of interest are their electrical and magnetic properties, for which certain applications can already be envisioned. For example, some of the alloys might make a suitable medium for magnetic "bubbles," the isolated domains of reverse magnetization that can serve to store information in a computer memory system. Another possible application is in the magnetic core of a power transformer, which is now made of magnetically soft iron in a crystalline phase. The adoption of a metallic glass might reduce the energy loss that results from the continual reversal of the magnetic field in the core.

Experience has shown that for any solid material there is always at least one crystalline phase that is stabler than the amorphous state. In other words, the crystalline form is favored thermodynamically (it is said to have a lower free energy) and so any glass will tend to crystallize spontaneously. That is true even of the silicate glasses, although at room temperature their rate of crystallization is nil. The silicate glasses crystallize so slowly because their atoms are interconnected by a network of covalent chemical bonds, each bond being directed from one atom to another. In order for the atoms to rearrange themselves in a crystal lattice many of the bonds would have to be broken and then reestablished in another configuration. Hence although the free energy of the crystal would ultimately be less than that of the glass, a substantial input of energy would be needed to effect the transition.

The chemical bonding of the atoms in a metal is more diffuse than that in the silicates or in similar insulating materials. Individual bonds are not strongly directed from one atom to another; instead the solid coheres through a mutual interaction of many positively charged ions and negatively charged electrons. As a result of the less directional bonding of a metal a crystal could be reconstructed from a metallic glass with a smaller investment of activation energy. It was for this reason that the prospects for solidifying metals in an amorphous state were considered remote.

For a glassy material to form it must be cooled to a temperature below a certain threshold called the glass temperature, which varies from one substance to another. Above the glass temperature, in the undercooled liquid phase, the atoms are free to make extensive translational movements; below that temperature they are immobilized except for vibrational motions about their average positions. Thus it is only at the glass temperature that the configuration of the atoms becomes frozen in an amorphous solid structure. It therefore appears that the most straightforward way to make a glass is to cool a liquid to below its glass temperature.

The trouble with this procedure is that for all known substances the glass temperature lies well below the freezing point, where crystallization can begin. To be more precise, the glass temperature lies below the liquidus temperature, where the liquid and crystal phases of the material can exist in equilibrium. As a result when the liquid is cooled, it crystallizes long before the glass has a chance to form.

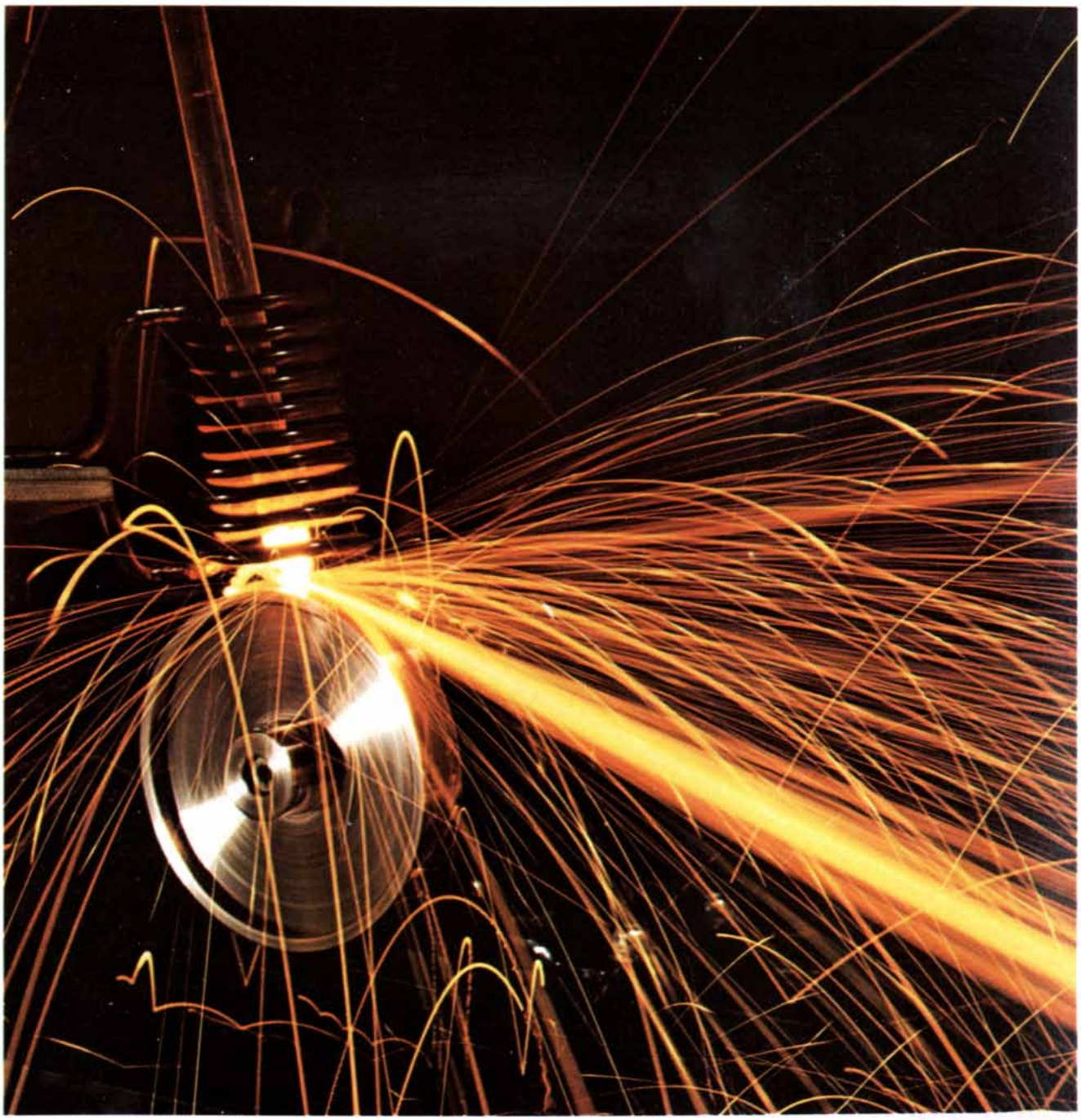
The principal method for making metallic glasses overcomes that problem by a simple strategy. When a liquid is cooled through the liquidus temperature, crystallization does not begin everywhere at once. Aggregates of a few atoms each, called nucleation centers, must first be assembled in the crystalline configuration. These centers then grow by accretion until the entire volume of the material has solidified. The formation and growth of nucleation centers requires a certain amount of time. The strategy for creating a metallic glass is to cool the liquid rapidly from above the liquidus temperature to below the glass temperature. If the passage through the intervening region is fast enough, there will not be time for crystals to form.

The first unequivocal demonstration that a metal could be quenched from a molten state to a glassy one was made in 1960 by Pol Duwez and Ronald H. Willens and their colleagues at the California Institute of Technology. The principle underlying their technique for making metallic glasses is still employed today in a method called melt-spinning. A jet of molten metal is driven onto the surface of a rotating metal disk or cylinder, which is held at room temperature

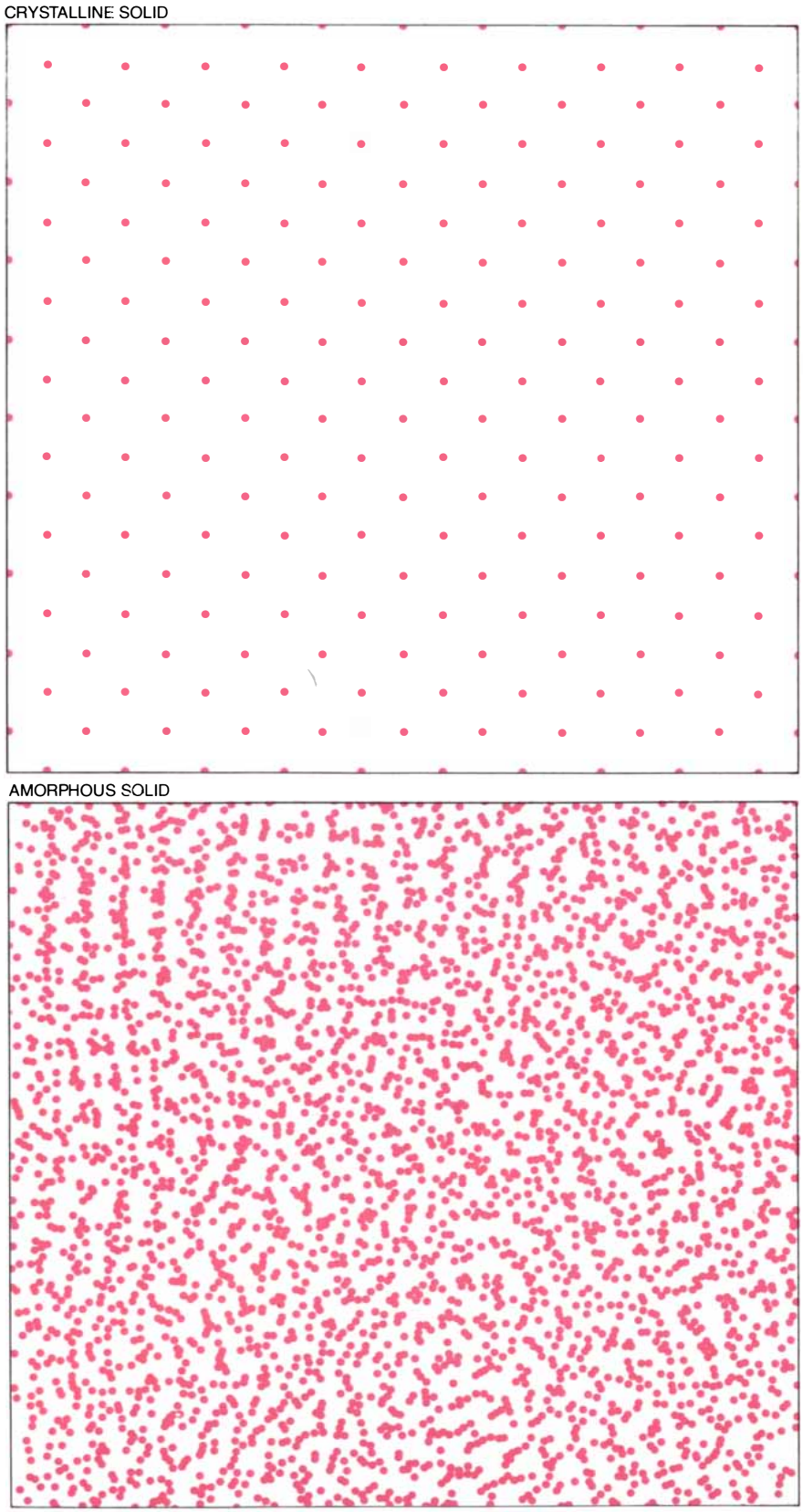
or below. The liquid is thereby drawn into a film no thicker than a few ten-thousandths of an inch. Because the film is so thin, because it is in intimate contact with a heat sink of comparatively large volume and because metals have an inherently high thermal conductivity, the metal cools and solidifies extremely fast. In round numbers, the metal can be cooled by 1,000 degrees Kelvin in a millisecond, which is equivalent to a rate of a million degrees per second.

By means of such rapid cooling Duwez and his co-workers solidified an alloy of gold and silicon with the composition $Au_{81}Si_{19}$ in a form that appeared to be amorphous. Later investigation established the noncrystallinity of the material more conclusively. Their results stimulated much of the subsequent work on glassy metals, which has led to the discovery of many other alloys that can be quenched to a glassy state in much the same way.

Amorphous metals can be formed by other methods as well, which do not require that the molten metal pass through the liquidus temperature. For example, an amorphous film can be deposited on a cold surface from a solution of metal ions or from a metal vapor. Indeed, such films had been observed even before Duwez' work, although their amorphous nature had not been firmly established. An amorphous solid can also be created by irradiating a crys-



RAPID QUENCHING of a molten alloy freezes the metal in a glassy, or amorphous, state. The metal, an iron alloy, is melted in a quartz tube by radio-frequency currents induced by the coil at the left. Pressure is then applied, and the metal squirts through a small opening onto the surface of a copper cylinder rotating at some 3,000 revolutions per minute. The metal is drawn into a film a few thousandths of an inch thick, which solidifies in less than a millisecond and peels from the rotor. The ribbon of metallic glass is the bright, wavering streak; the sparks are fragments or droplets of metal thrown from the spinning rotor. The photograph was made by Fritz Goro in the laboratory of one of the authors (Chaudhari) at the Thomas J. Watson Research Center of the International Business Machines Corporation.



CRYSTALLINE AND AMORPHOUS SOLIDS are similar in density, or average number of atoms per unit volume, but differ in the arrangement of the atoms. The structures of the solids are represented here by projections of the positions of the atoms onto a plane, as if the solids were illuminated by parallel rays of light and only the shadows were visible. In the crystal the structure is periodic over large distances; knowing the positions of only a few atoms, one could specify the positions of all the atoms throughout the crystal. In the amorphous solid there is no periodic structure, although the positions of the atoms are not entirely random. Order in the arrangement of the atoms extends over a short range only. Knowledge of the coordinates of the atoms in one region would be of no help in specifying the positions of distant atoms.

talline metal with high-energy particles, which disrupt the lattice of atoms.

It has been argued on occasion that the term "glass" should be reserved for materials formed by the continuous solidification of a molten substance. By that definition amorphous metals created by condensation or irradiation would not qualify as glasses. It now appears, however, that the amorphous materials formed by these various means are similar in their structures and properties. We therefore see little reason for preserving a distinction in nomenclature, and here we shall refer to all these materials as glasses.

A distinguishing characteristic of ordinary freezing (the transition from a liquid phase to a crystalline one) is that for pure substances it takes place discontinuously, at a fixed temperature. As heat is removed from a liquid its temperature falls until it begins to crystallize; then additional heat is given off without any further change in temperature until the freezing is complete. Many other properties also change discontinuously at the freezing point, such as the density and the heat capacity (the amount of heat that must be added to a substance in order to bring about a specified rise in temperature).

The configurational freezing that is observed at the glass temperature is not as sharp a transition, but neither is it a perfectly continuous one. The transition is marked by an abrupt rise in the time required for any adjustment or rearrangement of the atomic configuration. In the liquid this time is much less than a second; in water, for example, it is roughly 10^{-12} second. At the glass temperature it rises to a value on the order of a day.

The time required for a change in atomic configuration is reflected experimentally in the viscosity of a material, which measures its resistance to a change in shape. The unit of viscosity is the poise, which is defined as the force (in dynes per square centimeter) that must be applied to a fluid in order to maintain a velocity difference of one centimeter per second between parallel layers one centimeter apart. Common liquids such as water and mercury have a viscosity of about 10^{-2} poise; at the glass temperature the viscosity increases rapidly to about 10^{15} poises. A material that resists change in shape this strongly is rigid enough to be considered a solid.

The transition from a liquid to a glass is also accompanied by a sharp drop in the heat capacity of the material and in the coefficient of thermal expansion (the number that specifies the change in a material's volume in response to a given change in temperature). Both of these properties are related to the atoms' freedom of movement or to the number of distinct configurations accessible to them. As Walter J. Kauzmann of

The 1980 Mazda RX-7 GS

Just one look is all it takes to appreciate the exceptional value of the Mazda RX-7 versus Datsun 280ZX or Porsche 924.

As remarkable as the Mazda RX-7 is on its own merits, it looks all the better when compared with the competition. Because the sleek, aerodynamic RX-7 is virtually everything you could want in a refined sports car—at an almost unbelievable price.

It can reach 0-50 in 6.3 seconds. Its inherently compact rotary engine is placed behind the front axle, for ideal weight distribution and superb handling.

In auto racing, a specially-prepared RX-7 won its class at the Daytona 24-hour race. Another RX-7 set a world speed record at Bonneville.

The smoothness of the rotary engine makes the RX-7 a quiet sports car. All this performance from a car that can attain excellent gas mileage on the open road.

17 EST. mpg 28 EST. hwy mpg**

But the front mid-engine RX-7 offers infinitely more than performance. It also provides extraordinary comfort.

So if you know what you want in a sports car, and you don't want to pay a king's ransom to get it, take a look at the RX-7 GS or S Model. The beautifully-styled, high-mileage, high-performance sports cars from Mazda.

You're also going to like the looks of RX-7 GS standard features.

• AM/FM stereo radio with power antenna • Side-window demisters • Cut-pile carpeting • Tinted glass • 5-speed • Tachometer • Styled steel wheels • Steel-belted radial tires • Front and rear stabilizer bars • Ventilated front disc and finned rear drum brakes with power assist • Electric remote hatch release. 3-speed automatic transmission, air conditioning, aluminum wheels and sun roof available as options.

$8295*

*Manufacturer's suggested retail price for GS Model shown. S Model $7495. Slightly higher in California. Actual prices established by dealers. Taxes, license, freight, optional equipment and any other dealer charges are extra. (Wide alloy wheels shown $275-$295.) All prices subject to change without notice.

**EPA estimates for comparison purposes for GS Model with 5-spd. trans. The mileage you get may vary depending on how fast you drive, the weather, and trip length. The actual highway mileage will probably be less. California, 16 estimated mpg, 27 estimated highway mpg.

Mazda's rotary engine licensed by NSU-WANKEL.

mazda

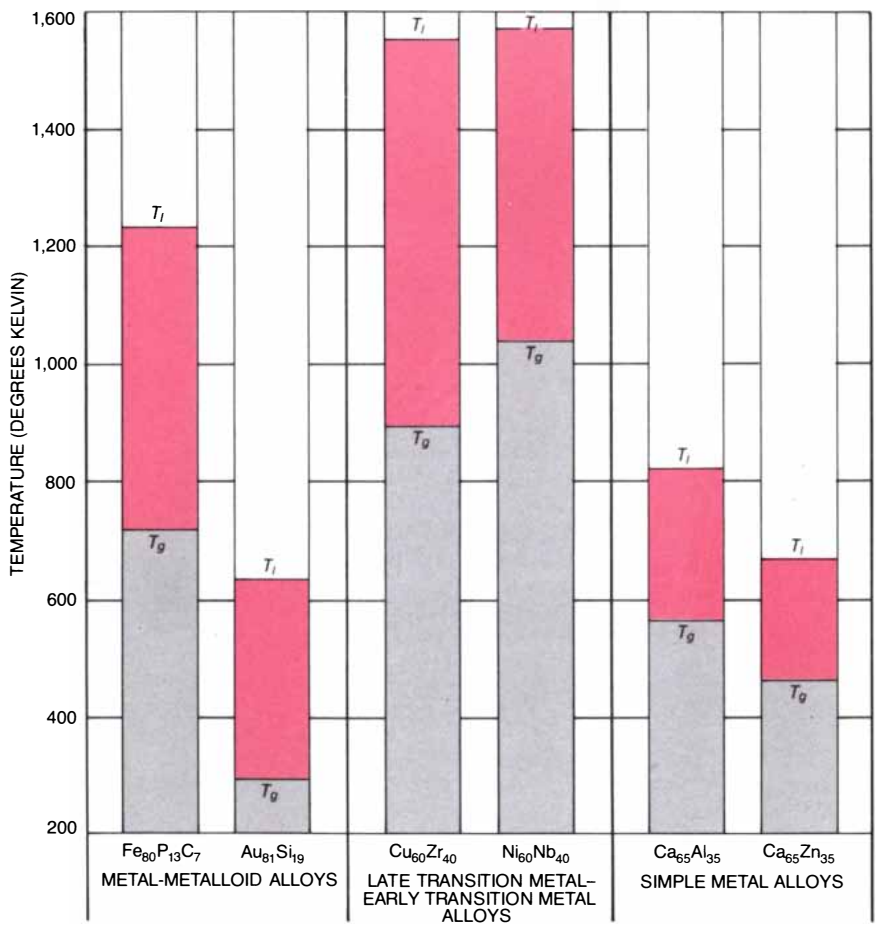
The more you look, the more you like.

Princeton University pointed out some time ago, the abrupt decline in heat capacity and in the coefficient of thermal expansion are directly associated with the onset of configurational freezing.

The characteristics of the liquid-glass transition described here were established mainly through investigation of the nonmetallic glasses. More recently it has been shown by Ho Sou Chen and one of us (Turnbull) that the glass-forming metallic alloys exhibit similar properties. Measurements of these quantities are complicated by the fact that the region between the glass temperature and the liquidus temperature is largely inaccessible to experiment, since liquid metals cannot be maintained at those temperatures without crystallizing. Nevertheless, it has been shown that on cooling through the glass temperature the viscosity rises steeply. It was also shown that the reverse transition, in which a glass is heated until it liquefies, is accompanied by an increase in the heat capacity and in the coefficient of thermal expansion, as would be expected.

In the various metallic alloys studied, both the glass temperatures and the liquidus temperatures take on a wide range of values. For the purpose of comparing one substance with another it is more meaningful to consider the ratio of these quantities, that is, the glass temperature divided by the liquidus temperature. The ratio is called the reduced glass temperature. It is to be expected that a material with a larger reduced glass temperature will be easier to solidify as a glass, with a lower cooling rate, since the interval of temperatures in which crystallization can take place is then smaller. For the most part that expectation is borne out by experiment. For materials that enter a glassy state even on slow cooling (such as the silicates) the reduced glass temperature is generally 2/3 or greater; in other words, the liquidus temperature is no more than half again as high as the glass temperature. Most of the metallic alloys, which require rapid quenching, have a reduced glass temperature of less than 2/3, and in some cases it is as small as .45.

The metastable nature of the amorphous phase becomes apparent when a glass is heated. Even before melting begins the material can crystallize by the formation and growth of nucleation centers in the solid state. The temperature at which this process is observed, the kinetic-crystallization temperature, depends on the number of nucleation centers present and on the rate of heating. Slow heating depresses the kinetic-crystallization temperature, since there is then more time for crystal growth. A rough measure of the resistance of a glass to crystallization is given by the displacement of the kinetic-crystallization temperature from the glass temperature. Some materials, such as fused silica, do not crystallize at all when they are free of extraneous freezing nuclei, no matter what the temperature is and no matter how long the experimenter waits. Among the metallic glasses, with a few exceptions, only a little heating above the glass temperature is needed to provoke crystallization. Indeed, there are many alloys in which the kinetic-crystallization temperature lies below the glass temperature and therefore obscures it. It should not be assumed, however, that metallic glasses are thermally unstable. In fact, many alloys remain in the glassy state indefinitely at room temperature.



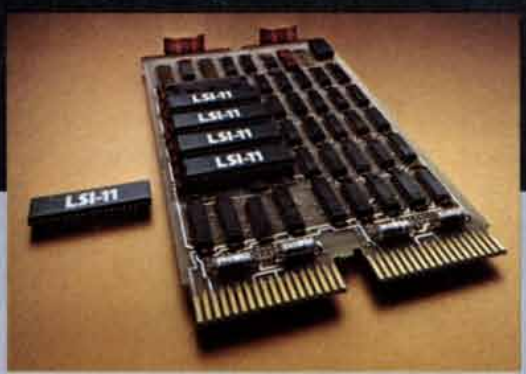
TRANSITION TEMPERATURES for the formation of crystalline metals and metallic glasses have a major influence on the ease with which an alloy can be solidified in the glassy state. The liquidus temperature (T_l) is the temperature at which the crystalline phase can first appear when the liquid is cooled. As the temperature is further reduced the material must pass through a region where crystallization is possible before the configuration of the atoms is frozen in at the glass temperature (T_g). The ratio of the glass temperature to the liquidus temperature (T_g/T_l) is called the reduced glass temperature (T_{rg}), and it defines the relative extent of the region where crystallization can interrupt the formation of a glass. In order to cross this region without crystallizing, the metal must be cooled quickly from above the liquidus temperature to below the glass temperature. Three classes of alloys can be put into a glassy state by such rapid quenching. Transition temperatures for representative alloys in each class are given.

It is a fundamental principle that there is no long-range order in the structure of a glass. Knowing the positions of the atoms in one region of an amorphous solid is not helpful in predicting the positions in a distant region. At short range, however, over distances of a few atomic spacings, order of some kind is to be expected. Only in a rarefied gas, where the atoms move essentially independently of one another, does their distribution approach the truly random. In solids and liquids the atoms must be packed together tightly in order to account for the observed density of the materials, and there are only a limited number of ways of doing so. It follows that there must be some short-range order in the materials' structure.

Liquids and solids, whether they are crystalline or amorphous, differ little in density. This observation argues that the number of nearest neighbors surrounding each atom and the average distance between atoms are similar in the two phases. Nevertheless, there are grounds for believing the topology of the atomic arrangement in the crystal differs significantly from that in the liquid. If care is taken to exclude external sources of nucleation, many simple liquids can be undercooled by 20 to 30 percent of the liquidus temperature without crystallizing. This resistance to freezing even

We've sold more high performance microcomputers than anyone.

Anyone.



By the end of 1979, Digital Equipment Corporation had sold more 16-bit micros than any other company in the business.

Over 100,000 of them.

And the reason is simple. We give you more to work with. More hardware. More software. And more true systems capability.

That means you can develop your products faster, and offer your customers the right balance of cost and performance every time.

What's more, Digital's micros are software compatible. Not just with each other, but with our whole PDP-11 minicomputer family as well. So you'll never run out of ways to expand your business.

Behind all Digital's micro products is a support commitment that's unmatched in the industry. 13,000 people worldwide. Technical consultation and training. And a wide range of support agreements—from do-it-yourself service using our special kits, to full support including coverage for your customers.

It's the total approach to micros. And it's the reason Digital has sold more high performance micros than anyone.

Anyone.

Digital Equipment Corporation,
Dept. NR2/2, 146 Main Street,
Maynard, MA 01754.

It took the minicomputer company to make micros this easy.

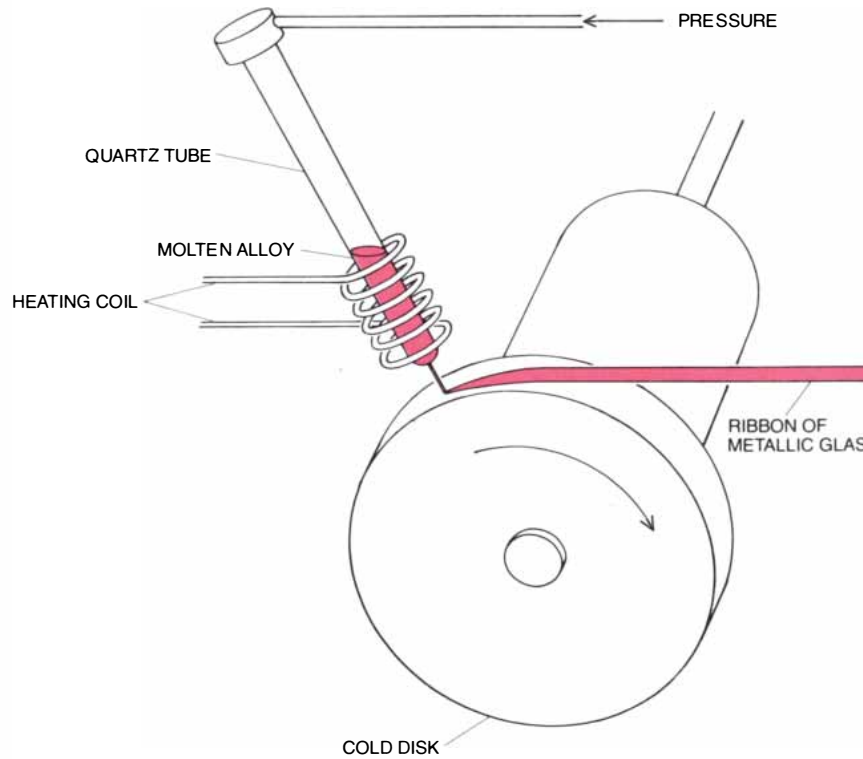
digital

when freezing is energetically favored suggests that the crystalline structure is one not likely to be encountered often during random fluctuations of the atoms in the liquid. Hence the short-range order of the liquid does not seem to be closely related to that of the crystal. On the other hand, a strong resemblance is to be expected between the short-range order of the liquid and that of the amorphous solid.

In constructing models of the atomic structure of a simple metal it can be assumed that the forces acting between the atoms are undirected and hence are symmetrical around any given atom. The structure that will have the smallest total energy is the one yielding the highest density, in which the atoms are closely packed. On the other hand, the atoms cannot overlap to any large extent, because at very close range there is a strong repulsion between them. In many theoretical models the atoms are described as perfectly hard spheres, so that no overlapping is possible.

Consider for a moment the packing of the atoms in a two-dimensional system with centrosymmetric forces. Here the atoms are represented by disks, and the densest packing unit consists of three disks all tangent to one another, so that their centers define an equilateral triangle. Additional atoms can be added to this unit, generating identical triangular cells, which can tile the entire plane. Each atom in this configuration is surrounded by six others, which form a regular hexagon. The structure is obviously crystalline in that the atoms occupy periodically repeating positions over unlimited distances. It is important to emphasize, however, that quite apart from its long-range order it is the structure favored by the operation of the short-range interatomic forces. Whether the system consists of just three atoms or of many, no other configuration can have a higher density or a lower energy. For this reason the short-range order of a two-dimensional medium should be much the same whether the material is in a liquid phase, a crystalline phase or an amorphous solid phase. Moreover, the two-dimensional material should have little resistance to crystallization.

The packing of objects in three-dimensional space is different in one crucial respect. With the atoms represented by spheres the densest fundamental packing unit consists of four atoms in contact with one another, one atom at each vertex of a regular tetrahedron. A geometric fact of profound importance for the structure of solids is that space cannot be filled by packing together regular tetrahedrons. It is true that a few tetrahedrons can be fitted together without difficulty, but additional tetrahedrons can then be added only by dis-



MELT-SPINNING of a molten alloy is the predominant method of achieving the high rate of cooling needed to form a metallic glass. The film of metal on the surface of the rotor cools quickly because it is thin, because the rotor provides a heat sink of large volume and because metals are good conductors. Cooling rates of a million degrees Kelvin per second have been attained. Similar techniques have been adopted for commercial preparation of metallic glasses.

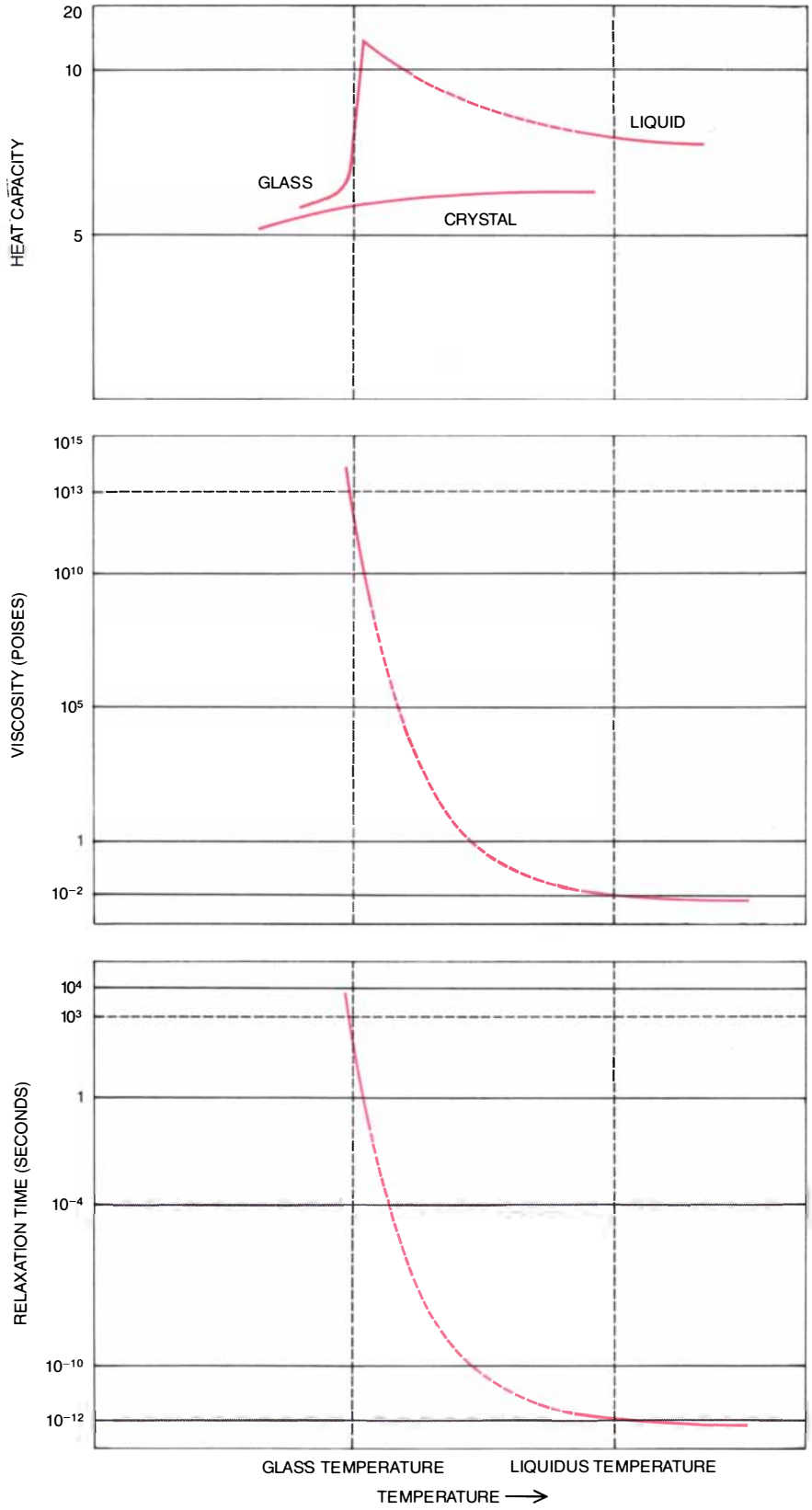
torting them or by leaving voids. Either strategy diminishes the density of the resulting solid and increases the total energy. Thus the tetrahedron alone cannot serve as the fundamental unit of any crystalline structure; the densest crystal packing interpolates one octahedron for every two tetrahedrons, but the resulting structure is less dense and has a higher energy per atom than the tetrahedron alone.

This geometric constraint on the packing of atoms in three dimensions has had a strong influence on the development of models of amorphous structures. Although some crystal structure always represents the state of lowest overall energy for a large collection of atoms in three-dimensional space, the same is not true for a cluster of only a few atoms. Such a cluster can achieve a denser and lower-energy packing by assuming a polyhedral configuration. Several models that attempt to reproduce the structure of liquids and of amorphous solids take this fact into account.

Three main classes of models for the metallic glasses have been devised. Microcrystallite models propose that amorphous metals actually consist of innumerable small regions with a crystalline short-range order embedded in a matrix of randomly interconnected atoms. On the average the microcrystallites might include only about 100 atoms each, far fewer than even the finest grains in a truly crystalline metal. Since the miniature crystals would be randomly dispersed throughout the solid and randomly oriented, no long-range order would be discernible. The nature of the matrix in which the microcrystallites are to be embedded has not been specified in detail.

A second kind of model is of historical note, having been devised by J. D. Bernal to account for the structure of simple liquids. It describes the dense random packing of hard spheres. A procedure for generating the model consists in adding spheres one at a time to a cluster of spheres. Each ball is added at whatever available position is closest to the center of the cluster as a whole. In this way the densest possible configuration should be created. The first four spheres inevitably form a tetrahedron. The fifth sphere can be put on any of the four symmetrical faces of the tetrahedron, since they are equidistant from the center. When the cluster grows much larger, finding the correct position for the next ball becomes more difficult and the geometry of the evolving structure is less obvious.

The first investigation of the dense random packing was carried out with a physical model. Bernal and his colleagues poured steel ball bearings into the rubber bladder of a soccer ball and kneaded the bladder until it could be



LIQUID-GLASS TRANSITION is accompanied by sharp changes in several properties. The heat capacity, the amount of heat that must be added to a substance in order to bring about a given rise in temperature, increases gradually as a liquid metal is cooled below the liquidus temperature, then declines abruptly when the liquid is converted into a glass. The viscosity, which measures the resistance of a fluid to a change in shape, rises sharply at the glass temperature. So does the configurational relaxation time, the time required for rearrangement of the atoms. Portions of the curves shown in broken lines lie at temperatures where properties cannot be measured because the material would crystallize during the time required to make a measurement.

compressed no further. Wax was poured into the bladder to immobilize the ball bearings and the bladder was stripped away. Then the coordinates of each ball in representative volumes of the sample were meticulously recorded. Today it is commoner to construct a model with the aid of a computer, which can determine the correct positions for the balls mathematically. The equivalent of kneading by hand is a procedure for "relaxing" the model by testing the forces acting on each ball; if they are not in balance, the positions of the balls can be altered slightly to relieve the strain. Such relaxational processes surely operate to reduce the energy of real solids.

What structure actually results from applying this procedure? Bernal showed that it could be described as an assembly of tetrahedrons distorted in various ways and combined with small voids, which are bounded by triangular faces. It has since been shown by one of us (Chaudhari) and his co-workers, and independently by G. A. N. Connell, now at the Xerox Palo Alto Research Center, that the dense random packing is topologically equivalent to a random network in which vertexes are connected to one another by four bonds each.

The third class of models derives explicitly from the observation that a tetrahedral configuration is denser than any crystalline one for a cluster of a few atoms. F. C. Frank of the University of Bristol showed that the tetrahedral packing is favored for as many as 13 atoms. More recent calculations, based on plausible assumptions about the forces acting between atoms, have been done by Michael R. Hoare of the University of London and by James J. Burton of the Gur Ayeh Institute in New York; they have shown that a polyhedral cluster is stabler than a crystalline one with as many as 50 atoms. There is also indirect experimental support for the idea of polyhedral clusters. J. Farges of the University of Paris has shown that clusters of a few tens of argon atoms can be formed by condensation from the vapor. The structure of these clusters seems to be much like the one predicted for the polyhedral aggregates. It should be pointed out, however, that the argon clusters exist in isolation, whereas polyhedral assemblies in an amorphous metal would have to be interconnected by a matrix of atoms in some other configuration.

All these models have shortcomings. An important one is that they all describe pure or one-component materials (all the spheres are identical) whereas no pure metal has yet been solidified in the glassy state. It seems that only alloys of two or more metals form glasses. The microcrystallite and polyhedral models have an additional limitation in that the interconnecting matrix, which might amount to half of the material, is ig-

New from the National Academy of Sciences
An Authoritative Look at the 1980s and Beyond

Energy in Transition
1985-2010

The National Academy of Sciences

This authoritative report from the National Academy of Sciences answers the increasingly tough energy questions we will face in the next quarter century.

Drawn from the work of dozens of distinguished scientists and produced at a cost of over $3,000,000, *Energy in Transition* offers readers an incomparably comprehensive reference. It gives straight answers, backed with hard evidence, to the most commonly voiced concerns about the energy crisis:

- When—if ever—will solar energy be a practical source of power?
- What can we do to conserve energy—and how much can conservation measures *really* help?
- Isn't coal much more dangerous than nuclear power?
- Will we ever find a safe way to dispose of nuclear wastes?
- How efficient is the world's largest geothermal power plant—located near San Francisco?
- Is controlled nuclear fusion the ultimate answer to our energy problems?
- What risks does each form of energy pose and how can these risks be minimized?
- Which forms of energy are the most cost-efficient?
- How much longer will we need to rely on foreign oil?
- What is the current U.S. energy policy, and how must it be changed?

The only book of its kind—a thorough look at energy by experts on energy—this volume is a must for every American in a position to influence, or be influenced by, the choices we must make in the next decades.

April 1980, 608 pages (approx.), 41 illustrations

Science and Technology
A Five-Year Outlook

The National Academy of Sciences

It is difficult to imagine a world without science and technology. The way we see the earth is shaped by the work of geologists, astronomers, and ecologists; our ability to communicate is enhanced by scientists perfecting electronic technology and exploring artificial intelligence; our sense of ourselves cannot be separated from the work of biologists, psychologists, and demographers.

The influence of science and technology is indeed so extensive that most of us find it difficult to keep abreast of current developments and to anticipate future ones. Commissioned by Congress for the citizens of the United States, this comprehensive volume is the work of dozens of specialists for the National Academy of Sciences, bringing readers up to date and offering fascinating predictions for the future. *Science and Technology* considers not only advances in scientific research and its applications but the broader national and international implications as well.

In their introduction, the authors note that "Science and technology continue to transform our world"; this book enables the reader to better understand, and participate in, that transformation.

1979, 544 pages, 54 illustrations

Guarantee: If for any reason you are not satisfied with these volumes, simply return them within fourteen days for a full and prompt refund or credit.

W. H. Freeman and Company
660 Market Street, San Francisco, California 94104

Please send me the books indicated below. I enclose payment or credit card information with order. Publisher pays postage and handling.

Science and Technology: A Five-Year Outlook, Hardbound $15.00 _____ Paperbound $9.95 _____

Energy in Transition: 1985-2010, Hardbound $19.95 _____ Paperbound $10.95 _____

Charge my ☐ VISA/BankAmericard ☐ Master Charge ☐ Payment enclosed. *California residents add appropriate sales tax*

Card Number _____ Expires _____

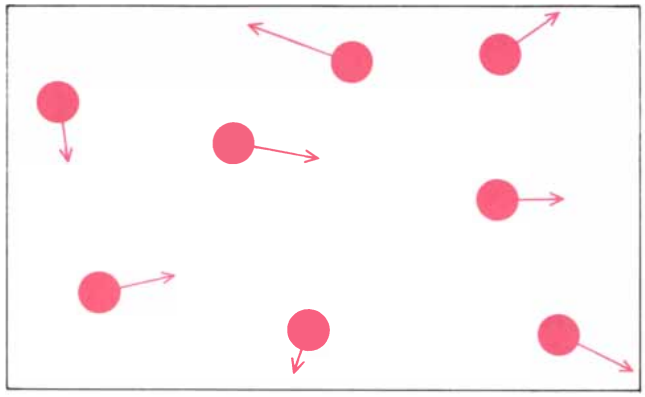
Signature _____
(required on credit card orders)

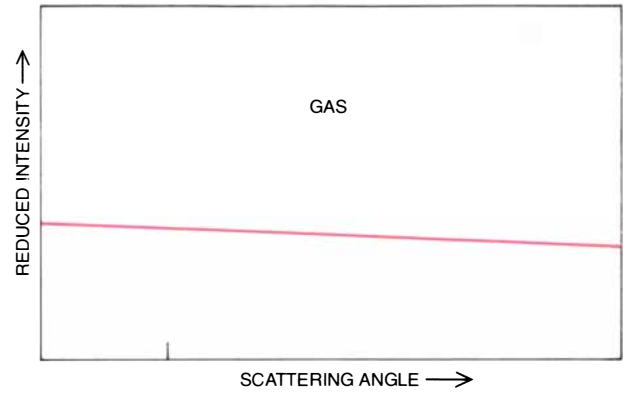
Name _____

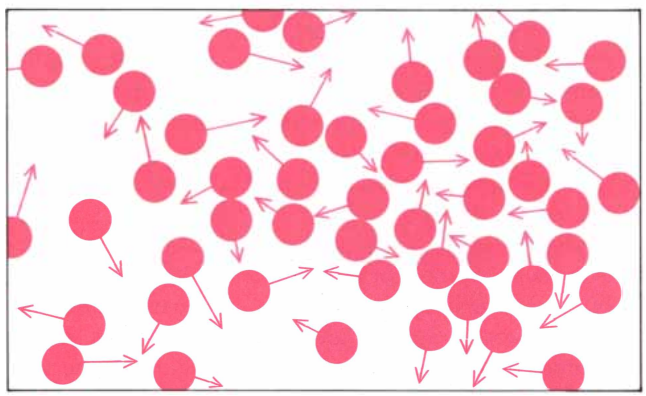
Address _____

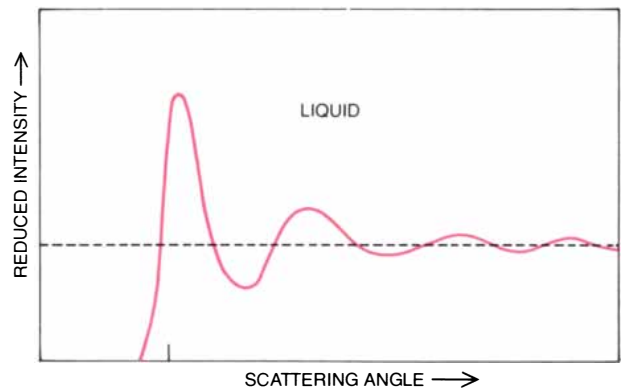
City/State _____ Zip _____

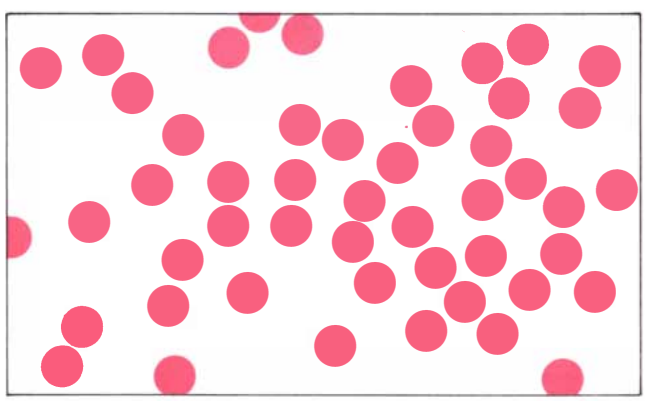
XA881

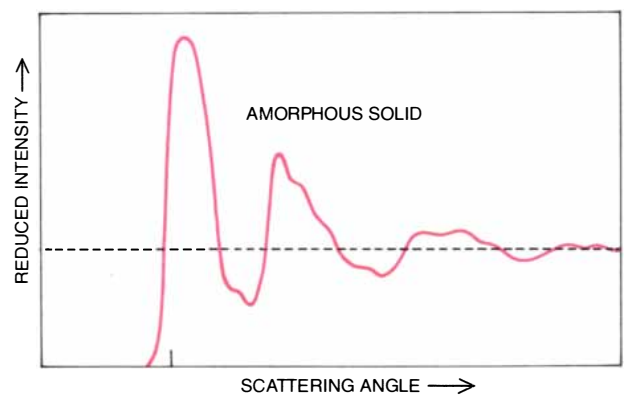


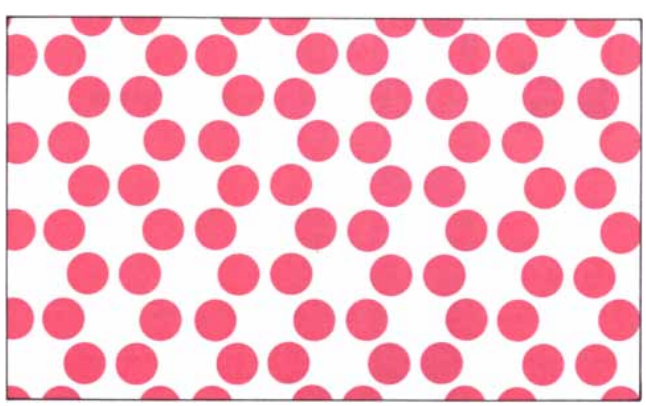


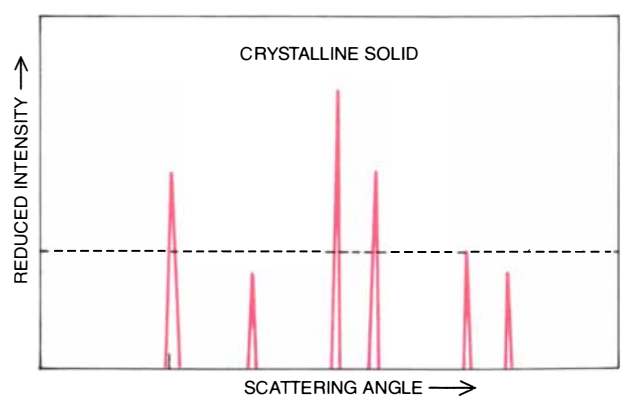












DISTRIBUTION OF ATOMS in a substance can be inferred from patterns created when X rays are scattered by the atoms. The graphs record the reduced intensity of the scattered radiation as a function of scattering angle. The reduced intensity is derived from the measured intensity by a normalization procedure. For a rarefied gas the reduced intensity is essentially uniform over a broad range of scattering angles, indicating that the distribution of atoms is random. Liquids and amorphous solids yield reduced-intensity curves that are strongly modulated. A curve of this form suggests that positions of nearby atoms are correlated, but there is no long-range order. The reduced-intensity curve for a crystal is a series of sharp spikes, reflecting the regular arrangement of the atoms over large distances.

