# SCIENTIFIC AMERICAN

GRAVITATIONAL LENS

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*November 1980*

# INTRODUCING THE NEW WORLD CAR

## ENGINEERING TEAMS FROM AMERICA AND OVERSEAS JOIN FORCES TO CREATE A NEW CAR WITH BETTER IDEAS FROM AROUND THE WORLD

Top engineers drawn from the worldwide resources of Ford Motor Company teamed up to create Escort.

They pooled their expertise ... compared, tested, evaluated, experimented—to come up with better ideas. The result: a high-mileage car built in America to take on the world. Escort will be made in America for American drivers ... with other models built and sold overseas.

## HIGH MILEAGE THROUGH ADVANCED TECHNOLOGY

Escort's fuel efficiency comes from highly efficient new power teams, the use of special weight-efficient steel, refined aerodynamics and other new and better ideas, not less car. In fact, Escort has the room of a compact (based on EPA Volume Index).

| ESCORT | 30 EPA EST MPG* | 44 EST HWY* |
|---|---|---|

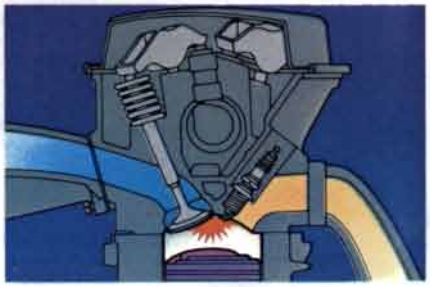
EVEN HIGHER GAS MILEAGE THAN THESE LESS ROOMY SUBCOMPACTS.

| | | |
|---|---|---|
| VW RABBIT (GAS) | 28 | 42 |
| TOYOTA COROLLA H/B | 28 | 39 |
| HONDA ACCORD | 27 | 36 |

*Applicable only to sedans without power steering or air conditioning. For comparison. Your mileage may differ depending on speed, distance, weather. Actual hwy mileage and Calif. ratings lower. Excludes diesels.

## ONE OF THE MOST POWER-EFFICIENT ENGINES AVAILABLE IN AMERICA

Escort's advanced-design compound valve hemispherical head (CVH) engine focuses the incoming



combustion charge for power efficiency. Result: high mileage plus power for freeway driving.

And Escort has a new manual transmission with fuel-efficient fourth gear overdrive standard.

## FRONT-WHEEL DRIVE AND FOUR-WHEEL INDEPENDENT SUSPENSION

Escort has front-wheel drive ... four-wheel fully independent suspension ... rack-and-pinion steering ... stabilizer bar and new all-season steel-belted radials. And Escort makes use of a special steel—high-strength steel—along with other weight-efficient materials, for high mileage. Plus Escort offers a special all-new fast-cooling air-conditioning system.

# FORD ESCORT

Escort Liftgate...4 doors and wagon room when you need it.

**DRIVE A WORLD CAR**

Whether you buy or lease, see your Ford Dealer now to order your Escort ...3-door Hatchback, 4-door Liftgate —ten choices in all—even a Squire wagon option. And remember to ask about Ford's Extended Service Plan.

**EVERY ESCORT HAS ALL THESE FEATURES *STANDARD***

- Front-wheel drive for traction.
- Fully independent four-wheel suspension for smooth road-holding.
- New-design compound valve hemispherical head (CVH) engine.
- Fully synchronized manual transmission with fuel-efficient fourth gear overdrive (automatic available).
- Rack-and-pinion steering.
- Bucket seats...scientifically contoured for comfort.
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- All-season steel-belted radials.
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- Self-adjusting clutch.
- Front-wheel bearings need no periodic adjustment.
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FORD DIVISION Ford


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Established 1845 **SCIENTIFIC AMERICAN** November 1980 Volume 243 Number 5

ARTICLES



DEPARTMENTS





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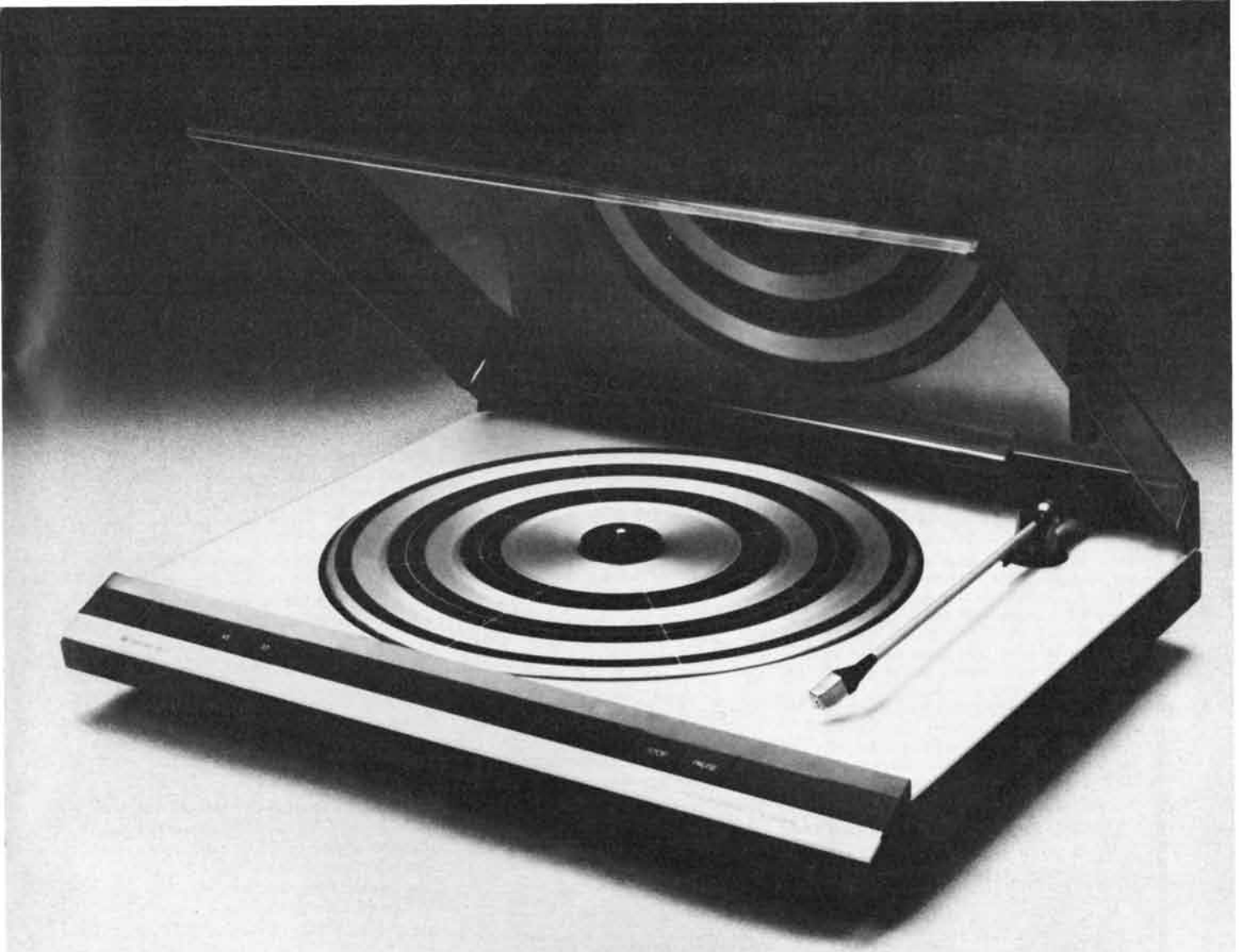
### THE COVER

The picture on the cover is a computer-generated display on a cathode-ray tube of one image of a quasar whose radiation had been deflected to form two images by an elliptical galaxy acting as a gravitational lens. The large multicolored area is the southern image of the quasar, and the small yellow spot is probably the galaxy. The northern image of the quasar as well as the southern one can be seen in other computer-graphics representations (see "The Discovery of a Gravitational Lens," by Frederic H. Chaffee, Jr., page 70). The colors (white, purple, light blue, dark blue, yellow, red and green) correspond respectively to regions of increasing intensity of radio waves with a wavelength of six centimeters. The data for the display were gathered in February by the National Radio Astronomy Observatory's Very Large Array near Socorro, N.M. The display was made by Perry E. Greenfield and Bernard F. Burke of the Massachusetts Institute of Technology and David H. Roberts of Brandeis University.

### THE ILLUSTRATIONS

Cover courtesy David H. Roberts, Brandeis University

| Page | Source |
|---|---|
| 18–30 | Ilil Arbel |
| 54–59 | Albert E. Miller |
| 61 | Robert T. Schimke, Stanford University (*top*); Lawrence A. Chasin and Gail Urlaub, Columbia University (*bottom*) |
| 62–64 | Bunji Tagawa |
| 65 | Robert T. Schimke, Stanford University |
| 66–67 | Bunji Tagawa |
| 68 | Bunji Tagawa (*top*); Robert T. Schimke, Stanford University (*bottom*) |
| 69 | Peter C. Brown, Stanford University |
| 71 | National Radio Astronomy Observatory |
| 72 | National Radio Astronomy Observatory (*top*), Smithsonian Astrophysical Observatory and the University of Arizona (*bottom*) |
| 73 | Hale Observatories |
| 74–77 | Allen Beechel |
| 78 | Alan N. Stockton, University of Hawaii at Manoa |
| 91 | Fredric Silverblatt and Craig Kuehn, Veterans Administration Hospital, Sepulveda, Calif. |
| 92–106 | Allen Beechel |
| 119 | Muriel D. Ross, University of Michigan Medical School (*top*); Dean E. Hillman, New York University Medical Center (*bottom*) |
| 120–127 | Patricia J. Wynne |
| 128 | Ralph Morse (*top*), Patricia J. Wynne (*bottom*) |
| 130 | Patricia J. Wynne (*top*), Ralph Morse (*bottom*) |
| 132 | National Aeronautics and Space Administration |
| 134 | Patricia J. Wynne |
| 139 | T. H. Geballe, Stanford University |
| 141–162 | Gabor Kiss |
| 175 | Tom Prentiss |
| 176–180 | Andrew Tomko |
| 183 | Klim Gollan, Australian National University (*top*); Matthew Spriggs, Australian National University (*bottom*) |
| 184 | Andrew Tomko |
| 185 | W. Wilson |
| 187–196 | Jerome Kuhl |
| 199 | Leon Glass |
| 203–208 | Michael Goodman |



# ITS BEAUTY IS MORE THAN SKIN DEEP.

Meet the Beogram® 3404...an intelligent, thoughtful and very well spoken turntable.

Like all Bang & Olufsen turntables, the 3404 effectively combines superior sound reproduction with simplified—not complicated—operation. That's the real beauty of the 3404.

That's why the controls are outside of the dust cover where they're easily accessible.

And that's why just a light touch of the START button does everything. It determines if a record is on the platter, and if so, quickly sets the correct speed and lowers the stylus to the record.

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A low inertia tonearm with a knife-edge bearing system eliminates audible distortion. The Bang & Olufsen MMC cartridge works in flawless harmony with the tonearm. The unique self-correcting electronic servo-drive is so precise that the need for a conventional strobe device is eliminated.

The Beogram 3404 even responds to remote control commands when used with the Beomaster 2400 receiver.

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**Bang & Olufsen**

Bang & Olufsen of America, Inc.
515 Busse Road
Elk Grove Village, Illinois 60007
Attention: Sonya Anderson

# LETTERS

Sirs:

Professor Daniel has given us a fine treatment of the nature and history of the megalithic monuments of Europe ["Megalithic Monuments," by Glyn Daniel; SCIENTIFIC AMERICAN, July]. It is regrettable that his account is marred by a caricature and contemptuous dismissal of viewpoints he disagrees with, without any attempt at reasoned argument.

The megalithic arrays of Britain and Brittany were built with a care and complexity far beyond that required simply to mark meeting places. The viewpoints developed in the work of Gerald S. Hawkins and Alexander Thom, and of other workers who have probed the nature of these arrays with broad questions, have yielded a unifying and predictive explanation for a number of features of many of them. Professor Daniel's thesis that the stone rings represent a nostalgia for long-gone forests is weak by comparison and does not explain why the stone alignments are locked so forcefully to astronomically important sightings. (Dr. Hawkins, incidentally, never maintains Stonehenge is a computer for specific eclipse predictions; he describes it as an observatory enshrining a knowledge of observational astronomy that is neither surprising nor difficult to achieve....)


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Archaeoastronomy is the study of the interest in astronomical phenomena of past cultures and the uses—ritualistic or practical—they put them to, as evidenced by archaeology and anthropology. No one in archaeoastronomy concludes that the builders of the arrays were "slaves to an astronomical cult." The point that emerges is that such obvious phenomena as the seasonal variations of the sun and the moon, the motions of the planets and the occurrence of eclipses were of tremendous importance to many cultures for many thousands of years. The American Indian, the Hindu and the Maya cultures, to give some disparate examples, all wove these phenomena into their religion, each in a unique and unexpected way, as we know from legend or the written record. In that context it is not surprising that the megalith builders would have abstracted their own subset of astronomical phenomena as being important; we find the evidence is simply recorded in a different style, exhibited in a unique technology they developed.

ROLF M. SINCLAIR

National Science Foundation
Washington

Sirs:

I was interested in Dr. Sinclair's letter. I think most archaeologists now agree that the theses of Professor Thom and Dr. Hawkins have no real basis in fact. The stone alignments at Carnac are not locked forcefully to astronomically important sightings. Professor Thom insists that the Grand Menhir Brisé was originally upright. There is no proof of this whatever. More and more evidence is coming in to show that although some of the survey work of Professor Thom is good, much of it is not.

There is no question that many megalithic monuments are aligned in a general way, particularly to the east or to the summer sunrise, or to the winter solstice, but that is very different from saying the megalithic builders had exact astronomical knowledge. It was not my intention to dismiss contemptuously the views of those who believe in archaeoastronomy; I merely sought to point out that the greater number of people who study prehistoric megalithic monuments in Europe remain unconvinced by the work of Thom, Hawkins and others who often write with a profound ignorance of the archaeological facts.

GLYN DANIEL

St. John's College
Cambridge

Sirs:

I must comment on Jean-Pierre Mey-

# Considering the effects of inflation– just how much life insurance should you carry?

With skyrocketing inflation, it's obvious your family needs more money year by year. And more protection.

If something should happen to you, how much money would your family need to maintain their standard of living?

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er's letter ["Letters," SCIENTIFIC AMERICAN, June] in which he asserts that the Babylonians knew Newton's rule for estimating the square root of a number. Meyer's evidence is Yale Babylonian Collection Tablet No. 7289, which shows a square with its diagonals and numbers indicating that the length of the diagonal is obtained on multiplying the length of a side by $1 + 24/60 + 51/(60^2) + 10/(60^3)$. There is, however, no recursion relation in this tablet. Hence all hypotheses about how the Babylonians arrived at this estimate are purely speculative. It is quite possible they squared estimates of the square root of 2 to find how close to 2 they could come. Another hypothesis is provided in Otto Neugebauer and A. Sachs's *Mathematical Cuneiform Texts*. They hypothesize that the Babylonians computed alternating approximations of $\sqrt{2}$ by arithmetical and harmonic means of previously found approximations. This procedure is mathematically equivalent to the recursion relation $A_{n+1} = (A_n^2 + 2) / 2A_n$. This method, coincidentally, is mathematically equivalent to Newton's rule, which involves taking the derivative of a function. But there is no evidence whatsoever that the Babylonians knew how to compute derivatives. Moreover, the tablet shows no evidence of knowledge of the Pythagorean theorem.

TIMOTHY WHITCOMBE

Yale University
New Haven, Conn.

Sirs:

Colin T. Pillinger of the Planetary Sciences Unit at the University of Cambridge has informed me that the U.S.-European mission to Halley's comet in 1986 has been named *Giotto* on the basis of my article ["Giotto's Portrait of Halley's Comet," by Roberta J. M. Olson; SCIENTIFIC AMERICAN, May, 1979]. Recently a friend brought to my attention the following item in the Italian periodical *Gente* for July, 1980:

"A European space probe baptized *Giotto* will overtake Halley's comet in 1986 on a voyage to the interior of the solar system and will cross the tail 1,000 kilometers from the nucleus in order to study its composition. This was decided by the European Space Agency, whose committee for scientific programs approved the mission for the comet, which presents itself only once every 76 years in the interior of the solar system. The probe was given the name *Giotto* because the painter made a fresco of the comet in the Scrovegni chapel in Padua after having seen it in 1301."

ROBERTA J. M. OLSON

New York

# Panasonic has a clock radio made just for your nightmare.

The "my kid fooled with the alarm" nightmare.

The "I need to know the weather and every station's playing music" nightmare.

The "there's a power failure and my clock doesn't know what time it is" nightmare.

The "two different wake-up times, one alarm clock" nightmare!

The last thing you should lose sleep over is your clock radio. That's why when the time comes, make sure you buy a Panasonic. We have AM/FM clock radios to solve every problem a clock radio could give you.

Our clock radios do just about everything but tuck you in. Many are equipped with Sure Time—Panasonic's battery backup system* that keeps time internally even if there's a power failure. Most models have childproof controls to make sure you wake up when you planned. And a fluorescent digital display. There's a model with two alarm settings for couples who get up at different times. Another gives you 24 hours of continuous weather information.†

All models have a doze alarm. A sleep timer to smooth your way into slumber. Great Panasonic sound, of course. And a limited 2-year warranty,†† something you won't get from anybody else.

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*Battery not included. †Not all areas broadcast weather information.
††Limited 2-year warranty on parts and labor with carry-in service and proof of purchase. See warranty card for details.

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just slightly ahead of our time.


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RC-95 with two alarm settings.

# 50 AND 100 YEARS AGO

## SCIENTIFIC AMERICAN

NOVEMBER, 1930: "At a meeting of the Geological Society of China in the last week of July, Prof. Davidson Black announced the discovery of another skull of Peking man. The remains of four skulls of *Sinanthropus* and the teeth of at least six other individuals have so far been found. Thus there is available for study in China a much richer material of early Pleistocene man than the fragments of the individual specimens of *Pithecanthropus* and *Eoanthropus* provide. Moreover, the geological age of the Chinese fossils can be established with more certainty than that of the other two primitive genera, which are assumed to be roughly contemporaneous. The fossils from Java and Sussex were found in gravels, where they had been deposited by running water. In the case of the men of Peking, who left their bones in the cave where they lived, there is less room for doubt that the bones of animals deposited alongside them provide more certain data for the estimation of their geological age."

"No trans-Atlantic flight or attempt to make an airplane crossing of this stormy ocean since the unsurpassed flight of Colonel Lindbergh in May, 1927, has so fired the imagination of the world as the three successful westward flights this past summer. A Briton and a German made the first two flights, each with one or more stops, and the climax came when a Frenchman made a nonstop flight from Paris to New York. When a Dieudonné Coste and his copilot Maurice Bellonte landed the red *Question Mark* at Curtiss Field on September 2, the final chapter in the long and tragic story of the conquering of the North Atlantic by airplane was written. They had taken off from Paris 37 hours 18½ minutes earlier. To these two daring flyers go, therefore, the laurels for the first non-stop crossing of the North Atlantic by airplane from the continent of Europe to the United States."

"A fireless, smokeless, odorless and noiseless photographic flash lamp has been developed by the incandescent-lamp department of the General Electric Company. The flash is confined entirely within a bulb, with resulting advantages that are expected to revolutionize flashlight photography. Requiring only a hundredth of a second to act, and being without hazard, it will make possible the taking of flashlight photographs in places heretofore practically impossible to 'shoot,' such as trains, airships and theaters. The lamp consists of a clear bulb of standard design, with the flashlight filament coated with a special preparation, and with a quantity of very thin aluminum foil in crumpled sheet form within the bulb. The bulb is filled with oxygen. When the circuit is closed, the filament is lighted, and this in turn lights the foil."

"Natural gas, possessing about twice the heating value of manufactured gas, has been used commercially for more than 60 years but has only recently become an industry of large proportions because of technical developments that have shown the way to the discovery of large natural-gas reserves and have made possible long-distance pipelines. In the current year the natural-gas industry has expanded at a greater rate than perhaps any other industry of importance, and that in spite of world-wide business depression. Its increase in pipeline mileage from 80,000 to 90,000 represents an increase in capacity of more than 12½ per cent."


NOVEMBER, 1880: "For some months it has been pretty generally recognized that there could be no serious doubt of the ultimate success of electric lighting by incandescence. At Menlo Park a number of Edison lamps have been kept alight for months together, furnishing as near an approach to perfection in the quality of the light for interior uses as one could ask for, and proving the durability and economy of the lamps. With much labor and ingenuity Mr. Edison has reduced the manufacture of his lamps to what may fairly be called a commercial basis. He has erected a large factory for lamp making, and has trained a numerous corps of glass blowers and other workmen. He has built a machine shop, and has constructed in it many costly and powerful dynamo machines and other apparatus needed in establishing the working plant of central stations for operating, in New York and elsewhere, practical systems of electric lighting. Mr. Edison has surveyed certain sections of New York preparatory to the general introduction of his lamps, and has made extended preparations for exhibiting the light at Menlo Park on a scale so large as to demonstrate beyond cavil the practical value of his system for general and economical illumination."

"Some three years ago an intelligent mineralogist discovered specimens of pitchblende on the waste dumps of Denver, Colo., and recognizing the value of the mineral, gathered a quantity and sent it to Swansea, where it brought five shillings a pound, equal to $25 a ton. Pitchblende, or uraninite, is an oxide of uranium, obtained in Saxony and Bohemia, and used in fine glass making. Glass colored with uranium has the peculiar property of showing green when looked at, although perfectly and purely yellow when looked through."

"Dr. Martin of Boston was the first American physician who, in view of the danger attending the use of smallpox virus taken from the human body, experimented successfully upon a return to Dr. Jenner's original method of using the bovine virus. Dr. Robbins, with his associate Dr. Lewis, is now engaged in the production on a large scale of virus derived from Beaugency stock. The *modus operandi* is to select the best calves and to shave on their belly areas six or eight inches wide. Vaccination is then proceeded with, and after six or seven days the matter is removed into tubes or quills. Drs. Robbins and Lewis have sent the vaccine to France, Egypt, China, Japan and to all parts of North and South America."

"The Freedom of the City of London was lately conferred on Sir Henry Bessemer, F.R.S., at a special Court Common Council. In acknowledging the honor thus conferred on him, Sir Henry referred to the conditions of steel manufacture before the introduction of his process. He compared the total steel production of the country, which did not exceed 51,000 tons a year, to the present output of nearly a million tons, and the reduction of price from £50 to £10 a ton."

"Capt. Eads writes us from St. Louis that he is setting out on November 14 for Mexico with a staff of engineers and counselors to make a complete survey of the Isthmus of Tehuantepec with a view to locating the proper position of a ship railway from ocean to ocean. Capt. Eads expects to be absent for two months, and will carefully examine the harbors on both sides of the country. The results of this labor will be looked for with much interest. The ship railway is so much more economical than the canal, in the matter of construction, that the railway is likely to be commenced as soon as a thoroughly good route can be located and surveyed."

"The slow progress which telephonic communication is making in England may be judged from the fact that the successful connection by telephone of the cities of Liverpool and Manchester on November 9 was deemed a circumstance worthy of a special cable dispatch to this country. Liverpool and Manchester have half a million inhabitants each, and are 31 miles apart!"


# Because you enjoy going first class.

In Paris or at home, life's more satisfying when you're enjoying the best. That's Passport. Enjoyed worldwide because it's made of Scotland's finest whiskies. Ask for Passport—go first class.

# Passport Scotch.

# "THE MOST SIGNIFICANT CAR OF THE LAST QUARTER-CENTURY."

**Don Sherman: Car and Driver, July 1980**

"I hereby nominate the Volkswagen Rabbit as the most significant car of the last quarter-century. It's the only automobile in the world that actually anticipated the energy cataclysm we've suffered through for the last six and a half years and conducted its affairs accordingly.

"The Beetle put millions of people on wheels, but it was the Rabbit that introduced them to efficiency. By efficiency, I mean the most people-miles per gallon, an index the Rabbit established roughly six years ago. The pretenders to this throne are ten deep at last count, and still more are waiting in the wings.

"We all love this car as family sedan, as

diesel car, as sports coupe (Scirocco), and also as convertible while our own Yankee ingenuity has spawned the VW Pickup Truck. As if this weren't enough, Volkswagen engineers have testified that a Rabbit capable of 80 mpg is well within the realm of possibility. You'd be foolish to doubt their word."

## IMPROVED.

How do you improve the most significant car of the last quarter-century? Significantly. But not recklessly. Or mindlessly. The magic change for 1981 is improved passing power and improved economy at the same time. EPA estimated 28 mpg, 42 mpg highway estimate. (Use "estimated mpg" for comparison. Mpg varies with speed, trip length, weather. Actual highway mpg will probably be less.) The 1981 interiors are lavish. (If you woke up in a Rabbit, you'd never guess it was a Rabbit.) The headlights, taillights and grille are sleeker and even more functional.

The thing to remember is that the improvements started with the Rabbit itself. We are proud and pleased to have been honored by Car and Driver, but not totally surprised. An awful lot of work went into it.

We will keep on working. And we hope to do as well in the next quarter-century.

# THE 1981 RABBIT VOLKSWAGEN DOES IT AGAIN

# Everything about David Plastow represents his company's philosophy. Which is why he wears a Rolex.

David Plastow is the custodian of a long and famous engineering tradition.

He is the Chief Executive of Rolls-Royce Motors, and indeed, his manner and personal appearance exactly reflect the ethos of that company. That of the skilled engineer.

Plastow takes a personal interest in any modification, however small.

"All our developments at Rolls-Royce are always evolutionary rather than revolutionary," he says.

"We are a highly personal business, and both our craftsmen and our customers have clearly defined ideas about what a Rolls-Royce should be. But while we don't tamper with those fundamental ideas, we are, of course, constantly searching for improvement. For instance, years ago, the gear selection on a Rolls-Royce car became completely electronic. But, a driver likes to 'feel' that the gear selection lever is doing something . . . so we engineered the 'feel' back into it – so it's satisfying to use."

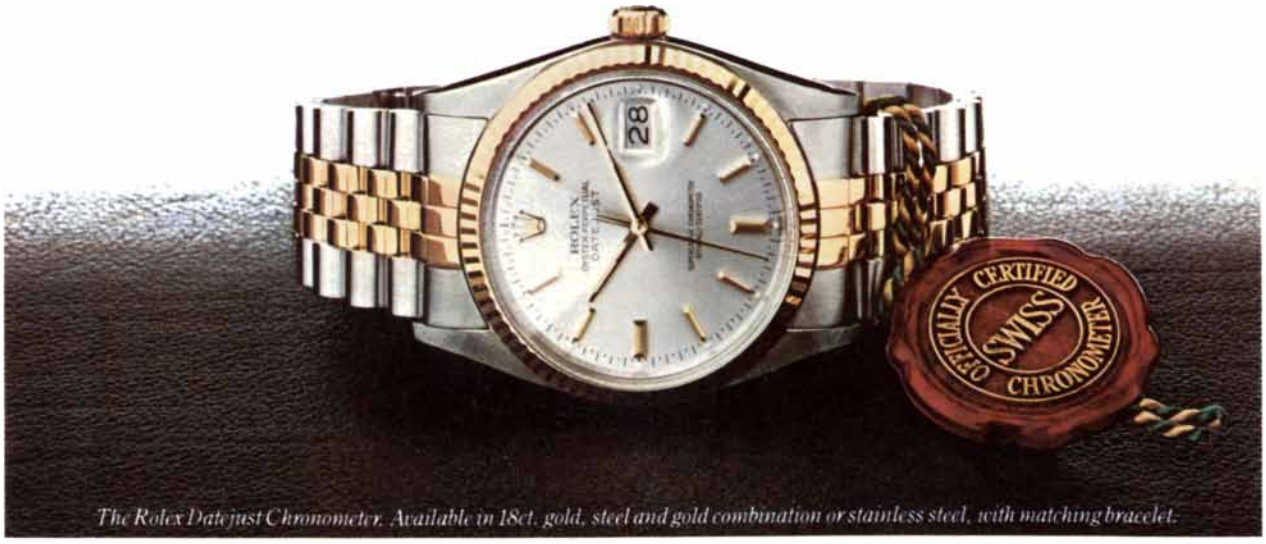
David Plastow recognises the similar philosophy behind the watch he wears.