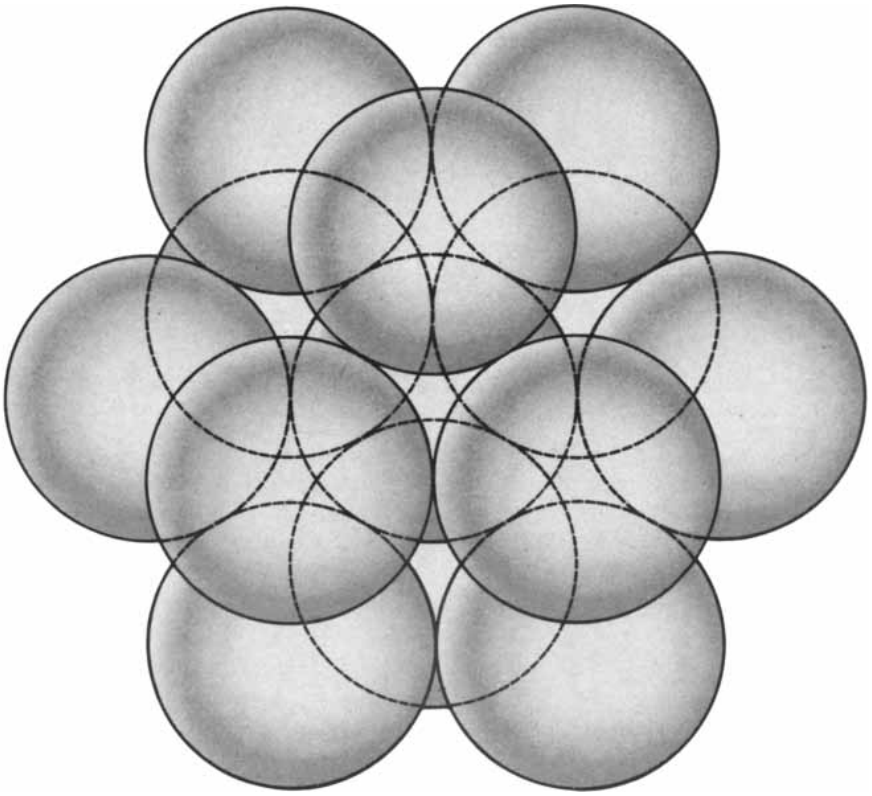
nored. It is nonetheless possible to compare the models with data on the structure of real amorphous metals.

The main source of information about the microscopic structure of glasses is the scattering of X rays, electrons and neutrons from the atoms. The specimen is irradiated with X rays (for example) whose wavelength is comparable to the diameter of an atom. The intensity of the scattered radiation is then measured as a function of the angle through which it is scattered. From the pattern of scattering the average distribution of the atoms can be deduced. X-ray scattering from a single crystal can yield precise coordinates of the atoms. With amorphous materials the information derived is less complete; because of the disorder in the structure only distances between atoms can be determined, not directions. The method was first applied to amorphous solids by Frits Zernike and J. A. Prins in 1927.

For a monatomic gas the curve recording the intensity of scattered radiation is almost featureless, signifying a complete lack of correlation between the positions of atoms. If one atom is taken as a reference, other atoms can be found at any distance with uniform probability. For a crystalline solid the scattered-intensity curve is a sequence of sharp peaks resulting from the almost perfect correlation of the atomic positions throughout the volume of the crystal. Liquids and amorphous solids yield a pattern intermediate between these extremes: there are strong modulations in intensity, but they are not as sharply defined as they are in a crystal, and they fade into a featureless background. The overall form of the curves is remarkably similar for the liquid and the glass, although the glass reveals some finer structure that is obscured in the liquid by the translational motion of the atoms.

Before the scattered-intensity curve is interpreted a mathematical transformation is applied to it. The transformed curve is called the radial-distribution function, and it gives the average density of atoms as a function of distance from a reference atom. A second derived curve is called the pair-distribution function. It is found by subtracting from the radial-distribution function certain contributions to the scattered intensity, such as scattering from individual atoms. The pair-distribution function gives the number of pairs of atoms as a function of the distance between the atoms that make up the pair.

A typical radial-distribution function for a metallic glass shows a series of four or five peaks of gradually diminishing amplitude. The area under a peak is proportional to the number of atoms at that distance; the width of the peak indicates how closely the atoms are clustered at a particular radial distance. The first peak, representing the contribution of the nearest-neighbor atoms, is comparatively sharp because the nearest neighbors fall within a narrow range of distances; indeed, they are packed as close as possible to the reference atom. At greater separations the peaks are broader, and beyond about four atomic diameters they are damped out entirely and the density of atoms approaches the uniform average density of the material as a whole.



MICROCRYSTALLITE MODEL of the structure of metallic glasses supposes they are made up of many crystalline clusters, each cluster incorporating only 100 or so atoms. The cluster shown has the densest possible arrangement of atoms for a crystal; in other words, it is the most compact configuration of atoms that can be extended indefinitely throughout space. In the microcrystallite model clusters of this kind must be interconnected by a network of atoms with some other arrangement. The nature of this connective tissue has not been specified in detail.

In a model of amorphous structure the positions of the atoms are known exactly. It is therefore a straightforward task to calculate a radial-distribution function or pair-distribution function for any given model; the procedure involves little more than tabulating the distances between all the pairs of atoms in the model. It is then possible to compare the calculated function for the model with the functions derived by scattering X rays or other radiation from real amorphous materials.

Such comparisons have raised serious doubts about the validity of the microcrystallite model. The calculated radial-distribution function for the model is a rather poor fit to the observed function. A much better correspondence is obtained with the dense-random-packing model, particularly with a version of this model in which the positions of the atoms have been relaxed.

The radial-distribution function is not much help in discriminating between the dense-random-packing model and the polyhedral model. There may, however, be another basis for choosing between these models. Among the most intriguing items of evidence in favor of a polyhedral configuration is Farges's recent demonstration that argon atoms adopt this structure when they condense from the vapor. At the very least this observation shows that a polyhedral configuration of atoms can be achieved physically.

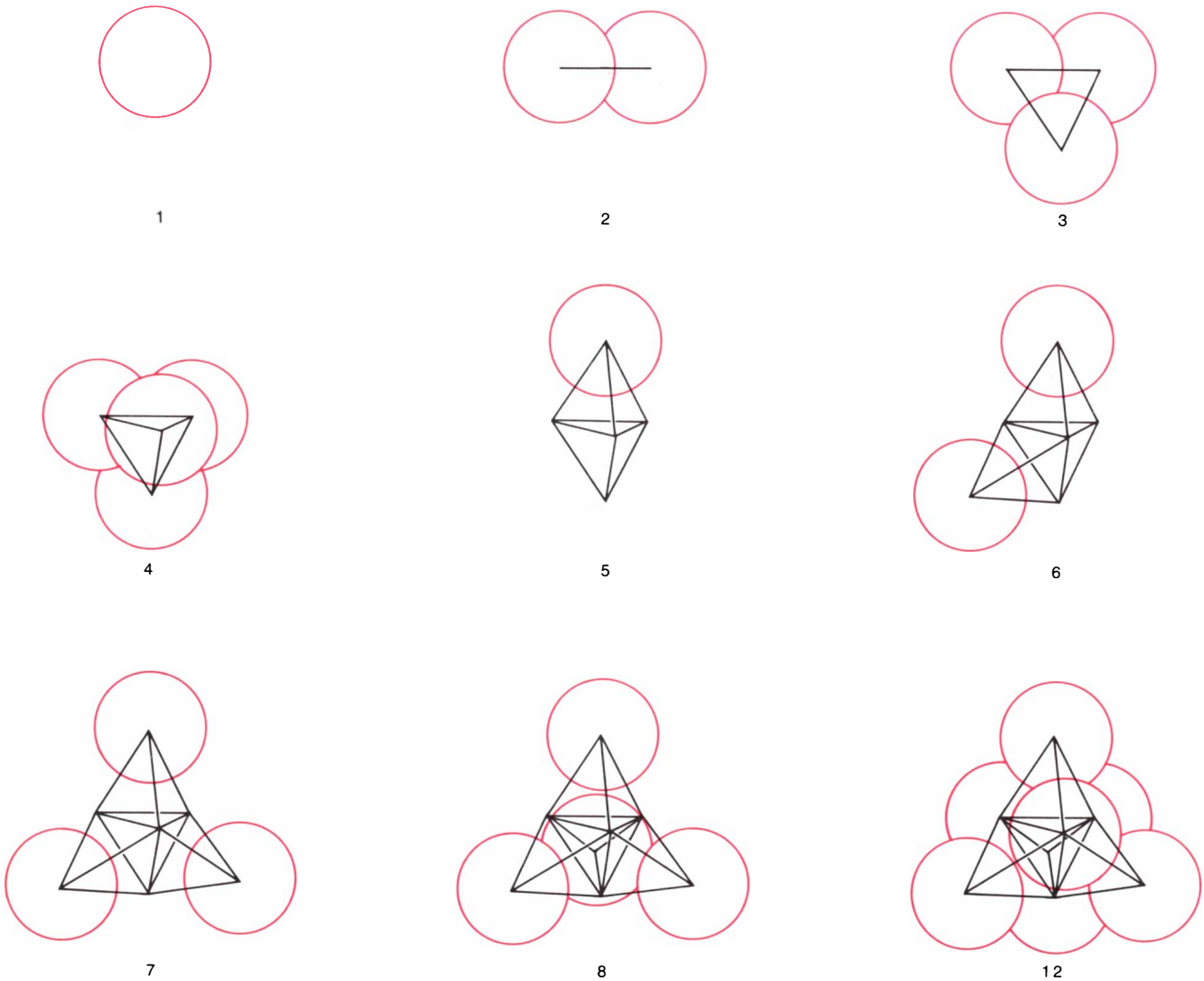
There is another side to the argument, however. The argon condensed by Farge was a pure element; if the polyhedral clusters of argon atoms were built up by the same mechanism that is supposed to operate in the formation of a metallic glass, then it should be possible to make glasses of pure metals. Even

if such elemental glasses could not be formed by the quenching of a liquid, they might be observed in materials formed by condensation from a vapor, as in the argon experiments. Actually the evidence suggests that some admixture of impurities is necessary in the formation of a glass by either method.

The elements that have been incorporated into amorphous alloys come from several regions of the periodic table. Among them are transition metals, including elements from both the "early" groups (such as zirconium and niobium) and the "late" groups (iron and nickel); noble metals (gold and palladium); simple metals (calcium and aluminum); rare earths (gadolinium), and metalloids (silicon, phosphorus, carbon and boron). Most of the alloys capable of being cooled from a molten state into an amorphous one fall into three groups. The first group is typified by the compound of gold and silicon first investigated 20 years ago by Duwez and his colleagues; these alloys combine a noble metal or a late transition metal with a metalloid or with more than one metalloid. The range of glass-forming compositions, which generally call for about 20 percent metalloid, includes some eutectic alloys with exceptionally low liquidus temperatures. Most of the iron-alloy glasses now being considered for possible technological applications fall into this group. Many of them were first prepared by Chen, Donald E. Polk and R. Ray, who were then working at the Allied Chemical Corporation.

The second group of metallic glasses, discovered by one of us (Giessen) with Nicholas J. Grant of the Massachusetts Institute of Technology and others, consists of alloys that blend an early transition metal with a late transition metal. An example is the niobium-nickel alloy $Nb_{40}Ni_{60}$. The alloys in the third group are made up exclusively of simple metals, as in the calcium-aluminum alloy $Ca_{65}Al_{35}$. The glass-forming potential of these metals was first demonstrated by Giessen and Polk, who is now at Northeastern University, and their coworkers there, and by H. Matyja and others at the Technical University of Warsaw.

The list of metals that can be condensed from a vapor in an amorphous phase includes many of these alloys and some others as well, which can be made glasslike only in this way. Among the latter are alloys of niobium and germanium, of silver and copper, of gold and cobalt and some of gadolinium and cobalt. The earliest studies of vapor-deposited amorphous alloys were done by S. Mader of the International Business Machines Corporation and Arthur S. Nowick, who is now at Columbia University, and independently by W. Bückel and R. Hilsch of the University of Göt-



DENSE-RANDOM-PACKING MODEL of the short-range order of a metallic glass is constructed by assembling hard spheres in a compact configuration. At each step in the construction of the model a ball is added at whatever available position is closest to the center of the developing cluster. The first four balls form a regular tetrahedron. The tetrahedral configuration is the densest one possible (and it is denser than any crystal), but it cannot be extended indefinitely because regular tetrahedrons cannot fill space without voids being left among them. Nevertheless, the structure that evolves from dense-random-packing procedure is made up mainly of tetrahedral units.

THE MARK™ T/A®

Introducing the high performance Radial T/A that adds elegance and superb handling to magnificent machines.

From BFGoodrich,® The Mark™ T/A® radial. The newest member of America's first family in high performance radials. The ones more people buy than any other.

With The Mark T/A, you possess more than an elegant radial. Its appearance complements any quality machine. You ride with the assurance of superb handling, tough durability, straight tracking, and a tread designed to offer excellent wet traction.

The DuroGard® folded belt system wraps The Mark T/A radial in a network of strength, while the dual compound tread resists heat build-up and provides a commanding grip on the road.

Ride T/A radials. Ride number one.

USA ♥ T/A™

BFGoodrich

#1 IN HIGH PERFORMANCE RADIALS.

tingen. The glasses formed by alloying rare earths with transition metals were discovered by workers at IBM and at the Naval Ordnance Laboratory.

The commonest methods for preparing the metallic glasses from the molten state are all versions of the melt-spinning technique, in which a jet of the molten alloy is driven onto a cold metal rotor. The cooled glass is thrown off the rotor tangentially as a continuous ribbon. The process has been adapted to a larger scale for the production of commercial quantities of glassy alloys. Because the ribbon or sheet emerges directly from the molten state in need of little further processing the method is inherently economical; indeed, it may sometimes be cheaper than the steps needed to process a crystalline metal. For this reason metallic glasses may be adopted even in applications where their properties are no more than equal to those of crystalline metals.

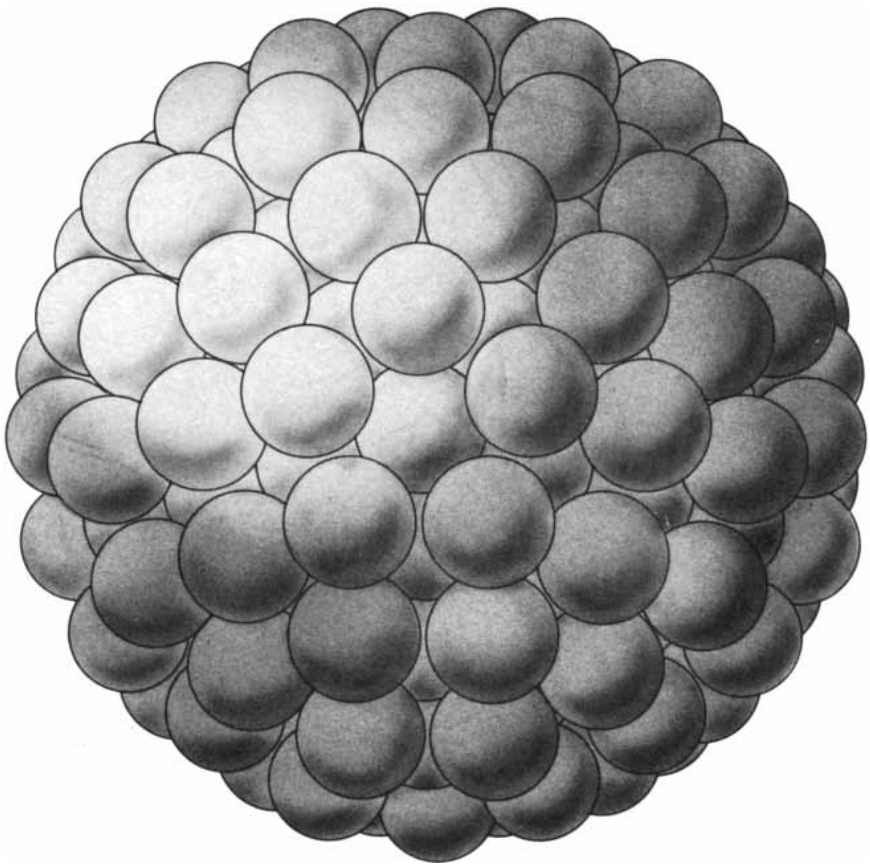
Many properties of a metallic glass, such as density, heat capacity and compressibility, hardly differ from those of a crystalline metal with the same composition. Differences arise mainly in those properties that measure the response of a body to a directed force. In a crystal the response to a magnetic or electric field or to a stretching force depends on the orientation of the field or force with respect to the crystal lattice; the response is said to be anisotropic. Since a glassy metal has no long-range order, its response should be perfectly isotropic, or independent of direction. Certain other differences in properties can be attributed to the fact that the amorphous structure is essentially continuous and homogeneous throughout large volumes. Most crystalline materials, on the other hand, and in particular most crystalline metals, are composites of small crystal grains that have irregular boundaries and random orientation.

Silicate glasses are hard and very brittle materials. In general so are crystalline solids with compositions similar to those of the alloys that can be made into glasses by quenching from the molten state. Some of the metallic glasses themselves, in contrast, are ductile and in tension are among the strongest of all alloys. The response to a stretching force is isotropic, and it differs in character from that observed either in silicate glasses or in polycrystalline metals. A silicate glass fractures when it is overstressed; a crystalline metal yields by the movement of defects along crystallographically defined slip planes, which results in strain hardening, an increase in resistance to further deformation. When an amorphous metal is overstressed in tension, it generally yields by shearing along bands inclined at an angle of about 45 degrees to the stretching axis. There is no strain hardening. Similar mechanical properties have been observed in certain polymer glasses.

The brittleness of the silicate glasses is a consequence of the same chemical structure that keeps them in an amorphous state. Because of the highly directional covalent bonds between atoms stress can be relieved only by the breaking of bonds. In a metallic glass, on the other hand, the largely undirected bonds allow small displacements of atoms in response to applied stress, so that the material deforms plastically.

In polycrystalline metals grain boundaries and chemical heterogeneities are often preferred sites of chemical attack. Present evidence suggests that glassy alloys are remarkably homogeneous in structure at all scales greater than a few atomic diameters. This uniformity of structure would lead one to expect that the metallic glasses might show unusual resistance to corrosion. Indeed, several investigators have reported finding high corrosion resistance in glasses formed of transition metal–metalloid alloys containing chromium.

Strength, ductility and resistance to corrosion represent an attractive combination of properties in a metal. Applications can be envisioned in which these properties would be exploited. What is more, the mechanical and chemical properties that make the glassy alloys easy to work and inexpensive to fabricate enhance their appeal in applications that exploit their distinctive electrical and magnetic properties.

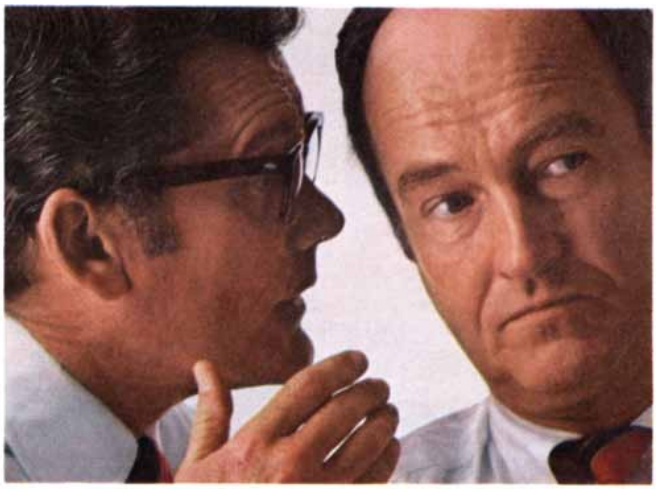


POLYHEDRAL MODEL of a metallic glass is built by fitting atoms together in an array that is regular but not crystalline. For clusters of up to about 50 atoms it has been shown that such polyhedral models have a lower free energy than any crystalline configuration. In an extended solid the clusters must be interconnected, however, by a network of atoms that would raise the energy of the structure as a whole to more than that of a crystal. The polyhedral model has fivefold symmetry; objects with fivefold symmetry cannot fill space completely. The model shown, which consists of 266 atoms, was constructed by Michael R. Hoare of the University of London.

All resistance to the flow of an electric current in a metal results from irregularities in the periodic arrangement of the atoms. In a crystalline metal the resistivity, or resistance per unit of cross-sectional area, has two main components: thermal vibrations of the atoms introduce a degree of disorder that diminishes with decreasing temperature, and impurities and structural defects make a contribution that is largely independent of temperature. The sum of these contributions is a resistivity that declines as the metal is cooled, approaching a constant minimum value at absolute zero.

Because extensive disorder is built into the structure of amorphous metals they tend to have high resistivity, typi-

"JUST BETWEEN YOU, ME AND THE COMPUTER..."



There's information about you in a computer somewhere. Probably in several computers.

It's a fact of modern life.

You have credit cards and insurance policies. You reserve seats on airplanes. You borrow money occasionally. You pay taxes.

All these things require information about you, and you're concerned how safe it all is in a computer system.

So are we.

At IBM, we think computers should be as good at protecting information as they are at processing it.

Here are some things we're doing about that.

So that only the right people see information about you, IBM systems can be programmed to demand identification in various ways. They can require passwords, or numbers, or keys, or magnetically coded I.D. cards, or combinations of them.

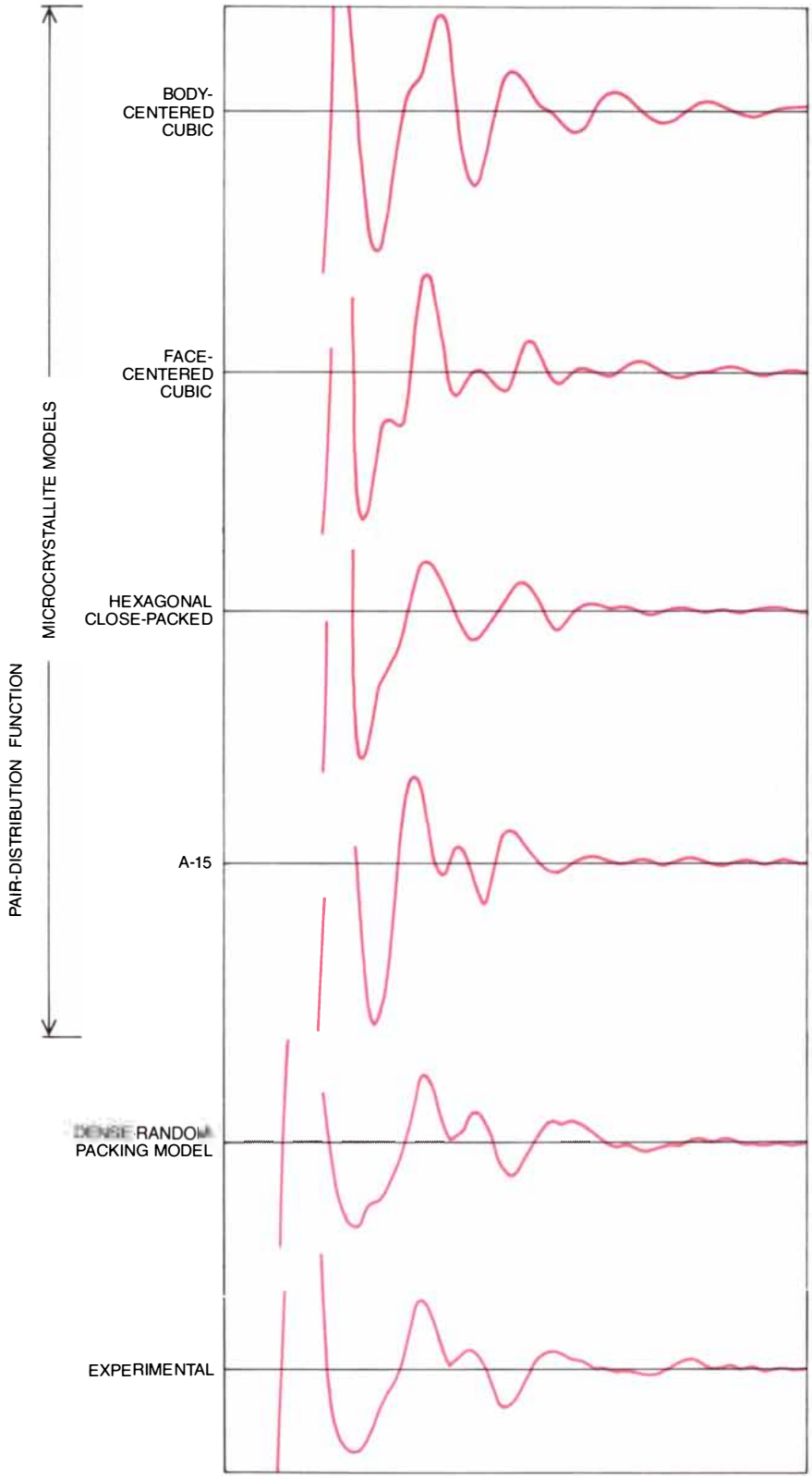
With many IBM systems, certain information can be reserved solely for the people who need it. A person who needs only your name and address cannot learn anything else about you.

We have systems that scramble computer signals sent over wires. So eavesdroppers can't listen in.

We're even experimenting with devices that recognize people by their signature rhythms.

With innovations like these, computers can be more than safe places to keep information.

They may well be the safest place to keep it. IBM®



PAIR-DISTRIBUTION FUNCTION serves to compare the microcrystallite model and the dense-random-packing model with experimental data on the structure of a real metallic glass. The function, which can be derived from X-ray scattering patterns, gives the average number of pairs of atoms as a function of the distance between the atoms in a pair. Functions are calculated for four kinds of microcrystallite, assuming that the crystals have every possible orientation but taking no account of the material between them. The dense-random-packing model employed is one that has been "relaxed" by adjusting the positions of some atoms to relieve strain. The experimental function is for an amorphous iron alloy. The dense-random-packing curve matches the experimental one better than any of the microcrystallite curves do. Experimental data and calculated values are from the work of T. Ichikawa of Tohoku University.

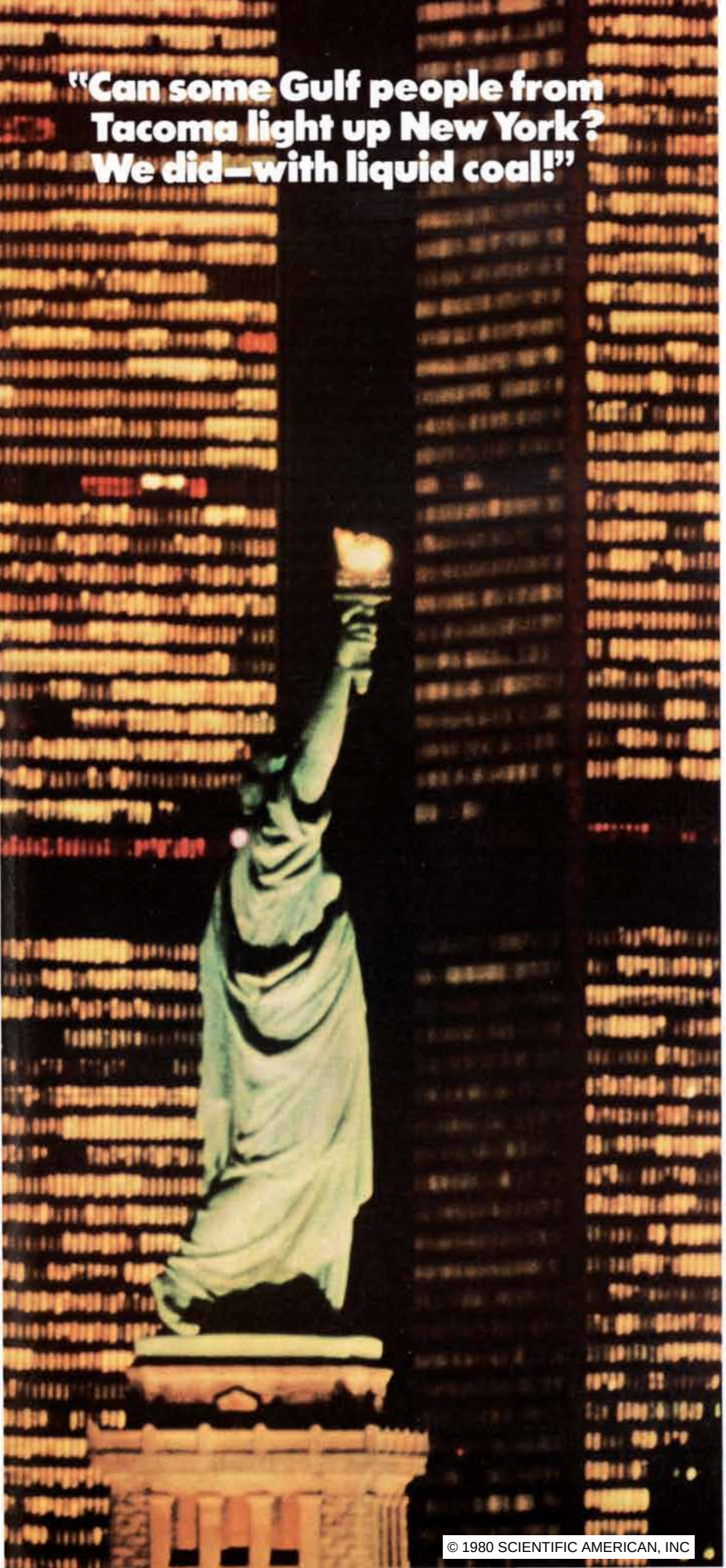
cally an order of magnitude larger than the resistivity of the same alloy in crystalline form. Moreover, the contribution from structural disorder and from impurities far outweighs the thermal component. It follows that the resistivity is not very sensitive to temperature; the temperature coefficient of resistivity is small. The coefficient can even be adjusted by changes in composition to be zero or negative at room temperature.

The stability of the resistivity of glassy alloys in spite of changes in temperature suggests their use as resistance standards. A related application would be in magnetoresistance sensors, which are employed to detect the presence of magnetic fields, notably in bubble memory devices. The principle of operation of a magnetoresistance sensor is that variations in a magnetic field give rise to small changes in the resistivity of a metal; obviously extraneous fluctuations in resistivity caused by changes in temperature tend to obscure the signal.

Another kind of sensor for magnetic fields that might employ amorphous alloys is based on the extraordinary Hall effect. When an electric current is flowing in a thin film, an applied magnetic field gives rise to a voltage perpendicular to both the current and the field. In ferromagnetic materials the effect is called extraordinary because the voltage is much greater than it is in other metals. Amorphous ferromagnetic films might make possible still larger Hall voltages. The voltage is proportional to the square of the metal's resistivity, and so it should be 100 times greater in an amorphous alloy than it is in a crystalline film of the same composition.

For now the most promising applications of the metallic glasses are those based on the unusual magnetic properties of the amorphous metals. In crystalline materials there is usually one axis of preferred magnetization. In order to deflect the magnetization from this axis to any other direction, energy must be expended. Many metallic glasses, in contrast, seem to be completely isotropic with respect to magnetic fields. There is no easy axis of magnetization, and so the magnetization can be rotated at a much smaller cost in energy. In the core of a power transformer the magnetization must reverse direction twice during each cycle of the alternating current, or 120 times per second in the U.S. The energy loss associated with such reversals can be substantial. It has been shown that amorphous magnetic materials can at least equal the efficiency of the best crystalline alloys, and they may ultimately exceed it. The magnetic glasses are generally alloys of iron with varying amounts of boron, carbon or silicon. The limit on their efficiency seems to be magnetic anisotropy introduced by elastic strain during fabrication.

The magnetic "softness" and high re-



"Can some Gulf people from Tacoma light up New York? We did—with liquid coal!"

"It happened last October," says Gulf Plant Manager J. K. Ward. "During a week of tests, the solvent-refined coal that we made in Tacoma, Washington, helped light up Manhattan.

"It's a lot easier and cheaper to transport liquid coal than the solid, lumpy kind."

"Of course, scores of Gulf people helped create and develop SRCII (that means solvent-refined coal) and the processes we use to make it.

"We're all enthusiastic about the test. SRCII did all we expected. It looks like oil. It pumps like oil. Best of all, it burns as clean as high-grade fuel oil: emissions were well under the new EPA standards. But it's coal, liquefied and with almost all the pollutants left out.

"SRCII is still experimental. Gulf and the U.S. Department of Energy are working on it together to develop a practical alternative to imported crude oil.

"But we know how to make it on a small scale; we know it will burn well. The next step is to find out if SRCII can be produced in large quantities, and produced economically. If this can be done, then liquid coal could be used instead of precious petroleum by utilities, industry and consumers, reducing America's reliance on imported crude oil.

"We've got a few centuries' supply of coal here in the U.S. Some day, instead of helping light up New York, we may be lighting up many of the cities on the East Coast.

"Responsible energy management is a big challenge. Clean-burning liquid coal is one of the ways Gulf is developing energy for tomorrow."

Gulf

Gulf people: energy for tomorrow.

Gulf Oil Corporation

OLD VOLVOS NEVER DIE. THEY PASS ON.

When it comes to cars, the good don't die young. And Volvos are so well-made they seem to go on forever. (The current life expectancy of a Volvo is now up to 17.9 years in Sweden.)

Witness the case of William Mozer a broadcast engineer. Over the years he's bought five Volvos and they're all still in the family. You see, instead of trading in his old Volvo every time he wants a new one, he passes it on to a member of his family. Because he believes his family is better off in a used Volvo than in any new car.

According to Mr. Mozer, "Every time I get a new Volvo, my family is as excited about it as I am. After all, they know someday it'll be theirs."

So if you're tired of buying cars you run into the ground in no time, do as Mr. Mozer did. Buy a car that could run in the family for years.

VOLVO
A car you can believe in.

Bill Mozer with his new Volvo. And his family with his old ones.

sistivity of glassy alloys also make them likely candidates for the "read" and "write" heads in magnetic tape recorders and magnetic disk memories. The frequency with which the field must reverse in such a device ranges up to several thousand hertz, and so losses might again be reduced by the adoption of amorphous alloys. The emphasis in this context, of course, is not on energy conservation but on extraction of the maximum signal level.

In one proposed application of amorphous metal films, magnetic-bubble memories, the natural isotropy of the materials is a significant impediment. The magnetic bubbles are cylindrical magnetic domains that can be created in a thin film having an axis of preferred magnetization perpendicular to the film. If the bulk of the film is magnetized with the north pole up, each bubble is an isolated domain in which north points down. The presence or absence of a bubble represents one "bit" of information. In the memory devices available today the bubbles have a diameter of one micrometer or more. The smallest bubbles yet observed in crystalline materials are about .5 micrometer across.

The customary material for magnetic-bubble memories is a single crystal of synthetic garnet. It came as a considerable surprise to find that the bubbles can also be created in thin films of amorphous rare earth–transition metal alloys. The discovery, made by J. J. Cuomo, R. J. Gambino and one of us (Chaudhari), was surprising because the bubbles form only in the presence of a magnetic anisotropy, which is generally not to be expected in metallic glasses. It has since been found that an anisotropy can be induced in the films by applying an anisotropic field or force at a temperature high enough to allow local rearrangement of the atoms.

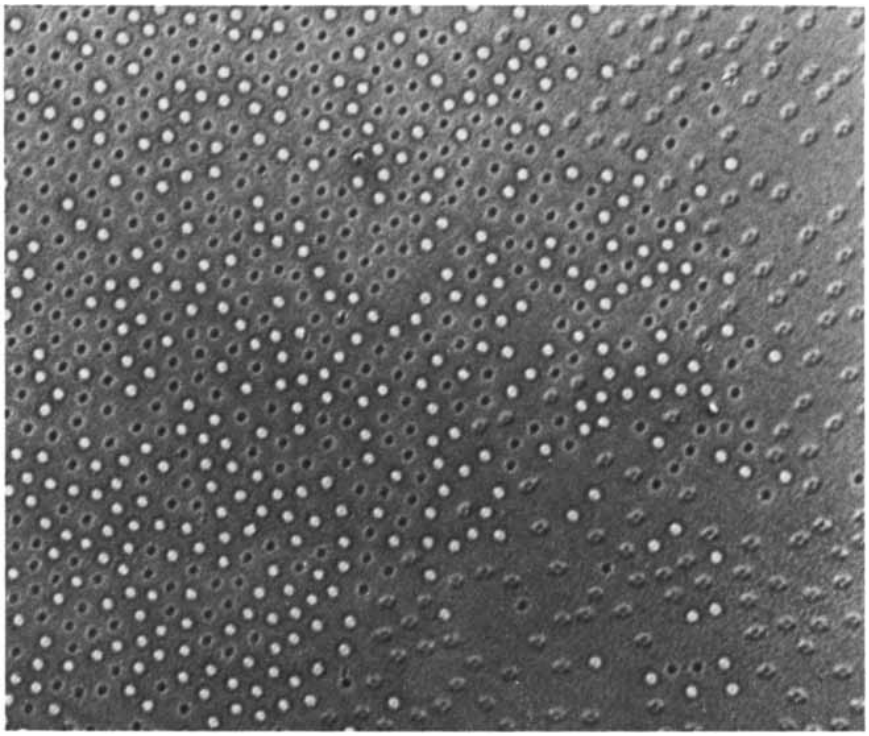
The smallest bubbles that have been observed in amorphous films are considerably smaller than those common in garnet: about .1 micrometer. In principle that fivefold reduction in bubble diameter could allow information to be stored at a density 25 times greater. Moreover, the films could be deposited on a variety of substrates and could be made arbitrarily large. For all these reasons magnetic-bubble devices fabricated from metallic glasses might substantially reduce the cost per bit stored.

One final class of possible applications should be mentioned. Although the metallic glasses generally have high electrical resistivity, some of them nonetheless become superconductors, losing all resistance, at temperatures near absolute zero. That is possible because the mechanism of ordinary conduction and the mechanism of superconduction are quite different. The high normal resistivity does, however, have an influence on the properties of the superconducting alloys. When a material has become superconducting, regions of normal conductivity, called vortexes, persist. The size of the vortexes is determined in part by the resistivity of the material, and in amorphous metals the vortexes are unusually small, perhaps as small as .005 to .01 micrometer. The vortexes in amorphous materials can be exceptionally mobile. In crystalline solids the vortexes tend to become pinned at grain boundaries, but of course there are no grain boundaries in a glass.

The small size of the vortexes should make amorphous superconductors exceptionally tolerant of magnetic fields. For any superconductor there is a critical magnetic-field strength where the superconductivity is extinguished and the material reverts to the normal mode of conduction. The critical magnetic field is expected to be greater in the glassy superconductors than it is in crystalline ones. For this reason the alloys might be appropriate materials for the windings of superconducting magnets. The mobility of the vortexes is a disadvantage here, however, because movement of the vortexes dissipates energy. They would probably have to be pinned by partially crystallizing the film or by introducing inhomogeneities in some other way.

High mobility of the vortexes would be essential in another contemplated application of superconducting glasses. Just as information can be represented by a pattern of magnetic bubbles, so it could be stored in the form of vortexes in a superconducting film. Therefore another computer-memory technology can be envisioned. Because the vortexes are smaller than the smallest magnetic bubbles by a factor of at least 10 the amount of information that could be stored per unit area would be at least 100 times greater.

Metallic glasses are not distinctive in their chemical composition; in at least some cases the species of atoms present and their ratios are not at all out of the ordinary. What sets these metals apart from all others is the way the atoms are arranged and interconnected. The distinction is entirely geometric or topological, but it can have a profound influence on the properties of the materials. Although the exact nature of the atomic arrangement is not yet fully understood, enough has been learned for the exploitation of these unusual properties to be now in prospect.



MAGNETIC BUBBLES in an amorphous alloy might be employed to store information in a computer system. The bubbles are domains of reverse magnetization in a film of metallic glass that has been magnetized along an axis perpendicular to the plane of the film. They are made visible here in a transmission electron micrograph made by Sigrid R. Herd and one of the authors (Chaudhari). Some of the bubbles appear bright with a dark border, others are dark with a bright border and a third kind are bright on one side and dark on the other, so that they give the illusion of being either pits or mounds. Actually all three kinds differ only in the topology of the boundary region where the magnetic field rotates from normal to reverse polarity. Each bubble has a diameter of about .1 micrometer, a fifth the size of the smallest bubbles that seem to be feasible with a crystalline material, such as synthetic garnet. Hence a magnetic-bubble memory based on an amorphous medium might store information at a density 25 times greater.

The Structure of the Early Universe

The large-scale structure of the universe today is regular to within one part in 1,000. There is evidence that it has been that way since 10^{-35} second after the start of the big bang

by John D. Barrow and Joseph Silk

The cosmological principle is the powerful concept that the universe is homogeneous and isotropic. In other words, the large-scale features of the universe would appear the same to an observer in any galaxy no matter in which direction he looked. Much observational and experimental work supports the cosmological principle, which is deeply rooted in physics and natural philosophy. How did the universe acquire its large-scale uniform structure? Either it has pretty much always been that way or it was highly irregular and chaotic right after the big bang and has evolved into its present form because of certain smoothing and heating mechanisms. According to the latter possibility, called chaotic cosmology, the smoothing and heating mechanisms would give rise to the current regular universe regardless of the extent of the initial irregularity. Therefore chaotic cosmological theories eliminate the vexing problem of having to know the initial conditions of the universe.

Attractive as the elimination of the problem is, such theories may have a fatal drawback. We believe the proposed smoothing and heating mechanisms would irreversibly generate more thermal energy than seems to exist in the universe today. We think the universe as a result had only an infinitesimal degree of irregularity at the time of its creation. What happened at the precise moment of creation is not yet known because unfamiliar physical principles unique to the immense densities and temperatures of that moment mask the initial structure of the universe. Matter behaves in a way that gives little inkling of what the universe was like in the first 10^{-35} second of its existence.

The cosmological principle gains observational support from the fact that the universe is undergoing an expansion in which every galaxy cluster is rushing away from every other. In 1923 Edwin P. Hubble discovered that the rate of expansion increases with distance from the observer. He detected the recessional motion of the distant galaxies through measurements of their optical spectra. The wavelength at which electromagnetic radiation from a distant object reaches the earth is increased by the velocity of recession of the object with respect to the observer. This is the well-known red shift, so named because if the radiation from the receding object is in the visible region of the spectrum, it is made redder.

The amount of the red shift is given as a number corresponding to the fractional increase in the wavelength of the received radiation. For example, galaxies 20 million light-years away (among the closest to our own galaxy) have a red shift of .001 and galaxies 10 billion light-years away (among the most distant) have a red shift of .75. By measuring the red shift Hubble was able to calculate the recessional velocities of distant galaxies and thus the expansion rate of the universe.

The nature of the expansion can be understood by a traditional visual metaphor: likening the universe to a spherical balloon with dots painted on its surface, each dot representing a galaxy. As the balloon is inflated the distance between any two dots (as measured on the surface of the balloon) increases at a rate proportional to the distance between them. An observer at any dot would see all the other dots receding from him uniformly in all directions; no observer would occupy a privileged position. To put it another way, the expansion has no center.

It is not known whether the expansion of the universe will continue forever or whether someday the galaxies will stop receding from one another, start moving in the opposite direction and eventually fall together. Either possibility is consistent with prevailing cosmological theory, which maintains that the universe began with an explosion from a superdense state. The type of expansion is determined by the space-time geometry of the universe. Infinite expansion means an "open" universe; finite expansion followed by collapse means a "closed" universe. The critical intermediate case, advocated by Albert Einstein and Willem de Sitter in 1932, is where the universe has the minimum energy needed to overcome the decelerating influence of gravity and expand forever to infinity. Whether the universe is open or closed is difficult to determine because the expansion energy is near the critical value. This is the subject of continuing investigation in astronomy.

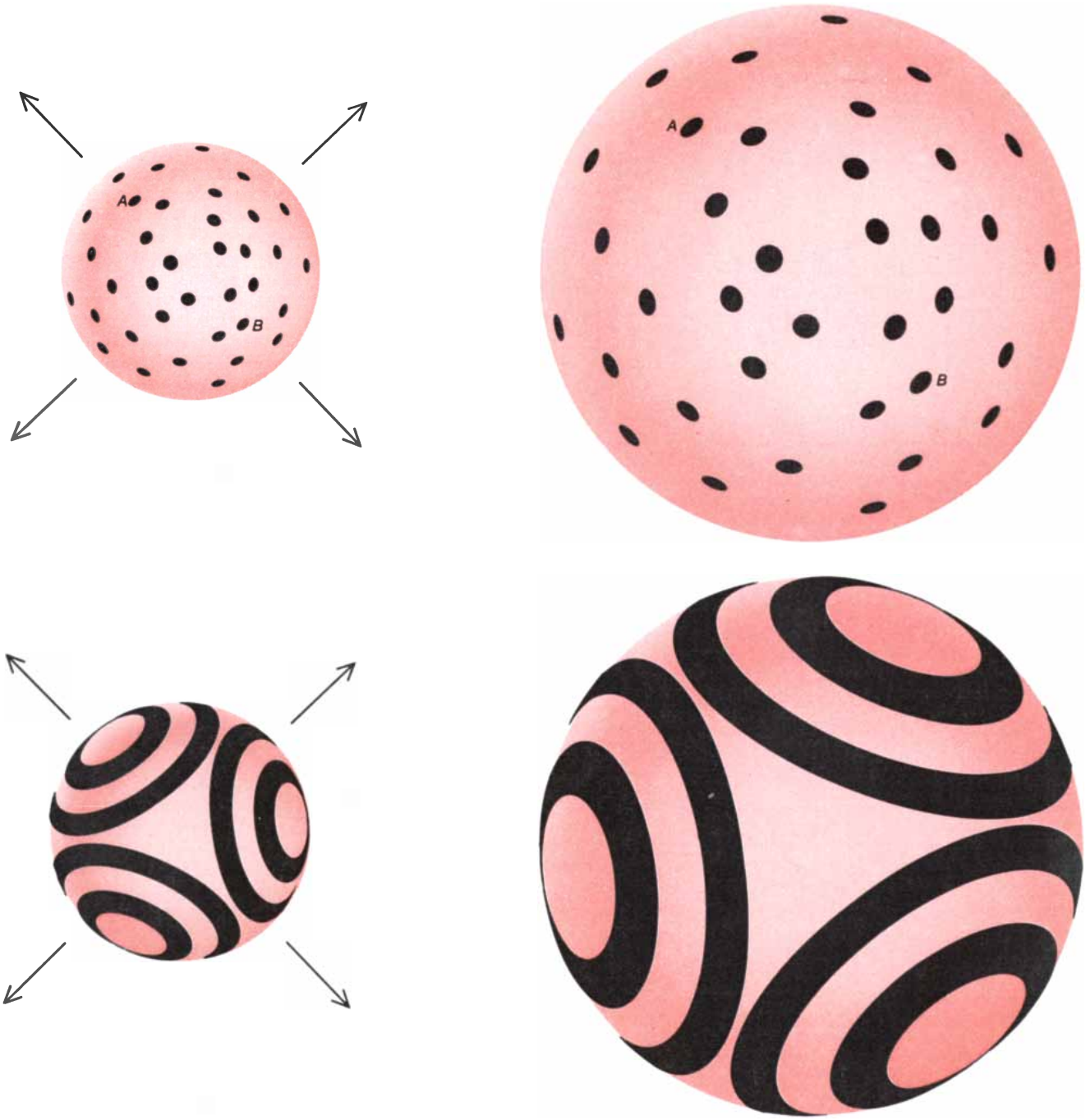
The universe is isotropic and homogeneous not only in its rate of expansion but also in its distribution of constituent objects. Hubble counted the number of distant galaxies in separate quadrants of the sky and in different volumes of space. He found that the larger the volume is, the more galaxies it contains. Moreover, the distribution of galaxies with direction varied hardly at all. More recent surveys have probed the uniformity of the distribution of galaxies in the universe to much greater distances. For example, when distant regions with a radius of a gigaparsec, or 3×10^9 light-years, are compared, their populations of radio-emitting objects (galaxies and quasars) are found to be equal to within 1 percent.

The most compelling evidence of isotropy comes from the background of microwaves, or radio waves with wavelengths in the millimeter range, that seem to flood the entire universe. The radiation was discovered in 1965 by Arno A. Penzias and Robert W. Wilson of Bell Laboratories. Sky maps of microwave radiation based on measurements made by antennas carried to high altitudes in aircraft and balloons show that the intensity of the radiation is isotropic to better than one part in 1,000.

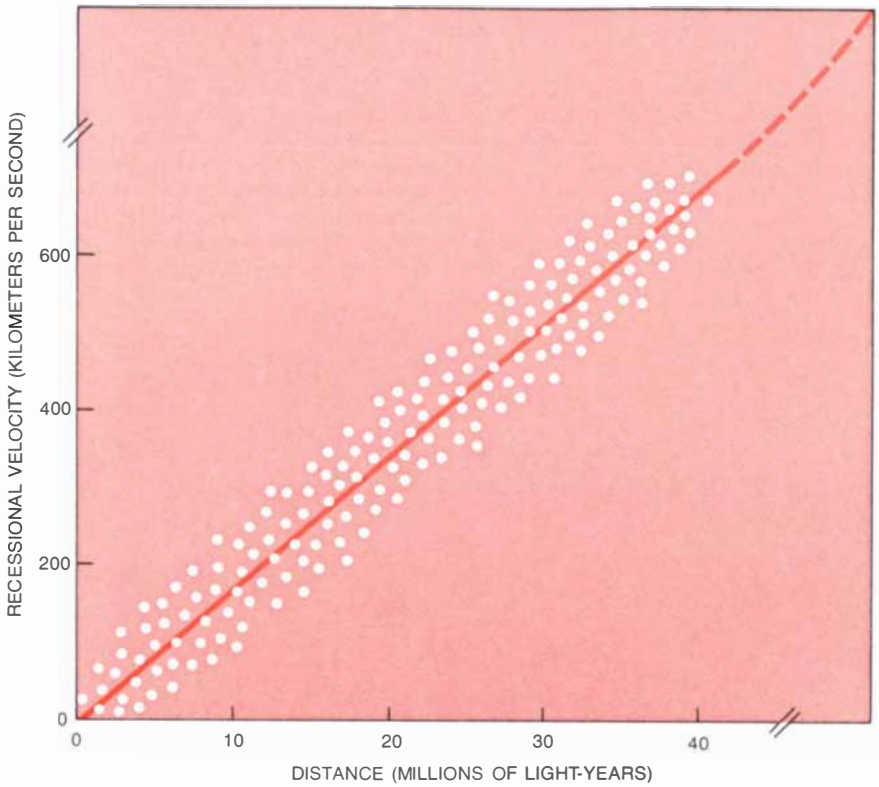
The homogeneity of the universe is more difficult to express quantitatively. The universe is of course highly inhomogeneous on a small scale such as that of the solar system or our galaxy. On a larger scale the homogeneity of its content of matter is indicated by the uni-

formity of the distribution of visible galaxies and radio sources and also by the uniformity of a universal background of X rays. On the scale of the entire observable universe the most sensitive indicator of homogeneity is the universal background of microwaves, which is homogeneous to better than one part in 1,000. The measurement is not definitive, however, because the radiation might have been rescattered by the intergalactic medium on its journey to the solar system and hence its variations might have been smoothed.

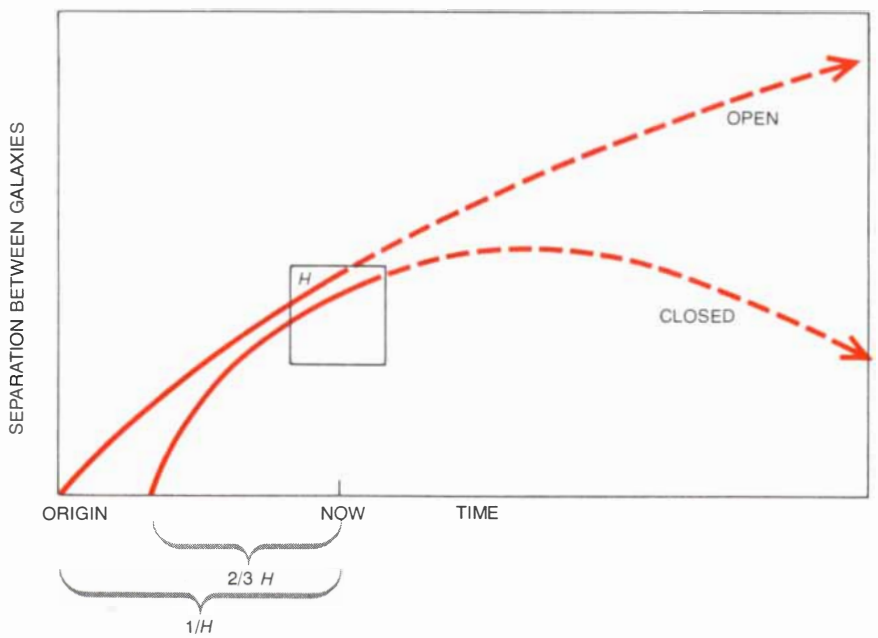
The microwave background radiation establishes much more than the validity of the cosmological principle for the recent history of the universe. The spectrum of the radiation is identical with the one that would be generated by a black body (a perfect emitter of radiation) at a temperature of 2.9 degrees Kelvin (2.9 degrees Celsius above absolute zero). The radiation is today only a feeble glimmer, but it attests to a fiery past. For the radiation to have the spectrum of a black body the early universe must have passed through a hot, dense phase. One of the most remarkable predictions of modern cosmology was the suggestion made by George Gamow (and his co-workers Ralph A. Alpher and Robert Herman) that a remnant of



BALLOON MODEL OF THE UNIVERSE is a traditional one suggesting how the real universe expands uniformly in all directions. Each dot on the surface of the balloon at the top left corresponds to a galaxy. When the balloon is inflated (*top right*), the distance between any two dots on its surface increases at a rate proportional to the distance. No matter which dot is singled out (for example *A* or *B*) all the other dots recede from it uniformly in all directions on the surface. This demonstrates that the expansion has no center. As the balloon is inflated the geometrical distribution of the dots does not change. A balloon with a design painted on its surface (*bottom left*) will bear the same design when it is inflated (*bottom right*). The expansion of the actual universe is homogeneous to one part in 1,000.



RECESSIONAL VELOCITY OF A GALAXY is proportional to its distance from the observer. The Hubble constant (*solid colored line*), which is the increase in recessional velocity with distance, is about 17 kilometers per second per million light-years. (The Hubble constant is a constant only in the sense that it is the same for every galaxy today. It will change as the universe expands further.) The ratio of velocity to distance may depart from the Hubble constant for an individual galaxy (*white dots*) that has an orbital velocity as a result of the fact that the galaxy is a member of a cluster. The recessional velocities have probably declined since the big bang because of the gravitational attraction of the expanding matter. Consequently the ratio of the velocity to distance may have been larger at extreme distances (*broken colored curve*).



MODELS OF COSMIC EVOLUTION indicate how the separation between the galaxies changes with time. If the universe continues to expand forever, the age of the universe is the Hubble time: the inverse of the Hubble constant (H). An infinitely expanding universe is considered to be open. On the other hand, if the universe eventually stops expanding and starts contracting, the age of the universe is less than $2/3\ H$. Such a universe is considered to be closed.

the big bang should still be visible as a pervasive background of black-body radiation. Gamow believed all the chemical elements with the exception of hydrogen could have been created in the hot, dense phase of the universe just after the big bang. To him the universe was a giant fusion reactor, and the simple requirement that the universe not immediately burn all its hydrogen into helium led directly to the prediction that the radiation, although greatly cooled and diluted by the expansion, should still be present with a temperature of about five degrees K.

Today it is known that the universe did not stay hot and dense long enough for the heavy elements such as carbon and iron to be built up in successive reactions from primordial protons and neutrons. It is now known that the heavy elements were synthesized in the interior of stars. The oldest stars seem to be deficient in heavy elements, which means that at the time of their formation their environment was poor in such elements. Yet the helium abundance of the old stars is essentially the same as that of much younger stars rich in heavy elements. Moreover, many kinds of galaxies are alike in their helium abundance. The uniform universal distribution of helium, which is second only to hydrogen in its cosmic abundance, indicates that it was chiefly created not in stellar interiors but in the hot aftermath of the big bang, as Gamow visualized. The general agreement between his prediction of a black-body radiation of five degrees K. and Penzias and Wilson's discovery of radiation of 2.9 degrees K. and the accurate prediction of the primordial helium abundance are the most compelling arguments for a hot big bang.

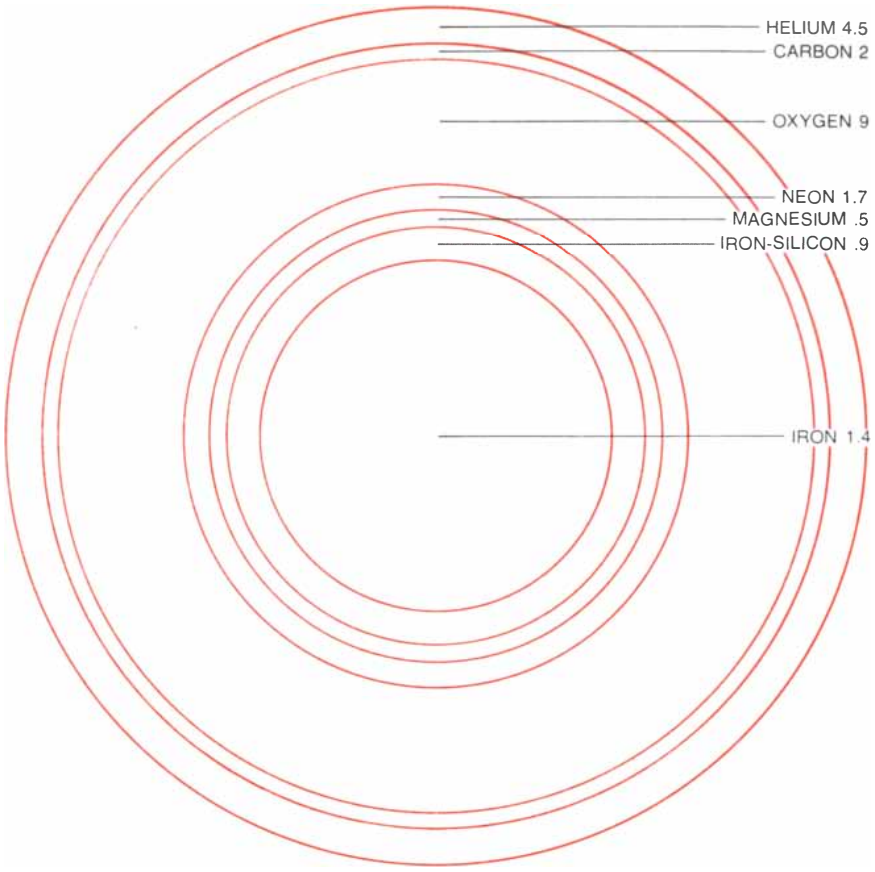
From data on the microwave background radiation theorists were able to calculate a new fundamental quantity: the ratio of the number of photons (the massless particles of electromagnetic radiation) in the universe to the number of nucleons (the massy protons and neutrons). The ratio is about 10^8 photons to one nucleon and is a measure of the average thermal entropy associated with each nucleon. Entropy, usually represented by the letter S, is defined as a number that indicates how many states are possible in a system. To put it another way, entropy is a measure of randomness or disorder. A liquid is an example of a high-entropy system because its atoms can arrange themselves in a huge variety of ways; a crystal lattice is an example of a lower-entropy system because its atoms are arranged in a highly ordered way. The ratio of the density of photons to the density of nucleons averaged over a large volume of the universe is a measure of the average entropy because photons constitute the most dis-

ordered states of thermal energy and nucleons constitute the most ordered states. Hence the relative abundances of these two kinds of extreme state are a measure of the average entropy.

According to the second law of thermodynamics, the total entropy of the universe increases continuously as time goes on. This means that at the time of the big bang S was less than 10^8. The isotropic expansion of the universe did not dissipate much heat, so that any increase in S must be due to other mechanisms. An entropy of 10^8 is quite large compared with the entropy of about 1 exhibited by systems in the terrestrial environment. This means that the universe as a whole is a relatively hot place. A physicist's first reaction to a hot system with a high degree of regularity is to suppose much thermal energy was dissipated in the history of the system, the heat and the regularity being the aftermath of frictional smoothing processes. We shall try to demonstrate, however, that for the universe this interpretation is unlikely to be correct.

By extrapolating backward from the present-day expanding universe to the time before galaxies formed, cosmologists have traced the origin of the universe to a singularity: a state of apparently infinite density. The singularity represents the origin of space and time perhaps 10 billion years ago. Before that time the laws of physics known today did not apply. Does that testify to the physicist's knowledge or to his ignorance? Before 1965 cosmologists debated the physical significance of this singularity. Some theorists thought it might be a spurious manifestation of the particular coordinate system chosen to describe the dynamics of the expansion of the universe, a manifestation similar to the singularity in geography. On a terrestrial globe there is a coordinate singularity at the North and South poles, where the grid squares of longitude and latitude vanish as the meridians of the globe intersect. Yet the fabric of the world does not physically break down at the poles.

Since 1965 several theorists have independently shown that the cosmological singularity is not the result of a poorly chosen coordinate system. On the contrary, the singularity seems to be general, physically real and an inevitable consequence of the fact that gravity is attractive and acts indiscriminately on everything, including photons. The singularity was probably characterized by infinite density and curvature, although all that is known with certainty is that a material observer moving back into the past would experience an abrupt and disconcerting end to his trip through space-time when he encountered it. He would be unable to travel any farther because the laws of physics require the universe to have a space-time boundary. (The traveler need not, however, experience the big bang with its infinite densities and temperatures.)



ELEMENTS HEAVIER THAN HELIUM were synthesized not in the big bang but in the interior of stars. If the star has a mass more than 20 times that of the sun, it is unstable and explodes as a supernova, dispersing the heavy elements into space. As such a star contracts under the mutual gravitational attraction of its constituents the pressure and temperature of its interior increase until thermonuclear reactions transmute hydrogen into helium. After most of the hydrogen in the core is transmuted into helium the star contracts further until its internal temperature is high enough to transmute some of the helium into carbon. As the star continues to contract its temperature rises until carbon starts to be transmuted into heavier elements. At each stage a shell of lighter material is left behind. The masses of the shells are in solar masses. In the star depicted here virtually all the hydrogen has been transmuted into heavy elements.

The cosmological singularity is similar to the singularity in the event horizon of a black hole, the hypothetical surface in which matter and light rays are confined by gravity. Nothing leaves a black hole because the velocity needed to escape the grasp of its gravity is greater than the speed of light, which the laws of physics require cannot be exceeded. It has been shown that an unfortunate astronaut who fell freely into a black hole would reach a physical singularity within a finite time (as time would be measured on his own watch). The singularity would be invisible to external observers since it lies inside the event horizon of the black hole. Now, since photons feel the pull of gravity, it is possible to determine whether at some time early in the history of the universe the photons that currently make up the microwave background radiation could have exerted sufficient gravitational pull to create a trapped region analogous to a black hole. Within that region would be a cosmological singularity, which the physicist defines as the beginning of the universe.

That the universal expansion originated at a singularity has a far-reaching consequence in terms of the points in the universe that causally influence one another. Since no signal can move faster than the speed of light, an observer can be affected only by events from which a photon would have time to reach him since the beginning of the universe. Such events are described as lying within the observer's horizon. Consider two points with a spatial separation x at the beginning of time. Before the time it takes for light to travel between them (x/c, where c is the speed of light) the points will not "see" each other, "know" of each other's existence or be able to affect each other in any way. In general, regions of the universe with a spatial separation greater than ct will not know of each other's existence until a time t has elapsed. What this means is that regions of the

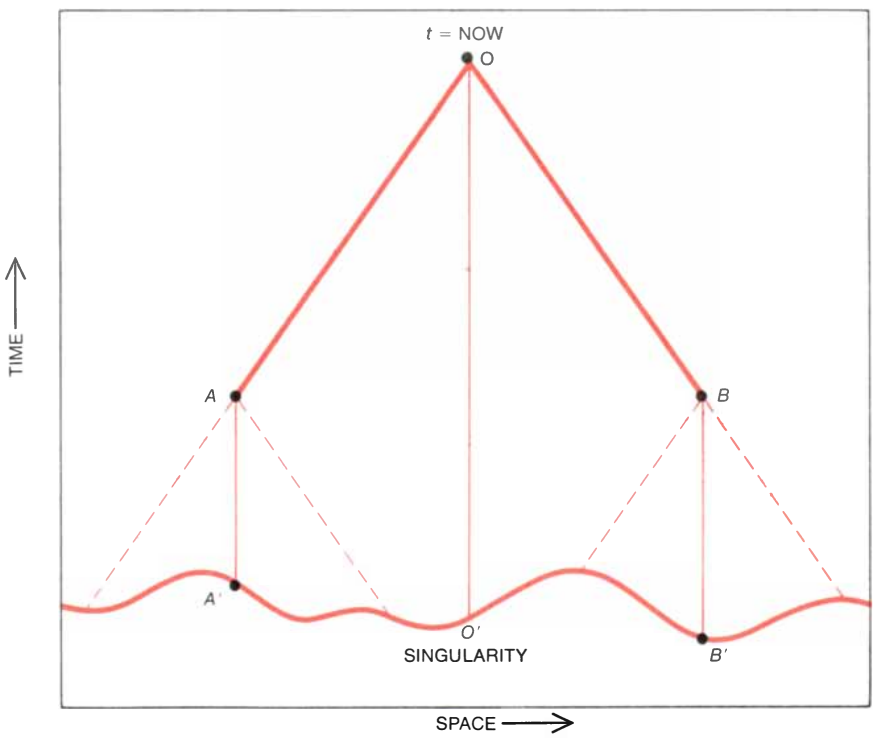
isotropic microwave background in different directions of the sky (say more than 30 degrees apart) could never have causally influenced each other at any time in the past. That creates a paradox: How did causally disjoint primordial regions of the universe come to have the same temperature and expansion rates today to within at least one part in 1,000?

A further twist to the conundrum of the origin of the uniform background radiation comes from the fact that although the universe is quite regular on the scale of several tens of millions of light-years, it does have on a smaller scale some spectacular inhomogeneities in the form of galaxies and clusters of galaxies. The strength of the gravitational field exerted by the largest of these inhomogeneities suggests that their ancient precursors would have created an anisotropy in the microwave background radiation over a scale of a few angular degrees. Observational astronomers are currently searching for such an anisotropy. Anisotropy would also arise from the remnants of ancient directional disparities in the universal expansion rate. It is not clear what physical mechanisms have smoothed the irregularities into the structured universe of today.

What cosmologists are trying to account for are the entropy and the large-scale structure of the universe, which appear to have existed when the universe was less than a minute old. Such epochs are best defined, however, not in temporal units such as minutes or years, which are subject to correction as the yardsticks of astronomy are refined, but in units of red shift, which express the amount by which the universe was compressed with respect to its present size.

On the one hand there are "chaotic" cosmologists, who like biologists maintain that the properties of the universe are the result of evolutionary processes. They have tried to show that a kind of gravitational natural selection could deliver the present large-scale structure as the inevitable result of physical smoothing and heating processes that have been going on since the big bang. If it could be demonstrated that the present structure would have arisen no matter what the initial conditions were, then the uniqueness of the universe would be established in theory as well as in actuality.

On the other hand there are "quiescent" cosmologists, who appeal largely to the initial conditions to explain the present structure of the universe. They hypothesize that when the universe was created at the singularity, it had certain definite and preferred structural features for reasons, say, of self-consistency, stability or uniqueness. This means that gravitational evolutionary processes played a role not in shaping the overall configuration of the universe but only in molding substructures such as galaxies, stars and planets. A good deal of the theoretical work in cosmology over the past decade has centered on finding ways of distinguishing between the two alternative cosmologies. We shall devote the remainder of our discussion to this work.



AN OBSERVER'S "HORIZON" is that part of the universe consisting of events that can causally affect him. Because information cannot be transmitted faster than the speed of light an observer can be influenced only by events from which light could have traveled to him since the time of the big bang. Here *O'* corresponds to the "singularity" with which the universe began and *O* corresponds to the present time. The cone below *O* represents the horizon of events on the earth. As the universe continues to evolve the earth moves farther out along the time axis and hence the cone gets larger. The singularity may have been so complex that different parts of the universe began their expansion at different times. For example, the big bang could have taken place at *B'* before it did at *A'*. There are regions of the universe (*A, B*) that judging by their radiation received on the earth have the same temperature and expansion rate to within one part in 1,000. Yet these regions have never been causally connected at any time in the history of the universe. This gives rise to a paradox: How can the two regions be so similar?

It is now believed that at ordinary temperatures all natural phenomena are governed by four fundamental forces: the gravitational force, the electromagnetic force, the weak force and the strong (or nuclear) force. These forces in conjunction with a small number of additional parameters such as particle mass determine the structural characteristics of the universe. As the history of the universe is traced backward in time from the present to the singularity at a red shift of infinity some 10 billion years ago, each of the four fundamental forces will at some point come to dominate the others. Today the gravitational force is the one that governs the dynamics of the large-scale expansion. Although the gravitational attraction of two protons is 10^{40} times weaker than their electromagnetic repulsion, gravity becomes increasingly important in a system with a huge number of particles such as the universe. In the universe the number of positively charged particles should be equal to the number of negatively charged particles, and so on the whole the attractive and repulsive electromagnetic interactions cancel out and exert no significant long-range forces over large regions. Since gravity is only attractive, however, it plays a major role in massive systems. It is the influence of the gravitational force, which has infinite range and acts on the photons of radiation as well as on the particles of matter, that determines the size of the largest objects in the universe, such as planets, stars, galaxies and clusters of galaxies.

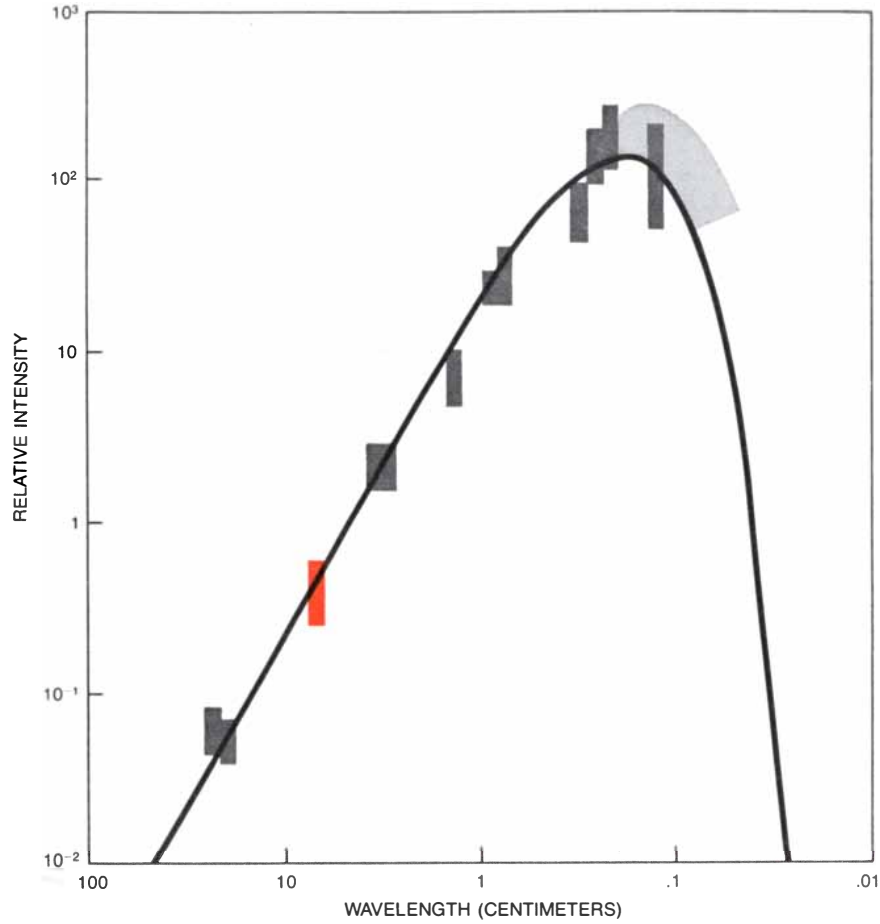
If a local region of the early universe happened to have a density higher than that of the surrounding regions, it would gravitationally attract more matter than the less dense regions. As it contracted under the influence of its own gravity, it would increase in density and attract matter even more efficiently. What began as a fluctuation in a fairly homogeneous universe would eventually snowball into a huge inhomogeneity. Galaxies seem to have formed at times equivalent to red shifts between 10 and 100 and to have come together in clusters at later

times. It is not known with any certainty, however, whether galaxies formed out of fragments of much larger fluctuations that disintegrated or out of smaller fluctuations that came together because of their mutual gravitational attraction.

At a time equivalent to a red shift of 1,000 (about 300,000 years after the big bang) gas pressure is stronger than gravity over a dimension equivalent to that of about 100,000 suns, but gravity is much stronger than gas pressure over larger dimensions. Fluctuations on the order of these larger dimensions grow until they eventually become large enough to collapse and form bound objects spanning a range of masses from those of globular star clusters to those of galaxies. At times equivalent to red shifts greater than 1,000 the chief source of pressure is not gas pressure but the pressure of thermal radiation. In that epoch the dynamical behavior of density perturbations is determined by the electromagnetic force.

Under these circumstances photons form a viscous fluid that inhibits the movement of electrons and protons. An electron, for example, would scatter impinging photons, which it feels as electrical pulses. Because of the law of the conservation of momentum the scattering would slightly alter the electron's trajectory. The net result is that the electron, locked into the radiation field by the ceaseless barrage of photons, cannot go anywhere. Once the electron joins a proton to form a hydrogen atom, however, it effectively no longer feels photons because it is interacting primarily with the electric field of the proton. The lack of movement of individual electrons means that fluctuations in the density of matter, called isothermal density fluctuations, are preserved until the time when electrons and protons combine to form electrically neutral atoms. Such atoms can travel freely through the radiation, and so the gravitational growth and collapse can proceed. The isothermal density fluctuations start to collapse when they acquire a mass of more than 100,000 suns. Such fluctuations come together to form galaxies.

Objects could also form from another kind of perturbation, called an adiabatic fluctuation, in which matter and radiation are perturbed together. If matter and radiation were squeezed slightly in a confined space, the excess pressure would create a kind of sound wave. Yet just as sound waves in air eventually dissipate and fade, so would a primordial sound wave. The critical length and mass below which the wave would be damped completely is determined by the ability of photons to escape from the adiabatic fluctuation in the time since the beginning of the universe. By a time equivalent to a red shift of 1,000 only adiabatic fluctuations more massive than the observed size of a massive galaxy or a group of galaxies survive the damping. In other words, less massive adiabatic fluctuations are smoothed out, whereas the more massive ones perhaps survive, grow and eventually collapse into massive galaxies and groups of galaxies.



RADIATION EMITTED BY THE BIG BANG at microwave frequencies was detected in 1965 by Arno A. Penzias and Robert W. Wilson of Bell Laboratories. Their measurements (*colored region*), together with those of other workers (*shaded regions*), show that the spectrum of the radiation is the spectrum of a black body at 2.9 degrees Kelvin (2.9 degrees Celsius above absolute zero). The radiation is uniform regardless of the direction to within one part in 1,000.

In summary, this reconstruction of the probable evolution of the hot early universe consists of two kinds of density fluctuation, the isothermal and the adiabatic, which roughly correspond respectively to a globular star cluster or a dwarf galaxy and to a cluster of galaxies. The picture is undoubtedly a gross oversimplification because in general an arbitrary inhomogeneity would be expected to have an admixture of both isothermal and adiabatic components. Moreover, newly formed structures could merge or fragment, leaving no trace of their previous individual identity. In spite of these qualifications cosmologists would be rash to ignore this simple picture because the preferred masses that emerge out of the two kinds of fluctuation are comparable to the masses of the objects whose origin they are trying to explain.

At a time equivalent to a red shift of 10^{10}, when the universe was only a few seconds old and its temperature was 10^{10} degrees K., physical processes are mediated by the weak force. This force governs certain radioactive decay processes involving a free neutron or a neutrino: a spinning pointlike particle with no charge and negligible mass. At times equivalent to red shifts greater than 10^{10} the weak force keeps the protons and neutrons in thermal equilibrium: a statistical state where the number of particles with properties (position, mass, energy, velocity, spin and so on) in a specified range remains constant because the rate of particles entering that range is equal to the rate of particles leaving it. When particles achieve a state of thermal equilibrium, their behavior is determined not at all by their history but entirely by a set of statistical laws based on their temperature. This means that it is unnecessary to pry any farther into the past to understand the behavior and the relative concentrations of protons and neutrons.

The weak force in conjunction with the big-bang model of expansion leads to the prediction that the abundance of

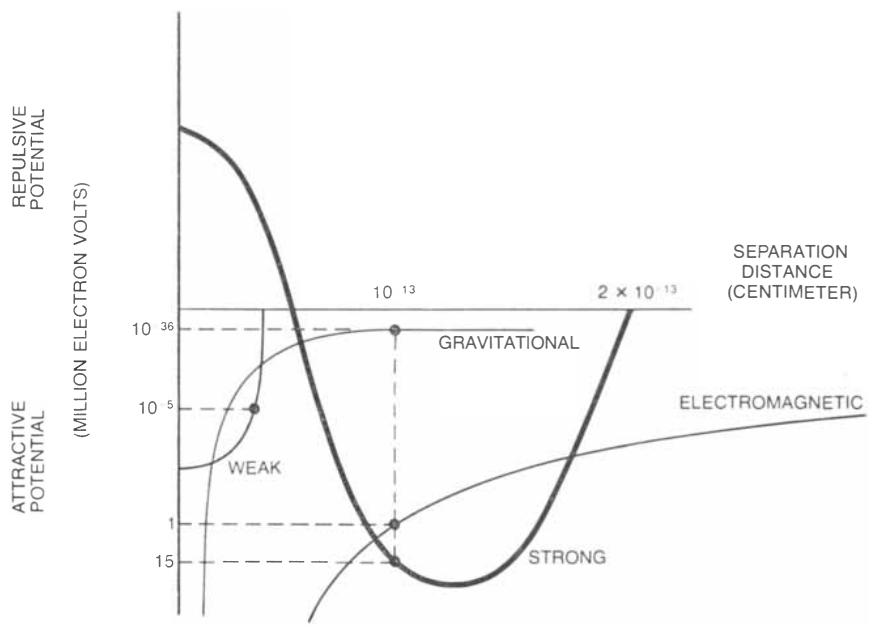
primordial helium in the universe is between 25 and 30 percent. This prediction, which has now been confirmed, has led to a precise and direct observational test of big-bang cosmology. What the success of the prediction means is that a few seconds after the big bang the universe was at least as regular on a large scale as it is today and had almost the same entropy. Cosmologists are trying to determine the degree of regularity before that time.

At times equivalent to red shifts greater than 10^{10}, neutrinos and their antiparticles (antineutrinos) play a big role. Today these particles are quite elusive because they almost never interact with anything in the rarefied medium of the present universe. Yet when the universe was a little less than a second old matter and radiation were so dense that neutrinos rapidly interacted strongly with them. At a time equivalent to a red shift of 10^{10} a typical neutrino traversed a significant extent of the universe before it collided with another particle. This means that the neutrinos could effectively transport energy and momentum over extremely large distances. They would do so by absorbing energy in high-energy regions of the universe and transferring it by occasional collisions to low-energy regions. As a result the neutrinos act to smooth out any nonuniformities in the distribution of matter that might have been created by directional differences in the overall expansion of the early universe.

The possibility of smoothing by neutrino-transport processes was suggested in 1967 by Charles W. Misner of the University of Maryland in the hope that such processes could remove a host of irregularities associated with the initial singularity of a chaotic universe. This hope has now foundered on the realization that if the initial expansion were sufficiently asymmetrical, the universe would expand so rapidly that there would not be enough time for neutrinos to collide with other particles. In other words, a highly anisotropic universe could remain that way. It seems that neutrino transport and other smoothing processes could only remove anisotropies below a certain level. No matter how efficient a smoothing process was postulated, it was always possible to imagine a model universe that would nonetheless remain much more irregular than the present-day universe actually is. This consequence of the weak force cannot satisfy the central tenet of chaotic cosmology: the evolution of the regular present-day universe from any initial state no matter how irregular.

Perhaps the homogeneous universe could be the result of more complex smoothing processes, such as Misner's ingenious "mixmaster" universe in which matter would be mixed periodically by explosions expanding at the speed of light first in one direction and then in another. This process is an exotic and complex one developed on the basis of the general theory of relativity. The probability of such explosions, however, seems to be infinitesimal. In fact, the conditions required for such mixing are almost as special as those required for the initial universe to be precisely regular. This means that the mixmaster model explains very little. The search for complex smoothing processes that would require fewer special conditions is part of the continuing work in chaotic cosmology.

INTERACTION	SOURCE	FIELD QUANTUM	RELATIVE STRENGTH NOW	RANGE (CENTIMETERS)	MANIFESTATION	UNIFICATION ENERGY (ELECTRON VOLTS)
ELECTROMAGNETIC	ELECTRIC CHARGE	PHOTON	10^{-12}	∞	ATOMIC AND MOLECULAR FORCES, ELECTRICITY	10^{11}
WEAK	LEPTONS MESONS	(*W* BOSONS)	10^{-14}	10^{-15}	RADIOACTIVE BETA DECAY	10^{23}
STRONG	BARYONS MESONS	PION, KAON	1	10^{-13}	NUCLEAR FORCES	10^{28}
GRAVITATIONAL	MASS-ENERGY	(GRAVITON)	10^{-40}	∞	LARGE-SCALE DYNAMICS OF MATTER	



CHARACTERISTICS OF THE FOUR FUNDAMENTAL FORCES that govern all the interactions of matter and energy are given in the table at the top; the range and relative strengths of the forces are given in the diagram at the bottom. Above a certain energy called the unification energy the forces lose their individuality. The more than 200 kinds of subatomic particles all respond to at least one of the forces. The particles fall in two broad categories: the hadrons (including the proton, the neutron and the pion), which seem to have an inner structure, and the leptons (the electron, the muon, the tau particle and the neutrinos associated with each of them), which have no constituent parts. The hadrons are further divided into the baryons, which decay ultimately into the proton, and the mesons, which decay into leptons and photons (quanta of electromagnetic radiation) or into pairs consisting of a proton and an antiproton.

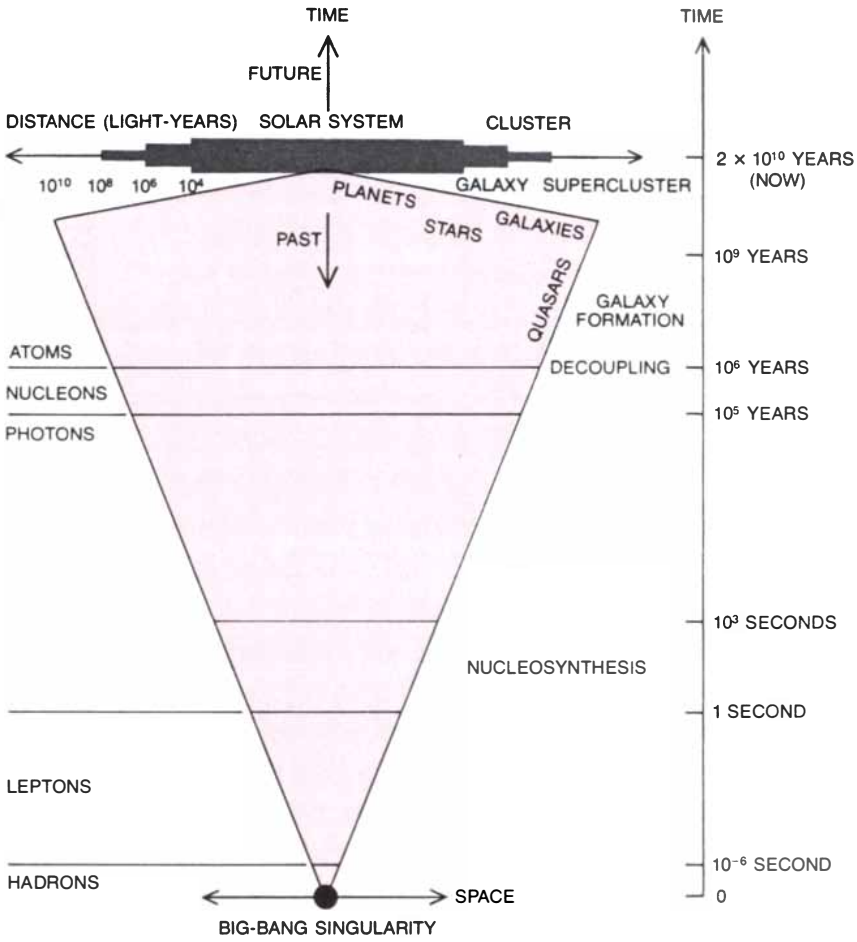
It is time to leave the epoch of the weak force to move closer to the cosmological singularity and tentatively probe the first milliseconds of the universe. There, where the temperatures and the particle energies exceed those achieved by the most powerful man-made accelerator and the radiation density is comparable to the density of the atomic

nucleus, the dominant force between particles is the strong force. The extrapolation of our model into these earliest times is somewhat precarious because the understanding of the basic physics is not complete. When the strong force annihilates a proton and an antiproton, it gives rise to two energetic photons moving in opposite directions. In the first millisecond of the universe the temperature would have been so high that such an annihilation and the inverse process, the spontaneous production of nucleons and antinucleons from photons, would be quite efficient. Nucleons and radiation would have been indistinguishable. The average entropy of 10^8 photons per nucleon observed today implies that when the last annihilation took place, one proton survived for every 10^8 photons created by the destruction of other pairs of particles and antiparticles.

It seems that just before the universe was a millisecond old there was a minute imbalance between matter and antimatter: 1.00000001 particles per antiparticle. Until recently the origin of this peculiar imbalance was a complete mystery because of a principle having to do with baryons: heavy particles, including nucleons, that feel the strong force. Physicists believed the number of baryons in a system minus the number of antibaryons was absolutely fixed for all time. No interactions or transformations of the particles could ever change this quantity. If this were true for the universe as a whole, the asymmetry of one part in 10^8 of matter over antimatter must have been built into the initial structure of the big bang.

Over the past year cosmologists have been actively investigating the consequences of a new extension of the theory of matter in which the electromagnetic, the weak and the strong force are all unified at sufficiently high temperatures. Above 10^{26} degrees K. these forces lose their individuality, whereas at lower temperatures they seem to be independent (although they are actually different aspects of an underlying unity). This kind of unification is possible only if the quarks that make up protons and other elementary particles are able to decay. Such decay has a surprising consequence: the proton is an unstable particle, although it has an average lifetime of about 10^{31} years. In spite of the infrequency of proton decays, physicists hope to observe some decay within the next year or so by an experiment examining a sufficiently large mass: 1,000 tons of matter consisting of roughly 10^{32} protons.

The possibility of such unusual processes indicates that the level of particle-antiparticle asymmetry in the universe, which determines the observed entropy, is not absolutely invariant. It can change dramatically in the first 10^{-35} second of the universe, when the processes that mediate the decay of protons are abundant. Recent work shows that after this early instant a stable level of asymmetry between particles and antiparticles is eventually frozen into the universe, and the predicted value is close to the observed asymmetry of one part in 10^8. The observed entropy need not be strongly dependent on the initial conditions of the big bang in the first 10^{-35} second.



SPACE-TIME DIAGRAM of the universe traces its history from the singularity of roughly 20 billion years ago. The shaded region represents the horizon of a hypothetical observer at the singularity. Each fundamental force came to dominate the behavior of matter at some point.