"It's a Rolex Oyster Datejust. I'm told that the engineering concept of the Oyster case first appeared in 1926.

"Obviously this watch has changed and improved over the years but Rolex have stayed with the basic idea because it was a very good one. It's extremely tough, very reliable, and superbly engineered. After 50 years of development it's almost perfect".

Which, from the man who makes the finest cars in the world, is quite a compliment.

ROLEX
*of Geneva*




*The Rolex Datejust Chronometer. Available in 18ct. gold, steel and gold combination or stainless steel, with matching bracelet.*

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*World headquarters in Geneva. Other offices in Toronto and major cities around the world.*

# THE AUTHORS

REUEL A. STALLONES ("The Rise and Fall of Ischemic Heart Disease") is dean and professor of epidemiology at the School of Public Health of the University of Texas. He is also James W. Rockwell Professor of Public Health at the university and adjunct professor of environmental science and engineering at Rice University. He received his undergraduate education at Visalia Junior College, Ripon College and the University of Michigan. He got his M.D. at Western Reserve University in 1949 and his M.P.H. (Master of Public Health) at the University of California at Berkeley in 1952. In 1950–51 he was a battalion surgeon in the U.S. Army. From 1954 to 1956 he was assistant chief in the department of epidemiology at the Walter Reed Army Institute for Research. From 1956 to 1968 he was on the faculty of the University of California at Berkeley. He joined the faculty of the University of Texas in 1968. Stallones' principal research interest, which is reflected in the theme of his article, is the epidemiology of cardiovascular disease.

ROBERT T. SCHIMKE ("Gene Amplification and Drug Resistance") is professor of biology at Stanford University. He received his A.B. at Stanford in 1954 and his M.D. at the Stanford School of Medicine in 1958. From 1960 to 1966 he worked at the National Institutes of Health. He joined the faculty at Stanford in 1966 and became chairman of the department of biology in 1978. Schimke's principal research interests have been the mechanisms of hormone action in metabolic regulation and development, and the mechanisms of the control of protein turnover in animals.

FREDERIC H. CHAFFEE, JR. ("The Discovery of a Gravitational Lens"), is the resident astronomer at the Smithsonian Institution's Mount Hopkins Observatory in the Santa Rita Mountains near Tucson, Ariz. He got his A.B. in physics at Dartmouth College in 1963 and his Ph.D. in astronomy from the University of Arizona in 1968. He then joined the staff of the Smithsonian Astrophysical Observatory in Cambridge, Mass.; he took up residence at the observatory's new site in Arizona in 1970. Chaffee's main research interests are in the high-resolution spectroscopy of stars, interstellar clouds and most recently quasars.

NATHAN SHARON ("Carbohydrates") is head of the department of biophysics at the Weizmann Institute of Science in Israel. Born in Poland, he emigrated with his family to Israel (then Palestine) in 1934. He studied at the Hebrew University of Jerusalem, where he received his master's degree in 1950 and his Ph.D. in 1953. He joined the staff of the Weizmann Institute in 1954. In 1977–78 he was Fogarty Scholar in Residence at the National Institutes of Health and visiting professor in the department of biological sciences at the University of California at Santa Barbara. This year he is serving as chairman of the Federation of European Biochemical Societies. The range of his scientific interests is best illustrated by the titles of the articles he has contributed to SCIENTIFIC AMERICAN: "The Bacterial Cell Wall" (May, 1969), "Glycoproteins" (May, 1974) and "Lectins" (June, 1977). Sharon is currently studying sugars on the surface of lymphocytes as markers for lymphocyte differentiation and maturation, and sugars on the surface of epithelial cells that act as receptors for bacteria.

DONALD E. PARKER ("The Vestibular Apparatus") is professor of psychology at Miami University in Oxford, Ohio. He received his B.A. at DePauw University in 1958 and his Ph.D. in experimental psychology from Princeton University in 1961. In 1961 he was a postdoctoral research fellow in the Auditory Research Laboratory at Princeton. From 1962 to 1965 he was an experimental psychologist in the Aerospace Medical Research Laboratories of the Wright-Patterson Air Force Base. In 1965 he joined Hermann Schöne at the Max Planck Institute for Behavioral Physiology at Seewiesen in West Germany to study the psychophysiology of the vestibular system on a postdoctoral fellowship. Parker joined the faculty of Miami University in 1966. In addition to his research on the vestibular system he is investigating the influence of audio-frequency sound, infrasound and vibration on perception and performance. He is particularly interested in phenomena associated with temporary or permanent hearing loss. He writes: "I have a long-standing collaboration with a group of respiratory physiologists at the University of Kentucky concerning the perception of respiratory resistance. (How hard is it to breathe through a filter from a Coke bottle?)" Parker also writes: "My favorite entertainment is flying. I enjoy using the complex Air Traffic Control System—people, computers and radar—to ensure a safe flight in marginal weather conditions, particularly if a good ballet or opera company is performing at the destination."

T. H. GEBALLE and J. K. HULM ("Superconductors in Electric-Power Technology") are physicists with a common interest in the theme of their article: superconducting electrotechnology.

Geballe is Rosenberg Professor of Applied Physics at Stanford University and Materials Consultant to Bell Laboratories. He received his B.S. at the University of California at Berkeley in 1941 and his Ph.D. from Berkeley in 1950. In 1950–52 he was a research associate at Berkeley. From 1952 to 1968 he was a member of the technical staff of Bell Laboratories. He joined the faculty at Stanford in 1968. He did his Ph.D. thesis work at Berkeley with W. F. Giauque, a pioneer of low-temperature physics. Geballe writes: "Long hours were spent liquefying precious amounts of helium in order to experiment at low temperatures. I feel fortunate to have participated in the early years of the scientific quest for an understanding of superconductivity. That this quest has now opened the way to technologies such as those we describe in our article is an unexpected and pleasing development." Hulm is director of corporate research at the Research and Development Center of the Westinghouse Electric Corporation. Born in Britain, he obtained his B.A. in solid-state physics at the University of Cambridge in 1943 and his M.A. and Ph.D. from the same institution respectively in 1945 and 1949. From 1949 to 1951 he worked at the Institute for the Study of Metals at the University of Chicago; he was assistant professor of physics at the university from 1951 to 1954. He joined Westinghouse in 1954. Hulm has also served as science attaché at the U.S. Embassy in London.

P. S. BELLWOOD ("The Peopling of the Pacific") is senior lecturer in prehistory at the Australian National University. Born in Britain, he received his B.A., M.A. and Ph.D. at the University of Cambridge. From 1967 to 1972 he was lecturer in prehistory at the University of Auckland in New Zealand, where he began his research on Polynesia. He has been lecturer at the Australian National University, where he enlarged his research to include Indonesia and Malaysia, since 1973. He also teaches Middle Eastern archaeology, in which, together with the ancient civilizations of the Americas, he has a strong but subsidiary interest. On delivering this information to SCIENTIFIC AMERICAN Bellwood concluded: "Back to work in my cave (with a team of Malaysian coworkers from the Sabah Museum) in Kota Kinabalu, East Malaysia."

ROBERT T. McIVER, JR. ("Chemical Reactions without Solvation"), is professor of chemistry at the University of California at Irvine. He got his B.S. in chemistry at the University of Kansas in 1967 and his Ph.D. in physical chemistry from Stanford University in 1971, when he joined the faculty at Irvine. In 1979 he received the Distinguished Research Award of his university.

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# MATHEMATICAL GAMES

## *Taxicab geometry offers a free ride to a non-Euclidean locale*

by Martin Gardner

Altering one or more postulates of Euclidean geometry makes it possible to construct all kinds of strange geometries that are just as consistent, or free of internal contradictions, as the plane geometry taught in secondary schools. Some of these non-Euclidean geometries have turned out to be enormously useful in modern physics and cosmology, but the two most important, elliptic geometry and hyperbolic geometry, have a structure that is impossible to visualize. Hence most laymen find these geometries too difficult to comprehend and are certainly not able to search their structure for new theorems or to work on interesting non-Euclidean problems.

This month we shall take an elementary look at a quite different kind of non-Euclidean geometry, one so easy to understand that anyone exploring its structure on ordinary graph paper can have the excitement of discovering new theorems. Often called taxicab geometry, this system can be modeled by taxicabs roaming a city whose streets form a lattice of unit-square blocks. In many ways this taxicab geometry is curiously like ordinary plane geometry. Yet it is sufficiently different that exploring it can be great fun. Moreover, such exploration provides a strong feeling for how geometries may vary in bizarre ways from Euclidean geometry and still form a logically consistent formal system.

As far as I know taxicab geometry was first seriously proposed by Hermann Minkowski, a mathematician born in Russia who was the young Albert Einstein's teacher in Zurich. Minkowski later gave special relativity its beautiful formulation in a four-dimensional geometry of space and time, and the space-time graphs widely used in relativity theory are named for him. At about the turn of the century he published in Germany *Gesammelte Abhandlungen* (reprinted in the U.S. by Chelsea Publishing Company in 1967), in which he analyzed a variety of metric systems: topological spaces consisting of a well-defined set of points and a rule for measuring the "distance" between any two points.

Taxicab geometry is a metric system in which the points of the space correspond to the intersections of the horizontal and vertical lines of square-celled graph paper, or to the intersections of the streets in our idealized city. If two points, $A$ and $B$, are at intersections on the same street, the distance between them is measured, as it is in Euclidean geometry, by counting the number of unit blocks from one to the other. If $A$ and $B$ are not on the same street, however, then instead of applying the Pythagorean theorem to calculate the distance between them we count the number of blocks a taxicab must travel as it goes from $A$ to $B$ (or vice versa) along a shortest-possible route. The structure of taxicab geometry can be formalized with definitions and axioms in a variety of ways, but here I shall dispense with such technicalities and simply describe it in intuitive terms.

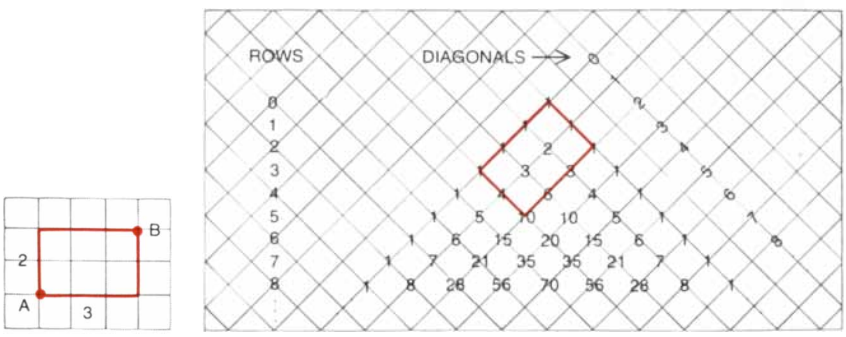
In Euclidean geometry the minimum distance between two points (as the crow flies) defines a unique straight line. In taxicab geometry there may be many paths, all equally minimal, that join two points. In what follows "path" will be used to mean any taxicab route that covers the distance between two points with the minimum mileage.

If two points are not on the same street, how many distinct paths connect them? Pascal's famous number triangle comes to our aid on this question. Consider the points $A$ and $B$ at opposite corners of a 2-by-3 rectangle of blocks, as is shown at the left in the illustration on this page. The colored lines at the right in the illustration show how the rectangle can be drawn on Pascal's triangle to solve the problem. The lowest corner of the rectangle marks the answer: There are 10 distinct paths between $A$ and $B$. Note that Pascal's triangle is left-right symmetrical, and so it does not matter in the least if the rectangle is drawn so that it leans the other way. The same answer is obtained. (Remember that in Pascal's triangle each number is the sum of the two numbers above it. For more on Pascal's triangle see Chapter 15 of my *Mathematical Carnival,* published by Alfred A. Knopf, Inc., in 1975.)