So far we have been taking into account only the corpuscular properties of matter. As we speculate on what happened right after the big bang the wave properties of matter must also be considered. According to quantum mechanics, every particle behaves as a wave with a length equal to 2.1×10^{-37} divided by the particle's mass. This wavelength, called the Compton wavelength, is infinitesimal by everyday standards, but only 10^{-23} second (the Compton time) after the big bang the Compton wavelength (10^{-13} centimeter) of a proton would be equal to the size of the causally connected region of the universe. There is nothing fundamental about this scale, however, because there is nothing fundamental about protons, which are of course made up of quarks.

The ultimate barrier is reached at times close to 10^{-43} second (the Planck time) after the big bang, because causally connected regions of the universe were compressed to a scale smaller than the Compton wavelength of their entire mass content. Before the Planck time the usual interpretation of space-time is probably invalid because quantum-mechanical fluctuations dominate the geometry of space-time. Undoubtedly many secrets of the universe would be revealed by an understanding of pre-Planck time, but achieving such an understanding is currently a remote possibility. Achieving it will probably have to await a new physical theory that synthesizes the theory of relativity and quantum theory. Cosmologists now regard the Planck time as being in effect the moment of creation of the universe; they leave to speculation any possibility of an earlier phase of evolution.

The epoch between the Planck time and the Compton time is a little more accessible to theoretical work. In that epoch quantum mechanics points to a mechanism that might have erased irregularities in the universe. According to quantum mechanics, all space is filled with pairs of "virtual" particles and

antiparticles. Such particles, which materialize in pairs, separate, come back together and annihilate each other, are called virtual because unlike real particles they cannot be observed directly by particle detectors, although their indirect effects can be measured. If a pair of virtual particles is subject to a force field that is either extremely powerful or rapidly varying, its components might separate so quickly that they could never come back together. In this case the virtual particles would become real ones, their mass being supplied by the energy of the force field. Close to the Planck time the required force field might be generated by the changing expansion dynamics of the universe itself.

The Russian astrophysicist Ya. B. Zel'dovich has proposed that the production of real particles from virtual ones would erase the anisotropies and nonuniformities in the initial structure of the universe. It is imagined that radiation and particles would be preferentially spawned in the overly energetic regions of space. The newly formed particles would transfer energy from high-density regions to lower-density ones. Moreover, they would tend to equalize the rates of expansion in different directions. Much as people stepping onto a rotating merry-go-round tend to slow it down, the sudden appearance of particles would slow down the rapidly spinning and moving regions. Perhaps it is this quantum-physical mechanism that is responsible for the homogeneous large-scale structure of the present-day universe.

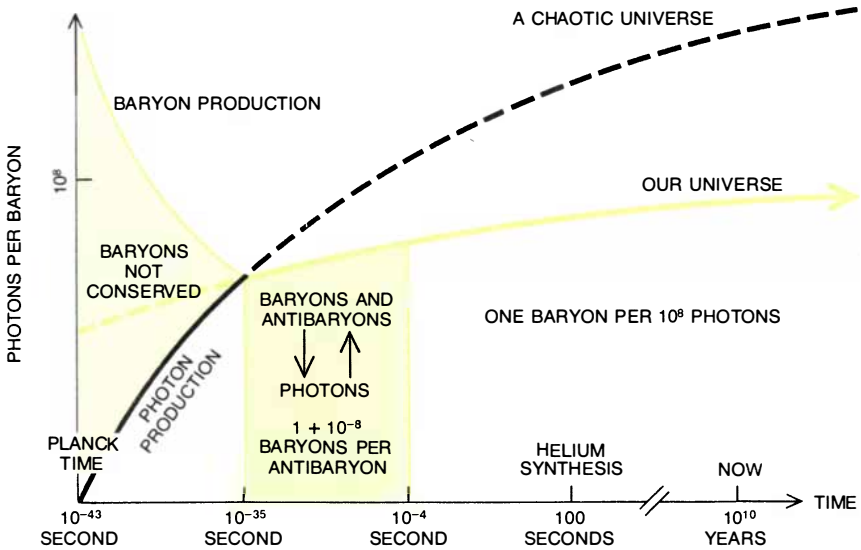
In the above discussion we have reviewed several smoothing mechanisms that might be responsible for the present regularity of the universe, mechanisms such as neutrino transport and the creation of real particles from virtual ones. As promising as these mechanisms may seem, we believe thermodynamical considerations demonstrate that they are severely limited. Since entropy increases with time, the present level of entropy in the universe (10^8) puts an upper limit on the amount of dissipation that has occurred during the past history of the universe. The smoothing of anisotropies and inhomogeneities in the initial structure would irreversibly convert the energy of irregularity into heat energy. The erasure of primordial chaos would generate radiation, but the low level of the microwave background radiation means that there could not have been an arbitrarily large amount of heating and smoothing in the past.

Moreover, it has been shown that in general the sooner after the big bang the irregularities are damped out, the more thermal radiation would be generated. Most of the dissipative mechanisms we have discussed would be fully operative right after the big bang. This means that if the universe were made with anything but a small degree of irregularity, entropy would be created at the singularity in excess of the observed level. But how small must the initial irregularity have been? The work of Barry Collins and Stephen Hawking of the University of Cambridge shows that a highly but not perfectly regular universe is unstable. The slightest deviation from regularity would tend to grow in time as the universe expanded regardless of the dissipative mechanisms. To put it another way, a universe beginning its expansion in anything but a precisely regular configuration would tend to become increasingly irregular. This means that the initial irregularities could only have been infinitesimal. Our own work indicates that there is a hierarchy of irregularities in the universe. As progressively larger volumes of space are examined, the degree of irregularity decreases in a way that suggests the initial irregularities were only statistical fluctuations of a regular state.

What we are saying is that the present entropy level shows that the universe has evolved in an exceedingly regular way from as far back as the first 10^{-35} second of its existence. Before that time complex processes involving the nonconservation of the symmetry of particles and antiparticles and the quantum properties of the gravitational field erased any memory of the initial entropy per nucleon. Although the dissipation of chaos at those early times could also have generated many photons, nucleons would have been created as well, and the net number of photons per nucleon might have decreased or increased. Of course, the total entropy of the matter and radiation in the universe must always increase.

An unsettled question is whether the initial conditions are unique or whether another set of conditions could have done the same job. Several candidates for initial conditions have been proposed by theorists. One possibility is that the strong force served to keep matter highly rigid at the time of the singularity. At extremely high densities two nucleons could repel each other in the same way that two like magnetic poles do. Such a repulsion, which would prevent heavy nuclei from collapsing, might come to dominate the overall behavior of the interacting particles. An early state dominated by the strong force would remain quite regular because the high pressure would prevent distortions or turbulence from developing as the density increased.

Another possibility, developed by Roger Penrose of the University of Oxford, is based on the proposal that the overall gravitational field of the universe itself has an entropy that is proportional to and dependent on its uniformity. Since gravitational entropy, like all other forms of entropy, should always increase with time, the initial state of the universe would have been one of low gravitational entropy and regularity. To minimize gravitational entropy the universe might have acquired a regular, isotropic configuration, as a soap bubble minimizes the entropy associated with its surface area by assuming an isotropic spherical shape. As the universe ages and expands, the



THERMAL EVOLUTION OF THE UNIVERSE is shown in terms of the number of photons per baryon, which is a measure of entropy: the number of possible states in a system. Little is known about the epoch before 10^{-43} second because under the conditions that prevailed in that epoch the general theory of relativity and the theory of quantum mechanics seem to contradict each other. Before 10^{-4} second there was an imbalance of matter and antimatter that may have arisen spontaneously at about 10^{-35} second. If the universe had been chaotic after 10^{-35} second, any smoothing processes that led to the highly homogeneous form of the present-day universe would have given rise to many more photons per baryon than are observed today.

COSMIC TIME	EPOCH	RED SHIFT	EVENT	YEARS AGO
0	SINGULARITY	INFINITE	BIG BANG	20×10^9
10^{-43} SECOND	PLANCK TIME	10^{32}	PARTICLE CREATION	20×10^9
10^{-6} SECOND	HADRONIC ERA	10^{13}	ANNIHILATION OF PROTON-ANTIPROTON PAIRS	20×10^9
1 SECOND	LEPTONIC ERA	10^{10}	ANNIHILATION OF ELECTRON-POSITRON PAIRS	20×10^9
1 MINUTE	RADIATION ERA	10^9	NUCLEOSYNTHESIS OF HELIUM AND DEUTERIUM	20×10^9
1 WEEK		10^7	RADIATION THERMALIZES PRIOR TO THIS EPOCH	20×10^9
10,000 YEARS	MATTER ERA	10^4	UNIVERSE BECOMES MATTER-DOMINATED	20×10^9
300,000 YEARS	DECOUPLING ERA	10^3	UNIVERSE BECOMES TRANSPARENT	19.9997×10^9
$1–2 \times 10^9$ YEARS		10–30	GALAXIES BEGIN TO FORM	$18–19 \times 10^9$
3×10^9 YEARS		5	GALAXIES BEGIN TO CLUSTER	17×10^9
4×10^9 YEARS			OUR PROTOGALAXY COLLAPSES	16×10^9
4.1×10^9 YEARS			FIRST STARS FORM	15.9×10^9
5×10^9 YEARS		3	QUASARS ARE BORN; POPULATION II STARS FORM	15×10^9
10×10^9 YEARS		1	POPULATION I STARS FORM	10×10^9
15.2×10^9 YEARS			OUR PARENT INTERSTELLAR CLOUD FORMS	4.8×10^9
15.3×10^9 YEARS			COLLAPSE OF PROTOSOLAR NEBULA	4.7×10^9
15.4×10^9 YEARS			PLANETS FORM; ROCK SOLIDIFIES	4.6×10^9
15.7×10^9 YEARS			INTENSE CRATERING OF PLANETS	4.3×10^9
16.1×10^9 YEARS	ARCHEOZOIC ERA		OLDEST TERRESTRIAL ROCKS FORM	3.9×10^9
17×10^9 YEARS			MICROSCOPIC LIFE FORMS	3×10^9
18×10^9 YEARS	PROTEROZOIC ERA		OXYGEN-RICH ATMOSPHERE DEVELOPS	2×10^9
19×10^9 YEARS			MACROSCOPIC LIFE FORMS	1×10^9
19.4×10^9 YEARS	PALEOZOIC ERA		EARLIEST FOSSIL RECORD	600×10^6
19.55×10^9 YEARS			FIRST FISHES	450×10^6
19.6×10^9 YEARS			EARLY LAND PLANTS	400×10^6
19.7×10^9 YEARS			FERNS, CONIFERS	300×10^6
19.8×10^9 YEARS	MESOZOIC ERA		FIRST MAMMALS	200×10^6
19.85×10^9 YEARS			FIRST BIRDS	150×10^6
19.94×10^9 YEARS	CENOZOIC ERA		FIRST PRIMATES	60×10^6
19.95×10^9 YEARS			MAMMALS INCREASE	50×10^6
20×10^9 YEARS			HOMO SAPIENS	1×10^5

MAJOR EVENTS IN THE UNIVERSE'S HISTORY are listed. The time scale of ancient events must be regarded as tentative because the precise age of the universe is not known. It is therefore better to date such events in terms of the red shift, which is a measure of the degree of compression of the expanding universe. At the ultrahigh velocities characteristic of times close to the big bang the red shift is equal to $(1 + v/c)/(1 - v^2/c^2)^{1/2} - 1$, where v is velocity of the radiation source and c is velocity of light (3×10^8 meters per second).

gravitational entropy would increase to reflect the growth of such inhomogeneities as galaxies and clusters.

Still another speculative possibility for the initial conditions of the universe is based on Mach's principle: The motion of an object is determined not by the characteristics of some "absolute" geometrical space but solely by the material content of the universe. (The principle was first advanced in 1893 by Ernst Mach in a critique of Newton's concept of an absolute space to which the motion of all objects is referred.) Although Mach's principle is not a consequence of the theory of relativity, it has been introduced into the theory either as a boundary condition on the relativistic equations or as a sieve for eliminating solutions that are not physically acceptable. Derek Raine of the University of Leicester has developed a detailed version of the latter alternative, and out of his work comes the requirement that the infant universe be almost completely isotropic and homogeneous.

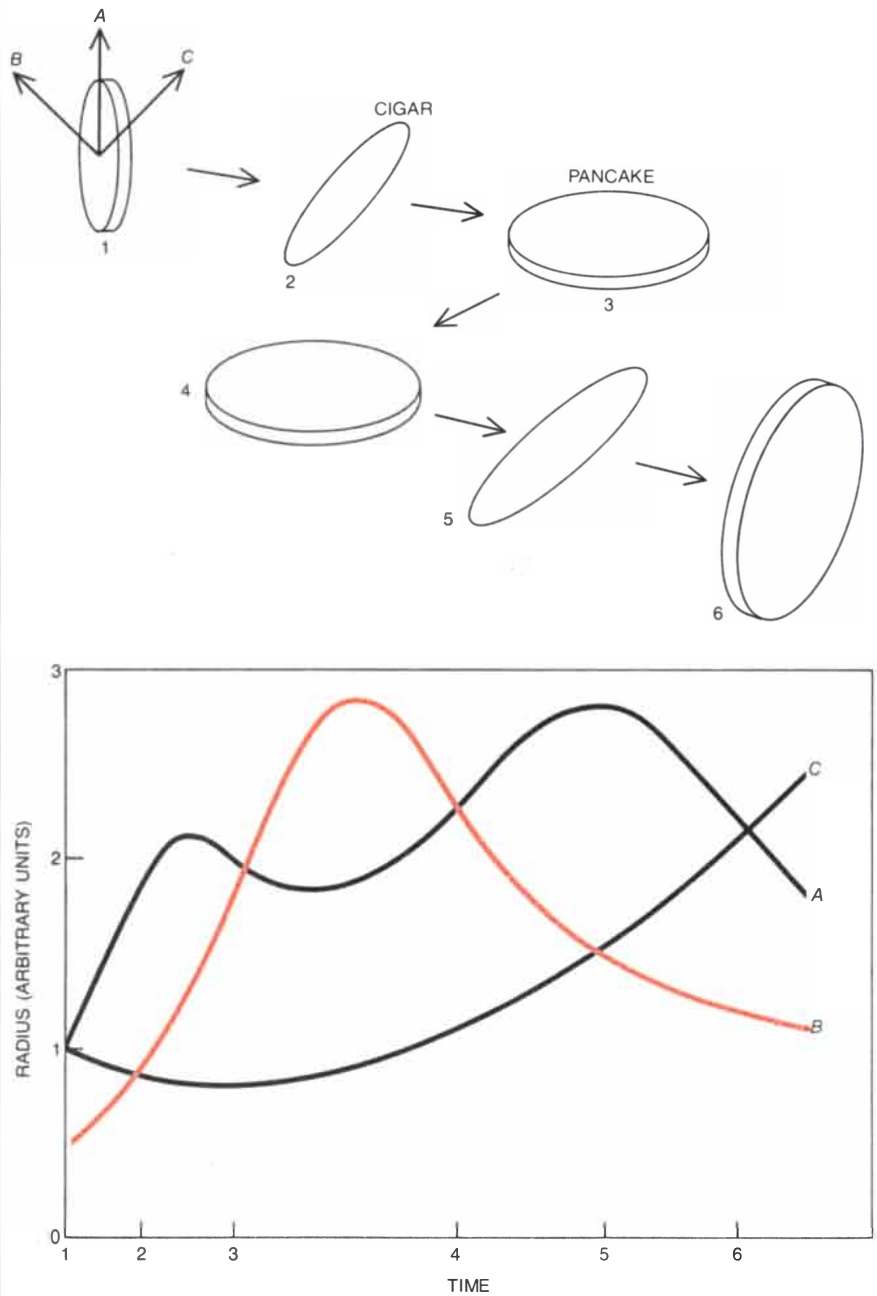
The last possibility we shall discuss is based on the idea that the initial conditions are limited by the very fact that they have led to human life on the earth. This idea, called the anthropic cosmological principle, was introduced by G. J. Whitrow of the University of London, Robert H. Dicke of Princeton University and Brandon Carter of the Meudon Observatory and was developed by John A. Wheeler of the University of Texas at Austin. Consider how this principle bears on the question of the size of the universe. Since the universe is constantly expanding, its size depends on its age. The anthropic cosmological principle has convinced us that the universe must inevitably be about 10 billion light-years in diameter. A smaller universe would have existed for less than the billion years necessary for the heavy elements essential to human life to be synthesized by thermonuclear reactions in the interior of stars. Moreover, if the universe were much bigger and hence much older, the stars needed to establish the conditions of life would have long since completed their evolution and burned out.

The anthropic cosmological principle bears on the universe's entropy level of 10^8. If this number were increased by a factor of 1,000 or so, it would not be possible for protogalaxies to condense to the density at which stars would form. Without stars the solar system and the heavy elements of living matter would not have been created. If the universe were initially fairly irregular, it would have irreversibly generated copious quantities of heat radiation because of the many efficient entropy-generating channels open to it at the time of the singularity. Again this would have resulted in an entropy and a radiation pressure in excess of the values favoring the condensation of protogalaxies. Such a universe could not have been observed by us. These ideas indicate one thing: man's existence is a constraint on the kinds of universes he could observe. Many features of the universe that are remarkable to ponder are inevitable prerequisites of the existence of observers.

This unusual approach has even been extended to the values of the fundamental constants of nature. Consider a change in the strength of the strong-interaction coupling constant of only a few percent. As small an increase as 2

percent would block the formation of protons out of quarks and hence the formation of hydrogen atoms. A comparable decrease would make certain nuclei essential to life unstable. By the same token small changes in the electric charge of the electron would block any kind of chemistry and rule out the existence of stable planet-supporting stars.

Although the anthropic cosmological principle indicates why the structural features of the universe are in some sense inevitable, it leaves the reason for these features a mystery. Whatever the scientific status of the anthropic cosmological principle may be, its impact on the history of ideas may be significant. The principle overcomes the traditional barrier between the observer and the observed. It makes the observer an indispensable part of the macrophysical world.



"MIXMASTER" MODEL OF THE UNIVERSE, developed by Charles W. Misner of the University of Maryland, is a complex cosmological model that is consistent with the general theory of relativity. The mixmaster universe is a ball of fluid that expands through a series of randomly oriented cigar and pancake shapes. As the universe expands in one direction it contracts in a perpendicular direction (*top*). The variation in the radii of three orthogonal axes (*A, B, C*) as a function of time shows the transition from the pancake form to the cigar form as the universe increases in volume (*bottom*). The numbers on the time axis correspond to the six shapes.

When someone needs the fire department, it's no time to be looking up a phone number.

The last thing *anyone* should have to do in an emergency is rummage through a telephone directory.

Now, instead of looking up the firehouse or police station, a doctor or relative, there's a simpler way.

You can ring them up by just touching one of four master pushbuttons on a remarkable new phone.

The phone? A brainy piece of equipment called the Security Phone,™ developed by the people of ITT.

All you do is plug this phone into a wall jack. (Your local telephone company will install jacks if you don't already have them.)

Then you merely punch in the four major emergency numbers, plus any six other numbers you call often or may need to call in a hurry.

And to make you even more secure, our Security Phone will work under any conditions.

Even in a blackout.

At ITT we make telephones for people with many needs.

But none is more basic than our Security Phone.

Because what's more basic than peace of mind?

ITT

The best ideas are the ideas that help people.

The Social Ecology of Coyotes

The nature of their food supply seems to determine whether they live alone or in a pack. Such patterns of behavior may bear on the question of whether or not they are a threat to livestock

by Marc Bekoff and Michael C. Wells

Motion-picture films about the American West almost always depict coyotes in the same way, as solitary animals howling mournfully on the top of a distant hill. In reality coyotes are protean creatures that display a wide range of behavior. They are characterized by highly variable modes of social organization, ranging from solitary (except for the breeding season) and transient individuals to gregarious and stable groups that may live in the same area over a long period of time. Between the two extremes are single individuals and mated pairs that tend to remain in one area. Indeed, a single coyote may in its lifetime experience all the different grades of sociality. This remarkable flexibility in the ways coyotes interact with one another can best be understood by examining their ecology, or the ways they interact with their environment.

It is generally accepted that most animal characteristics are the product of an interaction between inherited predispositions and the environment. In other words, although the cumulative passing of genes by successfully reproducing individuals establishes certain tendencies in each animal, many observable traits are subject to modification by proximate, or immediate, factors in the animal's environment. Thus many of an animal's traits, in particular behavioral ones, can be viewed as adaptations to the environments in which the animal has lived or is living. For example, the Dutch ethologist Hans Kruuk, who has done intensive studies of hyenas, has concluded that for many large carnivores, which typically have few predators (other than man), the nature of food resources is an important proximate factor that influences social behavior. More precisely, it appears that variations in the sociality of carnivores of the same species can often be traced to differences in their food supply.

For the past three years we have been observing the behavior of coyotes in the wild, mostly in Grand Teton National Park near the town of Jackson in northwestern Wyoming. Our studies indicate that the social organization of coyotes is indeed a reflection of their food resources and that three variables have a direct and significant impact in this regard: the size of the available prey, the prey's spatial distribution and its temporal, or seasonal, distribution. We shall report on our findings about both the specific behavioral adaptations coyotes seem to make to different types of food supply and the advantages these adaptations seem to confer. Before we undertake to sort out this aspect of the complex relation between coyotes and their environment we shall briefly describe the animals and the setting in which we are studying them.

Coyotes (*Canis latrans*) belong to the same mammalian family as jackals, foxes, wolves and domestic dogs. There are 19 recognized subspecies of coyotes, but because the animals are currently more mobile than they used to be and crossbreed to a greater extent there seems little reason to retain the more refined classification. Coyotes mate once a year and are generally monogamous, so that the same pair may mate in the same area over long periods, often returning to the same den site year after year. (Coyotes bear their young in holes in the ground, which they may or may not dig for themselves; the coyotes we observed generally made use of holes that had already been excavated by badgers.)

In a study of coyotes in the Canadian province of Alberta, Donald Bowen of the University of British Columbia noted that coyotes living in packs not only eat, sleep and travel in close association with one another but also tend to exhibit dominance relations. Franz J. Camenzind, who has studied coyotes on the National Elk Refuge adjoining the town of Jackson, has made similar observations. In general pack members are more sociable with one another than they are with outsiders, such as single coyotes living in the same area or passing through. It appears that most members of a coyote pack are genetically related. Indeed, the basis of coyote social structure is probably the mated pair supplemented by those offspring that do not leave the pack when they are old enough to care for themselves.

Typically only one male and one female breed in each pack. Some of the nonbreeding individuals may help to raise other members of the pack, most probably their younger siblings, and to defend food supplies, mainly against other coyotes. Packs may also include nonbreeding hangers-on, probably also offspring of the mated pair in the pack, that continue to live in the vicinity of the pack but interact very little with it. (It is possible that these individuals benefit from such a minimal association by "inheriting" a breeding area after a parent leaves it or dies.)

Coyotes are found in diverse habitats in Canada, Central America and most of the states of the continental U.S., but even within a single geographical setting their social behavior can vary dramatically. Our primary site for the long-term observation of wild coyotes is the area around Blacktail Butte in the southeastern corner of Grand Teton National Park. This is a particularly good place for a study of behavior and ecology because the animals that live in the park are relatively unaffected by man. Moreover, from Blacktail Butte, which rises some 300 meters from the surrounding valley floor, it is easy to observe coyotes going about their normal activities. Our findings for the Blacktail Butte area have been supplemented by observations of coyotes one of us (Bekoff) made with the aid of several students in Rocky Mountain National Park in Colorado. In the Moraine Park section of that park, where the study was carried out, the environmental conditions were quite different from those found at Blacktail Butte, and so in many cases comparing data from the two locations has helped us to identify variables influencing social behavior. We have also done experiments with animals in captivity, so that relevant competing variables could be more closely controlled.

For studies such as ours it is important to be able to identify various mem-

bers of a wild population, but in the case of coyotes distinguishing characteristics such as size (ranging from eight to 20 kilograms for males) and coat color (a highly variable blend of white, gray, brown and rust) may change with time. As a result it has been necessary to capture and mark individual coyotes, and for this purpose we generally rely on foot traps, the jaws of which are wrapped with thick cotton padding to reduce the likelihood of injury to the trapped animal. To keep the coyote from thrashing around in the trap we frequently attach a tranquilizer pellet, which the animal usually swallows. The tranquilizer sedates the trapped coyote but does not render it unconscious. The trap lines are covered on foot, on skis or by automobile every six to eight hours so that the coyotes are restrained no longer than is necessary.

Once a coyote has been captured it becomes extremely docile, and so when we find a coyote in one of our traps, we immediately release it and then proceed to weigh it, note its sex, make an assessment of its physical condition and estimate its age. Next we attach a colored identification tag to each ear and fit it with a collar bearing a small radio transmitter. In this way after the coyote is released we can identify it even when it is out of sight, and we can always tell which coyotes are associating with one another. Because the area around Blacktail Butte is quite open, however, we are usually able to see the coyotes (with binoculars or a spotting telescope if not with the eye), and the radio transmitters serve primarily for the gathering of data on wide-ranging movements of individuals and groups.

There are many ways in which the nature of food resources might influence the social behavior of coyotes. For example, when large prey animals such as ungulates (hoofed mammals) are available, several carnivores (including lions, wolves, jackals and African wild dogs) have been seen to band together in packs for cooperative hunting. Pack living may also be an adaptation for the defense of major food supplies such as caches of carrion. The observations of David Macdonald of the Animal Behavior Research Group at the University of Oxford indicate that this is the case for golden jackals (*Canis aureus*) found in Israel. We have observed that for coyotes, at least in the conditions under which we are observing them, group hunting is a rare and generally unsuccessful undertaking. In fact, from our vantage on Blacktail Butte we have never seen either a group of coyotes or a single coyote attacking a large live ungulate. On the other hand, our findings and Bowen's indicate that coyotes do group together to defend certain food resources.

In the area around Blacktail Butte there is a significant seasonal fluctuation in the food items that sustain coyotes. In "summer" (the period from May through October) the coyotes feed mainly on rodents such as pocket gophers, field mice and Uinta ground squirrels. In "winter" (the period from November through April) the major food supply is the carrion of ungulates such as deer, moose and in particular elk that have died from causes other than coyote predation. To put it another way, in summer the coyotes hunt and kill small prey that are generally distributed widely over the area in which the coyotes live and in winter they feed on large dead prey (mainly elk) that because of the formation of herds and legal hunting by human beings during a limited season generally tend to be distributed

MEMBERS OF A COYOTE PACK gather around the carcass of an elk in the snow on the National Elk Refuge adjoining the town of Jackson, Wyo. Coyotes display remarkably flexible patterns of social organization, ranging from transient individuals and mated pairs to large, stable groups that tend to remain in one area. Studies of these animals in the wild indicate that pack living represents an adaptation to large, clumped food resources such as the carrion of ungulates (hoofed mammals), whereas solitary living is associated with the availability of small live prey such as rodents (*see illustration on page 136*). Coyotes have rarely been observed to prey on the large ungulates (elk, moose and so on) whose carrion generally sustains them in winter; the elk shown in this photograph died of other causes.

as isolated clumps of carrion. The increased availability of carrion in winter is a widespread phenomenon, largely as a result of the higher ungulate mortality in that season.

Our basic hypotheses about the role that the size of food items and their spatial and seasonal distribution play in molding coyotes' social behavior suggest that it should be possible to see variations in the sociality not only of populations of coyotes with access to different food resources but also within a single population from season to season. To determine the effects of the seasonal fluctuation of prey at Blacktail Butte we compared the sizes of the coyote groups we found there in summer and in winter. Between September, 1977, and August, 1979, we made more than 1,000 sightings of 35 marked coyotes and about 15

PACK MEMBER DEFENDS CARRION (not visible) by "threat gaping" at an intruding coyote to chase it away. The two coyotes at the lower right belong to the same pack as the coyote at the center does and so remain unthreatened near the carrion. Ability to successfully defend such a food supply appears to be one of principal advantages of pack living. Photograph was taken by Franz J. Camenzind.

THREE-WEEK-OLD COYOTE PUPS require feeding and protection and remain close to the hole in the ground that serves as their den. (Although coyotes may excavate their own den, these pups are in an abandoned badger hole their parents enlarged.) Coyote pups begin to make forays away from the den when they are two to three months old, and they may strike out on their own when they are six to nine months old. It seems that most members of a coyote pack are genetically related and that the basis of coyote social structure is probably the mated pair supplemented by a number of nondispersing offspring. In most instances only one male-female pair in a pack breeds.

unmarked ones and found that in the summer months, when rodents were the major food resource, the average group size was 1.3 individuals and that in winter the average rose to 1.8. Hence the availability of large, clumped prey items did seem to be correlated with heightened sociability in these coyotes.

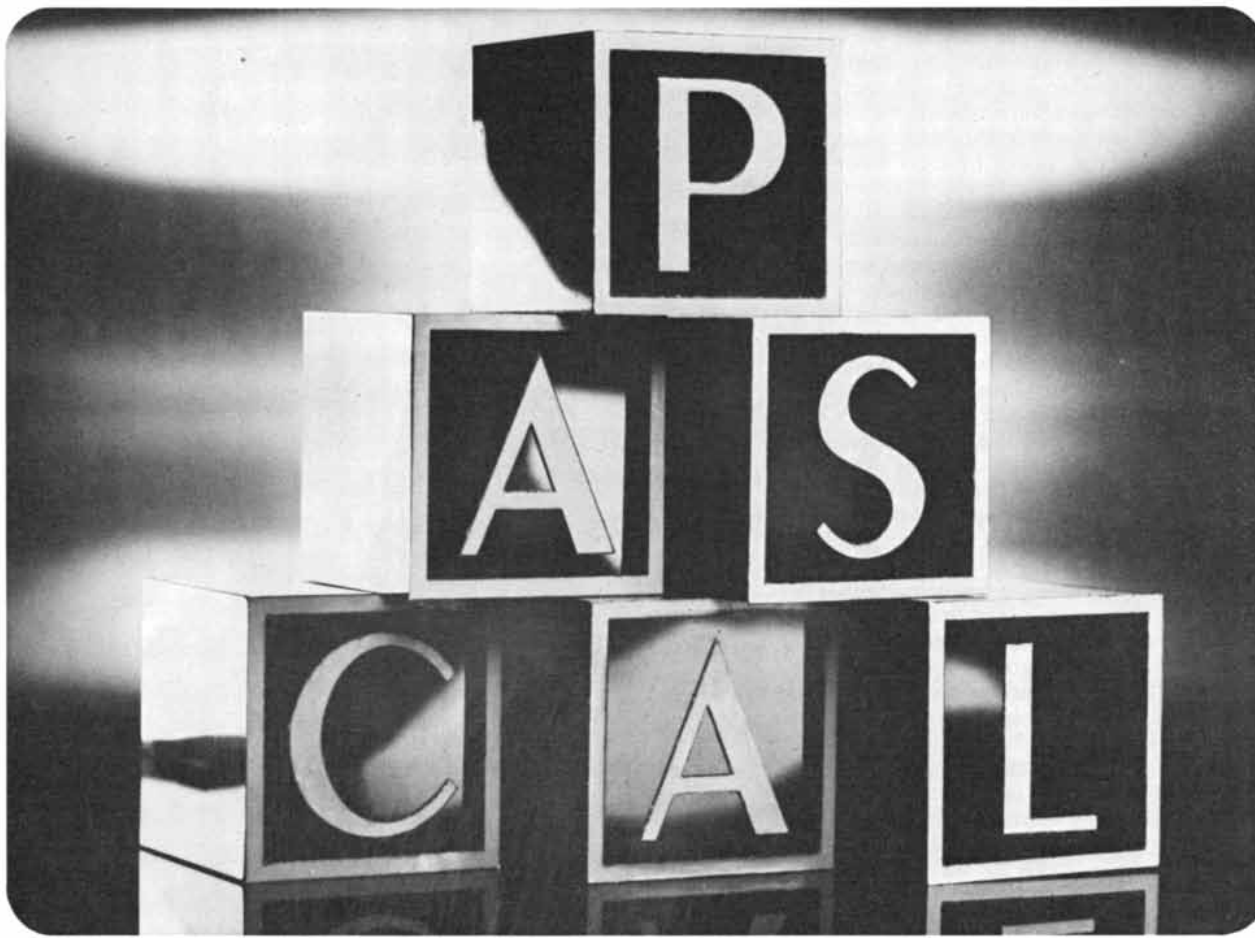
Moreover, we made another interesting discovery when we compared our findings with Camenzind's for coyotes on the National Elk Refuge. Camenzind's observation site is only about seven kilometers from our own, but since many more elk winter there, the supply of ungulate carrion is larger and denser. Camenzind found that on the elk refuge the coyote groups were also larger, with an average group size of 1.6 individuals in summer and three in winter. This finding suggests that the increased availability of ungulate carrion in winter not only serves to increase sociability in that season but also may have a cumulative effect, resulting in increased gregariousness the following summer. It is also interesting to note that in the Moraine Park area of Rocky Mountain National Park, where for three successive winters there was virtually no ungulate carrion, the situation was quite different. The coyotes were forced to depend on small rodents throughout the year, and the average group size in both summer and winter was 1.1.

We also compared the frequency with which three coyote social groupings—single individuals, mated pairs and packs of three or more individuals—were sighted at the various observation areas over an entire year. For example, at Blacktail Butte 35 percent of our sightings were of packs and about 50 percent were of single individuals, either transients passing through an area occupied by a pack (or by a mated pair) or solitary coyotes living on the edges of the area. On the carrion-rich elk refuge, however, only about 15 percent of Camenzind's observations were of single coyotes and about 60 percent were of packs. It would appear that in the vicinity of Blacktail Butte, where ungulate carrion is scarcer and is clumped in only a few small areas, fewer individuals can live in packs that defend these resources. The remaining coyotes, which are generally excluded from the clumped carrion, must forage widely for food, either alone or as a mated pair. This conclusion is supported by the fact that at the Rocky Mountain National Park site, where there was almost no carrion, 97 percent of the sightings were of single individuals.

In order to gain a better understanding of the nature of coyote groupings and the advantages of the adaptation to defendable resources we did not have to cover a large area. Indeed, the observation over the past three years of two groups of coyotes with contiguous home

What if you chose HP products to

For example: PASCAL/1000, a modern computer language that makes programs simple to write, easy to debug, and inexpensive to maintain.



Pascal/1000 is Hewlett-Packard's new, high-level, structured programming language for HP 1000 computers. By "structured," we mean that a Pascal program is written in modules in much the same way that a building is put together with standard building blocks.

Who uses Pascal? Those concerned about a program's total cost: the time spent designing, coding, debugging, and maintaining it. In all these areas, Pascal/1000 offers real benefits.

- In the design phase, Pascal's inherently independent modular structure promotes efficient, logical program design, and maximizes team programming efforts.
- In coding a Pascal program, data typing and statement control constructs are tools that help the programmer express the program logic clearly, thus avoiding logic errors and decreasing the testing time.
- During debugging, Pascal aids the programmer with extensive error checking.
- Pascal's control and data structuring facilities provide a level of readability invaluable for program maintenance—often an area of major software costs.

The result? Increased programmer productivity.

Pascal/1000's compiler is a full implementation of standard Pascal plus extensions of the language such as separate compilation, double-word integer and double-precision real data types, predefined procedures for random I/O, and the ability to link Pascal programs to external Pascal, FORTRAN, or assembly subroutines. (And to interface with HP graphics, data base management, and communications software.)

The Pascal/1000 software package price is $4000*

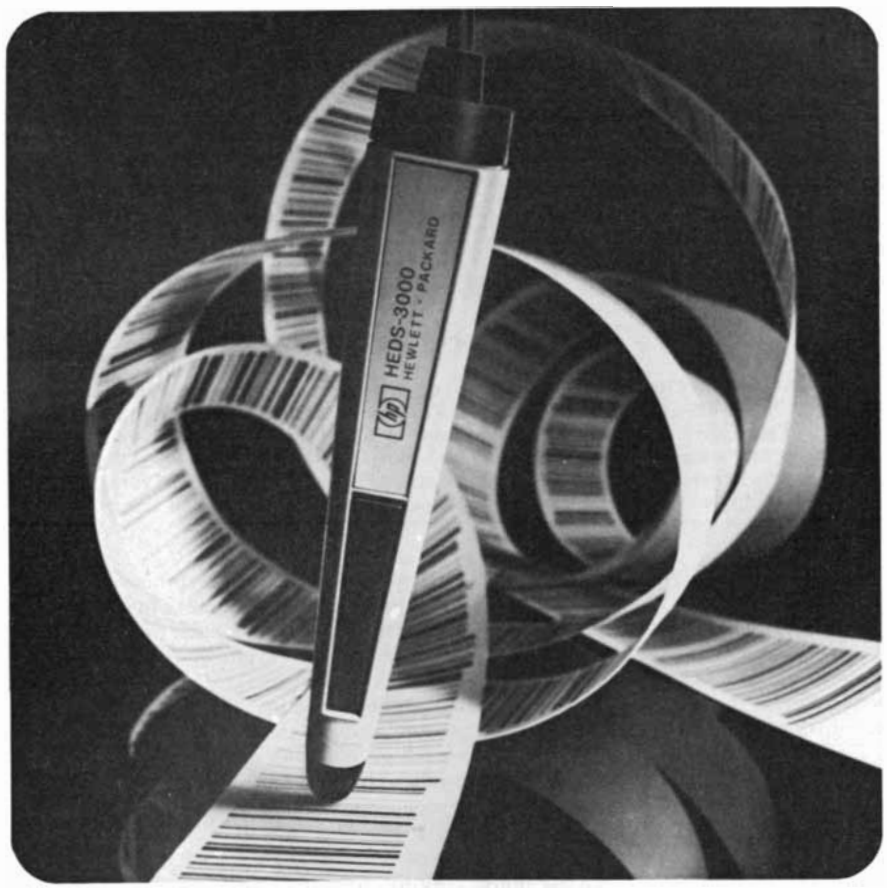
enhance your productivity?

For example: HP's new digital wand. It reads bar codes and transforms them into data a microprocessor can understand.

Anyone using a keyboard or pushbuttons for data entry could benefit from using bar codes. Bar code scanning is two to four times faster than key entry, and because it eliminates keying errors and contains built-in checksums to prevent misreadings, it is more accurate as well.

HP's new HEDS-3000 digital bar code wand compounds the advantages of bar code data entry with its speed, reliability, low cost, and ease of use. Contained in its 5.2-inch (13.3-cm) length is all the circuitry needed to scan bar code and convert it to microprocessor-compatible digital output. The heart of the wand is a precision optical sensor. Signal-conditioning circuitry—an analog amplifier, a digitizing circuit, and an output transistor—provide TTL- and CMOS-compatible logic-level output.

As part of a portable data entry system, the wand can be used to read shelf tags for inventory control and order entry. Another interesting and very practical use for the wand is an input device for computers and programmable calculators. It can read programs and data printed in bar code form, and load them into the computer in a matter of seconds. (HP is making its own use of this faculty: the wand will soon be available as an input device for the HP-41C fully programmable hand-held calculator.)



Not magic but close to it, the HEDS-3000 wand has a unit price of $99.50* in quantities up to 99.

For more information, mail the coupon to Hewlett-Packard, 1504 Page Mill Road, Palo Alto, CA 94304. Or call the HP regional office nearest you: East (201) 265-5000, West (213) 970-7500, Midwest (312) 255-9800, South (404) 955-1500, Canada (416) 678-9430.

These are only two of many thousand product reasons for choosing HP.

HEWLETT PACKARD

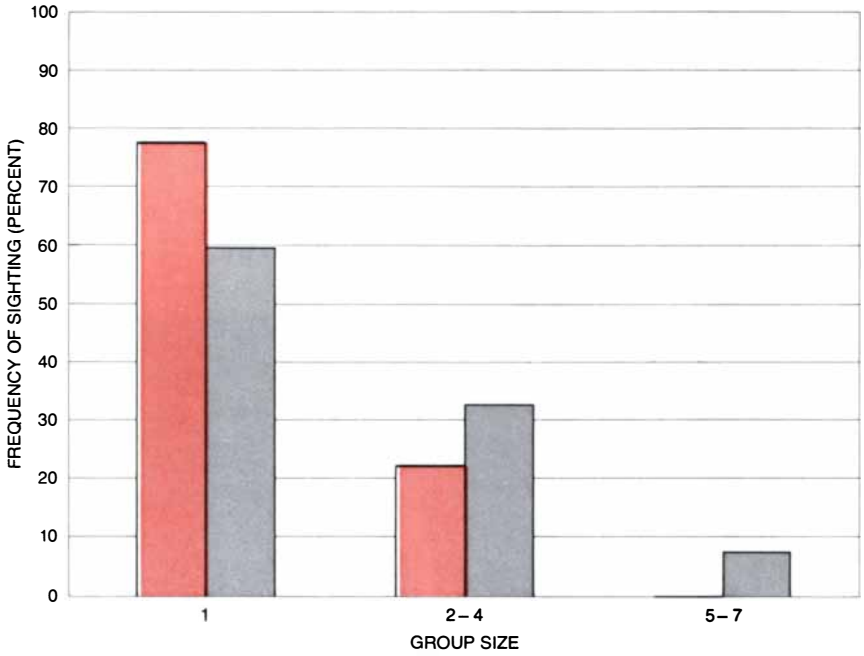
Mail to: Hewlett-Packard, 1504 Page Mill Road. Palo Alto, CA 94304
Please send me further information on

( ) Pascal/1000 programming language
( ) HEDS-3000 digital bar code wand

Name _____
Company _____
Address _____
City _____ State _____ Zip _____

*Domestic U.S. prices only.

00042



SEASONAL VARIATION in the sociability of coyotes may reflect a seasonal fluctuation in the availability of different prey items. This chart compares the frequency with which groups of different sizes were sighted from Blacktail Butte in Grand Teton National Park in Wyoming during the "summer" season (May through October) and the "winter" season (November through April). In summer (*color*), when coyotes sustained themselves by catching rodents, they were significantly less social than in winter (*light gray*), when ungulate carrion was available.

ranges in the vicinity of Blacktail Butte has provided us with ample evidence of the ways in which food supply can influence social behavior. (An animal's home range is defined as the area it covers routinely in the course of its daily activities.)

For example, in the winter of 1978–79 there was a significant difference in the quantity of elk carrion found on the two home ranges. Completely by chance (no attempt was made to control the distribution of carrion in the Blacktail Butte area) Group *A* had about 17 percent of the available carrion and Group *B* about 83 percent. As might be expected, Group *A* was the smaller one, consisting from November, 1978, through April, 1979, of only a single mated pair. All the young of the pair from previous years had dispersed. In the same period Group *B* had four members: a mated pair, an adult male born to them in 1977 and a male yearling born to them in 1978. (The older nonbreeding male helped to raise its siblings born in 1978.) The group also included two female hangers-on, one that was born to the mated pair in 1978 and another that we believe was born to them in 1977; these individuals rarely interacted with the members of the pack but were allowed to remain in their vicinity. From November, 1978, through the following May (and beyond) the four main members of Group *B* were highly cohesive: eating, sleeping, traveling and defending carrion in close association with one another. In this period only 6 percent of the sightings of pack members were of single individuals and more than 50 percent were of all four pack members together. From November through April the male and female of Group *A* were observed together 71 percent of the time, and on the remaining occasions each animal was seen in the vicinity of other coyotes, although not in close association with them.

It has been observed that when coyotes other than a mated pair spend a winter together, there is an increased probability they will also spend the summer together. Our observations of the two groups in the area of Blacktail Butte indicate that when winter food is in good supply, older pups may continue to share at least a part of their parents' home range, and that if the pups remain in association with their parents throughout their first winter, there is a good chance that as yearlings they will remain through the following summer and perhaps beyond. It is interesting to note that two of the young that left the home range of Group *A* (the mated pair) in the fall of 1978 returned to it (from the National Elk Refuge, where they had spent the winter) the following spring, their return coinciding with the seasonal increase in rodents on the parental home range. These yearlings have remained solitary, not helping to raise their younger siblings, and in general they appear to be less closely bonded to their parents than the yearlings in Group *B*, which never left the pack.

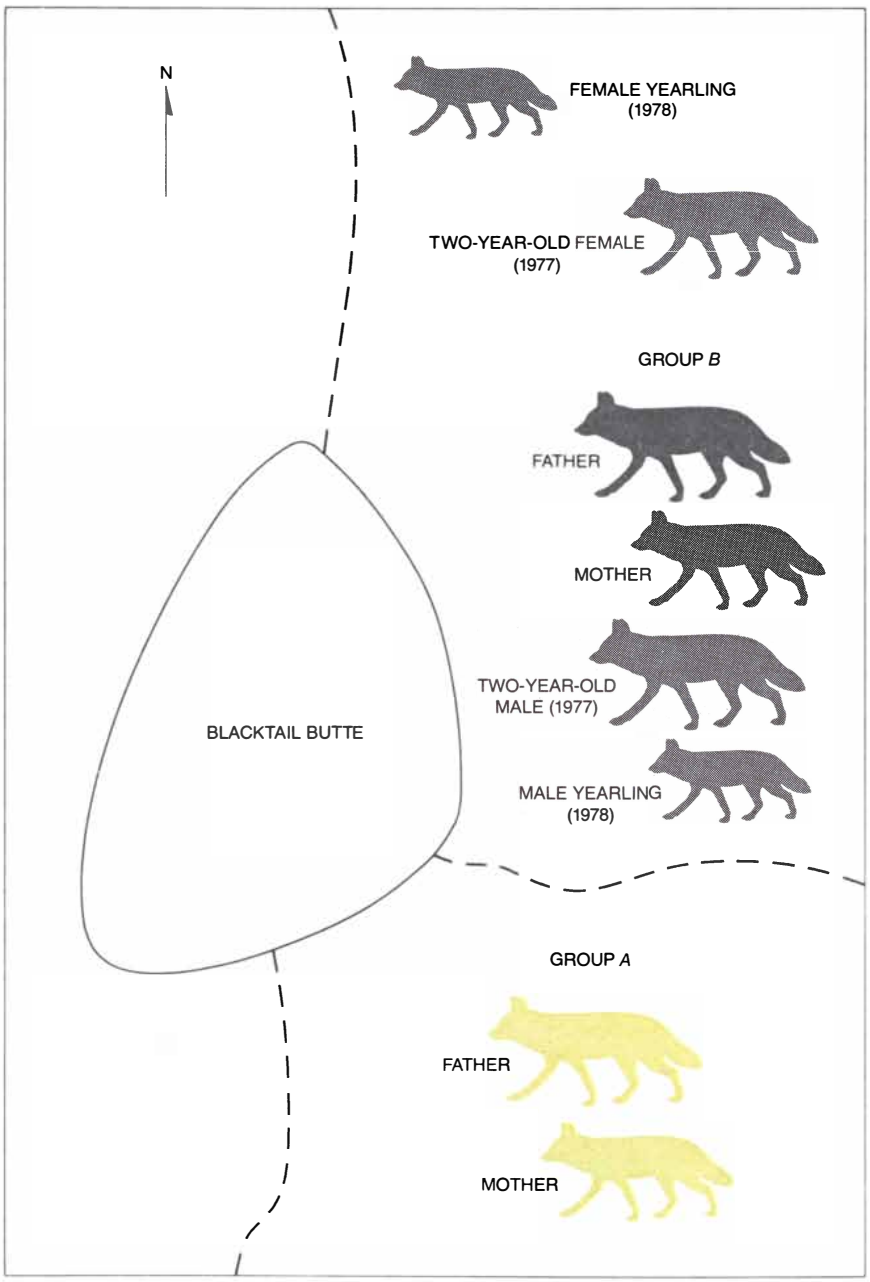
During the past winter (1979–80) there has been another interesting development in the relation between food availability and social organization in the coyote groups living in the vicinity of Blacktail Butte. In the previous two winters heavy snows fell in our study area in December, but this year snow did not blanket the home ranges of Group *A* (the mated pair) and Group *B* (the pack) until late January. As a result rodents were available in greater number and for a longer period than they had been in the preceding winters, supplementing the usual winter supply of elk carrion. In the previous two winters all the young from Group *A* had dispersed by November, but this year a juvenile born in April, 1979, was still with its parents in February. (In Group *B* three juveniles born in April, 1979, still remained with the pack in February.) Thus it appears that a naturally occurring change in the coyotes' food resources resulted in a change in their social organization, at least over a short period of time. The consequences of this change will be investigated in the future.

Social bonding is not the only aspect of coyotes' social behavior that is affected by variations in the food supply. Such variations also have a strong influence on how the animals make use of space. For the purposes of this discussion it is important to understand the distinction between a home range, the area an animal or a group of animals covers routinely in the course of its daily activities, and a territory. A home range has a flexible, undefended boundary, so that the home ranges of different individuals or groups may overlap considerably. A territory, on the other hand, is defined as the area that an individual or group occupies to the almost complete exclusion of other animals of the same species and that it will actively defend against them. In some geographical areas coyotes clearly defend their territory against other animals, but in other areas there is no evidence that they are territorial. Our own findings indicate it is only coyotes in packs that are territorial; individuals with a fixed home range but living alone or in mated pairs are not. Consider the two coyote groups we observed in the area of Blacktail Butte.

The four members of Group *B* maintained as a group a territory with rigorous boundaries between themselves and Group *A*, the mated pair. They also repelled many other coyotes from their territory, sometimes chasing an intruder for as much as two or three kilometers. (In April, 1979, we saw the breeding female of the pack chase an intruding coyote for a kilometer only a few days after she had given birth to a litter, and when she returned to the den, her mate chased the intruder for three more kilometers.) On the other hand, the two members of Group *A* were never seen defending a part of their home range against any

other coyote. These findings, which are confirmed by those of other workers, indicate that the intensity with which an area is defended by individuals or groups is related to the presence of a large, clumped food resource.

We also found that a shortage of food clearly brings about increased trespassing into neighboring home ranges and territories, particularly those in which desired food items can be found. For example, although Group *A*, the mated pair, made frequent forays into the territory defended by Group *B*, no member of Group *B* was ever observed intruding onto the home range of Group *A*. In fact, the members of the pack rarely left their own territory, which is not surpris-



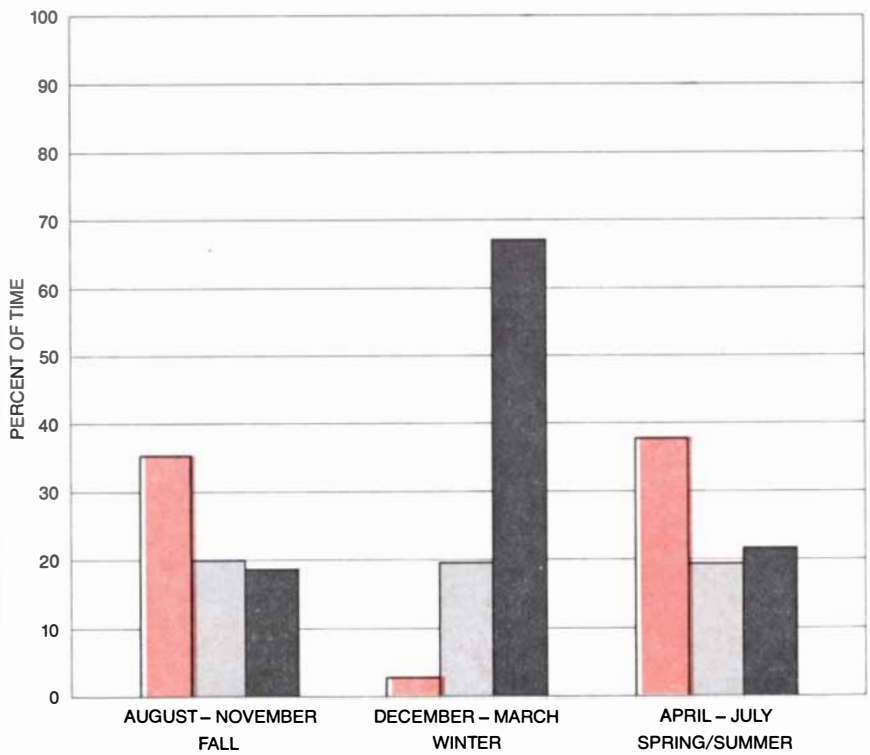
TWO COYOTE GROUPS inhabiting contiguous home ranges in the area around Blacktail Butte had access to significantly different amounts of elk carrion in the winter of 1978–79. (A home range is defined as the area an individual or a pack travels routinely in the course of its daily activities.) The home range of Group *A* held 17 percent of the available carrion, whereas the home range of Group *B* held 83 percent. As is shown here, the sizes of the groups differed accordingly: Group *A* (*color*) consisted of only a mated pair, all the young from previous years having dispersed; Group *B* (*gray*) consisted of a mated pair, a two-year-old male born to them in 1977 and a male yearling born to them in 1978. (One of the advantages of pack living may be that a breeding female receives help in caring for her young; the two-year-old in Group *B* helped to raise its siblings born in 1978.) Pack also included two hangers-on: a female born to the mated pair in 1978 and a female believed to have been born to them in 1977. These coyotes rarely interacted with their parents or siblings but were allowed to remain near them.

ing considering the wealth of ungulate carrion in it.

The sizes of coyotes' home ranges and territories vary markedly, although not consistently, with the locale, the season and the year and also with the age and the sex of the individuals. When we measured the home ranges of 10 adults in the Blacktail Butte area, we found that the average size was 21.1 square kilometers, with no discernible differences according to sex. When we classified the home-range sizes according to the coyotes' social groupings, however, we found that solitary individuals and mated pairs, which are excluded from carrion in winter, have a larger home range, with an average size of 30.1 square kilometers. Pack members, which defend a food resource in winter and tend to remain in their own territory, have an average home range of only 14.3 square kilometers. The sizes of pack members' home ranges also show considerably less variation, probably because of the clumped distribution of ungulate carrion.

Pack living confers advantages not only in the defense of food resources against competitors but also in reproductive activities. Coyotes generally mate in the period from January to April, the date varying from one locale to another. The female coyote's pregnancy rate, her productivity and her pups' rate of survival are clearly related to the general state of her health, which in turn is closely linked to the quantity and quality of the food available to her before and during pregnancy, that is, to the winter food supply. Therefore the increased ease with which pack members are often able to locate food items may represent an important reproductive advantage. Moreover, when we examined the amounts of time coyotes invest in other types of activity in winter and summer, we made an interesting discovery.

Coyotes typically are active in the early morning and early evening, but when we compared the time 50 coyotes (35 of them marked) devoted to hunting and resting, we found that in winter, when carrion is available but the food supply is usually low, much less time is spent hunting and considerably more is spent resting than is the case in summer, when small rodents are readily available but must be found, caught and killed. The higher ratio of resting time to hunting



RELATIVE AMOUNTS OF TIME that coyotes in the area of Blacktail Butte devoted to the activities of hunting (*color*), traveling (*light gray*) and resting (*dark gray*) in different seasons are shown. In winter, when the coyotes depended mainly on elk carrion, the animals hunted less and rested more than they did at other times of the year. Coyotes generally mate in the winter months, and their relative inactivity in this season may be beneficial for the breeding females. A comparison of the winter activities of traveling and resting for mated pairs living in packs and those living alone reveals additional energy savings for the former (*see illustration on page 140*). Percentages are based on 668 coyote-hours of observation (one coyote-hour is defined as observation of one coyote for one hour) from September, 1977, through August, 1979.

time may be generally beneficial for pregnant females, which must conserve energy for the nutritional demands placed on them during the nine-week gestation period and afterward. (There are six pups in an average coyote litter, and they are altricial, or dependent, at birth, requiring feeding and protection for the first few months of their life.) If females living in packs are able to spend more time resting than females living alone with their mate, then the pack-living females might reproduce more successfully. Moreover, as we have mentioned, females living in packs are more likely to receive help in raising their offspring.

Our findings about the pack-living adaptation of coyotes are supported by data gathered for golden jackals and hyenas, and we have been able to draw some general conclusions that should be tested with other species of carnivores. We have found that in situations where there are "haves" and "have-nots" with respect to the winter food supply (that is, individuals living in an area where a food resource is large and clumped as opposed to individuals living in one where the resource is scarce) the haves (1) are more social and cohesive than the have-nots, (2) are territorial and will defend the food resources, (3) have a more compressed home range, (4) are subject to higher rates of intrusion by members of the same species on the areas where the food is clumped and (5) in winter are able to travel less and so rest more. And the advantages of pack living can include any of the following: (1) food can be more successfully defended, particularly in winter; (2) food items can be more readily located; (3) individuals, particularly sexually mature females, can conserve energy needed for reproduction and care of the young, and (4) help, in the form of feeding and protection, can be provided for the young by individuals other than parents (most likely older siblings). Whether or not pack living confers an advantage in the acquisition of large prey remains an open question.

So far we have mainly discussed the pack-living adaptation to defendable food resources, but solitary living is also an adaptation to a particular food resource. For the coyotes we observed from Blacktail Butte the resource is rodents: prey items that coyotes cannot defend against other coyotes and that are difficult to share except with pups. Our studies have shown that even coyotes living in cohesive groups become temporarily solitary when they are hunting rodents. Hence just as it is important to study the various patterns of behavior associated with the group defense of territory and food, so it is important to study the various patterns of behavior associated with solitary predation. Not much is known about how wild coyotes

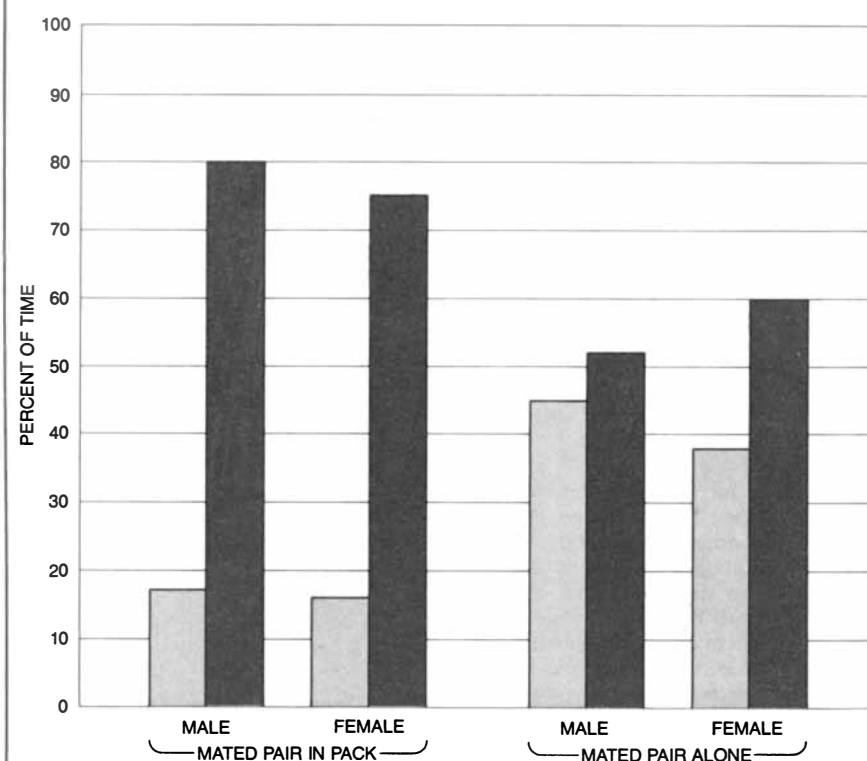
locate and capture prey, but we have done several experiments to throw some light on this type of behavior.

To begin with, the process by which any predator locates prey is complex, and different species of carnivores go about the task quite differently. Visual, auditory and olfactory stimuli are all clearly important and in nature probably interact to elicit the predator's response to the prey. It is interesting, however, to try to determine the relative importance of these three types of stimuli for coyotes and to try to relate such findings to the natural history of the species. The experiments required for the purpose are best done with captive coyotes, under conditions in which external stimuli can be rigorously controlled.

In the first set of experiments, conducted at Colorado State University in collaboration with Philip N. Lehner, coyotes were placed in a small room 30 meters square with a hidden rabbit. The time individual coyotes needed to find the rabbit with all possible combinations of the three types of stimuli was measured. Visual stimuli were suppressed by eliminating all light from the room (in which case the coyotes were tracked by means of infrared motion-picture photography), auditory stimuli by using a dead rabbit as prey and olfactory stimuli by either blowing a masking odor into the room (the odors from a rabbit colony) or by irrigating the coyote's nasal mucous membranes with a zinc sulfate solution.

The results of the experiments showed that when visual cues were present, the absence of auditory or olfactory ones led to only minor changes in the duration of the coyote's search for its prey. For example, with all three stimuli available the average search time was 4.4 seconds; with nothing but visual cues available the figure rose only to 5.6 seconds. With visual cues removed and only olfactory and auditory ones present, the average search time rose to about 36.1 seconds, or eight times the duration with all three types of stimuli. When auditory cues alone were present, the search time decreased slightly, to an average of 28.8 seconds; when olfactory cues alone were present, it went up to 81.1 seconds. With all three types of stimuli suppressed, it took the coyotes an average of 154.8 seconds, or more than 2.5 minutes, to find the prey by means of touch.

Thus under these experimental conditions the senses that facilitate the location of prey for the coyote are, in decreasing order of their importance, sight, hearing and smell. The fact that



MATED FEMALE IN A PACK spends significantly more time resting (*dark gray*) and significantly less time traveling (*light gray*) in winter than a female living alone with her mate, as is shown by this chart comparing these two activities for the breeding male and female in Group *A* (the mated pair) and Group *B* (the pack) in the vicinity of Blacktail Butte (*see illustration on page 137*). Females living in packs have not been observed to reproduce more successfully than other females, but it appears that if food became a limiting factor, then the pack-living females' substantial net energy savings might give them a reproductive advantage.

PONTIAC TAKES ON THE IMPORTS

GRAND PRIX vs. TOYOTA CELICA GT LIFTBACK AUTOMATIC

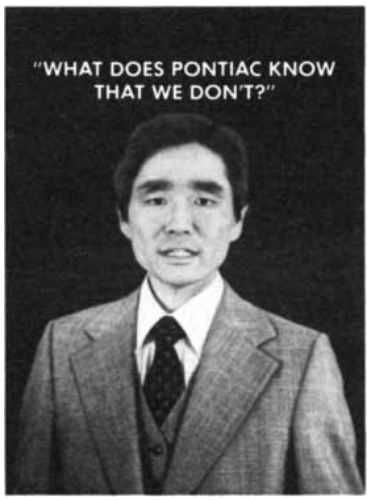
If you think grand touring cars with good gas mileage at good prices are strictly a Japanese art... take this quick appreciation class in the art of Pontiac Grand Prix.

GRAND PRIX IS PRICED $471 LESS.

A new six-passenger Grand Prix is priced at just $6448, while the smaller Toyota Celica GT is priced at $6919. This base car comparison of manufacturer suggested retail prices includes automatic transmission and dealer prep. Taxes, license, destination charges and available equipment additional. Destination charges vary by location and affect comparison. Level of standard equipment varies.

GRAND PRIX OFFERS THE SAME EST. MPG, BETTER HWY. EST.

Grand Prix and Celica GT both rate an impressive (20) *EPA EST. MPG*. But



Grand Prix's HWY. EST. of 27 is one mpg better than the Toyota's.

GRAND PRIX GOES FARTHER ON A TANK OF GAS.

Multiply Grand Prix's (20) *EPA EST. MPG* by its 18.1 gallon fuel tank and you'll see Grand Prix has an estimated range of 362 miles. While Celica GT's smaller 16.1 gallon tank gives an estimated range of only 322 miles. Remember: Compare the "estimated mpg" to the "estimated mpg" of other cars. You may get different mileage and range depending on how fast you drive, weather conditions and trip length. Actual highway mileage will probably be less than the estimated highway fuel economy. Mileage and range estimates lower in California. Grand Prix is equipped with GM-built engines produced by various divisions. See your dealer for details.

Add it all up and see if you don't agree Grand Prix is the winner. At your Pontiac dealer's now.

GM
MARK OF EXCELLENCE

AND WINS BY $471!

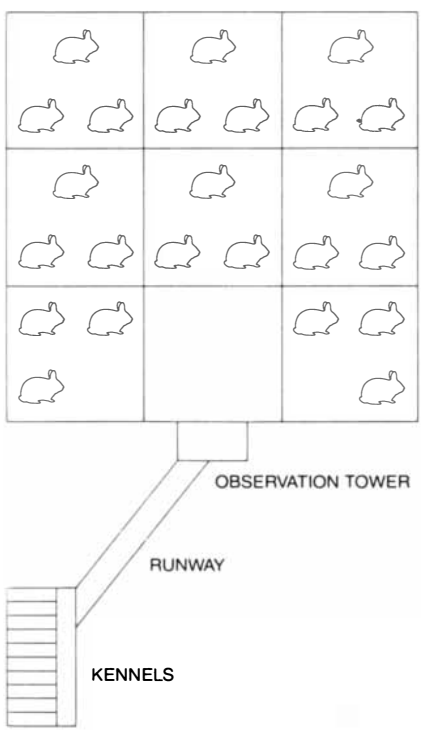
vision is of primary importance is confirmed by the results of another series of experiments in which coyotes were presented simultaneously with a hidden rabbit making sounds (breathing, rustling and so on) and a visible rabbit making no sound. The visible rabbits were without exception captured first. The coyote probably evolved on open plains covered with low-growing grasses, where prey would be highly visible, and its heavy reliance on vision is presumably the result of adaptation to this habitat.

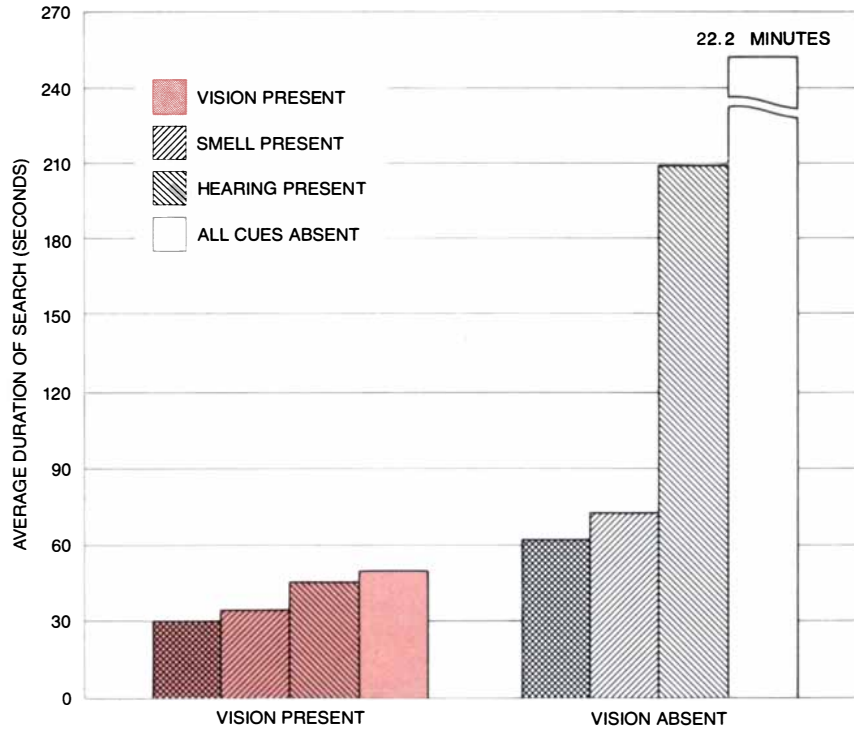
In order to replicate the coyote's natural hunting environment more closely a similar set of experiments was run outdoors in a large fenced-in area (6,400 square meters) at the Maxwell Ranch, owned by Colorado State University. With the larger search area and the larger number of distracting factors outdoors the average search times were all higher, but once again vision proved to be the most important sense in locating prey. Here, however, smell proved to be more important than hearing: the coyotes could find the rabbits faster with visual and olfactory cues present (when they needed an average of 34.5 seconds) than with visual and auditory cues present (when they needed an average of 43.7 seconds). Similarly, with only olfactory stimuli present the coyotes took an average of 72.7 seconds to locate the prey, and with only auditory stimuli the average search time rose to 208.8 seconds. When all three types of stimuli were present, the average search time was 30.1 seconds; when all three were suppressed, the average rose to about 22.2 minutes.

The differences between the results of the indoor experiments and those of the outdoor ones can be explained by taking into account the effects of the wind. Airborne olfactory stimuli are clearly important directional cues to a hunting coyote, as is indicated by the fact that outdoors, where smell was more important than hearing, 83.9 percent (47 out of 56) of the approaches to the rabbit were made from the downwind side. Similarly, at our study site in Grand Teton National Park we found that 74.9 percent of all the approaches we observed to mice by wild coyotes were from the downwind side. In addition, in the outdoor experiments where only olfactory cues were available to the coyotes, a significant correlation was observed between wind velocity and approach distance, or the distance at which a hunting coyote becomes aware of the location of its prey. More precisely, as the wind velocity increased the approach distance increased as well, so that when the wind was 10 kilometers per hour, the approach distance was about two meters, whereas when the wind rose to 40 kilometers per hour, the approach distance increased to about five meters.

Hence although the coyote seems to depend most heavily on vision when it is hunting, it appears to have effective backup systems that can be relied on when certain types of sensory cues are absent or inadequate. When prey are visible, pursuit based on visual cues is most likely to start before olfactory or auditory cues can come into play, but when the prey is well hidden, the coyote probably relies on some combination of olfactory and auditory cues. (The exact combination probably depends on the wind conditions and the amount of noise made by the prey.) Coyotes are highly efficient predators and can clearly switch back and forth between these various hunting modes in order to take maximum advantage of whatever the environmental conditions are at the time.

How does the coyote actually kill the prey it locates? Information on the subject may be useful not only to biologists interested in the comparative and evolutionary aspects of predatory behavior but also to those concerned with





EXPERIMENTAL SETUP for determining the relative importance of the senses of vision, smell and hearing for coyotes in locating prey is shown at the left. In each trial a rabbit is placed at random at any one of 24 possible locations in a large outdoor enclosure (6,400 square meters); a coyote is admitted to the enclosure, and the time required for it to find the rabbit is recorded. The procedure was repeated for five coyotes with all possible combinations of the three types of sensory stimuli present. Visual cues were eliminated by testing coyotes on a dark night (and observing them with a "starlight scope," which intensifies available light); auditory cues were eliminated by using a dead rabbit as prey, and olfactory cues were eliminated by irrigating coyotes' nasal mucous membranes with zinc sulfate solution. Average time required to locate prey under each condition is shown at right. Results of trials with visual cues present (*color*) have been separated from those with visual cues suppressed, showing that in locating prey coyotes' most important sense is vision. Hearing is least important.

SCIENCE/SCOPE

Two new TV-cameras-on-a-chip will serve as eyes for machines in a wealth of commercial and industrial applications. The devices, made possible by advanced charge-coupled technology, are called Hughes Omneye™ imagers. One chip consists of 1,024 light-sensing picture elements, the other of 10,000 picture elements for higher resolution. Typical uses of the imagers would be on assembly lines to help machines size, orient, and identify parts and objects. Compared to standard vidicon cameras, the devices are more reliable and rugged, and require less voltage and power.

Computers are freeing electronics engineers from monotonous tasks and giving them more time to be creative. With Computer Aided Design/Computer Aided Manufacturing (CAD/CAM) systems, engineers sketch designs on terminal screens and let computers create final drawings. They can have the computers assemble their parts or circuits and simulate the way they actually would work. In an important step toward "paperless" production, the computers also convert designs into coded form to run automated machinery in manufacturing. One Hughes CAD/CAM center helped to significantly reduce development costs of the AN/APG-65 radar, produced under contract to McDonnell Douglas for the F-18A Hornet.

After 13 years, despite a three-year design life, NASA's first Applications Technology Satellite continues to serve people from the South Pacific to Alaska. The Hughes-built ATS-1 was launched in December 1966 and stationed above the Pacific Ocean near Christmas Island. It took the first black and white picture of the entire earth from synchronous orbit and conducted communications demonstrations with several ground stations simultaneously. Users of ATS-1 include the American Lutheran Church, which holds educational teleconferences in the U.S. and abroad. The University of Hawaii, through its PEACESAT program, links educational and public institutions throughout the Pacific Basin. In Alaska, ATS-1 serves as an educational and doctors' call network.

Radar, air defense systems, electronic warfare, communications, anti-submarine warfare systems, and special-purpose and general-purpose computers -- these are among the programs being advanced at Hughes Ground Systems Group. That's why we're searching for electronics engineers, computer science graduates, mechanical engineers, mathematicians, and physicists. If you are one, and you want to move ahead of the industry tide, send your resume for immediate consideration to Hughes Aircraft Company, Ground Systems Group, Professional Employment, Dept. SE, 1901 W. Malvern Ave., Fullerton, CA 92634. Equal opportunity M/F/HC.

Remotely piloted vehicles using a new video processing technique could relay TV pictures with less chance of being detected or jammed by an enemy. The method, developed by Hughes for the U.S. Army, first separates potential targets from background clutter. Background areas are then converted into a white-on-gray outline picture that's updated every second. A window containing the prime target is allowed a fuller range of tones and is updated at a rate of 7-1/2 frames per second. Other targets receive lower resolution or are converted to symbols, and are updated every second. Though standard TV is sharper because it uses twice the line resolution and is transmitted at 30 frames per second, this compression technique transmits all vital data with one-thousandth the bandwidth.

Creating a new world with electronics

HUGHES

HUGHES AIRCRAFT COMPANY
CULVER CITY, CALIFORNIA 90230

the control and management of predators. Here it will be most convenient to distinguish between prey animals that are smaller than the coyote and those that are larger. (Coyotes do occasionally prey on large live animals, although as our observations of the coyotes in the area of Blacktail Butte indicate, this form of predation is rare.)

To begin with, we have observed seven distinct activities that can be included in the predatory behavior of a coyote when its prey is a small animal such as a rodent. In sequence they are long-distance searching (in which the coyote traverses large areas and scans the ground cover for a sign of prey), close searching (in which the coyote pokes around in the ground cover), orientation (in which the coyote assumes an alert posture, perhaps sniffing or pricking its ears to determine the exact location of detected prey), stalking (in which the coyote slowly and stealthily approaches its prey), pouncing (in which the coyote first rears up on its hind legs and then falls forward on its front legs to pin the prey to the ground), rushing (in which the coyote makes a rapid dash toward the prey) and finally killing. A coyote generally kills a rodent by biting it in the area of the head, and in many cases the coyote will also shake the prey vigorously from side to side.

It is important to understand that not all these activities are always included in a single predatory sequence. For example, we found that if the prey is a smaller rodent such as a field mouse, a coyote does not usually rush the rodent but simply stalks it and then pounces on it, pinning it to the ground so that a killing bite can be delivered. When the prey is a larger rodent such as a Uinta ground squirrel or a Richardson's ground squirrel, however, the coyotes we observed rushed it in more than 90 percent of the cases and pounced only rarely.

The success of the coyote's predatory sequences in catching and killing rodents varies considerably. Our data indicate that coyotes are successful between 10 and 50 percent of the time. We have not yet identified all the variables that influence the rate of success, but ground squirrels seem to be easier to catch than mice. The hunger level of a coyote may also be important. Observations in captivity reveal that satiated coyotes often play with a rodent before killing and eating it, and frequently the rodent escapes. Similar observations have been made in the field.

We also wondered whether the predatory skills of coyotes improve with age, and so we compared the time that nine young coyotes from three to six months old and 15 adults spent in the activities of searching, orienting and stalking when they were hunting mice or ground squirrels. The adults, it turned out, spent less time searching and orienting, and in addition the times adults devoted to these activities were much less variable than those of the pups. There was no difference in the time spent stalking, however, an activity to which coyotes in both age groups devoted an average of about 5.5 seconds. Therefore it would appear that the pups are less effective than the adults in locating their prey, but once the prey has been located coyotes in either age group will stalk briefly and then go in for the kill. Studies of coyotes in captivity also reveal that pups only 30 days old are capable of carrying out a successful predatory sequence on a mouse. In other words, although coyotes of that age rarely have an opportunity to kill a small rodent in the wild, they clearly have the ability.

Turning to the subject of how coyotes kill large wild prey, such as sheep, deer, elk and moose, there are for a number of reasons few observations from which useful generalizations can be drawn. To begin with, coyote kills are often indistinguishable from those of other wild predators or even domestic dogs. Moreover, it has been noted that most healthy ungulates living in the same locale as coyotes are able to defend themselves against a single coyote, so that instances of such predation are rare and hence difficult to observe. The few data that do exist indicate that two or more coyotes are usually required to take down, say, a healthy adult deer. In most cases coyotes appear to kill either young ungulates or weak ones, typically by attacking the head, neck, belly and rump. It is generally believed coyotes do not have any significant detrimental effect on wild ungulate populations.

The effects of coyote predation on domestic sheep are less clear-cut, which brings us to a more controversial aspect of coyote biology, namely the management and control of coyotes. Coyotes are said to have a significant detrimental effect on the sheep industry, and as a result for a century coyotes have been a particular target of predator-control programs. At present large amounts of time, energy and money (in many cases from public funds) are being devoted to such efforts. The returns on the investment are small, in terms both of reducing coyote populations and of preventing livestock losses and damage. The failure of the control and management programs is due essentially to the lack of sufficient background information on the behavioral and population dynamics of coyotes.

Indeed, very little is known about the predatory habits of wild coyotes with regard to domestic sheep. Guy Connolly and his colleagues at the United States Fish and Wildlife Service have found that even when coyotes are confined with sheep, their predatory behavior is surprisingly inefficient. In these experiments coyotes killed sheep in only 20 out of 38 encounters. Moreover, both

HP SOLVES MORE PROBLEMS...

...With a broader range of programmables and more extensive software solutions than anyone else.

Hewlett-Packard's extensive line of programmable calculators coupled with its vast range of software solutions lets you solve more problems more quickly and easily.

MORE SOLUTIONS

With programmable calculators hardware is only half the story. Hewlett-Packard's superior software support lets you spend your time solving problems rather than writing programs to solve your problems.

HP offers a growing collection of software solutions, from aviation navigation to x-ray diffraction. For use on-the-job or at your leisure. And HP software is available in several convenient forms: hundreds of easy to use, step by step key-in programs for all HP programmables; and preprogrammed magnetic cards, plug-in modules, and soon, bar-coded programs for fully-programmables. Plus thousands of software solutions in HP's Users' Library. So when you buy a Hewlett-Packard programmable, you're buying a more useful, efficient, and complete problem solver.

A PROGRAMMABLE FOR YOU

Hewlett-Packard has a full line of scientific and engineering programmables to choose from: six different programmables with a full range of capabilities. One of them is sure to meet your particular needs.

HP Scientific Programmables

HP-33E	Scientific Programmable	$ 90.00*
HP-33C	Scientific Programmable with Continuous Memory	$120.00*
HP-34C	Advanced Scientific Programmable with Continuous Memory	$150.00*
HP-67	Fully-Programmable	$375.00*
HP-97	Fully-Programmable Printing	$750.00*
HP-41C	Alphanumeric Fully-Programmable with Continuous Memory	$295.00*

The most extensive range of programmable calculators backed by the most extensive line of software solutions. It's an unbeatable combination and another example of Hewlett-Packard's commitment to the principle of "excellence by design."

For the address of your nearest HP dealer, CALL TOLL-FREE 800-648-4711 except from Alaska or Hawaii. In Nevada, 800-992-5710. For details, send the attached coupon or write: Hewlett-Packard, 1000 N.E. Circle Blvd., Corvallis OR 97330, Dept. 236Q.

HEWLETT PACKARD

HEWLETT-PACKARD
Dept. 236Q
1000 N.E. Circle Blvd.
Corvallis, OR 97330

Please send details on HP programmable calculators and software solutions.

NAME _____

TITLE _____

COMPANY _____

ADDRESS _____

CITY _____

STATE _____ ZIP _____

*Suggested retail price excluding applicable state and local taxes — Continental U.S.A., Alaska and Hawaii.

Displays photographed separately to simulate typical appearance.

610/03

Physician, did you miss any of these significant developments in medical science?

- **Adjuvant chemotherapy for breast cancer utilizing CMF enhances survival among premenopausal women with axillary lymph node involvement.**

- **Posttransfusion hepatitis is usually caused by "non-A, non-B" viruses.**

- **Lidocaine fails to control ventricular arrhythmias in as many as 20 percent of acute M.I. patients. Procainamide, given by a bolus and continuous infusion method, is effective in most of these cases.**

- **Cerebral embolism, producing both transient ischemic attacks and permanent strokes, is a complication of mitral valve prolapse.**

- **Cefoxitin is effective for disseminated gonococcal disease caused by penicillinase-producing organisms.**

- **Adenine arabinoside has been licensed for treatment of herpes simplex encephalitis.**

IF THESE ITEMS are familiar you must be a prodigiously energetic or prodigiously lucky reader. With 2,000 or more journals published each year, information that significantly affects patient management all too easily slips by. Textbooks are out-of-date before they are published.

SCIENTIFIC AMERICAN *Medicine* is the busy clinician's answer to this problem.

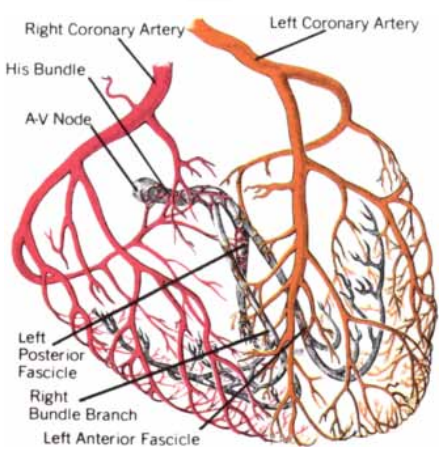
Because its authors update SCIENTIFIC AMERICAN *Medicine* every month, it is always current. Because the new information appears in a single source, it is there when you need it.

This 2,000-page, innovative union of publishing and electronic technology is the work of leading scholar-practitioners from Harvard and Stanford. The editors are Edward Rubenstein, M.D., F.A.C.P., and Daniel Federman, M.D., F.A.C.P.

Each month as authors update their contributions, revisions are entered on the magnetic tape on which the text and index are stored. The tape drives high-speed phototypesetting equipment so that subscribers receive about eight new chapters and a new index every four weeks; a bulletin highlights new developments.

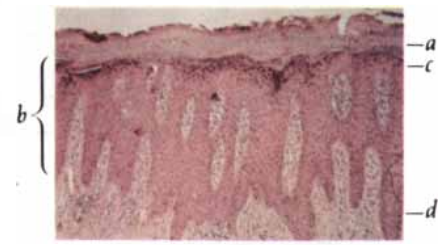
New material replaces old material in the living text, so that the information is there—up-to-date, at your fingertips.

A CME program of eight patient management problems offered over a 12-month period is available at no extra cost. As an organization accredited for continuing medical education, the Stanford University School of Medicine designates this continuing medical education activity as meeting the criteria for 32 credit hours in Category 1 for Educational Materials for the Physician's Recognition Award of the American Medical Association, provided it has been completed according to instructions. This program is approved by the American Academy of Family Physicians for 32 Elective Hours of CME credit.



Branches of the right and left coronary arteries supply blood to the AV node and intraventricular conduction system.

SCIENTIFIC AMERICAN *Medicine* is lucidly illustrated with drawings and photographs. Some examples are seen here and on the facing page.



Histopathologic changes in psoriasis.

Extensive psoriasis (top) cleared completely (bottom) after four weeks of treatment with anthralin.

Trial Offer

We invite you to try SCIENTIFIC AMERICAN *Medicine*—for two months at no cost. Send us the coupon and you will receive the two-volume text and two monthly updates. You may also take a CME test for credit. At the end of 60 days, if you decide to continue the subscription, we will bill you for $185 for the full 12 months (renewal is $160); otherwise just return the volumes to us.

Please mail the coupon today and let us take the hassle out of keeping up.

THE DISTINGUISHED AUTHORS AND THE FIFTEEN SECTIONS OF SCIENTIFIC AMERICAN ***MEDICINE***

1. Cardiovascular Medicine

Edgar Haber, M.D., Professor of Medicine, Harvard Medical School, Physician and Chief of Cardiology, Massachusetts General Hospital

E. William Hancock, M.D., F.A.C.P., Professor of Medicine, Stanford University School of Medicine

Roman W. DeSanctis, M.D., Professor of Medicine, Harvard Medical School, and Physician and Director, Coronary Care Unit, Massachusetts General Hospital

Adolph M. Hutter, Jr., M.D., F.A.C.P., Associate Professor of Medicine, Harvard Medical School, and Assistant Physician and Associate Director, Coronary Care Unit, Massachusetts General Hospital

Eve Elizabeth Slater, M.D., Instructor in Medicine, Harvard Medical School, and Chief, Hypertension Unit, Massachusetts General Hospital

2. Dermatology

Eugene M. Farber, M.D., Professor and Chairman, Department of Dermatology, Stanford University School of Medicine

Elizabeth A. Abel, M.D., Clinical Assistant Professor of Dermatology, Department of Dermatology, Stanford University School of Medicine

3. Endocrinology

Daniel D. Federman, M.D., F.A.C.P., Professor of Medicine and Dean for Students and Alumni, Harvard Medical School

4. Gastroenterology

Gary M. Gray, M.D., Professor of Medicine and Head, Division of Gastroenterology, Stanford University School of Medicine

Peter B. Gregory, M.D., Associate Professor of Clinical Medicine, Division of Gastroenterology, Stanford University School of Medicine

5. Hematology

Stanley L. Schrier, M.D., Professor of Medicine and Head, Division of Hematology, Stanford University School of Medicine

6. Immunology

John David, M.D., Professor of Medicine, Harvard Medical School, and Physician, Robert B. Brigham Hospital

7. Infectious Disease

Thomas C. Merigan, M.D., Professor of Medicine and Head, Division of Infectious Diseases, Stanford University School of Medicine

Morton N. Swartz, M.D., F.A.C.P., Professor of Medicine, Harvard Medical School, and Chief, Infectious Disease Unit, Massachusetts General Hospital

Cyrus C. Hopkins, M.D., Assistant Professor of Medicine, Harvard Medical School, and Hospital Epidemiologist and Associate Physician, Massachusetts General Hospital

Adolf W. Karchmer, M.D., F.A.C.P., Assistant Professor of Medicine, Harvard Medical School, and Associate Physician, Massachusetts General Hospital

Robert H. Rubin, M.D., F.A.C.P., Assistant Professor of Medicine, Harvard Medical School, and Assistant Physician, Massachusetts General Hospital

Harvey B. Simon, M.D., F.A.C.P., Assistant Professor of Medicine, Harvard Medical School, and Assistant Physician, Massachusetts General Hospital

Peter F. Weller, M.D., Assistant Professor of Medicine, Harvard Medical School

8. Intensive and Emergency Care

Edward Rubenstein, M.D., F.A.C.P., Associate Dean of Postgraduate Medical Education, and Professor of Clinical Medicine, Stanford University School of Medicine

9. Metabolism

George F. Cahill, Jr., M.D., Professor of Medicine, Harvard Medical School, Director of Research, Howard Hughes Medical Institute, and Physician, Peter Bent Brigham Hospital

10. Nephrology

Roy H. Maffly, M.D., Professor of Medicine, Stanford University School of Medicine, and Chief, Renal Service, Palo Alto Veterans Administration Hospital

11. Neurology

Robert W. P. Cutler, M.D., Professor of Neurology, Stanford University School of Medicine

12. Oncology

Saul A. Rosenberg, M.D., F.A.C.P., Professor of Medicine and Radiology, and Chief, Division of Oncology, Stanford University School of Medicine

13. Psychiatry

Ned H. Cassem, M.D., Associate Professor of Psychiatry, Harvard Medical School, and Chief, Psychiatric Consultation—Liaison Service, Massachusetts General Hospital

14. Respiratory Medicine

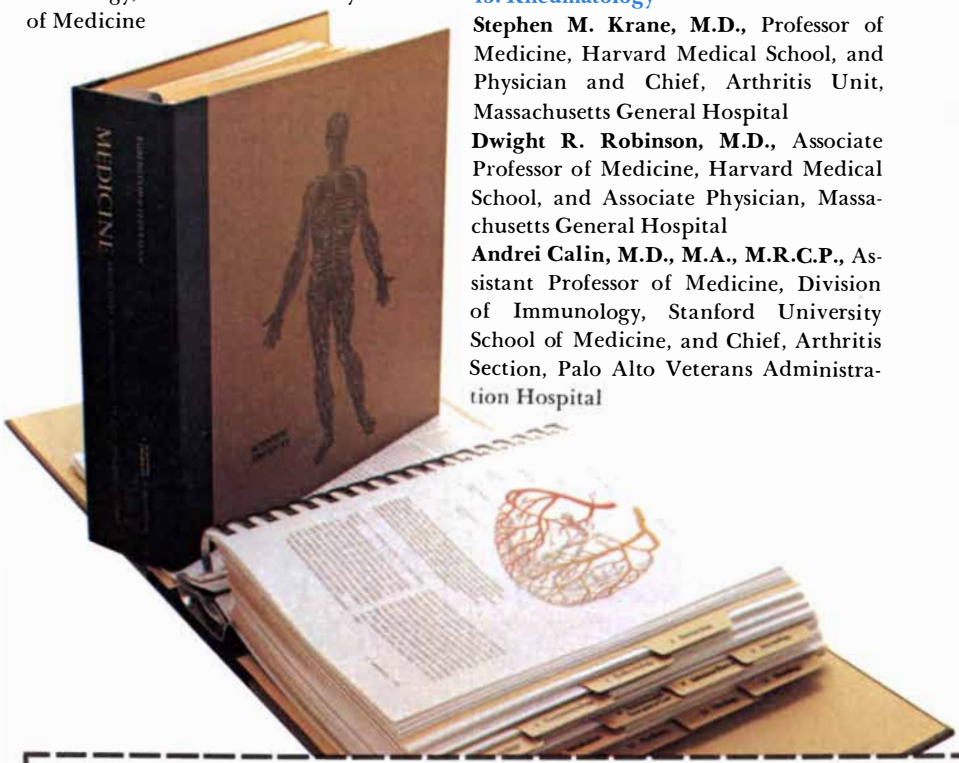
Eugene D. Robin, M.D., F.A.C.P., Professor of Medicine and Physiology, Stanford University School of Medicine

15. Rheumatology

Stephen M. Krane, M.D., Professor of Medicine, Harvard Medical School, and Physician and Chief, Arthritis Unit, Massachusetts General Hospital

Dwight R. Robinson, M.D., Associate Professor of Medicine, Harvard Medical School, and Associate Physician, Massachusetts General Hospital

Andrei Calin, M.D., M.A., M.R.C.P., Assistant Professor of Medicine, Division of Immunology, Stanford University School of Medicine, and Chief, Arthritis Section, Palo Alto Veterans Administration Hospital



the average time that elapsed before the coyotes attacked the sheep (47 minutes) and the average time that elapsed before the sheep were killed (13 minutes) were quite long, totaling an hour. The defensive behavior of the sheep deterred the coyotes in only 31.6 percent of the cases, and so it is understandable that the coyotes would take their time before killing the sheep. Of course, there are no instances of such inefficient predation in natural predator-prey interactions, where the prey either flees or actively fights off the predator as long as it can. It is clear, however, that sheep, which have been subjected to artificial selection by the great domesticator *Homo sapiens*, have been left virtually defenseless against predation.