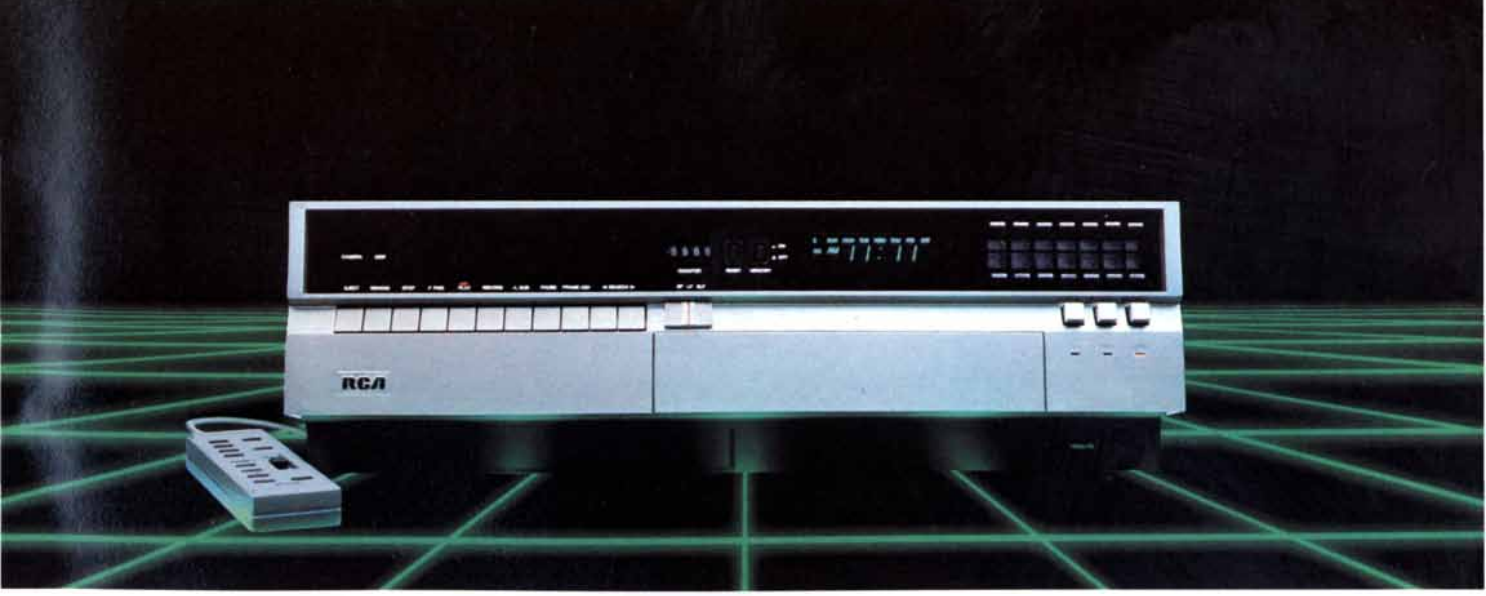
Readers familiar with combinatorics will recall how Pascal's triangle serves to instantly show how many ways a set of $n$ items can be selected from a larger set of $r$ items. The answer is the number at the intersection of the $n$th diagonal and the $r$th row of the triangle. In the case of the taxicab problem 10 is the number of ways two items can be selected from five. The two corresponds to one side of our rectangle of blocks and the five to the sum of its two sides. Ten is also the number of minimal routes a taxicab can follow from one corner of a 3-by-5 rectangle to the diagonally opposite corner.

It is not necessary to draw Pascal's triangle to determine the number of paths between two points in taxicab geometry. We can also use the familiar formula for calculating the number $N$ of ways to select $n$ objects from $r$ objects: $N = r!/(n!(r-n)!)$. For example, in our taxicab problem $r!$ equals $1 \times 2 \times 3 \times 4 \times 5$, or 120, $n!$ equals $1 \times 2$, or 2, and $(r-n)!$ equals $1 \times 2 \times 3$, or 6, so that the formula reduces to $N = 120/12$, or 10.

The fact that the rectangle can be




*Applying Pascal's triangle to count taxicab paths*



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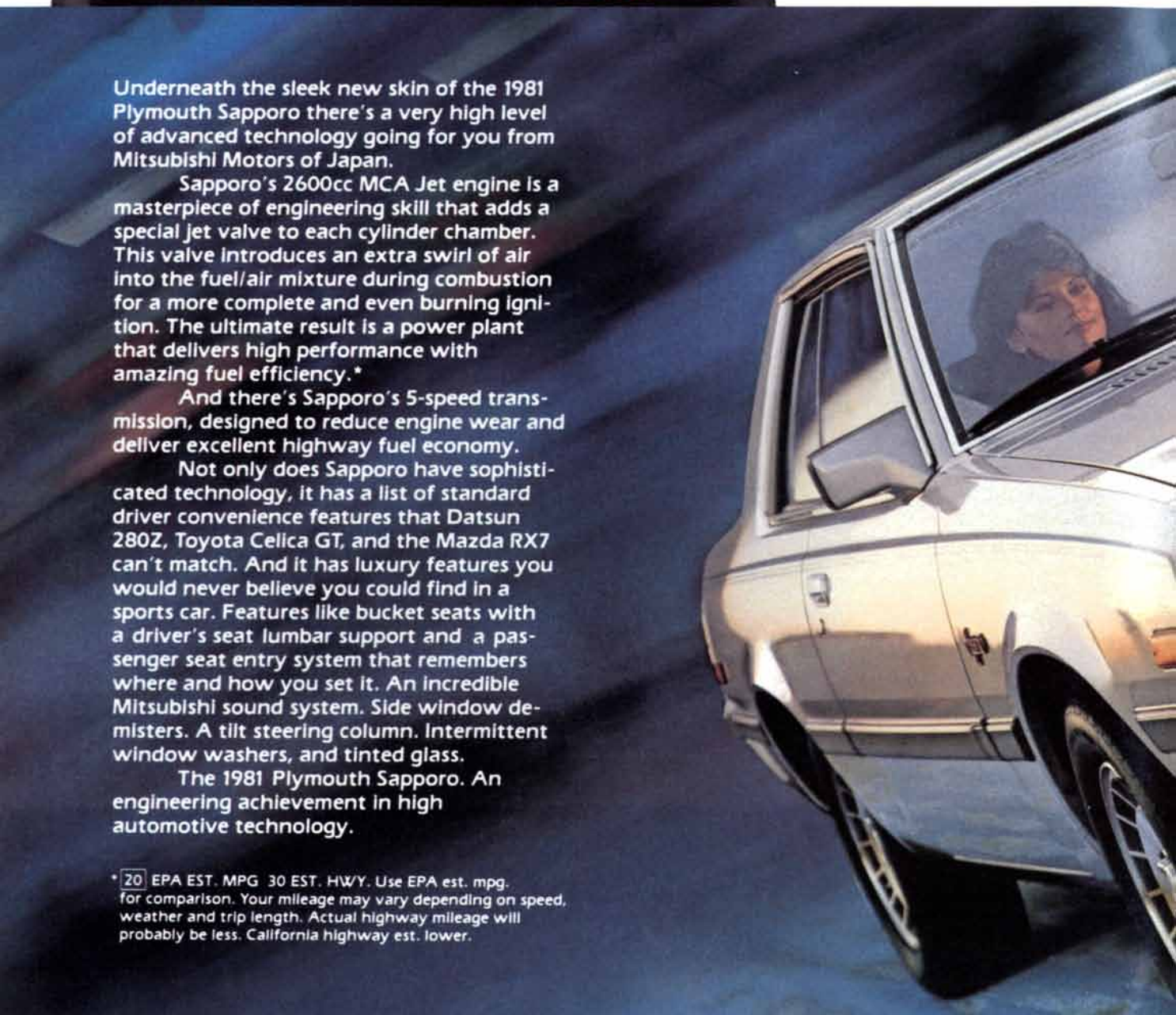
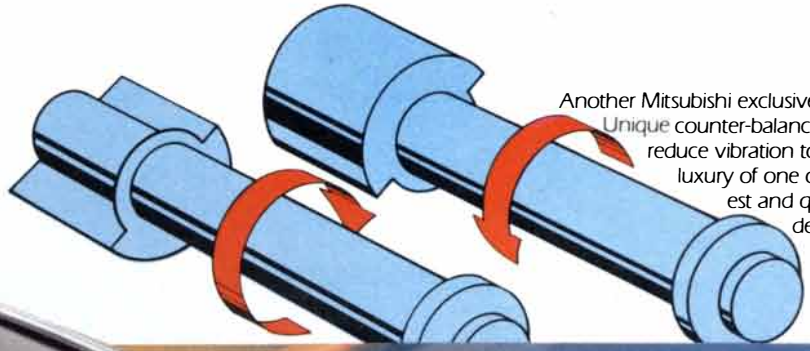


# '81 SAP

# THE TECHNOL



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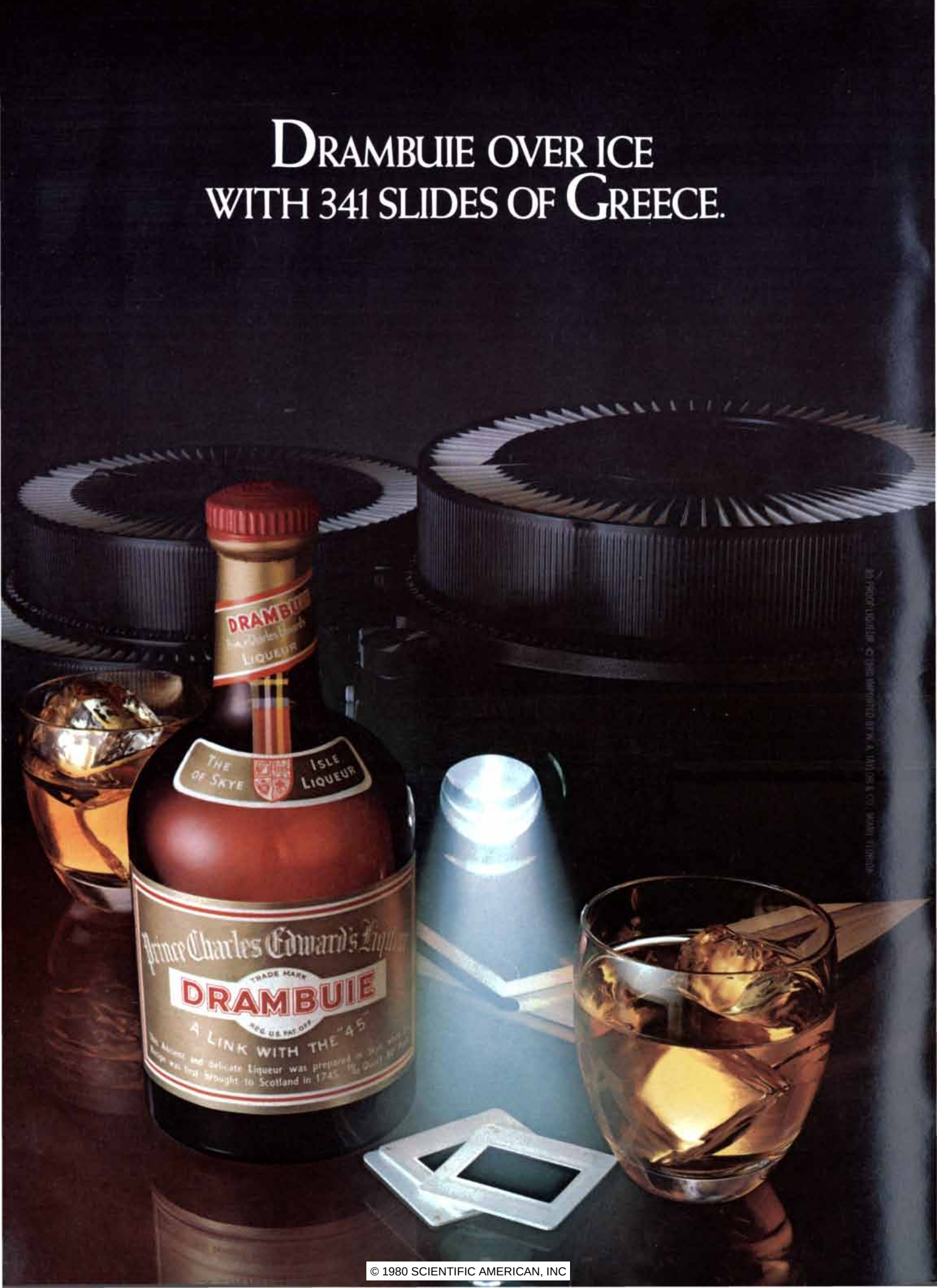


tipped in either direction on Pascal's triangle is a pictorial way of saying that the number of ways of selecting $n$ items from a larger set of $r$ items is the same as the number of ways of selecting $r - n$ items from a set of $r$ items. This fact becomes intuitively obvious if you consider that each time a unique set of $n$ items is selected from $r$ items, a unique set of $r - n$ items remains. In the taxicab model this means that if a Euclidean rectangle is drawn on the lattice, the number of distinct taxicab paths between any two diagonally opposite corners is the same as the number of paths joining the other two corners.

Since the "straight lines" (the shortest paths) of taxicab geometry may be crooked from the Euclidean point of view, the concept of an "angle" becomes either meaningless or radically different in this system. It is nonetheless possible to define close analogues of Euclidean polygons, including a two-sided "biangle" that is a stranger to Euclid's geometry. Some examples of biangles are shown in the top illustration at the right. It should be obvious that although different biangles can share the same pair of "corner" points, the two "sides" of any biangle must be equal because they join the same two points.

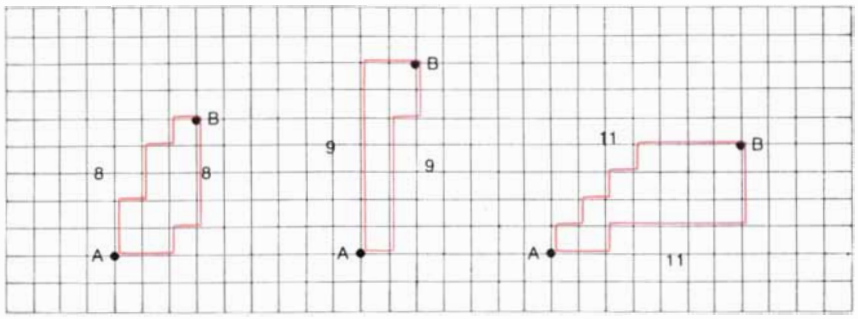
A taxicab scalene triangle with corners *A, B* and *C* and sides of 14, 8 and 6 is shown at the left in the second illustration from the top. The sides of taxi polygons must of course be taxi paths, and the paths that make up a polygon of specified dimensions may vary in shape but not in length. Observe how the triangle in the illustration violates the Euclidean theorem that the sum of any two sides of a triangle must be greater than the third side. In this case the sum of two sides equals the third: 6 + 8 equals 14. A taxi quadrilateral of sides 9, 6, 9 and 12 is shown at the right in the illustration.

Three taxi squares, all of side 6, are shown in the third illustration from the top. Only the square at the left obeys the Euclidean theorem that the diagonals of a square are equal. As these figures demonstrate, taxicab squares can have innumerable Euclidean shapes.

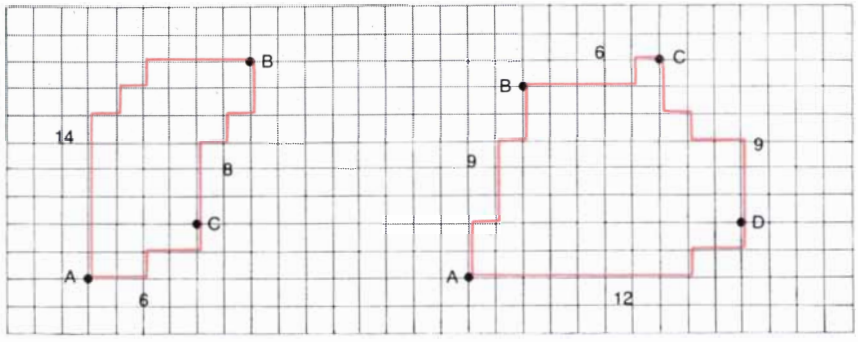
It is easy to define a circle in taxicab geometry, and the result is quite unexpected. As in Euclidean geometry a circle is defined as the locus of all the points that are the same distance from a given point. Suppose the distance is 2. The resulting circle consists of the eight points shown at the left in the bottom illustration—a neat way to square the circle! Note that only one radius goes from the center point *O* to points *A, B, C* and *D*, and there are two radiuses going to each of the other four points. It is not hard to show that any taxicab circle of radius $r$ consists of $4r$ points and has a circumference of $8r$. If we adopt the Euclidean definition of pi as the ratio of the circumference of any circle to its diameter, then taxicab pi is exactly 4.

Observe that our eight-point taxicab circle includes a variety of sets of vertexes for taxi polygons of 2, 3, 4, 5, 6, 7 and 8 sides. For example, there is the biangle *D,X,* the equilateral triangle *B,C,D,* the square *A,B,C,D,* the regular pentagon *A,W,X,Z,Y,* the regular hexagon *A,W,B,X,Z,Y,* and the regular heptagon *A,W,X,C,Z,D,Y.* And the eight points of the circle lie at the corners of a set of regular octagons.

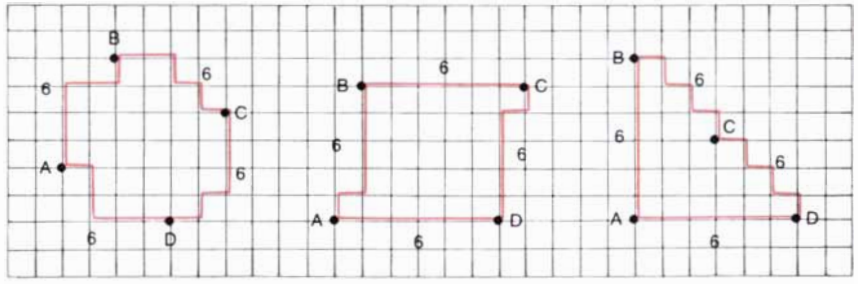
Another Euclidean theorem that taxi-



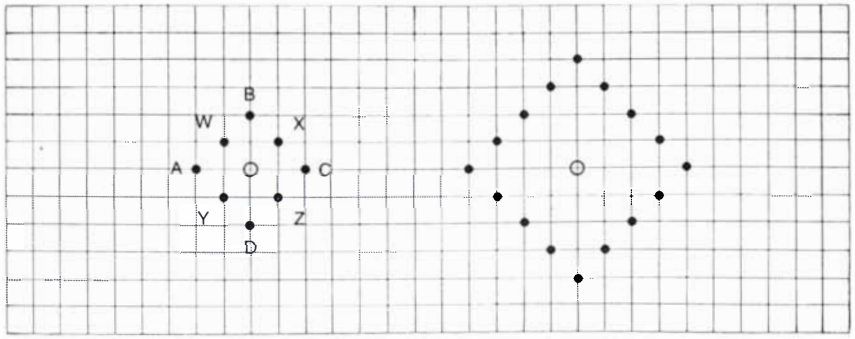

*Taxicab biangles*



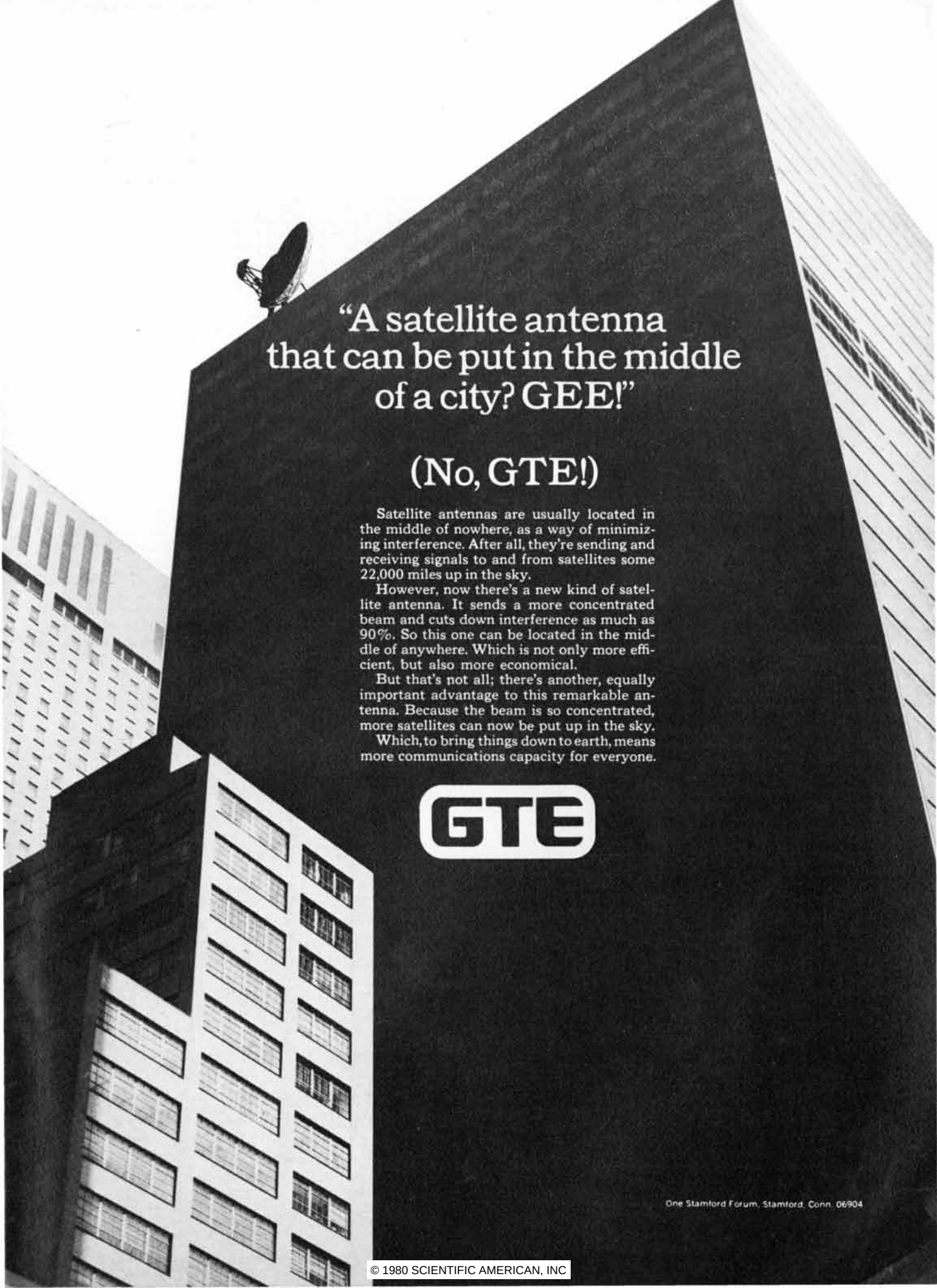

*Taxicab scalene triangle* (left) *and quadrilateral* (right)

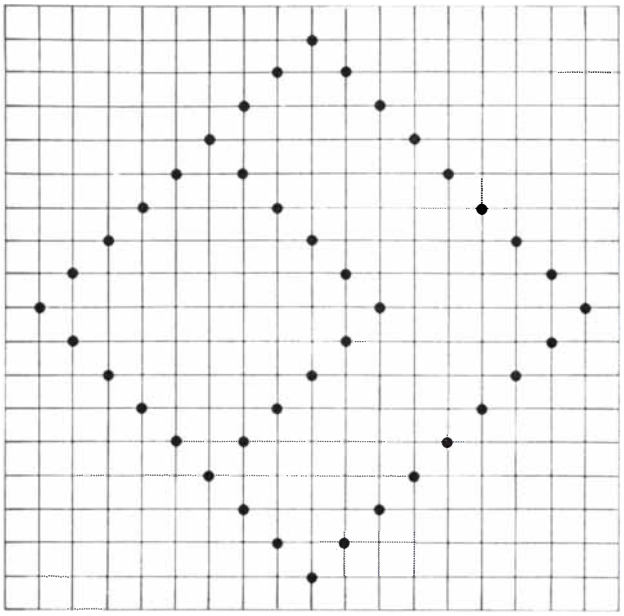



*Taxicab squares of side 6*

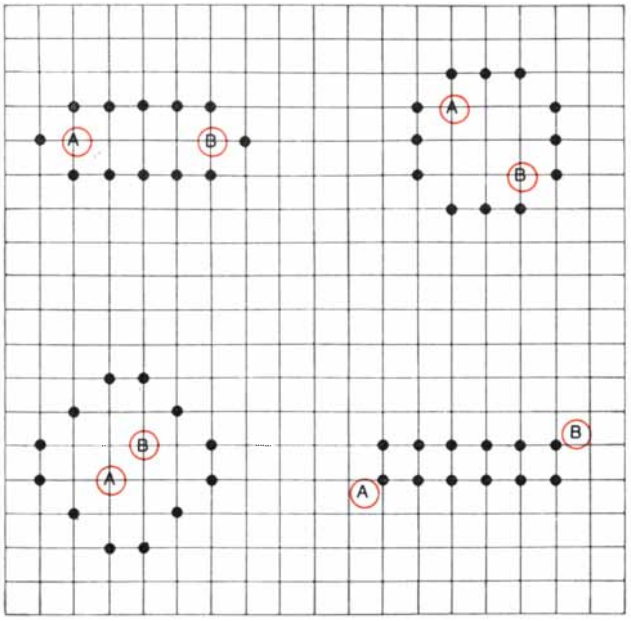



*Taxicab circles of radius 2* (left) *and 4* (right)





*Two taxicab circles intersecting at 11 points*

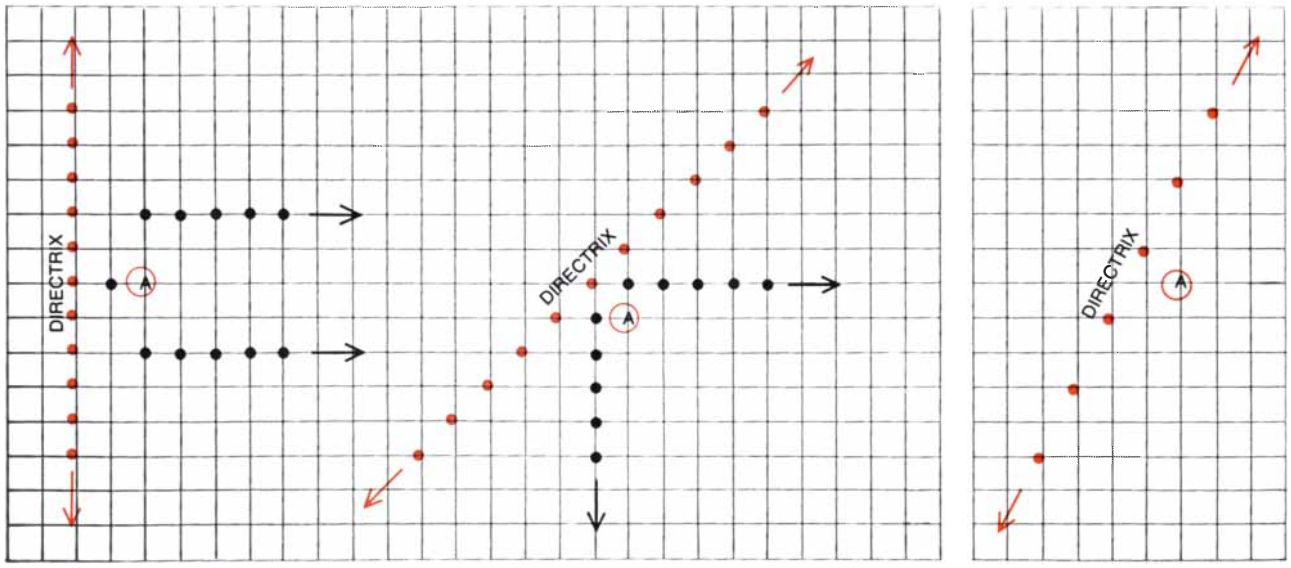



*Twelve-point taxicab ellipses with a constant sum of 6*

cab geometry violates is the one stating that two circles can intersect at no more than two points. As is shown in the illustration at the left above, two taxicab circles may intersect at any finite number of points. The larger the circles are, the more points at which they can intersect. A little experimentation turns up excellent taxicab analogues of the other three conic-section curves. The illustration at the right above shows four 12-point taxicab ellipses. As in Euclidean geometry, a taxicab ellipse is the locus of points whose distances from two fixed points *A* and *B* have the same sum. The points, called foci, are marked here with colored circles, and in all the examples shown in the illustration the constant sum is 6.