Coyotes do kill sheep, then, as well as other livestock and poultry. Many studies have shown, however, that factors other than coyote predation can cause considerably heavier losses. For example, it was reported in a recent study that in the early 1970's the value of the losses of ewes and lambs in the state of Idaho amounted to $2,343,438. Of this total 36 percent could be attributed to disease, 30 percent to unspecified causes and 34 percent to predation; only 14.3 percent of the losses could be attributed to predation by coyotes. Moreover, there are data to indicate that not all coyotes are sheep killers and that the indiscriminate killing of coyotes in areas where sheep are being killed is an ineffective method of control. A recent study of livestock predation in 15 Western states issued by the Animal Damage Control Program of the Department of the Interior concluded that the relation between such predation and the population dynamics of coyotes is obscure.

In a sense the coyote is victimized by success: it is threatened because it takes advantage of livestock that have been robbed of most of their defenses by shortsighted practices of domestication. It is to be hoped that in the future defensive behavior will be bred back into livestock. For the present one can only assume that the failure of predation control is due to a lack of basic knowledge about predatory species, a problem that can be remedied by further studies of behavior and ecology of the kind we have described here.

We have found the coyote to be a particularly good subject for such investigations. Further field study will be needed to determine to what extent our findings can be applied to other coyote populations, to closely related species and to carnivores in general. In the meantime coyotes should be appreciated as animals that have adapted remarkably well to the pressures exerted by their environment, including harassment by man and the severe restriction of their natural habitats.

Hold On To Your Hat!

while you consider these notable books for your science library (and this splendid spring offer) from WILLIAM KAUFMANN, INC.

The Universal Traveler
A Soft-Systems Guide to Creativity, Problem-Solving and the Process of Reaching Goals

DON KOBERG and JIM BAGNALL. 128 pp., illus.

Over 150,000 copies in print. *"This is probably the book most likely to open the door to problem-solving kinds of thinking. Its digestible-pieces format, full of big graphics, lists, wide-ranging content, could be applied to persons needing to do work in groups, to do group think, reach goals, get work done or solve problems; as well, it can be used... to size up the journey of life..." —The Rainbook: Resources for Appropriate Technology.*

$5.95 paperback **A**

Splendid Spring Offer!

Free with every purchase of $15.00 or more: A copy of *The Universal Traveler*, our "soft-systems" bestseller. Limited time only: *Offer expires 8/31/80.*

Chicken Soup & other medical matters

S. HARRIS. Foreword by WILLARD ESPY. 10" × 7", 108 pp., illus.

Like chicken soup itself, Sid Harris's new book is a sure cure for whatever ails you. *Chicken Soup* is his first book since *What's So Funny about Science?* (a best-selling book and a selection of the Library of Science Book Club), newly assembled from *Playboy, Saturday Review, The Wall Street Journal, The Washington Star, The Chicago Tribune* and many other newspapers and periodicals to which he contributes regularly.

$7.95 hardcover **B**; $3.95 paperback **C**

Draw!
A Visual Approach to Learning, Thinking and Communicating

KURT HANKS and LARRY BELLISTON. 10" × 9", 242 pp., illus.

Over 900 drawings, cartoons, sketches and photographs, and brief, easy-to-grasp discussions of the essential tools, methods and techniques of modern drawing and design. *"A veritable symposium on the visual media... Hanks and Belliston are really showing us how to turn on an unused channel of thinking; how can you refuse such an offer?" —Human Behavior Magazine.*

$19.75 hardcover **D**; $9.75 paperback **E**

The Earth and Its Inhabitants
Selected Readings from *American Scientist*

BRIAN J. SKINNER, Editor.

A new series of books of readings for students and lay readers interested in *The Earth and Its Inhabitants*. The books will be published in uniform 8½" × 11" trim size, and will consist of articles from *American Scientist* magazine, selected and organized under the general editorship of Brian J. Skinner, Eugene Higgins Professor of Geology and Geophysics, Yale University.

The books in the series will be published during the spring and summer of 1980, in time for use in courses starting in the fall. Each paperbound book in the series will contain the full text and illustrations from *American Scientist* and will be uniformly priced at $5.95. Included in the series are the following titles:

The Solar System and Its Strange Objects	**F**
Earth's History, Structure and Dating Methods	**G**
The Atmosphere, the Ocean and Climate	**H**
Earth's Energy and Mineral Resources	**I**
Animals, Plants and Their Environments	**J**
Paleontology and Paleoenvironments	**K**
Evolution of Man and His Communities	**L**
Use and Misuse of the Earth's Surface	**M**

When ordering, *please specify titles* you would like to receive. Individual titles will be shipped as they are completed during 1980.

Instructors: Examination copies of this book are available from the publisher on request.

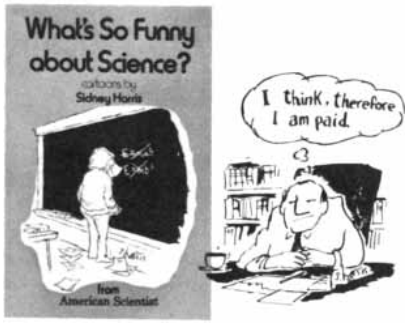
$5.95 paperback, per title

What's So Funny about Science?
Cartoons from *American Scientist*

SIDNEY HARRIS. 120 pp.

A collection of over 100 cartoons on a remarkable range of scientific and technical subjects, bringing out what is human and humorous in sophisticated scientific inquiry. S. Harris's inimitable cartoons have appeared in *Time, The New Yorker, Playboy* and many other publications. *"For years we were aware that Albert Einstein and Werner Von Braun weren't tickling our funnybones. Now we know what's so funny about science. It's Sidn Harris." —Bob and Ray. "America's premier science cartoonist." —Science 80.*

$7.95 hardcover **N**; $3.95 paperback **O**



"I think, therefore I am paid" T-Shirts

S. HARRIS T-Shirts adapted from his classic *What's So Funny about Science?* cartoon. Woman's shirt (French cut) features a female thinker; man's shirt (Regular cut), a male thinker. Please specify size (S, M, L, XL) and style (man or woman) with order.

$6.95 per T-Shirt **P**

Professor E. McSquared's Calculus Primer

HOWARD SWANN and JOHN JOHNSON. 214 pp., illus.

Through brilliant use of cartoons and ingenious analogy, the Professor and his friends introduce calculus with unbelievable energy, humor and clarity. Ideal for self-study. *"Incredible... throughout the authors have lavishly spread their humor, poking fun at the 'gobbledygook' and mystique of mathematics whilst putting across the ideas of analysis... Highly recommended." —London Times Educational Supplement. "Perhaps the most original primer on calculus yet devised." —New York Public Librar .*

$7.95 paperback **Q**

The Flight of Peter Fromm
A Novel

MARTIN GARDNER. 272 pp.

The first paperback edition of Gardner's *"brilliantly illuminating metaphysical novel"* (*The New York Times*), set in and around the University of Chicago in the years before and after World War II. *"The best book about evangelical Christianity I've ever read. [After reading a library copy,] I loved it so much that I ordered my own copy from the publisher, for I knew that in the years ahead I would want to read it many, many times. A book to savour and enjoy, The Flight of Peter Fromm is surely the most underrated novel of the last ten years." —Hamilton Gregory, Instructor of English, Asheville-Buncombe Technical College and Former Correspondent, The Associated Press.*

$8.95 hardcover **R**; $4.95 paperback **S**

WILLIAM KAUFMANN, INC.
One First St., Los Altos, CA 94022

Please send me the books and other items whose letters are circled below. I understand that if I am not completely satisfied, I may return the order within 30 days for a complete refund on my purchases. SciAmAp80

A B C D E F G H I J K L M N O P Q R S

T-shirt Size and Style _____

☐ Enclosed is full payment plus $1.00 shipping charges. *(California residents please add sales tax.)*

☐ Please charge my purchase to (circle one)
VISA MasterCharge

_____
Credit Card Number Exp. Date

_____
Print name as it appears on card

_____
Signature

Name _____

Address _____

City _____

State _____ Zip _____

☐ send a copy of your latest catalog.

Remember: A copy of *The Universal Traveler* will be sent **Free** with every order of $15.00 or more. **BONUS!** For all orders above $50.00, excluding tax and shipping, you may deduct 10% from the total.

Today's Bunker Ramo operates more aircraft in a day than the average pilot will fly in a lifetime.

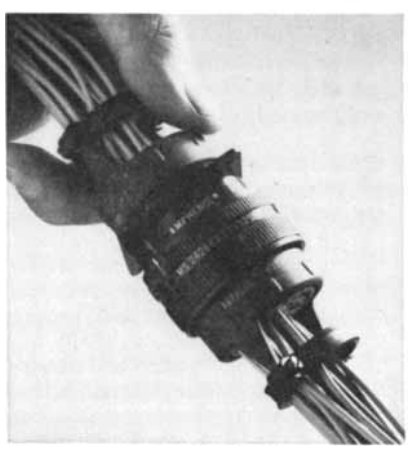
Among other things, a commercial airplane is a marvel of electrical, electronic and hydraulic components. All of which have to be connected to make that airplane operable.

That's why connectors become so critical. And when you consider that every commercial aircraft requires about 1500, you can easily understand why connectors are big business for Bunker Ramo.

Probably no connectors are better known than those marketed by Bunker Ramo under the Amphenol name. Ranging from low-cost simple designs to the highest-technology sophisticated environmental products for space and defense, Amphenol® connectors are also serving the needs of international customers in business equipment, instrumentation, federal technology, radio frequency communications and telephony.

To sustain and strengthen Amphenol leadership, Bunker Ramo invests heavily in new product development and in technologically advanced production equipment.

Today, through our well-known Amphenol connectors, Bunker Ramo has a leading position in the aerospace and aircraft industries, a strong foothold in telecommunications, and a growing role in fiber optics. In addition, we are a major producer of the data terminals and minicomputers that, together, comprise the information systems widely used by commercial banks, thrift institutions, insurance companies and brokerage houses.



Most important, we are a company with a reservoir of high technology, a solid base of innovative products, and a strong management team. All of which is why today's Bunker Ramo is a company that's on the move. For our latest financial reports, write Bunker Ramo Corporation, Dept. FR, 900 Commerce Drive, Oak Brook, Illinois 60521.

BUNKER RAMO

The Transport of Substances in Nerve Cells

Large molecules formed in the cell body move great distances through the axon to the nerve endings. Other substances are returned through the axon to be disposed of or reconstituted

by James H. Schwartz

Galen proposed in the second century that the brain governs movement and sensation by secreting a psychic "pneuma" that travels through imperceptible channels within nerves. As late as the 18th century the brain was considered a glandular organ; nerves were thought to be ducts carrying fluid secreted by the brain and spinal marrow to the periphery. Galen and his followers were wrong, of course, in attributing neural activity itself to the flow of material through nerves. Movement, sensation and other neural functions are the consequences of interactions between nerve cells triggered by electrical signals, which are propagated not within axons, or nerve fibers, but rather along their outer membrane. Yet there was truth in the notion that something important actually flows through channels in nerves. Substances that originate in the body of a nerve cell are indeed distributed along the axon and delivered to the axon's terminals by passage through the lumen, or bore, of a fiber, and these substances play a vital role in neural activity.

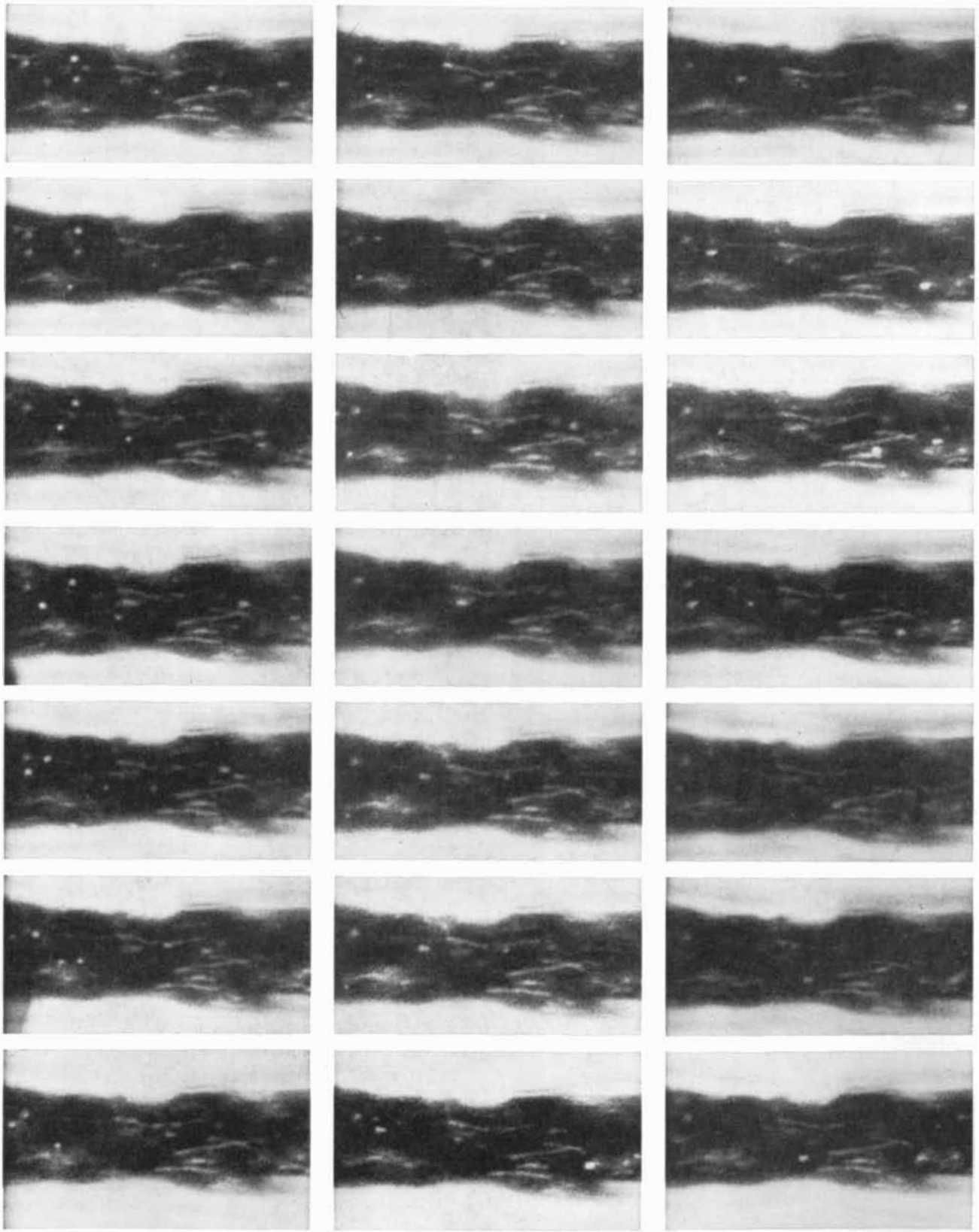
A neuron, or nerve cell, consists essentially of a cell body with processes: many dendrites and usually one long axon with branches that end in synaptic terminals. The arrival of an electrical impulse at a terminal releases neurotransmitter molecules stored in numerous small vesicles in the terminal; the transmitter diffuses across a narrow cleft to affect receptors in the dendrites or cell body of another neuron and thus generate or inhibit an electrical signal in that neuron. The generation and conduction of electrical impulses and the synthesis and release of neurotransmitters are local processes that do not depend directly on the cell body.

The cell body is critical, however, for the synthesis of many materials that sustain the life of the cell and carry out its functions, including the membranes that form the axolemma (the outer membrane of the axon), the synaptic terminals and the synaptic vesicles. Complex transport systems have evolved to carry those materials from the cell body throughout the length of the axon to the terminals and to return materials from the terminals to the cell body for reprocessing. There are two kinds of intracellular transport. The slower kind is called axoplasmic flow and the faster is called axonal transport. Axoplasmic flow conveys materials only from the cell body toward the nerve-fiber terminals; axonal transport goes in both directions. The two processes differ in many other ways, including their fundamental mechanism and the kinds of materials they convey.

Slow transport was discovered first. The questions that led to its discovery were chiefly developmental ones, having to do with how the neuron attains its special form. At the beginning of their development nerve cells are essentially spheroidal and lack processes, but their shape changes rapidly as the neuron puts out its axon and dendrites. By the time the cells are mature the axons and their terminals typically contain from hundreds to many thousands of times more material by volume than the cell bodies do. It is difficult to give a particular value applicable to neurons in general because their morphology varies so greatly, possibly more than that of any other cell type in the body. Some neurons have fairly short axons, extending for only several cell-body diameters, and some have no axons at all, but these are unusual. At the other extreme, and not at all unusual, are neurons with very long axon processes extending for many thousands of cell-body diameters. For example, an axon in the phrenic nerve of a giraffe extends from its cell body in the brain stem near the base of the skull to terminals that synapse on muscles of the diaphragm some five or six feet below. The axon of a motor neuron in the spinal cord that innervates a toe muscle of a six-foot man has a length of about 5,000 cell-body diameters. (If the cell body of the motor neuron were the size of a football, its axon would extend the length of 15 football fields.) Developmental studies have made it clear that during the outgrowth of the axon cytoplasm must move out from the cell body.

Similarly, when an axon in an adult animal is severed, it can grow back under proper conditions, with new axoplasm (as the cytoplasm that fills the axon is called) seeming to push its way slowly out along the regenerating fiber, ultimately to renew its connection with the end organ. In experiments on regenerating rabbit nerves done in the early 1940's the British biologists J. Z. Young and P. B. Medawar (motivated in part by the medical importance of peripheral-nerve injuries in World War II) measured the rate of growth of the regenerating fibers at three or four millimeters per day. From these experiments and similar ones done by other investigators it was generally inferred that axoplasm moves, and that its source must be the cell body.

It was Paul A. Weiss and his co-workers at the University of Chicago who in 1948 first proved experimentally that substances originating in the neuronal cell body do move at a steady rate from the cell body out along the axon. Weiss's procedure was to constrict surgically branches of the sciatic nerve in rats, chickens and monkeys. Immediately after the operation microscopic examination of individual fibers showed no distortion of the axon just proximal to the constriction (between it and the cell body). Examination several weeks later revealed a dramatic change in the shape of the axon: the region just above the constriction had become greatly swollen, suggesting that axoplasm had accumulated behind the blockade. In addition, as other workers had previously observed in severed nerves, the portion



TRANSPORT OF PARTICLES toward the cell body of a bullfrog neuron, or nerve cell, through the axon, or long fiber, of the neuron is seen in these frames from a motion picture made by David S. Forman, Ante L. Padjen and George R. Siggins at the National Institute of Mental Health. The movement is from right to left and is made visible by means of dark-field microscopy. The long, rodlike structures are mitochondria; they are usually stationary but do move occasionally. The round and elliptical structures are particles that are thought to be multivesicular bodies and other lysosomal structures. One can follow the movement of a particular particle: the elliptical one at the middle right in the first frame. Reading down the columns, one sees that the particle advances (the movement is by a series of jumps), stops for a time and finally reaches the point where it is about to go out of the picture. Axon's outer diameter is 17 micrometers.

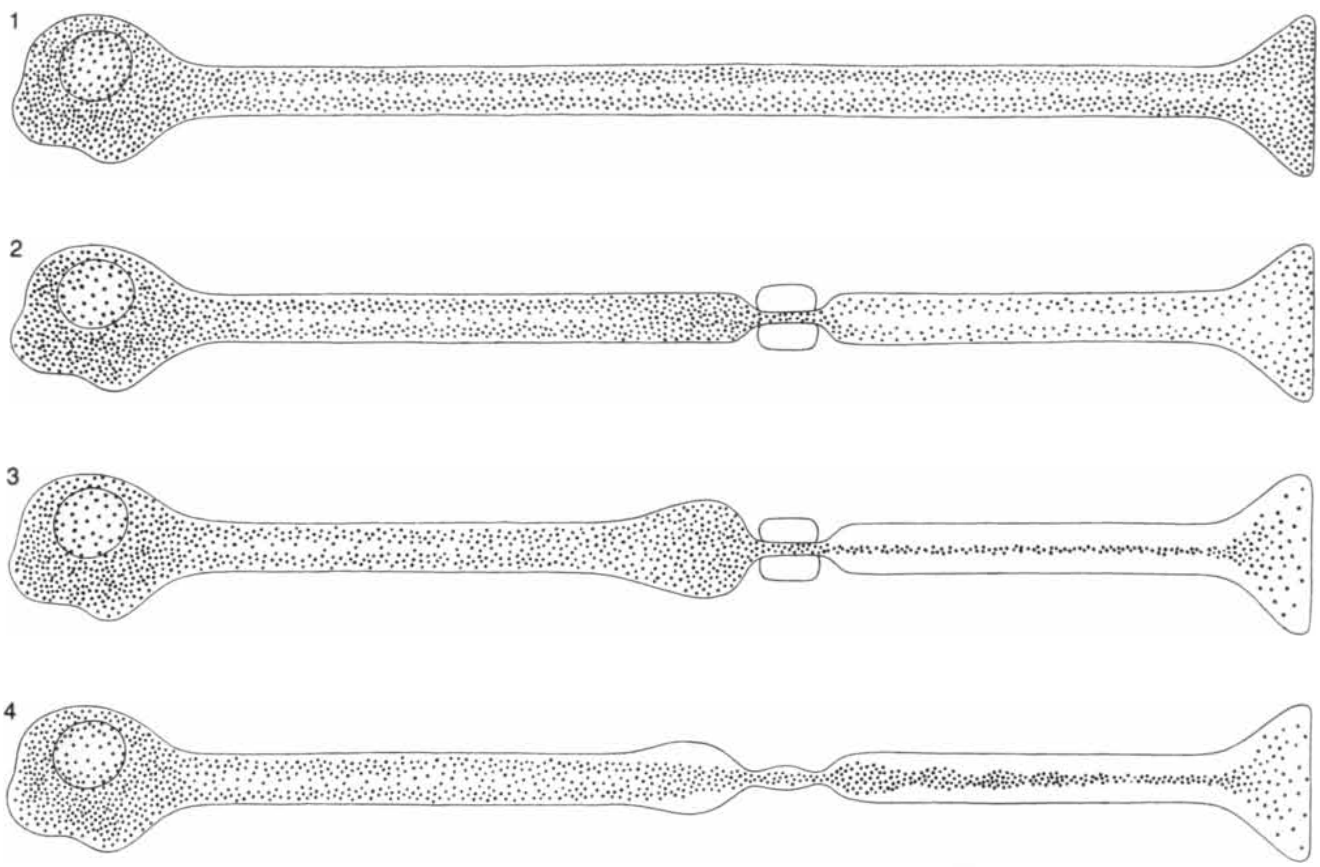
of the axon distal to (beyond) the constriction had degenerated. Weiss then removed the constriction and proceeded to clock the movement of the material that had accumulated behind the constriction during the several weeks it had been in place. He found that the accumulated axoplasm progressed down the regenerating fibers at a constant rate of one or two millimeters a day, values in substantial agreement with the rates of regeneration measured by Young and Medawar.

Weiss's experiments were timely because it was during the next few years that molecular biologists undertook the investigations that led to a comprehensive understanding of protein synthesis. That knowledge made it quite clear why axoplasm must originate in the cell body. The cell body contains the nucleus with its genetic material, DNA. The cytoplasm surrounding the nucleus is the only region of the neuron that contains all the cellular machinery needed to make protein. Ribosomes and the other structures required for the synthesis of proteins and their assembly into organelles are confined to the cell body and to the most proximal regions of the dendrites; they do not extend into the axon. Consequently no proteins can be synthesized within the axon and practically none in the dendrites.

Axoplasm, like the cytoplasm of other cells, has an enormous number and variety of constituents. Proteins make up about 80 percent of the dry weight of axoplasm, with lipids (fats) and sugars accounting for the remainder. The thousands of different proteins are of many different kinds: some exist free in solution, others are tightly embedded with lipids in membranes and still others are assembled into long, threadlike fibers. In spite of this chemical complexity more than 20 percent of the protein content by weight is accounted for by just three proteins: microtubules, neurofilaments and microfilaments. Each of them is a linear polymer, an assembly of small repeating monomers, or protein subunits.

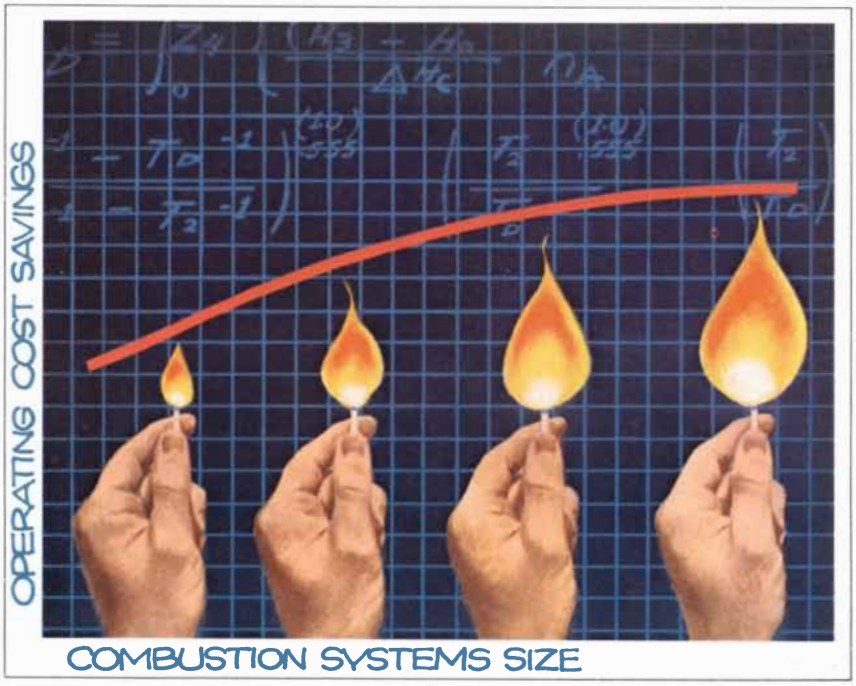
Microtubules are built up of two rather similar subunits named alpha tubulin and beta tubulin. They have been observed in the cytoplasm of most kinds of cells and in cilia, the projections fringing some types of cells, since they were first described by Keith R. Porter at the Rockefeller Institute for Medical Research. Neurofilaments, first studied by Peter F. Davison of the Massachusetts Institute of Technology, have recently been shown to contain three different protein subunits. Neurofilaments are similar in microscopic appearance to what are called "intermediate" filaments in other cell types. Recent chemical and immunological studies indicate, however, that unlike the tubulins, which are similar chemically in neurons and in other cells, the neurofilament proteins are different from those of intermediate filaments in other cells. Both microtubules and neurofilaments are extremely long, and they are oriented longitudinally, parallel to the axon's long axis.

Microfilaments are shorter. They are polymers of neural actin, which is chemically similar to but not identical with the actin that is one of the major contractile proteins of muscle. Actin was first extracted biochemically from nervous tissue by Soll Berl and Saul Puszkin at the Columbia University College of Physicians and Surgeons. The microfilaments in axons were shown to be composed of actin by Yvi J. LeBeux and Joan Willemot of Laval University in Quebec. Actin and other contractile proteins have been known for more than 40 years to be the biochemical basis of



CONSTRICTION EXPERIMENT done at the University of Chicago in 1948 by Paul A. Weiss and his colleagues demonstrated that material from the cell body of a neuron moves along the axon at a steady rate. The experiment is depicted here schematically for a single mature nerve fiber (*1*), with the cell body at the left and the axon leading away from it to the nerve terminal at the right. A constricting cuff was applied to the fiber (*2*). After several weeks the axon was swollen above the constriction (*3*) and reduced in size below it, showing that axoplasm (the material from the cell body) had been dammed up by the constriction. It flowed again (*4*) when the cuff was taken off.

WE ASKED OUR MATHEMATICAL MODEL HOW TO IMPROVE THE ENERGY COST EFFECTIVENESS OF A COMBUSTION HEATING SYSTEM. IT TOLD US: THINK BIG.



THE ENERGY-SAVING POTENTIAL OF OVERSIZED COMPONENTS IS ONE OF THE SURPRISING IDEAS WE'VE UNCOVERED IN DEVELOPING DIGITAL MODELS TO SIMULATE ENERGY CONVERSION SYSTEMS UNDER ACTUAL OPERATING CONDITIONS.

Just as the idea that "smaller is better" was beginning to gain universal currency, a Honeywell research team was getting its first look at data which suggested the opposite conclusion.

Our research results showed that, in a number of situations, high efficiency heating systems consume significantly less energy when they are sized with a larger heat exchanger surface per unit of energy input. This indicates that energy efficiency problems are complex, requiring individual case engineering rather than preconceived generalizations.

Engineering, however, has little to do with how our research efforts managed to stay one step ahead of conventional industry practice. The credit, in this case, goes to a research team headed by a physical chemist and a mathematician. With their unique combination of experience and skills, they developed a mathematical model which allows them actually to simulate and optimize the dynamics of a combustion heating system under field operating conditions.

So, without having to rely on lengthy and expensive field experiments, we can evaluate current and new options available to any combustion heating system. And quickly get an accurate idea of what the cost/efficiency trade-offs are.

This, and additional models for compression refrigeration equipment, gas-fired heat pumps, and process control systems, use inputs obtained from field measurements. And predictions based on data from these models have been verified by key experiments.

The insights gained from mathematical models help Honeywell engineers develop control systems strategies to do a better job of energy management.

In an imperfect world, the creation of mathematical models may be the key to identifying our most important problems. And solving them.

If you are interested in learning more about Honeywell's research work in mathematical modeling, you are invited to correspond with Dr. Ulrich Bonne. If you have an advanced degree and are interested in a career in systems analysis, solid state electronics, sensors, or material sciences, please write to Dr. W. T. Sackett, Vice President. Both may be reached at this address: Honeywell Corporate Technology Center, 10701 Lyndale Avenue South, Minneapolis, MN 55420.

Honeywell

Although Honeywell engineering is world-wide, the bulk of basic research and applied research is done in Minneapolis. The most recent *Quality of Life* Study conducted by Midwest Research Institute shows Minnesota to be one of the best places in the country to live and work considering cultural, social, economic, educational and political factors.

The Twin Cities is the home of many of America's advanced technology companies employing a great many scientists and engineers. This ideal research environment is further enhanced by Honeywell's ongoing program of affiliation with universities across the country: The University of California at Berkeley, MIT, Stanford, Carnegie Mellon, Illinois, Cornell, Waterloo of Ontario, Caltech, and Minnesota.

the movement of muscles; they have only recently been recognized as consequential constituents of other cells [see "The Molecular Basis of Cell Movement," by Elias Lazarides and Jean Paul Revel; SCIENTIFIC AMERICAN, May, 1979]. In axons the microfilaments run both longitudinally and circumferentially; often they appear to be associated with the axolemma.

All three of these filamentous proteins are carried away from the cell body by slow axoplasmic flow. Raymond J. Lasek of Case Western Reserve University and Masanori Kurokawa of the University of Tokyo Medical School have been studying the movement of microtubules, neurofilaments and microfilaments in dorsal-root ganglion cells. The dorsal ganglia are groups of neurons situated in symmetrical pairs at each vertebral level along the entire length of the spinal cord. At the level of the lower back the ganglia contain cell bodies with a long peripheral axon that runs in the sciatic nerve to the leg and a shorter central branch that enters the spinal cord; the peripheral axon and the short branch together carry sensory information from the leg to the central nervous system.

A surgically exposed dorsal-root ganglion in an experimental animal can be injected with a radioactively labeled amino acid that becomes incorporated into proteins synthesized in the cell bodies of the neurons; the incorporation proceeds for only a short time after the injection because unincorporated amino acid is rapidly lost in the bloodstream. The animals are kept for a week to allow transport of the radioactively labeled proteins to take place; then a few are sacrificed at weekly intervals and the injected spinal ganglia are removed with both the central and the peripheral nerves attached. The nerves containing the axons are cut into consecutive six-millimeter segments. Each segment is then analyzed for the types of labeled proteins it contains by gel electrophoresis carried out in detergent. The detergent depolymerizes the filaments into their simple subunits, which are then separated according to size by electrophoresis. The major proteins in each of the axon segments can therefore be recognized easily by the electrophoretic banding patterns, and the radioactive

AXOPLASM is enlarged 62,000 diameters in this high-voltage electron micrograph of a rat nerve made by Mark H. Ellisman of the University of California at San Diego. Included are cisternae and vesicles (round and elliptical bodies) and microtubules and neurofilaments (longer and respectively tubular and stringlike structures) in network termed microtrabecular system.

NEW DATSUN 280-ZX WITH T-BAR ROOF.

Turn it on and turn it loose. The legendary thrills have been turned inside-out. Announcing the very first Datsun Z-car with an open cockpit to the heavens! Just take off the two stowable roof panels and feel the rush of its fuel-injected fury. The surge of its five responsive gears. The shifting winds of every maneuver.

But the new T-bar "Z" is more than meets the sky. It opens up all the senses. Moves you on burly radials. Flies you on a fully independent suspension. Glides you with cruise control. Responds with 5 speeds and 4-wheel power discs. Cradles you in optional genuine leather reclining bucket seats. Surrounds you with the sound of 4-speaker stereo. Lays before you an eye-filling array of instrumentation including tachometer, resettable trip odometer, time/date quartz clock, Computer Sensor System...

You always wanted to open up a "Z." Now is the time... to experience the ultimate definition of AWESOME. Available for purchase or lease at your Datsun dealer now.

DATSUN
WE ARE DRIVEN

Take the mileage and run...

443 MILES EST.* RANGE

654 MILES EST. HWY. RANGE

21 EPA EST. MPG

31 HWY. EST. MPG

Projected 280-ZX ranges are based on EPA estimated MPG and highway MPG with five-speed transmission. Use estimated MPG for comparison. Your mileage and range may differ depending on speed, trip length and weather. Highway mileage will probably be lower than EPA highway MPG.
*California Range 422 654
California Mileage 20 31

NISSAN

If you have ever taken a luxury sports car through a tight turn, you know the feeling. It's the sense of supreme precision with which this trim, compact camera proclaims its Nikon heritage. A feeling that is borne out by the professional quality pictures the Nikon FE delivers with automatic ease. And one that, unlike other fine things in life, is readily affordable.

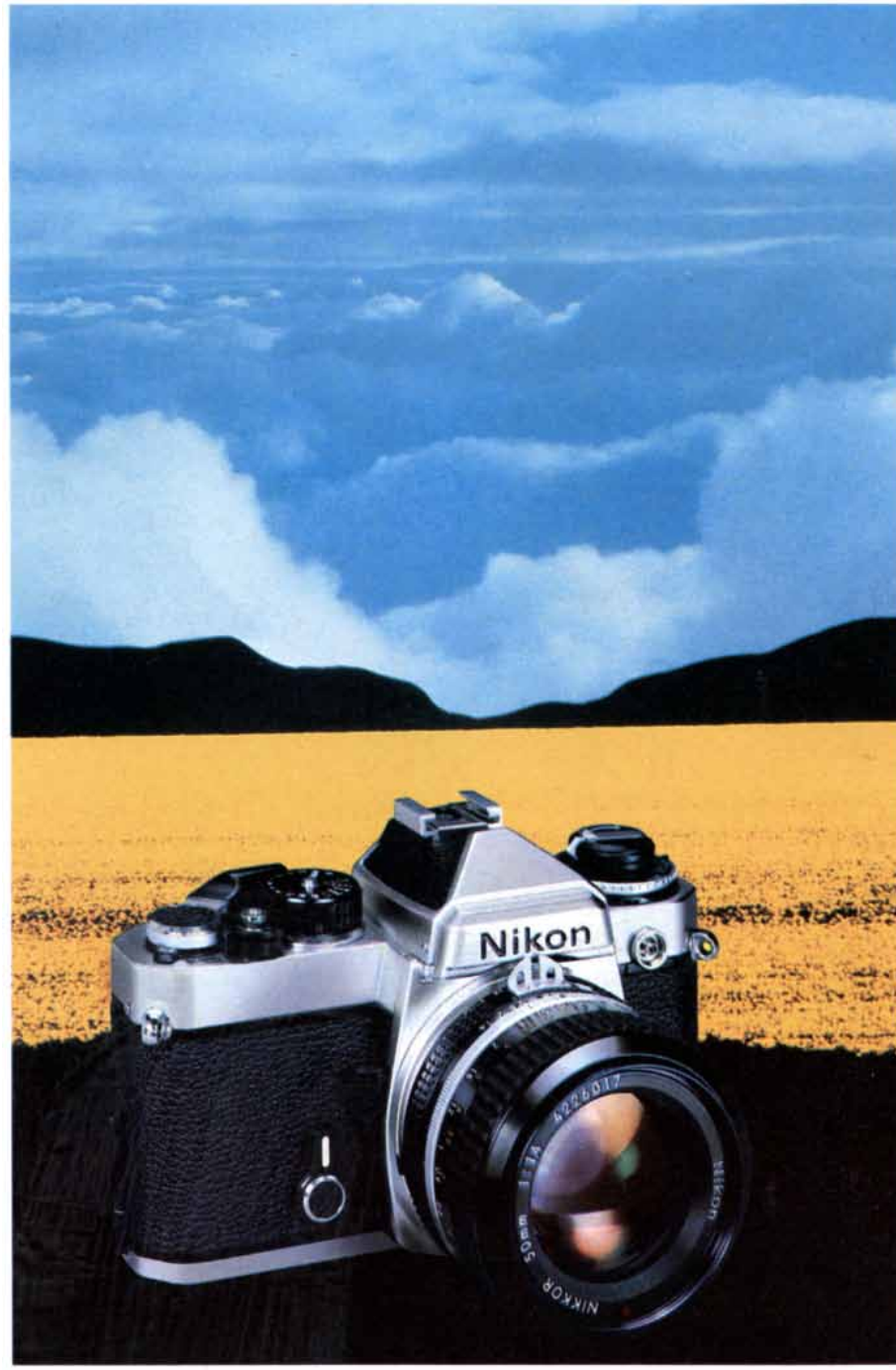
With the Nikon FE, you can simply focus and shoot... and rely on its Nikon electronics to give you sharp, magnificently exposed photographs, automatically. Or, switch to manual operation and enjoy complete creative control over every exposure, more easily than you ever thought possible.

Above all, this is a camera that makes no compromise in its supreme Nikon quality. Stroke the advance lever, and feel the smoothness of precision gearing machined to microscopic tolerances. Press the exposure button, and hear the shutter respond with hushed precision. Look through the bright, silver-coated viewfinder, and see your picture snap into sharp focus with a fingertip touch.

Know, too, that the world's greatest photographic system stands behind your Nikon FE. Add the dynamic firepower of motor drive, at up to 3.5 shots a second. Banish darkness with the ingenious automatic thyristor flash. Explore new perspectives through more than 60 Nikkor lenses, the same superb optics chosen by most professionals for their sharpness and color fidelity.

For the purist:
The Nikon FM
For those who prefer only manual exposure control, the Nikon FM offers the reliable guidance of one-step electronic metering. It's as compact and precisely responsive as the FE and costs even less. At your Nikon dealer.

Nikon Inc., Garden City, New York 11530.



Experience a sense of perfection. The Nikon FE.

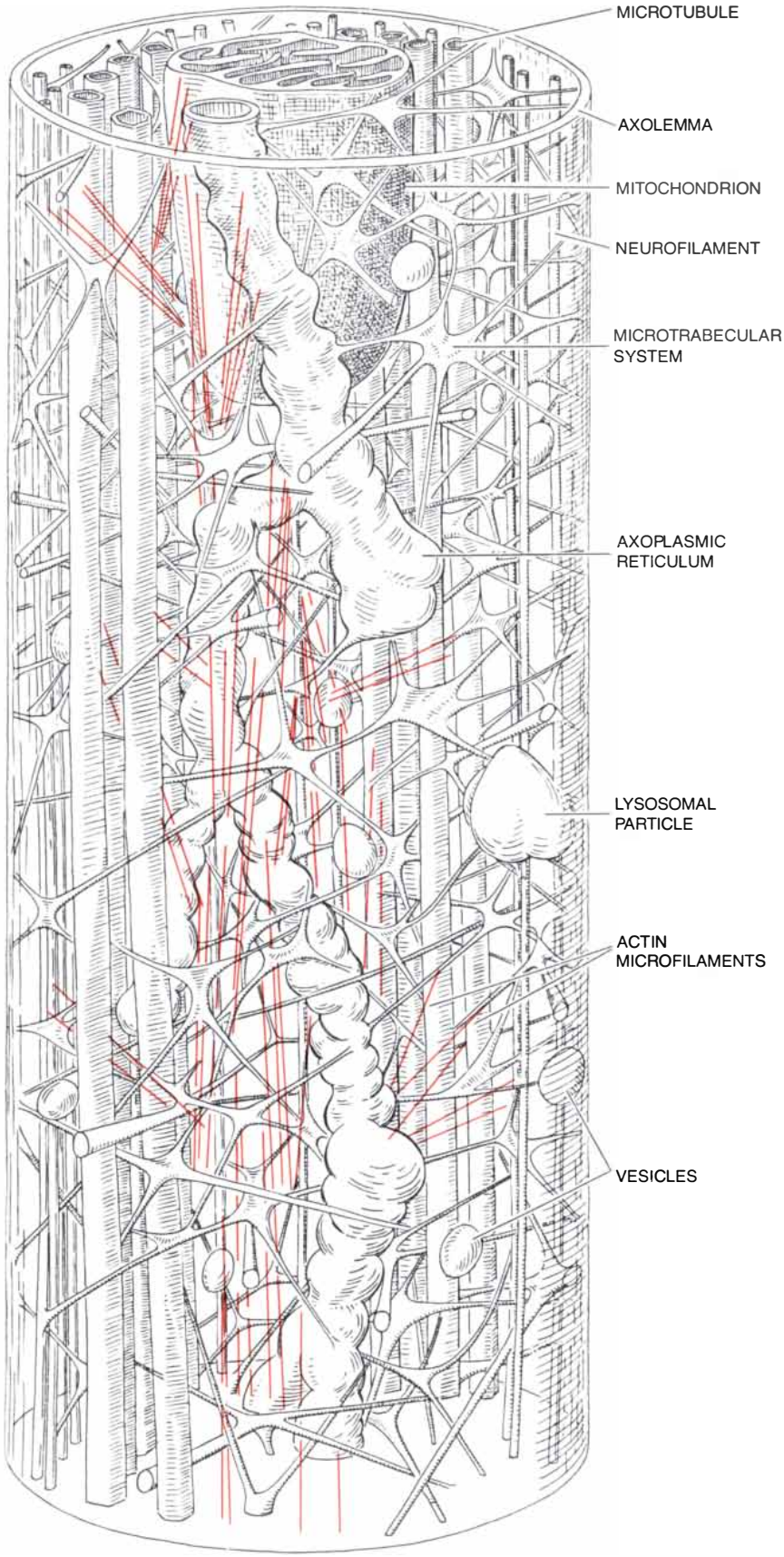
bands can be cut out and counted for radioactivity.

Lasek and Kurokawa found that the three fibrillar polymers—neurofilament proteins, the two tubulins and actin—constitute about 80 percent of all the proteins moving by slow transport. The remaining 20 percent are diverse, consisting primarily of soluble enzymes of all kinds, and because they are numerous no single one appears prominently enough to be distinguished as a band on the electrophoretograms. Therefore the rates of movement of microtubules, neurofilaments and microfilaments can be inferred from the banding patterns obtained in all the axon segments from ganglion cells examined at consecutive time intervals after the original labeling. The electrophoretograms are a series of successive still images that provide a record of continuous movement (much as the pages of toy "movie" books provide animated images when they are flipped rapidly).

The rate of slow transport appears to be tailored to the requirements of individual axons. In dorsal-root ganglion cells the rates of flow are from two to three times faster in the longer peripheral axon than they are in the shorter central one. A curious demonstration that axoplasmic flow is regulated by the length of the axon was devised by Marion Murray at the University of Chicago. Murray worked with the optic system of the flounder, a flatfish in which one optic nerve is a third longer than the other because both eyes are on the same side of the fish's head. After labeling proteins by injecting both eyes at the same time, Murray found that the material moving by means of axoplasmic flow reached the terminals of both optic nerves in the brain at the same time, indicating that there is a compensatingly faster rate of flow in the longer axon.

The function of slow transport in a developing or a regenerating axon is to supply the required new axoplasm; in an intact mature neuron its function is to renew the axoplasm continuously. In both growing and mature neurons it depends on the continued synthesis of new proteins in the cell body. The mechanism of slow transport is not yet known, but it is generally conceived to be comparable to the "protoplasmic streaming" of amoeboid motion. Axoplasm is pictured as being squeezed out of the cell body and through the axon much as toothpaste is squeezed out of a tube.