The fourth curve is actually a degenerate ellipse corresponding to the straight line that results when the constant sum that defines a Euclidean ellipse equals the distance between its foci. If this equality holds in taxicab geometry, then when *A* and *B* are on the same street, the result is a straight line of points. Otherwise the ellipse consists of all the points within the Euclidean rectangle of lattice lines that has *A* and *B* at diagonally opposite corners. For example, suppose that *A* and *B* are opposite corners of a square with lattice sides of length 4. In this case the taxi distance between *A* and *B* is 8, and for each of the square's 25 points the sum of their distances from *A* and *B* is 8. These 25 points will be the degenerate ellipse of constant sum 8 whose foci are *A* and *B*. If the constant sum is greater than the taxi distance between *A* and *B*, then as in Euclidean geometry the taxi ellipse becomes more circular as the foci move closer together. When *A* and *B* coincide, then once again as in Euclidean plane geometry the ellipse becomes a circle.

A Euclidean parabola is the locus of all points whose distance from a focus *A*




*Taxicab parabolas with a focus at* A

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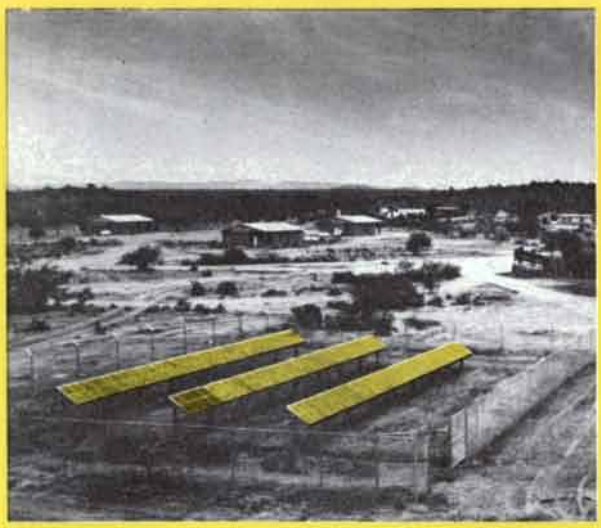
# This Indian village is Sun-Powered with the help of LEAD



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.

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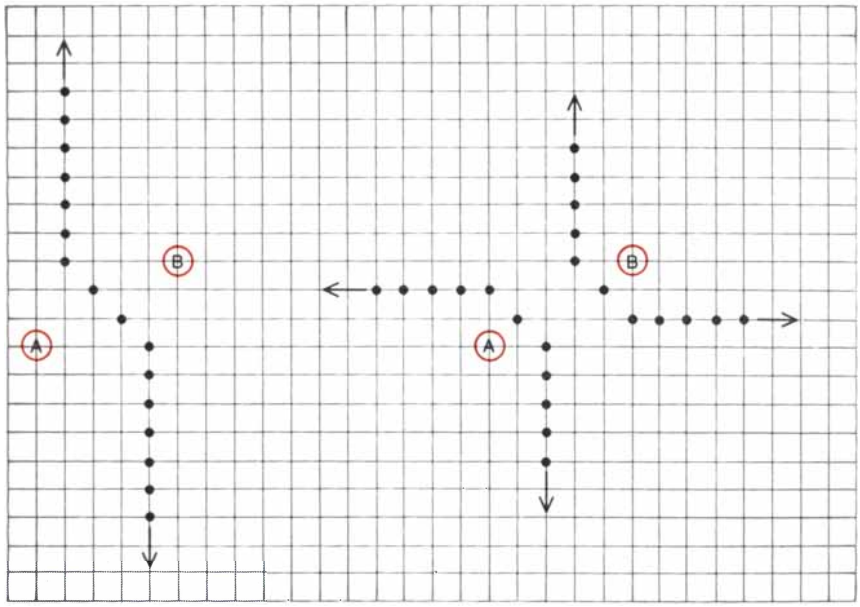
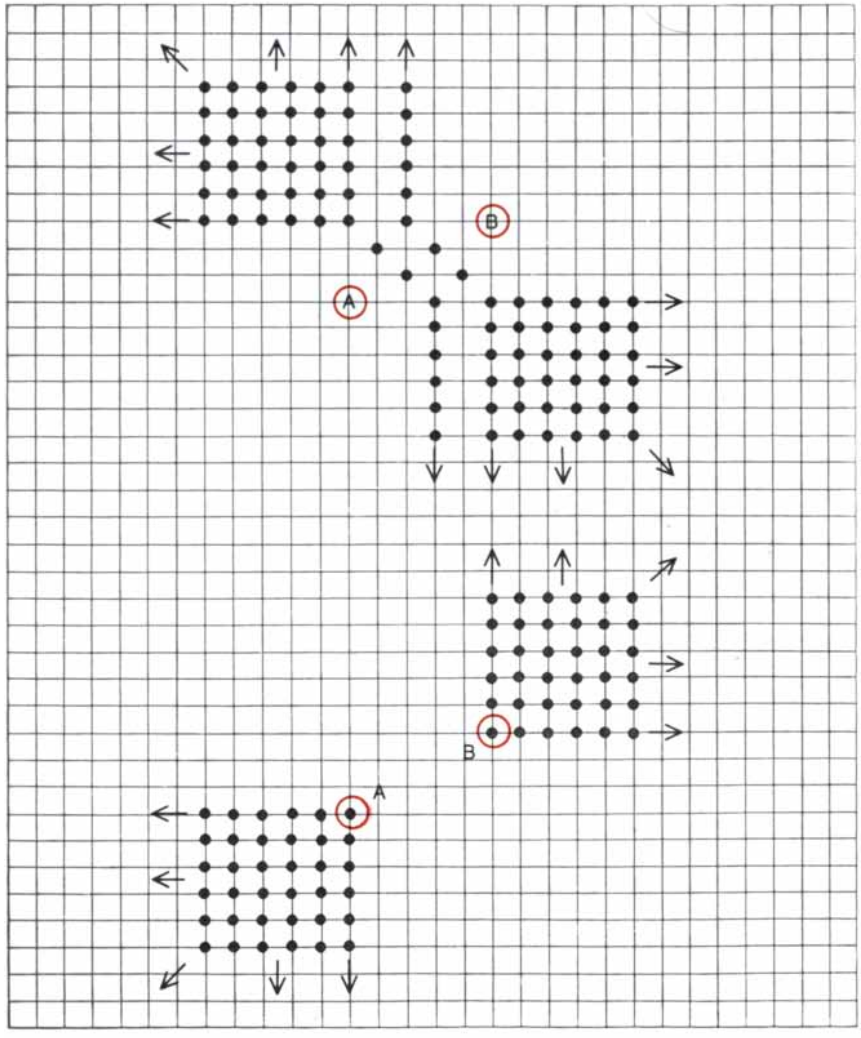



*Taxicab hyperbolas with a constant difference of 0* **(left)** *and 4* **(right)**




*Taxicab hyperbolas with a constant difference of 2* **(top)** *and 8* **(bottom)**

is equal to its shortest distance from a fixed straight line: the directrix. If a taxicab directrix is defined as the set of points along a Euclidean straight line, then taxicab parabolas can also be constructed. Two are shown at the left in the illustration at the bottom of page 26. Try drawing the parabola for the directrix and the focus shown at the right. Next month I shall provide the answer to this exercise, which is a bit trickier than it may seem.

Taxicab hyperbolas are more complex. A Euclidean hyperbola is the locus of all points for which the difference between the distances from a pair of foci *A* and *B* is constant. The appearance of a taxicab hyperbola varies considerably as the ratio of its basic parameters varies. In the figure at the left in the top illustration at the left the foci *A* and *B* are placed to show the limiting case, a degenerate hyperbola of just one branch, where the constant difference is 0. The figure at the right in the illustration shows two infinitely long branches of a taxicab hyperbola with a constant difference of 4.

Taxicab geometry springs another surprise in the top figure in the bottom illustration at the left. In this hyperbola the constant difference is 2. Here the two branches are two infinite sets of points, one in the sector of the plane at the upper left and one in the sector at the lower right, and each with a "tail" of infinite length. As is shown at the bottom in the illustration, the results are similar when the constant is 8, except that the infinite sets of points are in the sectors of the plane at the upper right and the lower left, and there are no tails.

With the foci placed as is shown in all of these examples the constant difference cannot be an odd number because the resulting figure would include points away from intersections, the only allowable points in taxicab space. As an exercise place *A* and *B* at diagonally opposite corners of a 3-by-6 Euclidean rectangle of lattice sides and draw the hyperbola for which the constant difference is 1. The result is two "parallel" branches, each resembling the degenerate hyperbola with a constant difference of 0. A not-so-easy problem is to define the exact conditions under which taxicab hyperbolas of the five general types are created.

Only one book has been published on taxicab geometry: it is *Taxicab Geometry,* a paperback by Eugene F. Krause, a mathematician at the University of Michigan. (This work along with a few of the dozen or so papers on the topic that have appeared in British mathematical journals over the past two decades are listed in the bibliography at the end of this issue.) Krause's book is recommended particularly to students who want to learn how taxicab geometry can

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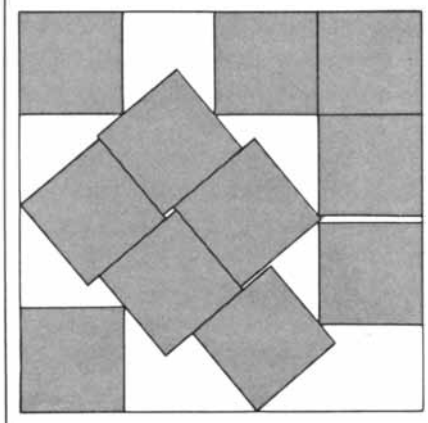
be elegantly generalized to the entire Cartesian plane, where all points are represented by ordered pairs of real numbers from the two coordinate axes. The rule of measuring distance by the shortest path along line segments that parallel the axes must of course be preserved, and so in this continuous form of taxicab geometry an infinite number of distinct paths, all of the same minimum length, connect any two points that are not on the same street.

Krause shows how continuous taxicab geometry satisfies all but one of the postulates of Euclidean geometry. Instead of violating the notorious parallel postulate, as elliptic and hyperbolic geometries do, taxicab geometry violates the side-angle-side postulate, which states that two triangles are congruent if and only if two sides and the included angle of one are congruent to two sides and the included angle of the other.

Midway between the discrete taxicab geometry I have described (which is confined to what is often called the lattice of integers) and the continuous version is another taxicab geometry in which the points of the associated space are defined by ordered pairs of rational numbers. Even on the lattice of integers, however, taxicab geometry provides a fertile field for investigation by recreational mathematicians and should present a splendid and enriching challenge for high school students. I have barely scratched the surface here, leaving many fundamental questions unanswered. How should parallel lines be defined? What is the best analogue of a perpendicular bisector? Are there useful ways to define area?

Moreover, taxicab geometry extends readily to integer lattices of three dimensions and higher. The exploration of taxicab geometries on other kinds of lattices, such as triangular or hexagonal ones that are either finite or infinite, is still a wide-open field. Indeed, the lattices need not be confined to a plane. They can be defined on the surface of cylinders, spheres, toruses, Möbius bands, Klein bottles—anything you like! Just make sure your cabbies stick to the streets and always take you by the shortest path to where you want to go.



*Improved packing for 11 unit squares*

My discussion of sporadic groups in June included some errors. My attempt to explain normal subgroups by defining left and right cosets was garbled, but the correct explanation is so complicated that I must refer readers to any textbook on group theory. Solomon W. Golomb also pointed out that Évariste Galois did not write his famous letter the night before he died. He wrote it the night before his tragic duel on May 30, 1832, but he clung to life until the next day. Joseph Gallian wrote to say that George Abram Miller did not try to prove the nonexistence of the simple sporadic group $M_{24}$. Rather he tried to prove that the group was not fivefold transitive on the integers 1 through 24, and it was this proof that turned out to be faulty and had to be retracted.

In answering a problem about the two order-4 groups in July I incorrectly stated that both groups have three normal subgroups of order 2. Only the Klein 4-group has three such subgroups. The cyclic 4-group has only one. All these subgroups are, however, isomorphic, so that the two 4-groups are the lowest-order instance of two different groups that have the same proper normal subgroup composition.

In a column on square packing in October of last year I gave the densest packing that was known for 11 unit squares into a larger square: a square of side $5/2 + \sqrt{2}$, or 3.914+. Many readers improved on this packing, but the most surprising results came by way of Hans Berlin of KabiVitrum, a pharmaceutical company in Stockholm. Berlin presented the 11-square problem to readers of *Ronden,* a periodical his company distributes to Swedish physicians. He received two letters with independently discovered patterns in which four squares (instead of three) are tipped 41.56 degrees to obtain a denser packing into a square of side 3.886+.

As *Ronden* was going to press with this result two mathematics students, Mats Gustafsson and Magnus Thulin, who together had sent one of the letters, discovered a still better solution obtained by tilting five squares at an angle of 40.18 degrees. This pattern, which now holds the record, is shown in the illustration at the left. The square's side is 3.877+. This finding probably answers a question raised by Ronald L. Graham: What is the smallest number of unit squares for which the densest packing into a square requires a tilting of unit squares at any angle other than 45 degrees?

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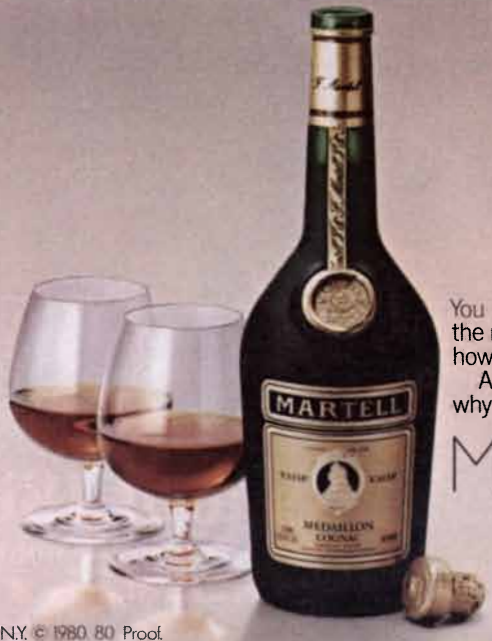


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# BOOKS

## *Strange worlds: Madagascar, asteroids and the microstructure of living things*

by Philip Morrison

A WORLD LIKE OUR OWN: MAN AND NATURE IN MADAGASCAR, by Alison Jolly. Photographs by Russ Kinne in black and white and color. Yale University Press ($29.95). The crumpled granite ridges of Tananarive not only hold the capital of the new Democratic Republic among green paddy fields; they are also the bones of Gondwanaland. A hundred million years ago the tropical island continent of Madagascar, larger than California, drifted south and east away from the edge of Kenya. Now the deep Mozambique Channel is a couple of hundred miles wide, a true barrier to land life, but for some 50 million years accidental rafting voyages, mostly from mainland Africa, were still possible, as when some "pop-eyed ancestral lemur clung with all its hands onto the wave-washed twigs." As remarkable as the flora and fauna of the big islands down under across Wallace's Line, those of Madagascar have evolved and converged in place, another self-reliant evolutionary economy, protected by the sea from the sweeping multinational innovations of the continents. No hoofed animals dwell on Madagascar at all, save the African bush pig brought by early human settlers and the pygmy hippopotamus that somehow snorted its way across the sea. Among animals and plants alike there is that "strange combination of richness and poverty—vast radiation from the few ancient founding stocks."

Our guide on an informal tour of this extraordinary island world is a well-known primatologist who spent a few specialized years there in the late 1960's, afield among the curious lemurs, our country cousins. She returned recently for a half-year tour, with her family and her photographic partner, to view the island more widely in the company of Malagasy colleagues, and she has written "to convey the scientific excitement" to a general readership, and to state the issues a thoughtful conservationist can draw out of the great drama of life staged with a new and unfamiliar cast. Acute in its formulations, full of empathy without surrender to sentiment, her brief volume is a modern naturalist's journey in the classic pattern. She engaged to tell the whole story, "ecology with people, not just your animals," and brings the task off with conviction, the text candid, sharp-eyed, often poetic.

There can be no doubt that the primates are the most interesting of all the remarkable forms there. We see them, *Lemur* and *H. sapiens* together, in rain forest and spiny desert, and in the brick-red bare prairie where lemurs are found only as fossil forms. The lemurs have been in Madagascar a long time indeed; they are varied and beautiful, mostly nocturnal. We see the tiny mouse lemur, perhaps the counterpart of the first primates of us all, orange eyes agleam by pairs in the headlamp beam every 100 meters along the trail. We hear the great indri, a black-and-white day leaper in the eastern rain forest, whose cries fill that forest, eerie sounds audible for a couple of kilometers. They are "a bit of a cheat," these loud-singing indri acrobats. They are leaf eaters, and energy is short in such fodder. A few glorious leaps take them into the foliage out of sight; there they rest while better-fed primates rush down the trail half a mile, excited and outsmarted. Among the indris, as among other lemurs, female dominance is the rule. Our own ancestors, the Old World monkeys and apes, "all share some form of male precedence."

Lemurs mark an ancient and separate track of primate evolution. Man and woman, on the other hand, are quite new to the island. They first arrived a little before the time of Charlemagne, directly from Malaysia (the musical polysyllabic language, common to all the islanders, shows a clear kinship) by outrigger canoe, some after detours in India and in Africa. These first settlers, called the Vazimba, brought a shifting cultivation, letting their burned-over clearings for upland rice and beans return to forest fallow after a couple of years. On the wet eastern coast all thrived as before in the ancestral evergreen Asian jungle. In the drier interior the clearing fires soon became a holocaust. The Great Fire lies as deep in Malagasy legend as the Great Flood does in ours. It may have been one single terrible blaze or the folk memory of a century of fires. It did, in fact, burn the center of the island bare, to a brick-red hard laterite, no longer under forest. There is in the entire Democratic Republic half the forest found in a similar area of the eastern U.S. from Maine to Virginia, even though that area of the U.S. has seven times the population of Madagascar.

Only 1,000 years of this new, cunning primate was too much for the fragile woodlands. Nowadays even the stabler wet coastal forest is steadily giving way to the tree feller and the cultivator; the Republic is forced to recognize the needs of its people. They cannot live on the leaves so suited to the indri. When human beings first came, they found and made an end of the great elephant bird, the ostrichlike *Aepyornis,* and many diurnal forms of big lemur, one as large as a small chimpanzee, adapted at least partly to life on the ground. Those lemurs perhaps were seed-and-fruit eaters like our own ancestors. Science does not know; the savants came too late, although they almost did make it. The roc of the Arab tales was based on the great flightless birds of Madagascar, and in the 17th century M. de Flacourt saw a beast with a round head and a man's face, front and hind feet like a monkey's, "large as a two-year-old calf." Indeed, there is the matter-of-fact story of old M. Andrault, who recalls today a hunt deep in the forest in 1932 or 1933, where he chanced to see a huge lemur with a flat, black face, not a muzzle, a creature like a gorilla, "'*trapu, costaud, lourdose*' (squat, robust, heavy-set)." There is still room for dreams and monsters in the Madagascar forests.

If the Vazimba began the job of speeding the slow course of evolution, it is our contemporaries who are finishing off this marvelous relict of the deep past, with its wonders and its unique legacy of medicinal plant alkaloids and of evolutionary insight. It is the most affecting part of Dr. Jolly's account that we meet and admire the energy, intelligence and resolution of M. Emmanuel. He lives with his wife and children in a thatch house about 12 feet square, lined with woven mats "like a sweet-straw bird's nest," shelves in one corner and a cooking fire in another. He is a literate and thoughtful man, sitting with his Adventist Bible on his lap. In his region it is not unusual for a primary school teacher to face two shifts of 100 children each, with a few books for each class. ("For a rural child to learn, he himself must decide that he will be one of those few in the front row.") He lives in a coastal clearing, with a few coffee bushes and hens for a cash crop ("their bank was the chickens"), and subsists on dry-land rice. He knows well how to handle his own land, is aware of experiment and recognizes the central problem. Man should respect the unending forest. But there is no more land for rice in the re-

gion, and so what are young people to do, except cut forest clearings?

We meet other people in these pages who put hard questions. The zoo director, Georges Randrianasolo, shows the only pictures of lemurs you can buy in Tananarive: they are two matchbox covers. They alone illustrate his lectures. No peasant can pay for one. "Even the *Birds of Madagascar* is not sold here. We have no foreign exchange for luxuries like a bird guide, and of course the French send us none free. I believe people need pictures to understand wildlife. How can you expect anyone to care for animals and forests they have never seen?" (He is himself the coauthor of the bird guide, and he does use his own worn copy for lectures.)

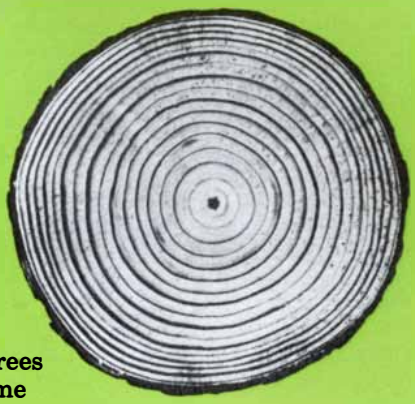
The Malagasy well remember the days of postwar rebellion, with machine-gun massacres like many a colonial tragedy. Their present state is far from desperate, but soon they must come to some terms with their limited land and go to permanent cultivation everywhere as the forest dwindles before the fires. Clearly the wide world has a real stake in those wonderful forests with their unique patterns of evolution. We ought to help pay for them somehow. It is in better terms of trade for the primary products of the Third World, in recognition of the human merits of the people of the tropical world, in generosity in matters of education and in effective aid toward self-improvement that the richer world can share the future with those it once profitably ruled. One percent of the land area of Madagascar, areas Dr. Jolly tabulates by type, could provide a minimum reserve to act as a wilderness refuge. That scheme will not work without steady, serious initiative from the Malagasy and their government, and that in turn can never come until the peasant neighbors of the wilderness are convinced of the long-term benefits. Tourists' tips and high hotel bills are not enough. The Malagasy now allot half of their reserve development funds to the surrounding communities. They know what we should learn: "Wilderness lives not by biology but by human economics."

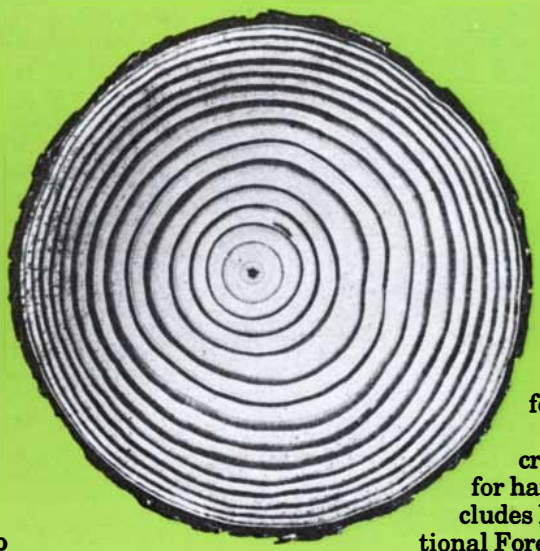
The editors have provided an index and suitable maps for this fresh and important book, but they have included no device to give easy access to the many footnotes. That is a great pity, because the long list of references is a most knowing guide to a diverse and inviting literature, both on this extraordinary land and on more general issues of ecology and human development.

ASTEROIDS, edited by Tom Gehrels, with the assistance of Mildred Shapley Matthews. With 69 collaborating authors. University of Arizona Press ($19.95). We have never yet seen an image of an asteroid. Everyone knows

A report on the great American forest.

# Look what happens when Mother Nature gets a little help.





These log slices dramatically show the value of modern, scientific forest management. Both (shown 36% of actual size) are from trees of about the same age. The smaller one grew in an unmanaged, overcrowded stand where it had to compete for sunlight and moisture. The other is from a grove that was thinned to give the best trees room to thrive.

This is just one of many ways forest management can help meet a predicted doubling of domestic demand for wood and paper products in the next 50 years.

The forest industry has learned how to help Mother Nature grow more trees, faster, by applying scientific forest management techniques: encouraging natural regrowth, planting superior seeds and seedlings, fertilizing, protecting against disease and insects, thinning, watching carefully until time to harvest — then starting the cycle again.

## Demand keeps rising.

Forest management like this is vital because every year Americans need more homes, more paper products, more packaging and containers, more fuelwood, more of the thousands of other essential products that only the forest can provide.

So far, the country's commercial forest has been able to keep up with demand. (*Commercial forest,* as defined by the U.S. Forest Service, is *all* forestland—whether owned by individuals, government or the 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 trees aren't grown equally fast by all commercial forest owners. Though industry has made striking advances on its lands, productivity is lower on privately owned lands and seriously lagging in National Forests.

## Productivity not up to potential.

Overall, the U.S. Forest Service estimates average productivity of all commercial forestland is only 61 percent of potential. And at the same time, actual acreage in commercial forests keeps shrinking, as land is withdrawn for homes, highways and other needs of an expanding population.

So we as a nation still have a long way to go if our wood and paper products are not to become scarce and expensive.

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.**

they are minor planets, many of them tiny ones no bigger than a small mountain, that orbit our sun. The name—starlike—refers to the fact that not one is big enough or close enough to be imaged by our telescopes as the true planets are. (They were the 19th-century equivalent of the quasar.) The final tables in this rich volume present 143 pages of hard data on the more than 2,100 members of the class we know. Almost 500 were found before this century, defined by the swift motion of a starlike point in the sky not too far from the plane of the planets. Even then it was realized that their brightness varied over a period of hours: they were irregular spinning bodies. Today we measure the rotation axis and the reflectance in different colors, we look for radar return and infrared emission, we note the orbits as they are and we correct those orbits for the resonant effects of the recurring gravitational disturbances induced by the big planets, particularly Jupiter. All of these data, with the list of the discoverers and the many bizarre names, and up-to-date (1979) reviews of all we know and what it might mean, are here in this source book aimed at graduate students, an invitation to research and a current record in a disciplined volume, deliberately organized by the learned editor.

Comets are different. They fly in from all directions, since they dwell in a huge near-sphere far from the sun. They are big dirty snowballs, or maybe ice-packed rock piles, or both, their ices volatilizing on the approach to their fiery master the sun. Meteorites are not so different; they seem mostly to be errant earth-caught fragments of the asteroids. (What comet nuclei deposit on the earth is mostly too volatile to collect.) The asteroids lie in orbits inside Jupiter's, not as marshaled and circular as those of the planets but much more so than the bulk of the comets. They are rocky and metal-bearing but are by no means fully refractory. The volume treats of these diverse bodies in seven parts: an introduction, a general exploration of their properties; their interrelations with comets, with meteors and with the gravitational will of the planets; their probable configurations; their composition, judged both by the varying light they send us and by the inferences from meteorites; theories of their evolution and origin, and the tables cited above: a benign TRIAD (Tucson Revised Index of Asteroid Data).