The analogy is not quite accurate because toothpaste and other familiar substances that move hydrodynamically are liquids and are therefore amorphous. There is good reason to think that microtubules, neurofilaments and microfilaments move as an extended cagelike structure and not individually as free subunits. There are several molecular candidates for substances that



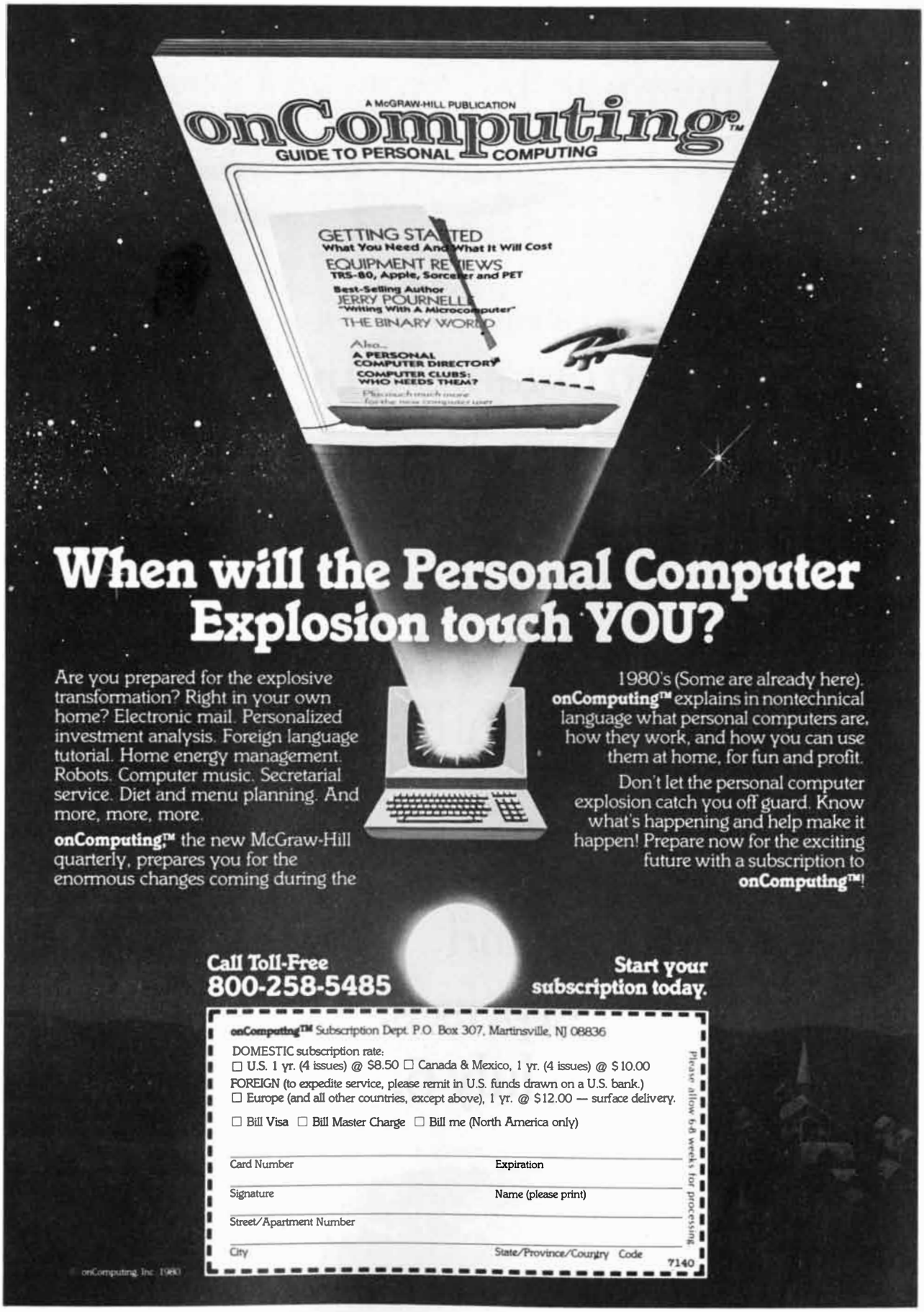
INTERNAL STRUCTURE of an axon is depicted on the basis of current hypotheses. The fine trabeculae make up a lattice that gives the interior of the axon a gel-like consistency. The vesicles, lysosomes and similar particles move in the axon, as the mitochondria do to a lesser extent. The microfilaments and microtubules are thought to play a role in fast axonal transport.

might cross-link the filaments into a coherent structure; various filament-associated proteins have been isolated biochemically. More direct evidence of structure has come from micrographs made with a high-energy electron microscope at the University of Colorado at Boulder by Porter and Mark H. Ellisman of the University of California at San Diego. Their technique made it possible to study thick sections of axon. The image of axoplasm that emerges is of a three-dimensional network of the fibrillar polymers interconnected by structures Porter and Ellisman call microtrabeculae.

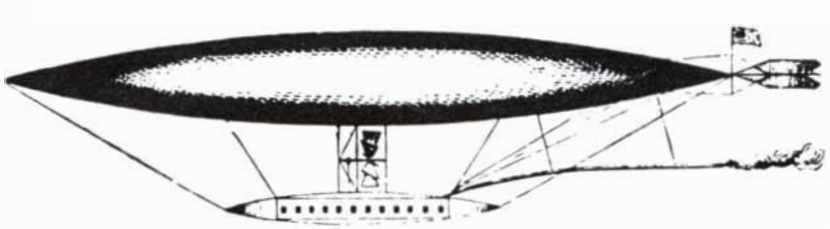
By the mid-1960's work done in several laboratories had made it clear that there was a more rapid component of transport in addition to the slow movement of bulk axoplasm. No single investigator claims this discovery. At a meeting in the spring of 1967 Samuel H. Barondes of the Albert Einstein College of Medicine in New York, Annica Dahlström of the Karolinska Institute in Stockholm, Bernice Grafstein of Rockefeller University, Lasek and Sidney Ochs of the Indiana University School of Medicine all presented experimental evidence for the new process.

Two general experimental approaches were taken in an effort to characterize this fast transport. The first, essentially an extension of Weiss's original constriction technique, was to measure the amounts of individual axoplasmic constituents that accumulate behind a surgically produced blockade in the nerve. An important series of early experiments was conducted by Liliana Lubińska of the Polish Academy of Sciences. She and her colleagues interrupted a branch of the sciatic nerve in dogs in two places, thereby isolating a 70-millimeter segment in the leg. At intervals after the operation the nerves were removed in order to measure the accumulation of a membrane-associated protein, the enzyme acetylcholinesterase, in the region just above the block farthest from the cell body. Lubińska compared the concentration of the enzyme behind the block with the concentration normally present along uninterrupted nerves. An accumulation was detected within two hours after the operation; the enzyme continued to pile up for about 20 hours, although at a decreasing rate.

A first approximation for the velocity at which the acetylcholinesterase is transported was obtained by dividing the initial rate of accumulation (in units of the enzyme per day) by the normal axonal content (in units per millimeter). The estimate was about 20 millimeters per day, from 10 to 20 times higher than the rate Weiss had measured for the movement of bulk axoplasm. Lubińska realized that the true rate must actually be still higher, however, because the cal-



Rufus Porter Rediscovered Artist, Inventor, Journalist 1792-1884



An exhibition organized by The Hudson River Museum which focuses on varied, interdisciplinary accomplishments of Rufus Porter, the founder of Scientific American: landscape mural paintings, miniature portraits, inventions and journalistic enterprises. From April 12 to July 6.

The book, *Rufus Porter Rediscovered, Artist, Inventor, Journalist 1792-1884*, published in soft bound edition in conjunction with Clarkson N. Potter is available in the Museum's Bookstore.

Major funding for this project has been provided by the National Endowment for the Humanities with additional grants from The New York State Council on the Arts, American Can Company Foundation, Mr. and Mrs. Gregory Halpern, Mr. and Mrs. Frederick J. Stock and Mr. and Mrs. Joseph DeBlasi.

A gala event, "Flying", will happen at the Museum on Saturday, May 17. For ticket information, call the Development Office.

The Hudson River Museum
Trevor Park-on-Hudson
Yonkers, New York 10701
914 963 4550

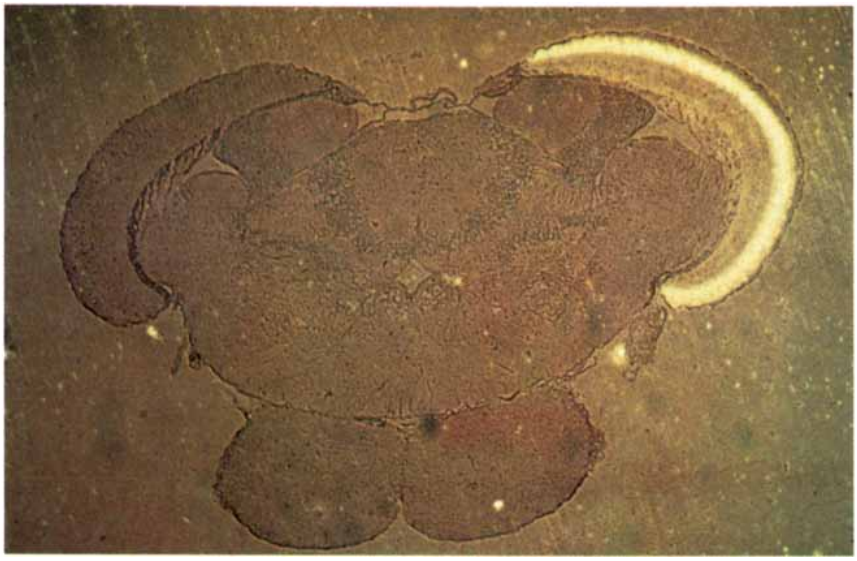
The Hudson River Museum

culation was based on the improbable assumptions that all the enzyme contained in the nerve is mobile and that the transport process is not affected by the injury to the nerve. Later experiments showed that only 10 percent of the acetylcholinesterase in the nerve can move, so that the actual rate must be at least 10 times higher than was originally calculated.

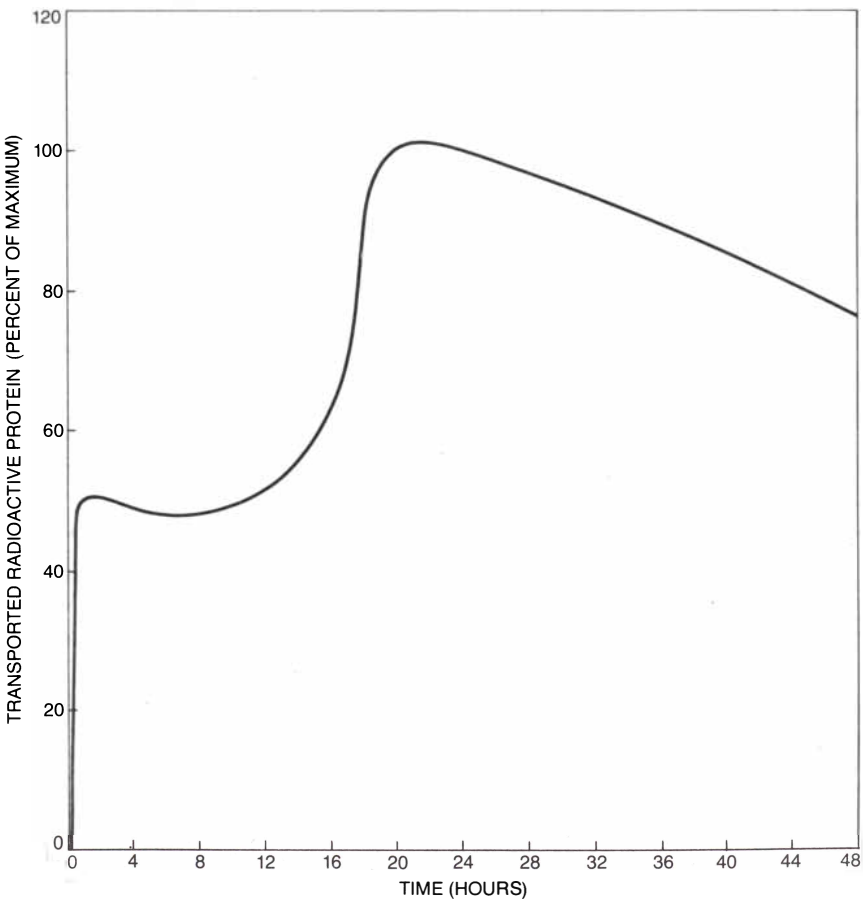
The second experimental approach depended on radioactive labeling of proteins synthesized in the cell body. For this kind of study the ideal neuron is one whose cell body is a considerable distance from its terminals. In addition to the spinal-ganglion cells already described, Weiss and his co-workers, now at Rockefeller University, introduced another useful preparation: the retinal ganglion cells of the eye, whose axons run in the optic nerve a substantial distance to the optic tectum within the brain. Grafstein, who began her work in Weiss's laboratory, worked on the visual system of the goldfish, injecting a radioactively labeled amino acid into one eye. The other eye served as a control and the two tectums were compared by quantitative autoradiography at intervals after the injection. In this method tissue sections are coated with a thin layer of photographic emulsion. Silver salts in the emulsion are activated by radiation from any radioactive source in the underlying tissue and, when the emulsion is developed, are reduced to visible grains of metallic silver that reveal the location of the emitting source.

Grafstein detected labeling over the tectum innervated by retinal cells in the experimental eye within hours after the injection, although the bulk of the labeled axoplasm reached the tectum only from two to three weeks later. It was clear, then, that proteins labeled during synthesis in the retina reach the brain in two discrete waves, one very much faster-moving than the other. As in the case of Lubińska's experiments, it was difficult to determine the velocity of transport accurately from this experiment; not only is quantitative autoradiography somewhat imprecise but also the rapidly moving proteins continued to appear in the tectum for several days after they were first detected. By making assumptions about the peak of the first wave and the average length of the optic nerve Grafstein estimated the rate at from 10 to 50 millimeters per day when the fish were kept at room temperature. The rate was much higher when the fish were kept warmer, doubling or tripling for each increase in temperature of 10 degrees Celsius.

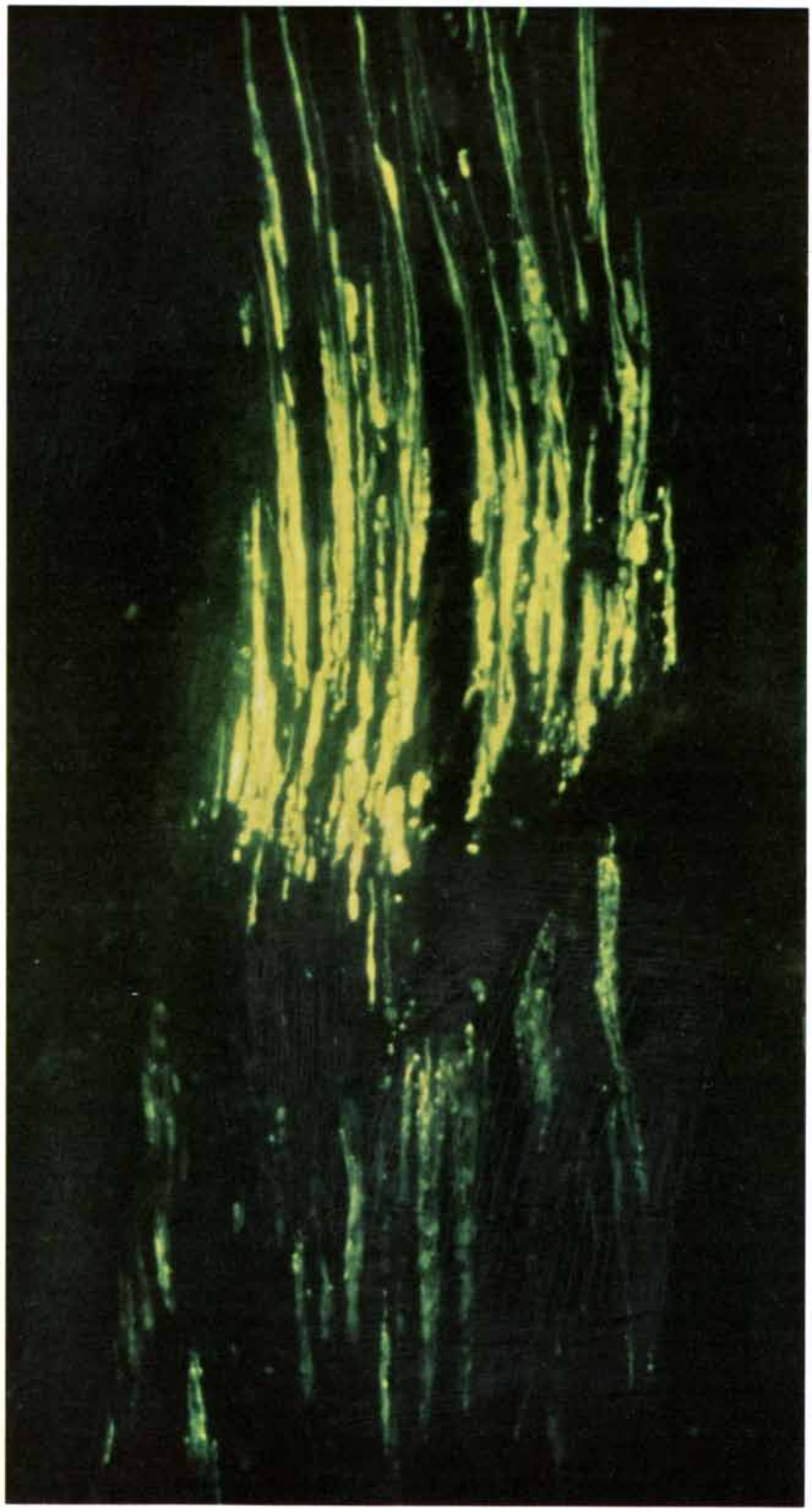
More precise measurements of the velocity of fast transport were achieved by studying the appearance of labeled proteins along the sciatic nerve of the cat. Ochs and Lasek, working



FAST TRANSPORT of proteins in axons was measured after administering a radioactively labeled amino acid to the retina of a goldfish, which contains the cell bodies of optic neurons. Sections of the optic tectum, where the neurons terminate, were obtained at various times and covered with a photographic emulsion. The greatest number of silver grains develop in the emulsion overlying areas of the brain that contain the highest concentration of radioactively labeled material. In this autoradiograph, made by Bernard W. Agranoff of the University of Michigan 24 hours after the injection of the amino acid into the eye, the brightness of the area at the right (the tectum) indicates that much of the protein that took up the labeled material while being synthesized in the cell bodies of retinal neurons had been delivered to terminals.



SPEED OF TRANSPORT of radioactively labeled protein in the optic nerve of a goldfish is charted. The curve sums up the data obtained by Bernice Grafstein and her associates at Rockefeller University from a number of fish; it indicates what percent of the labeled protein had arrived at the optic tectum at each of the times represented at the bottom of the chart.



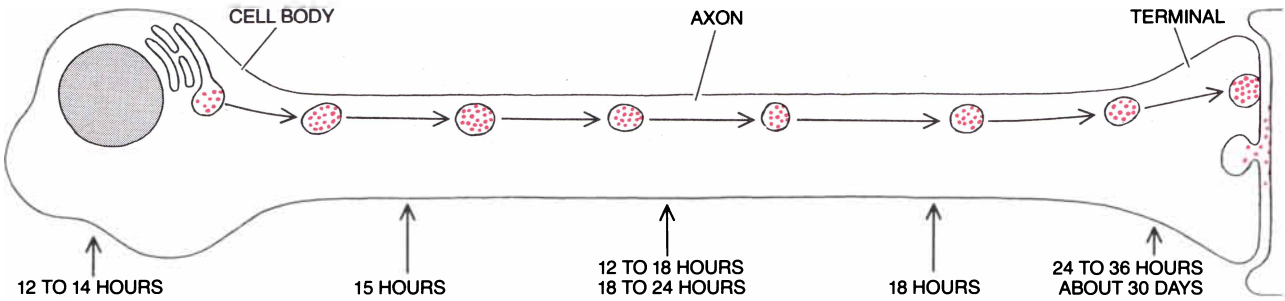
MOVEMENT OF A NEUROTRANSMITTER is made evident by its fluorescence when it is illuminated with ultraviolet radiation in the fluorescence microscope. Annica Dahlström of the University of Göteborg, who made this fluorescence micrograph of the sciatic nerve of a rat, administered reserpine, which decreases the nervous system's supply of neurotransmitters. Such substances are normally packaged in membranous vesicles, which release their contents at the nerve terminal on the arrival of an electrical impulse and thereby convey a signal to another neuron or to a muscle cell. The reappearance of fluorescence after the administration of reserpine shows that new storage vesicles have formed in the cell body and have been moved along the axon by fast transport. Here the presence of new vesicles is shown by bright area of fluorescence, which is on upper (cell body) side of an axon that had been blocked for 24 hours.

independently, injected labeled amino acid into a dorsal-root ganglion. Following an experimental procedure similar to the one described above for measuring slow transport but sacrificing the animals within hours after the injection, Ochs and Lasek cut the sciatic nerve into consecutive pieces and determined the distribution of radioactivity along the nerve. Analyses of time series of these distributions yielded a rate of 410 millimeters per day at normal body temperature.

Later studies in many warm-blooded animals have shown that this rate is remarkably constant. It is the same in sensory and in motor neurons, in neurons that are "silent" in the absence of stimulation or that are spontaneously active and in neurons that are stimulated experimentally; it is not affected by the length or the diameter of the axon. Since fast transport is an active process, it depends on an adequate supply of energy and oxygen, but it does not require the axon to have a continued connection to the cell body. This constitutes an important difference between axoplasmic flow, which originates at the cell body, and axonal transport. Once material has been synthesized and exported into the axon, it moves autonomously in fast transport (as the experiments of Lubińska and others with interrupted nerve segments had implied from the start).

Grafstein and her co-workers were the first to characterize the labeled proteins that move by fast transport, which they extracted from the goldfish visual system. Unlike the slow-moving fibrillar polymers and soluble proteins that are carried by axoplasmic flow, the fast-moving proteins were found to be constituents of membranes. Later studies in other laboratories on labeled proteins from olfactory, sciatic and other axons all concur in showing that fast transport serves to move new membrane material from the cell body. Much of this material is deposited along the axon, presumably to maintain and replace the axolemma; the rest of it reaches nerve endings, and the evidence suggests that this membrane material consists of synaptic vesicles and their precursors.

Some of that evidence came from studies by Dahlström on the distribution of neurotransmitter substances within neurons. She administered to rats the drug reserpine, which was known to decrease the nervous system's supply of norepinephrine and other transmitters of the group known as catecholamines. Reserpine works by damaging some element of the mechanism whereby these transmitters are taken up into the membranous vesicles in which they are normally packaged within the neuron. Electron-microscopic examination had shown that storage vesicles can be found throughout noradrenergic neurons (neurons with norepinephrine as a transmitter); the vesicles are sparse in the axon



COURSE OF RECOVERY of a neuron that has had its transmitter-carrying vesicles inactivated by the administration of reserpine to the animal is depicted. Recovery occurs through the formation of new vesicles (*color*); they move from the cell body and arrive at the times indicated along the axon. The recovery of full function at the terminal of the neuron requires approximately a month (*lower number*).

and are concentrated most heavily at nerve endings. By means of a sensitive new technique that reveals the presence of norepinephrine by fluorescence microscopy, Dahlström first showed that reserpine reduced the amount of the transmitter or depleted it totally in all regions of the neuron. In other words, reserpine effectively inactivated all existing vesicles.

With the slate thereby wiped clean Dahlström was able next to show that new storage vesicles form in the cell body and then move by fast transport along the axon. When she studied the reappearance of fluorescence due to norepinephrine-filled vesicles, she found that recovery began within a few hours after a large dose of reserpine had been administered. The fluorescence appeared first in a zone right around the nucleus, expanded to fill the entire cell body and eventually reappeared in the axon. In constriction experiments similar to Lubińska's with acetylcholinesterase Dahlström also found that fluorescence due to transmitter in new vesicles appeared rapidly behind a block, indicating that the vesicles had accumulated by means of fast transport. Dahlström's experiments were of particular importance because they suggested that the vesicles involved in neurotransmitter storage are important cellular constituents moved by fast axonal transport.

Axonal transport moves material not only away from the cell body but also in the opposite direction, from the axon terminals toward the cell body. This retrograde transport is, for example, the route by which the herpes and rabies viruses make their way to nerve-cell bodies, where they can multiply. Tetanus toxin also reaches the central nervous system by this route; the appreciable delay from the time of injury to the onset of tetanus symptoms is in part the result of the time required for axonal transport. Retrograde transport seems normally to be involved in returning membranes to the cell body to be degraded or restored. The degradation of intracellular membranes is the function of a family of organelles called lysosomes, and a major component of retrograde-transport traffic seems to be lysosomes that have engulfed membrane material.

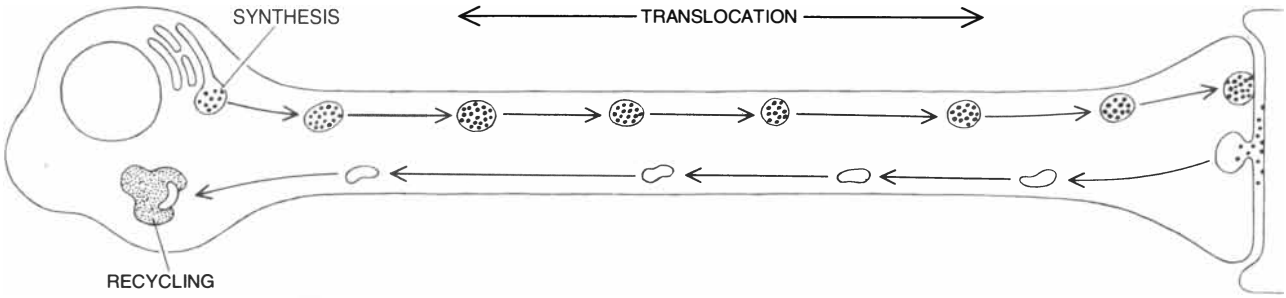
In the course of synaptic release the membrane of a transmitter-containing vesicle fuses with the presynaptic membrane of the nerve terminal; the vesicle opens up and empties into the synaptic cleft its content of transmitter, which diffuses across the cleft to work its effect on the postsynaptic membrane. To recapture the vesicle membrane the neuron is believed to reverse the emptying procedure: the synaptic membrane becomes invaginated, and the pocket is pinched off to form a new vesicle. Vesicle membrane is emptied and filled many times in this manner. At random, however, a small fraction of the vesicle population is taken up by lysosomes and returned to the cell body.

In the recycling process the invaginating membrane encloses a small amount of fluid from the synaptic cleft, and by this means a substance introduced into the extracellular space in nervous tissue can also be taken up by nerve terminals. If the substance can be detected easily, it can be followed for evidence of uptake and retrograde transport. The enzyme horseradish peroxidase is particularly convenient for this purpose: it is readily taken up at active synaptic terminals, it is so large that it behaves as a discrete particle and it is easily detected by a histochemical technique that produces a dark precipitate. The horseradish-peroxidase technique was originally introduced by Eric Holtzman of Columbia University and was developed further by Jennifer and Matthew LeVail of the University of California at San Francisco. It has been a significant new tool for neuroanatomical research, above all as a means of tracing an axon from its terminals to the distant cell body.

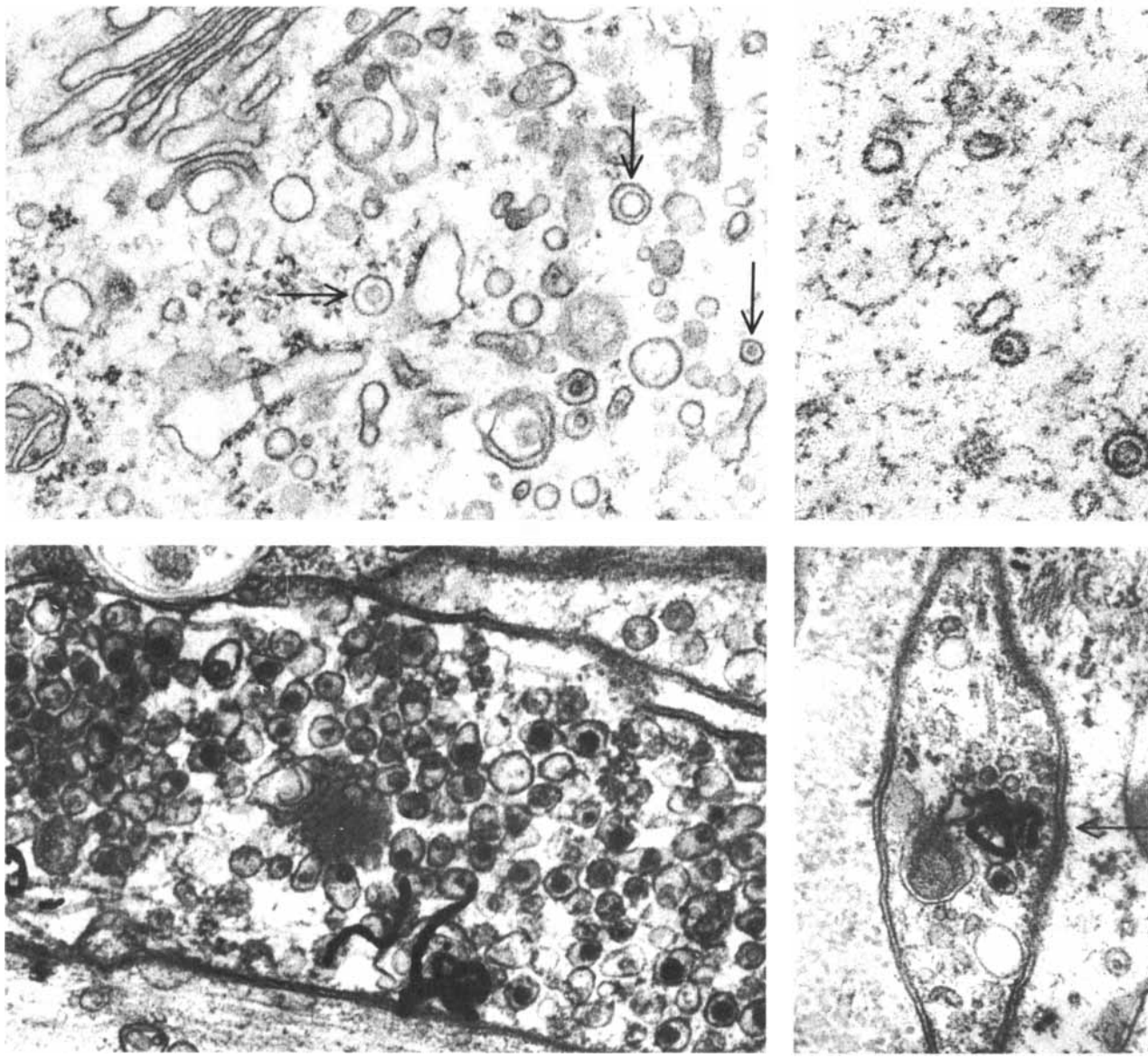
The technique has been applied to great advantage for tracing hitherto unknown pathways in the brain, but it is hard to get quantitative results with it that demonstrate the kinetic properties of retrograde transport. Direct light-microscopic observation of moving cellular organelles and other particles moving along living axons has been more fruitful for examining the rate and mechanism of fast transport. Because of the limitations of the light microscope this can be done only with extremely thin tissues such as single nerve fibers isolated from the animal or single nerve cells grown in tissue culture. Moreover, only particles large enough to be seen with the light microscope can be studied. Transmitter vesicles, with a diameter of from .04 to .15 micrometer, are too small, but lysosomes, which are from .2 to .6 micrometer in diameter, can be seen.

Although direct microscopic observation of living axons was begun in the 1920's, only recent advances in optical methods and the introduction of cinemicrography and computer analysis have made it possible to examine the behavior of individual particles. David S. Forman and his colleagues at the Naval Medical Research Institute have shown that particles tentatively identified as lysosomes move, predominantly in the retrograde direction, in a discontinuous series of jumps. The particles seem to move independently of one another. Individual saltations cover widely varying distances at a wide range of speeds. The average speed of retrograde transport, like the speed of transport away from the cell body, is highly dependent on temperature. Forman has compiled the rates measured by many investigators and found that the average rate of transport toward the cell body is from about one-half to two-thirds as high as the rate at which the traffic away from the cell body is moving.

To investigate the movement of membranous organelles by fast transport my colleagues and I chose to focus on one kind of synaptic vesicle in a giant neuron of the marine mollusk *Aplysia californica*. Assured by decades of physiological research that the functioning of invertebrate neurons is governed by principles common to neurons of all higher animals [see "Small Systems of Neurons," by Eric R. Kandel; SCIENTIFIC AMERICAN, September, 1979], we work with *Aplysia* cells because they offer important experimental advantages. Most of what is known about fast transport has been learned from experiments with whole nerves; a nerve contains many thousands of axons whose neurons have varied properties, differing even in type



LIFE CYCLE of vesicles and other membranous organelles involved in the transmission of nerve signals at a synapse (the specialized region of contact between a nerve terminal and another neuron or a muscle cell) begins with their synthesis in the cell body. Organelles move outward along the axon by fast axonal transport. Some of the material is deposited along the axon to maintain the axolemma, the external membrane along which electrical signals are propagated, and some, including the synaptic vesicles, is delivered to the terminal. The material is then returned to the cell body in retrograde movement, also by fast transport, and there it is either restored or destroyed.



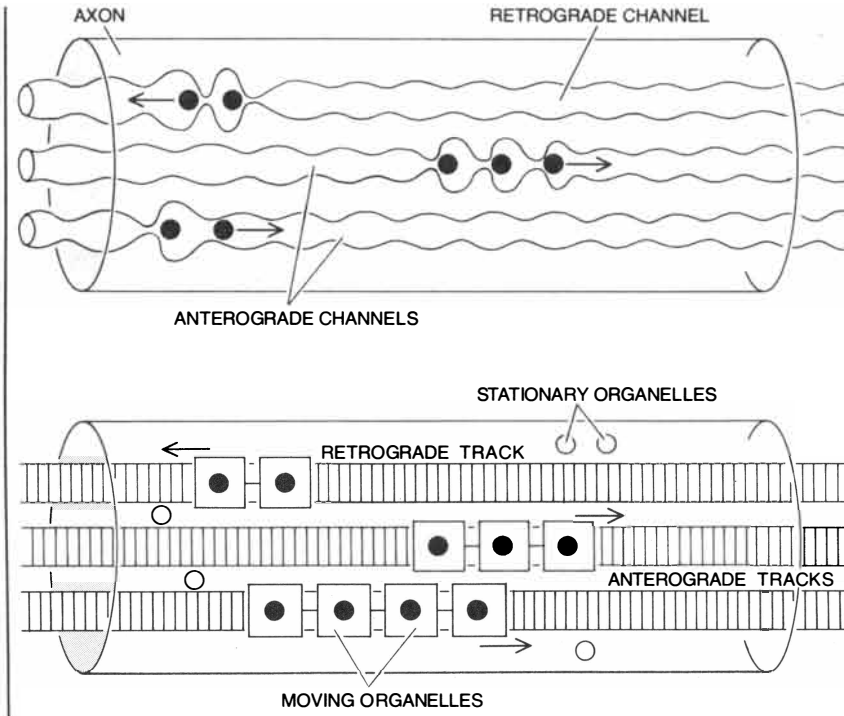
DEVELOPMENT OF VESICLES as they are transported from the cell body to the nerve terminal is apparent in these electron micrographs made by Ludmila J. Shkolnik in the author's laboratory at the Columbia University College of Physicians and Surgeons. They show various points in the giant neuron of the marine mollusk *Aplysia californica*. The vesicles, which were radioactively labeled, carry the neurotransmitter serotonin. The micrograph at the upper left shows several of them (*arrows*) in the cell body. In the next micrograph they are seen as they move along the axon. Although the vesicles are well formed by the time they leave the cell body, they develop further when they reach nerve endings, as is indicated by their different shapes in a micrograph (*lower left*) showing a terminal of a neuron. The last micrograph shows a synaptic terminal with an active zone (*arrow*) where vesicles release the transmitter, thereby conveying the nerve signal to another cell. The twisted black structures in the lower micrographs are silver grains employed in the neuron-tracing process.

of transmitter and vesicles. In *Aplysia* the transport process can be examined in a single neuron whose transmitter has been identified. In addition, *Aplysia* nerve-cell bodies are typically from 10 to 100 times larger than vertebrate neurons, and their axons are correspondingly large. The large size makes possible the direct biochemical analysis of individual neurons or parts of neurons and also allows one to inject directly into a particular cell substantial amounts of radioactive precursors, drugs and protein molecules too large to penetrate into cells if they were administered in the bloodstream.

Transmitter vesicles can be detected and tracked if one labels either the protein or lipid of their membrane envelope or the content of the envelope: the transmitter substance itself. We have done both in my laboratory, first at the New York University Medical Center and more recently at the College of Physicians and Surgeons. Richard T. Ambron, James E. Goldman, Ariel A. Sherbany and I microinjected a radioactive amino sugar that is readily incorporated into membrane glycoproteins and glycolipids in the cell body of the giant cerebral cell, an identified *Aplysia* neuron whose transmitter is serotonin. The cell body of this neuron, which is about a quarter of a millimeter in diameter, is in the cerebral ganglion. Within the ganglion the neuron's single axon bifurcates into two branches of equal size after running for about a millimeter; these branches leave the ganglion in two separate nerves, in which they travel for one or two centimeters before arborizing into numerous terminal branches that form synapses.

Knowing the biochemical characteristics of the components labeled by the amino sugar, we can trace the fate of the new membrane material in several ways. For example, we spun cell material in a centrifuge or fractionated it by various other procedures that separate cellular particles according to size. Measurement of the radiation emitted by the various fractions showed that much of the new membrane is assembled within the cell body into organelles that are the size of transmitter vesicles. Staining and other histochemical techniques and electron-microscopic autoradiography revealed the distribution of newly synthesized membrane in various regions of the neuron and enabled us to examine the life cycle of the vesicle.

Axonal transport is only a relatively short episode in the life of a synaptic vesicle. The vesicle membrane originates in the cell body and the vesicles play their principal physiological role at nerve endings; between its genesis in the cell body and its arrival at the synapse a vesicle membrane undergoes several developmental transformations. One advantage of studying axonal transport in



MECHANISM OF FAST TRANSPORT is considered in two separate hypotheses. In the first model (*top*), originally proposed by Weiss, materials are moved passively between the microtrabeculae in the axoplasm or within tubules of the axoplasmic reticulum. The means of propulsion could be either peristalsis (successive contractions of the wall of a channel) or the movement of hairlike cilia. In the model (*bottom*) proposed by Sidney Ochs of the Indiana University School of Medicine and favored by the author a continuous array of fibrils in the axoplasm provides a tracklike structure along which the transported materials are moved by filaments. One end of each filament is hooked to the organelle being moved and the other end is hooked to a microtubule running along the axon. The movement is limited to one way on each track.

a single neuron is the assurance that the various membrane structures found in different regions of the cell all belong to the same neuron. Ludmila J. Shkolnik and I have examined the varied appearance of transmitter vesicles in the cell body, axons and terminals of the giant *Aplysia* neuron. We have been able to identify populations of membranous structures that are characteristic of each region and can be related to one another in a coherent developmental sequence.

The movement of labeled vesicles can be measured by techniques similar to those I described above for studying transport in complex nerves. Because the material is in the axon of a single neuron the kinetic characteristics one measures do not reflect averages of many different kinds of particles moving along populations of axons; rather they are properties of a specific set of organelles all belonging to a single cell. Daniel J. Goldberg, Sherbany and I analyzed the movement of vesicles in axons of the giant cerebral neuron by labeling their content of the neurotransmitter serotonin. We found that the vesicles, labeled by the microinjection of radioactive serotonin into the cell body, move along the axons at a constant speed of 130 millimeters per day at room temperature. As in other animals, this velocity is very sensitive to changes in temperature. Translocation of the vesicles does not depend on the presence of the cell body: vesicles move in isolated segments of axons in the same way they move in the intact nervous system. Our results so far indicate that transport in the molluskan axon is identical with the process described in other animals.

Experiments in single neurons can yield information about the possible mechanism of fast transport. We were able to discover two kinetic features of the transport of serotonin vesicles that were not obvious in earlier studies with heterogeneous populations of vertebrate axons. Both features can be understood if the movement of individual vesicles is discontinuous, occurring in jumps, and if a vesicle jumps only when it comes in contact with some force-generating system. First, we found that a population of vesicles that starts out as a compact group becomes dispersed as it travels down the axon; the dispersion indicates that individual particles do not move in concert. In this respect fast transport differs from slow transport, in which the fibrillar constituents of axoplasm, connected in a meshwork, all move together. Dispersion is apparently a universal characteristic of axonally transported materials. Günter Gross, working at Florida State University, labeled neuronal membrane proteins by

HARRIS technology on the job

HARRIS 1680 distributed data processing system at General Foods

In information systems, Harris Corporation produces data processing terminals, general-purpose computers, word processing systems and supervisory control systems.

Multi-function distributed data processing systems from Harris Corporation provide remote access to central computers *plus* on-site computing power, helping business and government handle growing data processing workloads.

HARRIS technology works worldwide—in communication equipment, information systems, government systems, semiconductors and printing equipment. For information, write: Harris Corporation, Melbourne, Florida 32919.

HARRIS

COMMUNICATION AND INFORMATION PROCESSING

The 1980 Silver Anniversary Thunderbird

The Proudest Bird of All

The Silver Anniversary Thunderbird grows naturally out of twenty-five years of triumphant Thunderbirds.

In honor of that occasion, we have produced the Silver Anniversary Thunderbird. It is, in a word, a knockout.

Both the inside and the outside are all silver. A silver bird representing the ultimate in Thunderbird's sophisticated automotive design.

Many Thunderbird options are standard. AM-FM stereo, air conditioning, power windows, power brakes, power seats, white sidewalls, power antenna and speed control.

Other options standard on the Silver Anniversary Thunderbird are: owner's nameplate, digital speedometer, keyless entry system.

Like all 1980 Thunderbirds, it was conceived and produced in a new contemporary size. This size and the new automatic overdrive transmission which is standard on this car, optional on other Thunderbirds, result in excellent ratings of (17) EPA est. MPG—**29** est. hwy. MPG.*

If you're looking for a car that expresses you, consider joining the many who find Thunderbird an expression of their individuality. The Silver Anniversary Thunderbird.

Road Test awards Thunderbird "best domestic car for 1980."

*Compare this to other cars. Your mileage may differ depending on speed, weather and trip length. Actual hwy. mileage will be lower than estimates. Calif. ratings lower.

THUNDERBIRD

FORD DIVISION Ford

injecting a radioactive amino acid into the snout of the long-nosed gar pike. He found that the proteins spread out as they moved along the foot-long olfactory nerve of this primitive bony fish.

The second new feature to emerge from our experiments in a single *Aplysia* axon is that vesicle movement appears to be affected by the local concentration of the vesicles themselves. Under conditions that reduced the number of vesicles in the axon, the vesicles that were present moved at a rate lower than normal. In contrast, when the concentration of axonal vesicles was doubled or tripled, the rate of transport doubled. This kind of kinetic behavior can be explained by several mechanistic models, but they all have in common the fact that the vesicles can exist in two states (either moving or at rest) and that a longer time is spent in the moving state when more vesicles are present. To put it another way, individual vesicles take longer jumps under crowded conditions and shorter jumps when they are alone. This feature (which may be a peculiarity of *Aplysia* neurons, since it has yet to be observed in vertebrate axons) tends to keep a vesicle population moving along the axon at a constant rate. If by chance an exceptional vesicle pulls ahead of the crowd, it slows down; if sluggard vesicles accumulate, they tend to speed up.

Giant neurons are ideal for studying the molecular mechanism of axonal transport because one can test agents that block the process specifically. The alkaloids colchicine and vinblastine are known to depolymerize microtubules. These drugs block fast transport in *Aplysia* giant neurons and in the smaller neurons of other animals, suggesting that microtubules have some role in the transport mechanism. The most likely candidates for providing the motive force in transport, are actin and perhaps other contractile proteins (including myosin, which combines with actin to give rise to contraction in muscle but is present in nerve cells in much smaller amounts than actin). Conclusive evidence for the participation of contractile proteins in fast transport is hard to obtain in small neurons, however, because agents that block their action are (unlike the alkaloids) too large to penetrate the cell's outer membrane. Microinjection into giant neurons makes it possible now to test large molecules by introducing them directly.

The pancreatic enzyme deoxyribonuclease I has been shown to bind individual actin monomers, thereby depolymerizing actin filaments. Actin filaments are also depolymerized by another protein, an "actin-depolymerizing factor" purified from serum by Renée Norberg and Astrid Fagraeus of the National Bacteriology Laboratory in Stockholm. Goldberg, Beverly Lubit, David Harris and I have microinjected both of these proteins into *Aplysia* giant neurons and have found that each inhibits its axonal transport profoundly. Gerhard Isenberg and Georg Kreutzberg of the Max Planck Institute of Psychiatry in Munich observed a similar result after microinjecting deoxyribonuclease I into a giant neuron of the leech. These experiments implicate microfilaments, which are polymers of actin, in the mechanism of axonal transport.

There are two popular models for explaining fast transport, both of which might make use of microtubules, actin and myosin [*see illustration on page 168*]. In the first model, initially put forward by Weiss and since then elaborated by Bernard Droz of the Centre National de la Recherche Scientifique in Gif-sur-Yvette, materials are moved passively between the microtrabecular elements of the axoplasm. On this hypothesis membrane, either formed particulate organelles or sheets of membrane destined to be transformed into organelles, is translocated actively along channels in the axoplasm, driven either by peristalsis (waves of contraction) or by cilia. Both peristalsis and ciliary action could be powered by the contractile proteins; microtubules and other cytoskeletal proteins would be required to keep the channels in proper shape or to anchor the cilia.

In the other model, which I favor, a continuous fibrillar component in the axoplasm provides an essentially stationary (apart from slow axoplasmic flow) and passive track on which particulate organelles move in a stepwise manner. The tracks would be polar, with movement on any one track taking place in only one direction. Translocation in either direction would be the result of repeated local energy-dependent reactions. A familiar mechanical analogy would be the movement of electric trains: the train does not move until contact is made with the track. A model of this type was first proposed in 1968 by Francis O. Schmitt of M.I.T. In 1972 Ochs put forward a detailed model for transport involving microtubules and filaments composed of contractile proteins. A filament would attach at one end to the organelle to be moved and at the other end to a microtubule running along the axon. Shortening of the filament, like the contraction of the actomyosin complex in muscle, would displace the organelle along the microtubules; repeated or continuous displacement might be achieved by repetition of the process.

A decade has passed without a specific test that can validate one or the other of these models. Given the current renewed interest in intracellular motility in general and the availability of giant neurons for introducing molecular probes by microinjection, it should be possible soon to determine the actual mechanism of fast axonal transport.

THE AMATEUR SCIENTIST

Visual illusions in random-dot patterns and television "snow"

by Jearl Walker

Human perception seems to try to impose order on disorder. This month I shall discuss two illusions that are based on this tendency. The first illusion is an array of random dots that, viewed in a certain way, seem to form concentric circles. The other illusion is seen in the patterns and motions on a television screen that is tuned to a channel over which no signal is being transmitted. The random "snow" that covers the screen can apparently be ordered by the visual process.

I first became interested in random-dot displays last year when I got a letter from A. G. Klein of the University of Melbourne. With his letter came a transparency of randomly arranged dots, some less than a millimeter across and others several millimeters. Klein had made the transparency by sprinkling graphite powder on a sheet of paper and then running the paper through a 3M transparency producer. He also enclosed with his letter a photocopy of the transparency.

Following instructions from Klein, I aligned the transparency on the copy and then slightly rotated the transparency about a point near the center. Suddenly the random array of dots turned into concentric circles centered on the point of rotation. The circles were not complete, but the illusion that they were there was compelling. The question is why my visual system thus imposed order on disorder.

One can make similar transparencies of random dots in other ways. One way is to dip an old toothbrush into paint and then spray the paint onto a surface by running a finger over the bristles. You could spray the paint onto paper and make a transparency on a machine, or you could deposit the paint directly on a sheet of plastic. Alternatively you could insert two sheets of carbon paper between a sheet of regular paper and a sheet of acetate. Lay the sheets of carbon paper so that they are back to back. Then hit the four layered sheets repeatedly with the bristles of a wire brush. The points of impact will appear as identical dots on both the regular paper and the acetate. Photographs of sandpaper will also work, according to D. M. MacKay of the University of Keele in England, who in 1964 reported that illusions of circles and spirals can be seen in both positive and negative photographs of sandpaper. Regardless of the technique, a slight rotation of the two identical patterns after an initial alignment gives rise to the illusion of concentric circles.

Leon Glass of the University of Rochester has investigated this illusion for 10 years. In 1969 he described some of the simple observations one can make with the random-dot patterns and speculated about the aspect of the perceptual system responsible for the illusion. In 1973 Glass and Rafael Pérez published the results of a variety of experiments with the random-dot patterns. They made the patterns with a pseudorandom-number generator that is available in the computer language Fortran. Next a computer chose the positions of the dots, which were then inscribed with a Calcomp plotter. The plots were redrawn by hand and converted into transparencies.

In some experiments the patterns on the paper and those on the transparencies were the same size, so that the alignment of the two was precise. In other experiments one of the two was reduced, so that the alignment was close only in a small area. If the two patterns were at the same scale, Glass and Pérez observed the same types of illusions I have described. If the patterns were not at the same scale, two types of illusion were possible. One resulted if the experimenter aligned the dots in one small area and was careful not to rotate the transparency with respect to the paper. Then the superposed patterns gave the appearance of an explosion. A slight rotation of the transparency with respect to the paper transformed the explosion into a form that resembled a spiral galaxy.

Glass and Pérez noted that if only a small section of the superposed patterns was visible, the illusion of circles, explosions or spirals either was less apparent or was absent. The illusions depend on a correlation by the observer of the appropriate pairs of dots in the patterns (the ones that would coincide if the patterns were at the same scale and were exactly aligned). When the patterns are rotated, those pairs are separated. The observer apparently takes in the entire display, correlating the separated pairs. The correlation somehow suggests the illusion. If the field of view is limited to a small section of the pattern, however, the observer either cannot correlate the pairs as well or the number of correlations is insufficient to give rise to the illusion.

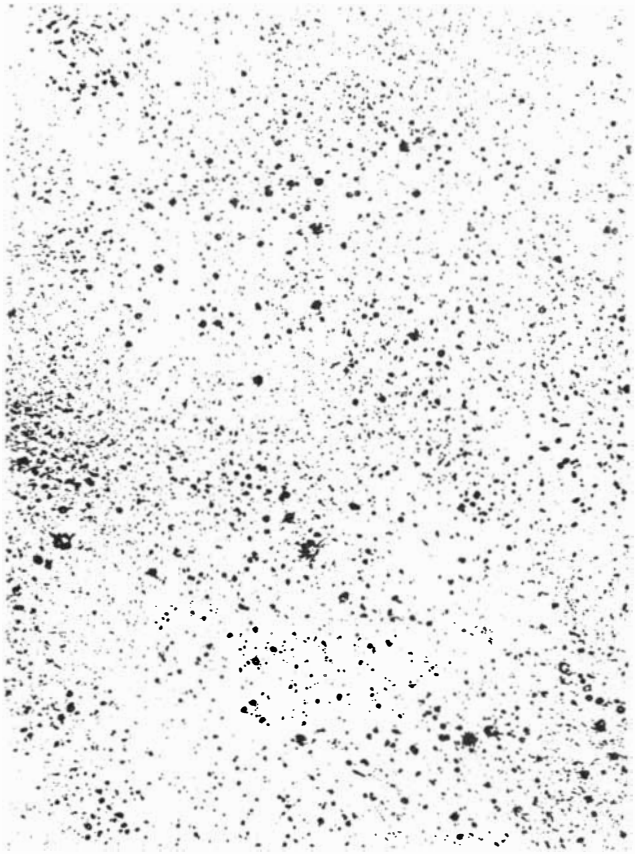
In another set of experiments Glass and Pérez made transparent negatives of a pattern in such a way as to create white dots on a black background. The patterns in the two transparencies were the same except that one was rotated with respect to the other. The transparencies were placed in a stereoscopic projector, and the observer viewed both of them simultaneously. The intensity of the light from each transparency could be independently controlled by a pair of crossed polarizing filters, one pair in front of each transparency. For example, if the experimenter wanted to decrease the amount of light coming from the right-hand transparency, he rotated one polarizing filter of the pair in front of that transparency.

In one of the experiments identical but rotated transparencies were viewed. As the intensity of light from one of the transparencies was decreased the circles appeared to rotate. For example, suppose transparency P' was initially rotated clockwise with respect to transparency P. Decreasing the intensity of the light from P' then resulted in a counterclockwise rotation of the illusionary circles.

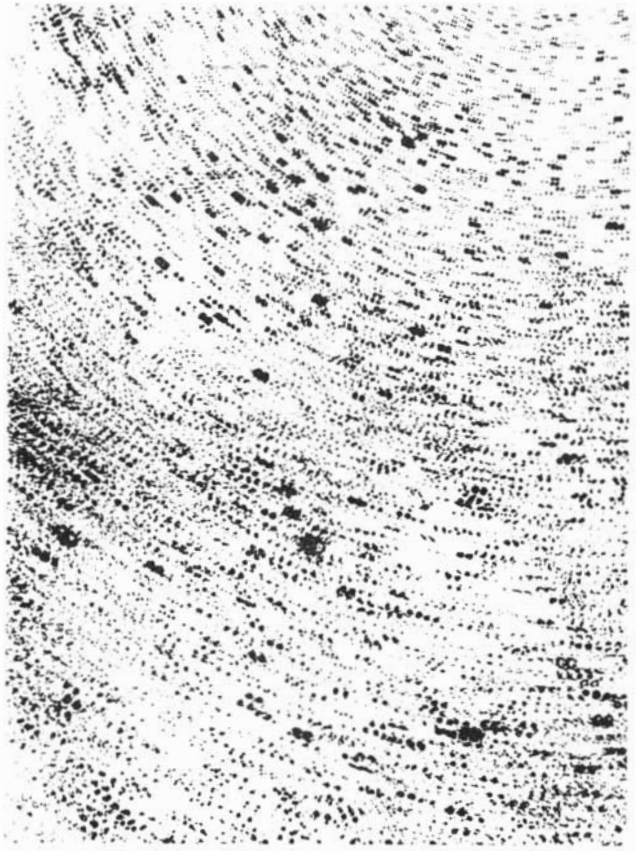
When the experimenters worked with a pair of transparencies that normally showed an apparent explosion, an adjustment of the intensity of the light from one of the transparencies gave the illusion that the size of the pattern had changed. If the intensity of the light from the transparency with the larger of the two patterns was decreased, the pattern seemed to shrink.

Glass and Pérez also experimented with colored filters inserted in the path of the light coming from each transparency. In this way they could give a different color to each of the displays of random dots. The illusions of circles and other patterns remained. Moreover, if the intensity of one of the patterns was varied, the apparent motion (rotation, contraction or expansion) was again present.

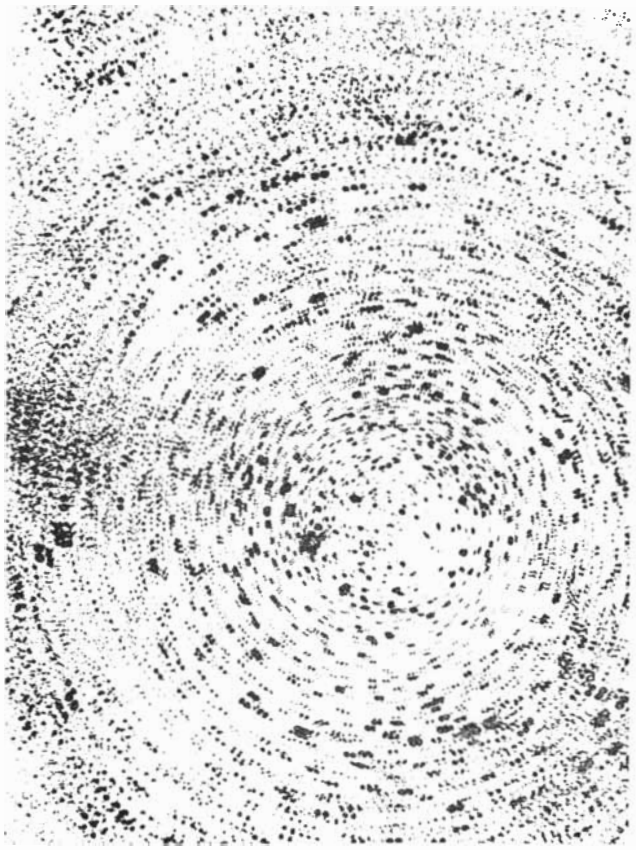
When I play with the transparency and its copy that Klein sent me, I first align the two as carefully as I can. At a chosen point on the transparency I press the tip of a pencil and gradually rotate



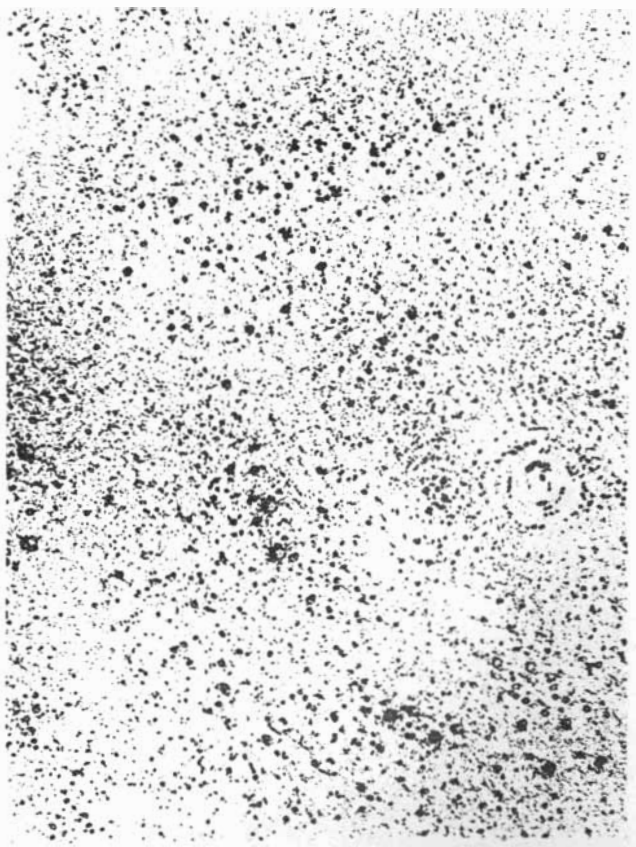
A. G. Klein's random-dot transparency



A slight rotation of the transparency over a copy of it



The result of further rotation



Loss of the illusion through overrotation

the transparency until the illusion of the circles begins at a large radius from the center of rotation. The illusion requires the separation of correlated dots, which begins at a large radius sooner than it does closer to the pivot point. Further rotation separates the dots closer to the pivot point and so brings the illusion inward to the center of rotation. Eventually the rotation is large enough to destroy the illusion. Then I see only a relatively dense array of random dots.

The smaller dots were more effective in producing the illusion, probably because the larger dots needed a good deal of rotation to achieve the proper amount of separation. By then many of the smaller dots were no longer contributing to the illusion. A pair of dots made their best contribution when they were separated by a distance that was a few times their diameter. In the relatively dense areas of the pattern the illusion was weak because the proper amount of separation between correlated dots usually meant that other dots were near enough to cause confusion.

I could adjust the direction of the circling in the illusion by pushing with my thumbs at the lower end of the transparency. A push upward with my right thumb generated circles with their center lying to the left, a push upward with my left thumb generated circles with their center to the right. In an intermediate adjustment I could make the lines in the illusion straight instead of curved. Rapidly sliding the transparency around on the copy led to an additional illusion: a white wave sweeping around the page. The white area appeared in the region where the dots were aligned and so gave no illusion of circular lines. The rest of the page had curved lines of some kind. As I slid the transparency the area of alignment moved over the page and therefore so did the white area.

I tried to produce the illusion of circles by turning the transparency over and aligning a few of its dots with dots on its copy. The alignment was poor, of course, except for a few dots that happened to be about the same size and in approximately the right places. When I rotated the transparency out of this inadequate alignment, no illusion appeared. As I would have guessed, the illusion requires more than just a few dots. Apparently much of the page must be in near alignment with its copy. As Glass and Pérez determined, the illusion stems from a "global" examination of the dot display, not from an examination of just a few dots.

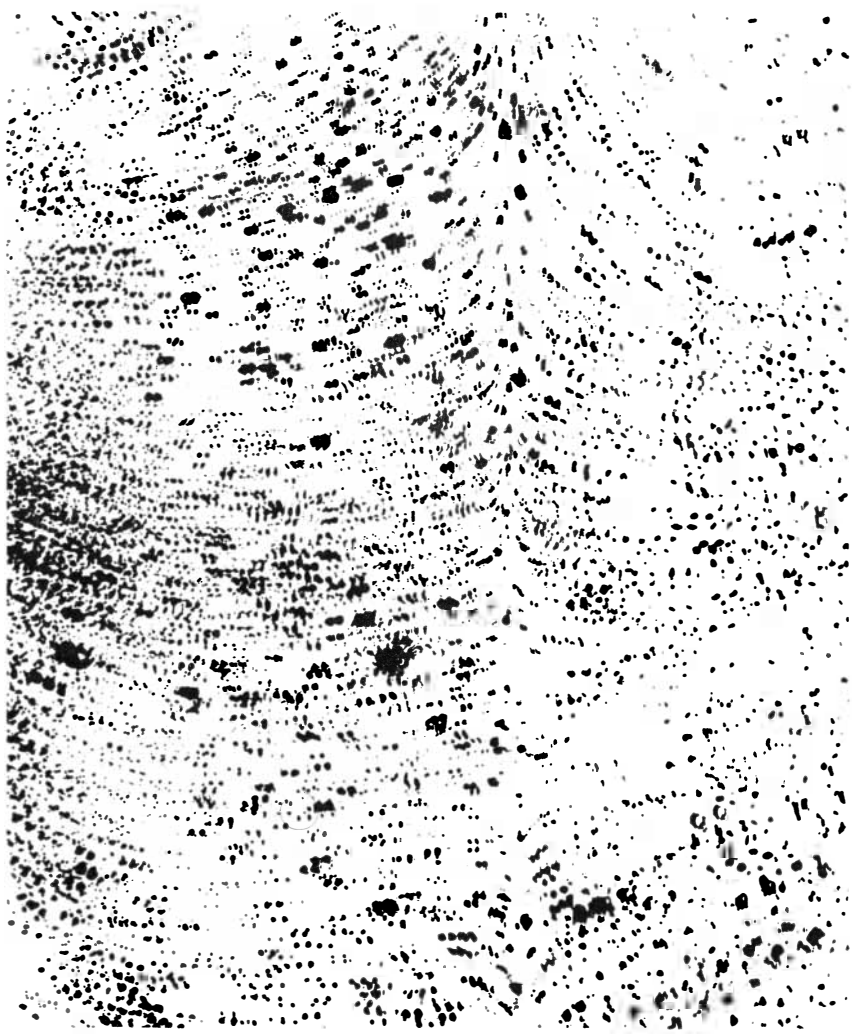
In the same vein I can investigate how little of the display must be viewed in order to maintain the illusion. I first adjust the transparency and its copy in order to produce the best illusion of circles. Then I cover the transparency with a sheet of paper in which I have cut a square hole. By using different sizes for the hole I can see different amounts of the pattern. If the area of my view is only a few times wider than the average dot size, the illusion is weak or absent. If the area of my view is increased to about 20 times the dot size, the illusion can be discerned. I seem to observe the full illusion when the area of my view is at least 50 times the dot size.

When I lift the transparency slightly from the photocopied page, the illusion changes from concentric circles to either an explosion or a spiral. Glass and Pérez created illusions of this kind by superposing patterns that were identical except for scaling. In effect I achieve the same thing because the transparency is closer to me than the page and so appears to be slightly larger than the page.

I can also get the explosion illusion by holding the transparency close to a mirror and then viewing both the transparency and its mirror image with one eye. An assortment of circles, spirals and explosions can be made by warping the transparency when it is placed over the photocopied page. For example, if I align the transparency and the photocopy and then distort the transparency, about halfway up the page I can force it into a "hill" that extends from the page. The result is that the lower end of the display has circles, the middle has either spirals or explosions and the top has large circles.

In addition to doing your own experiments with rotations in random-dot displays you may want to try your hand at producing art from the geometric patterns the illusions give. If you construct a relatively large random-dot display and warp the transparent sheet appropriately, you can make an illusion that changes with different perspectives. The circles and spirals vary as you move past the display. Probably someone has already done this in "op art," although I do not know who.

A different kind of random-noise display can be seen if you tune your television set to a channel to which no signal is being transmitted. The screen is filled with random snow picked up by the antenna. The display is one not of random dots but of randomly fluctuating intensities of light on the screen. Although the entire screen is fluctuating in intensity, the fluctuations in any small area of it have greater contrast than the fluctua-



Results of warping the transparency

tions of the entire screen. One therefore has the impression that white dots are darting about the screen.

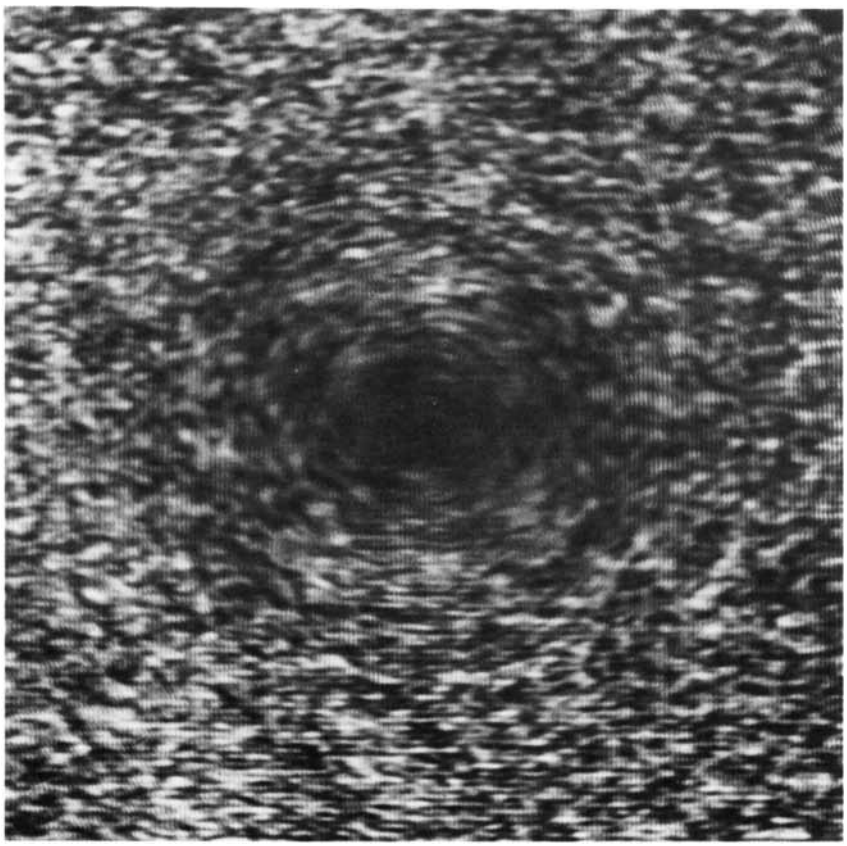
In 1961 MacKay reported several curious illusions that could be seen in the television snow. If you stare at the screen, you will probably find that in the center of your field of view the snowstorm is far more intense than it is away from the center. The effect is enhanced if you stare with one eye instead of two. MacKay noted that this region of enhanced agitation is associated with the foveal area of the field of view. The fovea is the part of the retina that affords the sharpest vision, because it has the closest packing of photoreceptors.

MacKay also pointed out that contrary to what one might think a screen viewed with one eye seems brighter and more densely packed with snow than the same screen viewed with both eyes. Moreover, with binocular viewing the apparent spots on the screen seem to be more persistent and their motion seems to have an oilier quality. If the screen's intensity is reduced, its appearance eventually becomes about the same for both kinds of viewing. At low intensities the screen appears to show discrete spots of light darting about and much of the frenzied quality of the movement is missing.

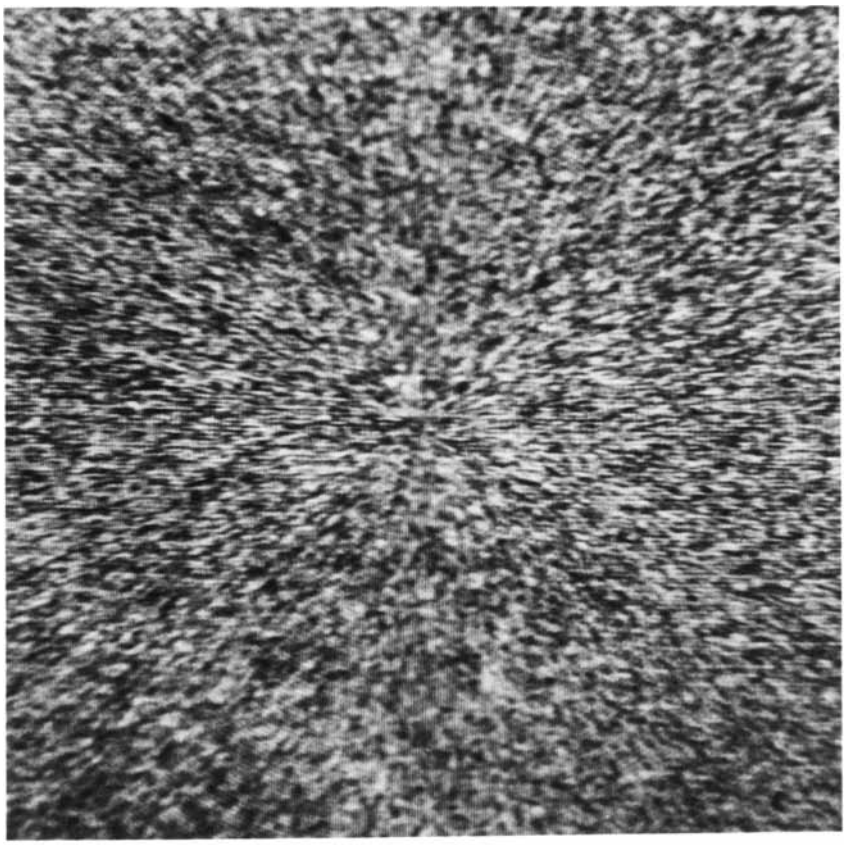
If a finger, a loop of wire, a black circle or some other such object is held in front of the screen, the spots appear to adhere to it, creating an illusion of a boundary layer at the contours of the object. One can even create an illusion of directed flow by choosing an appropriately shaped object. If a black circular loop is moved about in front of the screen, the spots of light appear to move with it, as if they had been lassoed. A moving finger seems to be pursued by a swarm of particles.

Earlier (in 1957) MacKay had demonstrated that a grid placed on such a screen can help the viewer to organize the random visual noise into a partly coherent pattern. When he placed a pattern of radial lines on the screen, the white spots on the screen appeared to move perpendicularly to the lines and so seemed to be swirling around the center of the grid. The swirling could be either clockwise or counterclockwise; at times areas of the display appeared to be turning in opposite directions. If MacKay rotated the grid, the pattern in the snow appeared to turn in the opposite sense. When he placed a grid of concentric circles on the screen, the dots again seemed to move in a stream that was perpendicular to the lines, but this time they flowed radially outward from the center of the grid pattern. The pattern in the snow also rotated slowly about the center of the grid. In some of MacKay's later experiments he found that putting a ring on the screen gave the illusion of snow drifting slowly around the ring.

I made similar observations with my



Circles in television snow from superposing moiré pattern No. 4



"Emission hole" in television snow created by pattern No. 5

own television screen and a set of moiré transparencies from the Edmund Scientific Company (101 East Gloucester Pike, Barrington, N.J. 08007). In the package of transparencies (Series A) the best effects came with patterns No. 4 and No. 5 placed on the television screen. No. 4 consists of a small central circle surrounded by radial lines; No. 5 consists of many closely ruled concentric circles.

When I held No. 4 on the screen, the center of the pattern forced the snow into frenzied activity and the radial lines made it spiral around either clockwise or counterclockwise. I could switch the apparent sense of rotation almost at will. To enhance the effects I adjusted the set's controls for brightness and contrast. My results were best when the brightness control was turned completely down and the contrast control was at its midpoint, but only experimentation will determine the optimum conditions for other television sets. The white dots appeared to be on a slightly curved surface lying just behind the plane of the glass of the screen. The various features of the illusions were present with both monocular and binocular viewing.

When I held the pattern close to one eye and shut the other eye, the illusion became extremely lively, particularly when I was able to reverse the flow or set up counterflows simultaneously. The flow near the edge of the screen seemed to be less active. If I lowered the intensity until the screen was almost dark, the organization of the dots decreased until they resembled small bugs randomly darting about the grid system.

Pattern No. 5 organized the snow into pulsations, as if the center of the pattern were either the source or the sink of radial lines. This "emission hole" effect was notably intense when I held the transparency close to my eye. Again the organization disappeared when I lowered the intensity of the light on the screen from its peak level. When the intensity was highest, I had the strong impression that ripples were flowing over the screen; they looked much like the ripples produced by a pebble tossed into a pond.

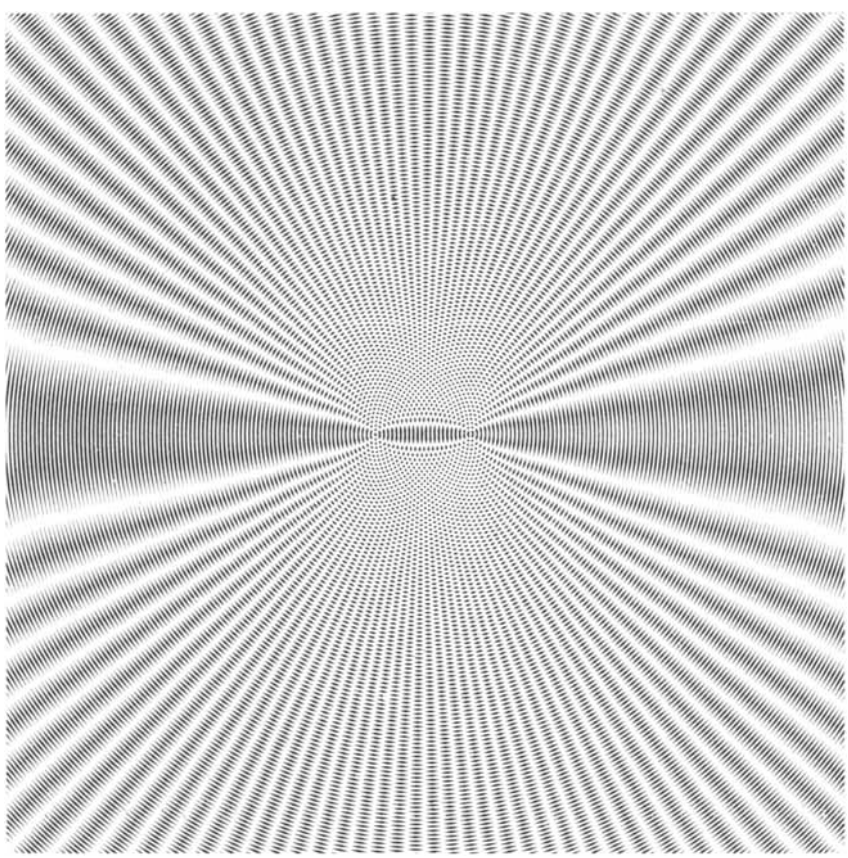
By slightly displacing one transparency of pattern No. 4 in laying it over a copy of the same pattern, I was able to create two areas of swirling. With two copies of pattern No. 5 I made two emission holes. When I carefully aligned the transparencies and then misaligned them, I could superpose the normal moiré patterns (seen when two identical patterns are superposed and also slightly misaligned) on the organization of the screen noise. One of my transparencies had black lines, the other red. The result of superposing the two transparencies was that red lines were added on the organized flow of the snow.

No one is sure why the visual process organizes the snow when an appropriate pattern is placed on the television screen. MacKay has suggested that the interaction of contour-sensing elements in the visual process may bring about the organization, but exactly how they do it is not known. Perhaps the elements in the visual network that sense the contours of the superposed pattern may then be insensitive to motion along the contours. As a result the observer would see only the motion perpendicular to the contours. Alternatively couplings of contour-sensitive elements may enhance the sensitivity of the visual system to motion perpendicular to the contours. It is not known which explanation is correct, but recent work by MacKay, H. J. M. Gerrits and H. P. Stassen has shown that if the superposed pattern is stabilized on the retina (by means of a suction cup attached to the eye), the pattern fades and the illusion of organization in the snow diminishes. (Stabilizing any pattern on the retina causes it to fade from perception.) Therefore perceiving the pattern is necessary for the illusion.

In 1974 R. I. MacDonald of Carleton University in Ottawa independently reported an observation about snow on a television set that was similar to one of MacKay's observations. MacDonald noted that when he stared at the snow first with both eyes and then with one eye, the snow appeared to move slower and the spots seemed to be smaller. He was able to reproduce the same effect with the random noise generated by a laser beam transmitted through a pair of ground-glass plates. As one of the plates was moved around in the light from the other plate, the light was projected onto a screen and examined by an observer.

MacDonald also checked to see if this effect depended on the correlation of the eyes when both eyes were used. An observer viewed the screen with two cardboard tubes directed so that each eye saw a different section of the screen. The observer then closed one eye. The effect was again present, implying that it does not depend on the correlation between the eyes when the screen is seen binocularly. You could check this result with the snow on a television screen by similarly employing cardboard tubes.

As a last experiment I tried defocusing my eyes while watching the snow on my television screen. When I gently pressed the lower portion of my eye, the screen noise became significantly more vigorous and appeared to flow up and down. I assume that the pressure altered the shape of my eye and therefore prevented it from properly focusing the image of the screen onto my retina, but why this impaired focusing increased the intensity of the noise I do not know.



Illusion caused by slightly separating two superposed versions of pattern No. 5

BIBLIOGRAPHY

Readers interested in further explanation of the subjects covered by the articles in this issue may find the following lists of publications helpful.

MATHEMATICAL GAMES

A BOOK OF CURVES. Edward H. Lockwood. Cambridge University Press, 1961.

MAXWELL'S OVALS AND THE REFRACTION OF LIGHT. Milton H. Sussman in *American Journal of Physics,* Vol. 34, No. 5, pages 416–418; May, 1966.

CHEMICAL WARFARE AND CHEMICAL DISARMAMENT

CHEMICAL WARFARE: A STUDY IN RESTRAINTS. Frederic J. Brown. Princeton University Press, 1968.

CHEMICAL AND BIOLOGICAL WEAPONS. Matthew S. Meselson in *Scientific American,* Vol. 222, No. 5, pages 15–25; May, 1970.

THE PROBLEM OF CHEMICAL AND BIOLOGICAL WARFARE. Stockholm International Peace Research Institute. Humanities Press, 1971–1975.

CHEMICAL WEAPONS AND CHEMICAL ARMS CONTROL. Edited by Matthew Meselson. Carnegie Endowment for International Peace, 1978.

POLITICAL ISSUES, VOL. 6, NO. 2: CHEMICAL/BIOLOGICAL WARFARE, A SELECTED BIBLIOGRAPHY. Center for the Study of Armament and Disarmament, California State University, 1979.

A PALEOLITHIC CAMPSITE IN BELGIUM

L'HABITATION MAGDALÉNIENNE N° 1 DE PINCEVENT PRÉS MONTEREAU (SEINE-ET-MARNE). A. Leroi-Gourhan and M. Brézillon in *Gallia Préhistoire,* Vol. 9, pages 263–371; 1966.

FOUILLES DE PINCEVENT: ESSAI D'ANALYSE ETHNOGRAPHIQUE D'UN HABITAT MAGDALÉNIEN (LA SECTION 36). A. Leroi-Gourhan and M. Brézillon in *Gallia Préhistoire,* Supplement 7, 1972.

STONE TOOLS, TOOLKITS, AND HUMAN BEHAVIOR IN PREHISTORY. D. Cahen, L. H. Keeley and F. L. Van Noten in *Current Anthropology,* Vol. 20, No. 4, pages 661–683; December, 1979.

SUDDEN INFANT DEATH

PROCEEDINGS OF THE FRANCIS E. CAMPS INTERNATIONAL SYMPOSIUM ON SUDDEN AND UNEXPECTED DEATHS IN INFANCY. Edited by Robert R. Robinson. Canadian Foundation for the Study of Infant Deaths, Toronto, 1974.

SUDDEN UNEXPLAINED INFANT DEATH, 1970 THROUGH 1975: AN EVOLUTION IN UNDERSTANDING. Marie Valdes-Dapena in *Pathology Annual,* Vol. 12, Part 1, pages 117–145; 1977.

SUDDEN INFANT DEATH SYNDROME (CRIB DEATH). Warren G. Guntheroth in *American Heart Journal,* Vol. 93, No. 6, pages 784–793; June, 1977.

USEFUL PROTEINS FROM RECOMBINANT BACTERIA

A BACTERIAL CLONE SYNTHESIZING PROINSULIN. Lydia Villa-Komaroff, Argiris Efstradiadis, Stephanie Broome, Peter Lomedico, Richard Tizard, Stephen P. Naber, William L. Chick and Walter Gilbert in *Proceedings of the Academy of Sciences of the United States of America,* Vol. 75, No. 8, pages 3727–3731; August, 1978.

SYNTHESIS IN *E. COLI* OF A POLYPEPTIDE WITH HUMAN LEUKOCYTE INTERFERON ACTIVITY. Shigekazu Nagata, Hideharu Taira, Alan Hall, Lorraine Johnsrud, Michel Streuli, Josef Escödi, Werner Boll, Kari Cantell and Charles Weissmann in *Nature,* in press.

THE SYNTHESIS OF EUKARYOTIC PROTEINS IN PROKARYOTIC CELLS. Lydia Villa-Komaroff in *Gene Structure and Expression,* edited by D. H. Dean, L. F. Johnson, P. C. Kimball and P. S. Perlman. Ohio State Press, in press.

METALLIC GLASSES

STRUCTURE OF METALLIC ALLOY GLASSES. G. S. Cargill III in *Solid State Physics: Advances in Research and Application,* Vol. 30, pages 227–320; 1975.

METALLIC GLASSES. John J. Gilman in *Physics Today,* Vol. 28, No. 5, pages 46–53; May, 1975.

STRUCTURE AND PROPERTIES OF METALLIC GLASSES. P. Chaudhari and D. Turnbull in *Science,* Vol. 199, No. 4324, pages 11–21; January 6, 1978.

THE STRUCTURE OF THE EARLY UNIVERSE

MODERN COSMOLOGY. D. W. Sciama. Cambridge University Press, 1971.

PHYSICAL COSMOLOGY. P. J. E. Peebles. Princeton University Press, 1971.

THE FIRST THREE MINUTES: A MODERN VIEW OF THE ORIGIN OF THE UNIVERSE. Steven Weinberg. Basic Books, 1977.

PARTICLE PHYSICS AND COSMOLOGY. David N. Schramm and Michael S. Turner in *Physics Today,* Vol. 32, No. 9, pages 42–48; September, 1979.

THE BIG BANG. Joseph Silk. W. H. Freeman and Company, 1980.

THE SOCIAL ECOLOGY OF COYOTES

THE WOLF: THE ECOLOGY AND BEHAVIOR OF AN ENDANGERED SPECIES. L. David Mech. American Museum of Natural History, Natural History Press, 1970.

FEEDING AND SOCIAL BEHAVIOR OF THE STRIPED HYENA (*HYAENA VULGARIS*). H. KRUUK IN *East African Wildlife Journal,* Vol. 14, pages 91–111; 1976.

BEHAVIORAL ECOLOGY. Edited by J. R. Krebs and N. B. Davies. Sinauer Associates, Inc., 1978.

THE CLEVER COYOTE. Stanley P. Young and Hartley H. T. Jackson. University of Nebraska Press, 1978.

COYOTES: BIOLOGY, BEHAVIOR, AND MANAGEMENT. Edited by Marc Bekoff. Academic Press, 1978.

THE RELATIONSHIP BETWEEN FOOD COMPETITION AND FORAGING SIZE GROUP IN SOME LARGER CARNIVORES. J. Lamprecht in *Zeitschrift für Tierpsychologie,* Vol. 46, pages 337–343; 1978.

THE TRANSPORT OF SUBSTANCES IN NERVE CELLS

AXOPLASMIC TRANSPORT (WITH PARTICULAR RESPECT TO ADRENERGIC NEURONS). Annica Dahlström in *Philosophical Transactions of the Royal Society of London,* Series B, Vol. 261, pages 325–358; 1971.

AXONAL TRANSPORT: THE INTRACELLULAR TRAFFIC OF THE NEURON. Bernice Grafstein in *Handbook of Physiology,* edited by Eric R. Kandel. American Physiological Society, 1977.

AXONAL TRANSPORT: COMPONENTS, MECHANISMS AND SPECIFICITY. James H. Schwartz in *Annual Review of Neuroscience,* Vol. 2, pages 467–504; 1979.

THE AMATEUR SCIENTIST

VISUAL EFFECTS OF NON-REDUNDANT STIMULATION. D. M. MacKay in *Nature,* Vol. 192, No. 4804, pages 739–740; November 25, 1961.

CENTRAL ADAPTATION IN MECHANISMS OF FORM VISION. D. M. MacKay in *Nature,* Vol. 203, No. 4948; August 29, 1964.

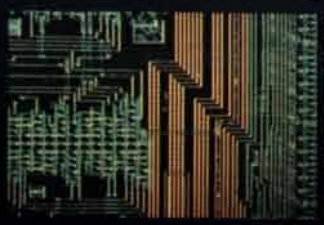
MOIRÉ EFFECT FROM RANDOM DOTS. Leon Glass in *Nature,* Vol. 223, No. 5206, pages 578–580; August 9, 1969.

PERCEPTION OF RANDOM DOT INTERFERENCE PATTERNS. Leon Glass and Rafael Pérez in *Nature,* Vol. 246, No. 5432, pages 360–362; December 7, 1973.

KINETIC CYCLOPEAN EFFECT. R. I. MacDonald in *Nature,* Vol. 249, No. 5453, page 192; May 10, 1974.

hexa·photo·cybernetic

Six-mode exposure control. System versatility. Newer electronics for wider applications.



The incredible Canon A-1. It's on the cutting edge of technology, with state-of-the-art electronics and computerized operation.

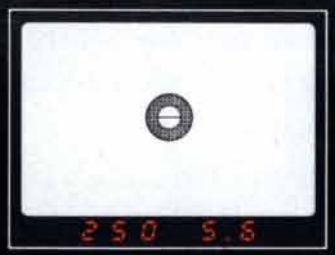
Yet, although the way we build it is complex, the way you use it is the ultimate in simplicity. If pushbutton-easy fine photography is what you're after, the A-1 can give it to you six ways.

1 Shutter-Priority automation: You pick the speed to freeze or blur action or prevent camera shake, the A-1 picks the perfect aperture automatically.

2 Aperture-Priority automation: Select the aperture you want for a soft background or total overall sharpness, the A-1 will give you the speed that's correct.

3 Programmed automation: On the A-1, this unique exposure mode picks both aperture and speed in ideal combinations depending on the light. You don't have to set *anything.*

4 Stopped-Down automation: This mode lets you get automatic exposure with any lens or accessory you can mount on the camera. Great for astrophotography, photomicrography, close-ups.



5 Flash automation: The A-1 has the easiest electronic flash of any camera of its type. With special Canon flash units, your aperture *and* speed are set automatically. Just mount the flash, turn it on and shoot for perfect exposures every time.

6 For any type of photography that's not already covered, there's manual.

There's more. Digital control and viewfinder display. Versatile control features. Accessories like a rugged motor drive, compact motorized film winder and interchangeable date/data back. Plus forty Canon FD lenses for unsurpassed image quality and scope.

You won't find another camera like it on the face of the earth. Because only Canon has the technology to make it.

Luckily, you don't have to go to the ends of the earth to get an A-1. Only as far as your local Canon dealer.

Canon® A-1

So advanced, it's simple.

Canon USA, Inc., 10 Nevada Drive, Lake Success, New York 11042 · 140 Industrial Drive, Elmhurst, Illinois 60126 · 6380 Peachtree Industrial Blvd., Norcross, Georgia 30071 · 123 Paularino Avenue East, Costa Mesa, California 92626 · Bldg. B-2, 1050 Ala Moana Blvd., Honolulu, Hawaii 96814 · Canon Optics & Business Machines Canada, Ltd., Ontario

The Honda Prelude. Our idea of a sports car.

Our idea is simple. We think a sports car should be nimble, stylish, economical to operate, and fun to drive. The fact is, we liked our idea so much we built the car. The Honda Prelude.

To go along with the Prelude's bold, clean styling, we gave it a power-operated moonroof as standard equipment. That's our idea of fun. We also gave it a quartz digital clock, comfortable front bucket seats with adjustable headrests, steel-belted radial tires, electronic warning system, and a 5-speed stick shift. Optional this year is our new fully automatic 3-speed transmission.

1980 HONDA PRELUDE 5-SPEED

25 EPA EST. MPG, 35 HWY. MPG. USE 25 MPG FOR COMPARISON. YOUR MILEAGE MAY DIFFER DEPENDING ON WEATHER, SPEED, AND TRIP LENGTH. ACTUAL HWY. MILEAGE WILL PROBABLY BE LESS. FIGURES LOWER FOR CALIF. AND HIGH ALTITUDE CARS.

Meanwhile, our Honda engineers provided the car with front-wheel drive, rack and pinion steering, 1751cc CVCC engine, and a four-wheel independent suspension system of advanced design. All this makes the Prelude one of the nimblest of all Hondas.

Finally, we come to what may be the nicest thing of all about the Honda Prelude. Once you get in, you don't want to get out. And with a sports car, isn't that the whole idea?

HONDA

We make it simple.

DEWAR'S® PROFILE

A thirst for living . . . a taste for fine Scotch.

BLENDED SCOTCH WHISKY • 86.8 PROOF
© SCHENLEY IMPORTS CO., N.Y., N.Y.

DAVID MANWARING

BORN: Hendersonville, North Carolina, 1946.

HOME: Brooklyn, New York.

PROFESSION: Theatrical artisan.

REVIEW: His armor for Lynn Redgrave's "Saint Joan" is regarded as some of the most realistic costuming and props on Broadway. And it's typical Manwaring.

QUOTE: "Theatre can no longer afford to cheat the imagination. The stage must compete with film and television; and my art must be more sophisticated . . . more authentic . . . to be equally convincing."

BIGGEST ACCOMPLISHMENT: The 7′-tall flocked-latex Incredible Hulk costume. "It looks real, moves right, and folds for shipping."

FIRST HERO: The Creature from the Black Lagoon. "The first great costume; you weren't entirely sure there was a man inside."

DREAM: The right tools, enough time, and an impossible assignment.

SCOTCH: Dewar's "White Label."® Especially, straight up. "I like to sip it, slowly, after beating a deadline."

David C. Manwaring