All a brief review can hope to give is some sense of the excitement that animates this rapidly changing science. Perhaps at last we have seen an asteroid or two face to face; there is good reason to believe that the two pock-marked little moons of Mars so well imaged by Viking are simply corralled asteroids. Their irregular, deeply cratered and stressed surfaces begin to modify our expectations. The biggest asteroids, the ones first found before 1810, might be dust-laden spheroids, gravity-formed as the planets themselves. The little fellows are stronger, and they are too small to be self-crushed. Their forms reflect instead a long history of collisions. We now know that the sizes, speeds and directions of these flying fragments imply collisions frequent over geologic time.

We have learned within the past decade that it is not enough to fit rough dusty spheres with light and dark patches to the light variations we see; infrared and optical data together demand strange shapes, not only flying bricks and potatoes but also barbells, perhaps even stringy clumps of four or five adhering mountains. There are strong signs, still not fully confirmed, that some asteroids are really doubles, two pieces in close orbit together, or even entire little groups in orbit. How they formed, what they tell us of the meteorites they bequeath to the earth and what it all means in the development of our complex solar system are questions approached here in paper after paper.

A little self-centered curiosity may not be amiss. Ice and water vapor are abundant in the cosmos. But we, like all life, live by liquid water, and liquid water is unknown in the cosmos except on the earth and perhaps transiently at the edge of the Martian ice caps. Yet many meteorites contain unequivocal mineral and chemical evidence of past liquid water. Can this odd stuff, the essence of life, be there on the asteroids? It seems impossible that they could hold pools or seas; the liquid evaporates too quickly. Water held in chemical bonding deep within a tiny planet might, however, be released from its weak combination by modest heating, to form an inner shell rich in liquid water. Nearer the surface dust the water freezes to a permafrost. That subsurface ice slowly sublimes, but within the body a deep-lying layer of water might be held for brief spans of geologic time, perhaps long enough to allow the watery processes the meteorite mineralogists see. Collisions plow up fragments and might release such products; a few of the myriad fragments are gathered up by the earth and enter the museums, there to present the puzzles we now slowly piece together.

One table coolly sets forth an even more intimate proposition. It estimates the frequency of encounters of the most interesting kind: earth collision with asteroids whose orbits cross our own. Extrapolating the direct observations, there seem at present to be more than 1,000 such bodies of mountain size. Some are pretty sure to hit us head on sooner or later. A big projectile may have done in the dinosaurs by dust pollution; it does awake our interest to learn that such collisions ought to occur

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**25 41**

The Plymouth Reliant has the highest mileage rating of any six-passenger car in America: 25 EPA est. MPG,* 41 est. hwy. Plymouth's advanced front-wheel-drive technology provides more effective engine power and reduces weight by eliminating heavy drive shaft parts.

*Reliant wagon 24 EPA est. MPG, 40 est. hwy. MPG. Use EPA est. MPG for comparison. Your mileage may vary, depending on speed, weather, and trip length. Actual highway mileage will probably be less. Calif. estimates lower.

### FRONT-WHEEL-DRIVE AND SIX-PASSENGER ROOM

Reliant's engine and transmission are mounted sideways over the front wheels with the power train, leaving room for a compartment that comfortably seats six.

### FRONT-WHEEL-DRIVE AND SERVICE

Reliant's new Trans-4 engine was designed exclusively for front-wheel-drive. It was also specially designed for easy and inexpensive serviceability.

### FRONT-WHEEL-DRIVE AND TRACTION

The Plymouth Reliant has excellent traction, far better than that of conventional cars, because its engine and drive train are mounted over its front drive wheels. This puts all the engine and transaxle weight over the drive wheels, and moves the center of gravity to the front. This makes Reliant not only far more resistant to wheel spin in wet weather, but able to pull through snow where conventional cars may lose traction.

### FRONT-WHEEL-DRIVE AND DIRECT POWER

In conventional cars, power from the engine travels down a long drive shaft to turn the rear wheels. The power from Plymouth Reliant's remarkable transverse-mounted engine and transaxle, however, goes directly to its front drive wheels without valuable energy being wasted by front-to-rear detours. This is Reliant's Direct Power System, and there is no more efficient way to get power to a car's wheels.

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# RELIANT-K
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Chrysler Corporation has a total of nearly a million small front-wheel-drive cars in use today. Based on estimates of 15,000 miles per car per year, that's a minimum of 10.5 billion miles of owner-driven front-wheel-drive experience.

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Over 2,000 quality inspections are performed before each car leaves the line.

Every engine is rated by computer for 54 operations. Unless it gets 54 A's, it doesn't get into a Reliant-K.

So confident are we of Reliant's quality, that it comes with a 30 day/1,000 mile money-back guarantee.†

† Buy a new 1981 Plymouth Reliant from a participating dealer for personal use. Drive it up to 30 days or 1,000 miles whichever comes first.

If you're not happy with it, bring it back in good condition with no metal damage. When the dealer gets clear title, you get your money back, excluding finance and insurance charges.

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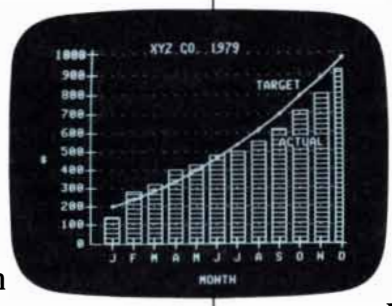


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|---|---|---|
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| **Screen Resolution (B&W)** | 280 x 192 | 560 x 192 |
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| **Keyboard** | Fixed | Programmable |
| **Numeric Key Pad** | Accessory | Built-in |
| **Input/Output** | 8 expansion slots | 4 expansion slots plus built-in: disk interface RS-232 interface Silentype™ printer interface clock/calendar |
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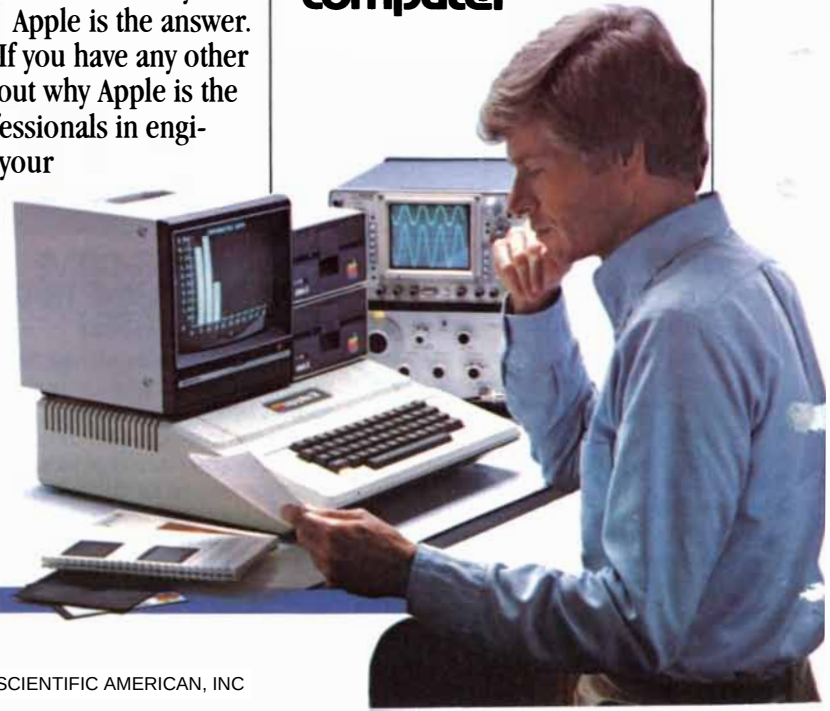

once every few hundred thousand years.

One paper, a posthumously published five-page work written in 1971 by Samuel Herrick of the University of California at Los Angeles, imagines the deliberate splitting and capture of a piece of asteroid No. 1620, Geographos. A chunk of the right size is cleaved off, correctively guided to hit the right place, with the 50-kilometer crater planned as a Central American canal and the heavy-metal content as a rich mineral resource! This spectacular and risky manipulation of nature by man is foreseen, however, as a necessary preventive measure: Geographos moves in an ominously oriented earth-crossing orbit.

Long-range plans are not foolish, even though this one is hyperbolic and premature. A watch over our fellow-traveling asteroids is nonetheless not such a bad idea, and flying past a few of them to get images and gather other data is not at all beyond our powers or our budget, even within the decade. We might even be able to fly by Philosophia (among others) by 1986. Getting samples back seems "relatively easy," though only with ion drive, which is not yet at hand. Eating the whole thing, however, must surely be deferred to the year 2001 and beyond.

"We may never do a better book," writes Professor Gehrels. He was wrong when he said this of the first in his series; he is probably wrong again. Even if he is right, he ought to rest content.

THE FIRST AMERICANS: ORIGINS, AFFINITIES AND ADAPTATIONS, edited by William S. Laughlin and Albert B. Harper. Gustav Fischer. Distributed in North America by Verlag Chemie International Inc., Suite E, Plaza Centre, 1020 Northwest Sixth Street, Deerfield Beach, Fla. 33441 ($29.80). "The first Americans were Siberians," said A. P. Okladnikov a generation ago. A tourist easily gets the point in the tedious waiting line at a Moscow airport; many of the delayed travelers would look quite familiar in Gallup, N.M., or Cochabamba in Bolivia, although in fact they are Soviet citizens eastward bound for home on long overland Aeroflot flights. This volume reports a symposium of physical anthropologists, with a biologist and a biochemist or two, men and women from the U.S., the U.S.S.R., Japan, Australia, France, Chile, Canada and Denmark who met under Wenner-Gren auspices in Austria four years ago to review the "last great migration of our single species": the one into the Western Hemisphere. That ancient epic gave proof that *Homo sapiens* could deploy into a diverse range of environments and yet remain one species, with only modest genetic diversity from Tierra del Fuego past Panama to Greenland, from tidal flat to high Andes.

The research strategies to answer such hard questions as whence, when and how are diverse and widespread. They are in a state of swift change, and better answers certainly await us in some years. A base line is needed, and "virtually every Siberian group has been investigated by a caliper-wielding anthropologist." Such classic methods remain of value, although their early interpretation by doubtful typologies instead of the statistical indexes they require has much diminished their acceptance today. Nowadays the calipers are molecular, and the red-cell antigens of blood type, the serum proteins and two dozen enzymes of the red cells offer more grist to the sophisticated number mill of the computers. Five of the 14 papers in this volume present such data on affinities; they remain rather inconclusive. The data are sparse, the changes small, the firm conclusions few. Still, the tables and the varied genetic maps fully support the view that "on a world scale the North American Indians, Eskimos, and Aleuts are a genetically distinct geographic race or breeding population, related most closely to the Mongoloid peoples of eastern Asia."

Disease offers hints, too. We know that on the arrival of Europeans in the New World smallpox, typhus and measles found the indigenous peoples without immunities. Those diseases had probably not existed in the hunters' Asia. Tuberculosis, on the witness of a single convincing diagnosis in a Peruvian mummy, did come along early. Syphilis remains uncertain still.

Language families are used as data by some of these builders of affinity maps, but there is no report by a linguist. One comes away with the clear impression that in the study of a time interval of 10,000 or 20,000 years language changes are plainly too fast and genetic changes are mostly too slow to offer clear results. One paper ends by remarking that the first Americans "still look very much like their Asiatic relatives. In marked contrast, the Australian Aborigines, who have apparently been in Australia for some 30,000 years or more, do not look (genetically or visually) like populations on the mainland of Asia." We can be sure that the New World has been a home to our species for 12,000 years at least; we know rich and well-dated sites that old.

We have no sign at all of occupancy on the deep time scale of the Old World, where a single cave can show human remains, if not all of our own species, for 50,000 years, and the remains of camps a couple of hundred thousand years old are not uncommon. The time of human arrival in the Americas, however, is still unsettled. The single place is almost sure, the now-submerged land bridge where the Bering Sea shallows out. A careful study of sea levels and ice forms leads to the conclusion that the

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ice sheets and the sea together never put a firm barrier in the way of human passage for more than a few millenniums out of the past 30 or 40. There was always a narrow path for those who could brave the cold weather to hunt on the dry Arctic steppe for the big game now gone: bison, mammoth, horse and camel. Caribou took over as the glaciers dwindled, 10,000 or 12,000 years back.

The great climatic and faunal change came as the ice melted swiftly between 14,000 and 10,000 years ago; it seems quite possible that it was there on the southern coast of the flooding land bridge that marine hunters, skilled boatmen and beach masters, invented the hunting of big sea mammals. The ancestors of the Aleuts and the Eskimos, closer kin than the other groups by a good many indexes, came late by a coastal route along the southern edge of the diminishing land. They could continue their advance as the oceans rose, since their range was the seacoast.

Along the coast these people slowly diverged, westward along the volcanic-island chain of the Aleutians and eastward along the north coast of North America all the way to Greenland. Nearly a third of the entire population of Aleuts and Eskimos eventually lived in those two terminal regions, the westernmost Aleutians and the Greenland coast. A thread of continuity in culture as in genetics can be followed between those distant foci. The rest of the New World was peopled rather earlier by those who came with projectile point and fire after big game, to spread overland quickly from the far north to Cape Horn, first mainly along the eastern side of the Cordillera. In time they learned to grow beans and maize, to weave in cotton, to build cities. The picture remains tentative, although it seems the clear import of most of the papers and the view of the editors, two Connecticut anthropologists.

The early Aleuts arrived at the seaward end of Umnak Island at least 8,700 years ago. The village of Nikolski there can claim local occupancy continuously since that time, with a bone-old sense of place no other U.S. citizens, no Winthrops nor Cabots, not even the people of Acoma or Second Mesa can hope to match. The Aleuts' population density, before the first great challenge of the 18th century, when Russian entry brought both disease and massacre, was more than one person per square kilometer, two orders of magnitude above that of the caribou hunters. Their catch was the abundant sea otter, the sea urchin, the seal and the walrus. Their life expectancy reached uncommonly high values for a foraging society. It was and is not uncommon for an Aleut to die in the ninth decade of life; the careful parish records of the Orthodox Bishop Veniaminov, who came to Unalaska

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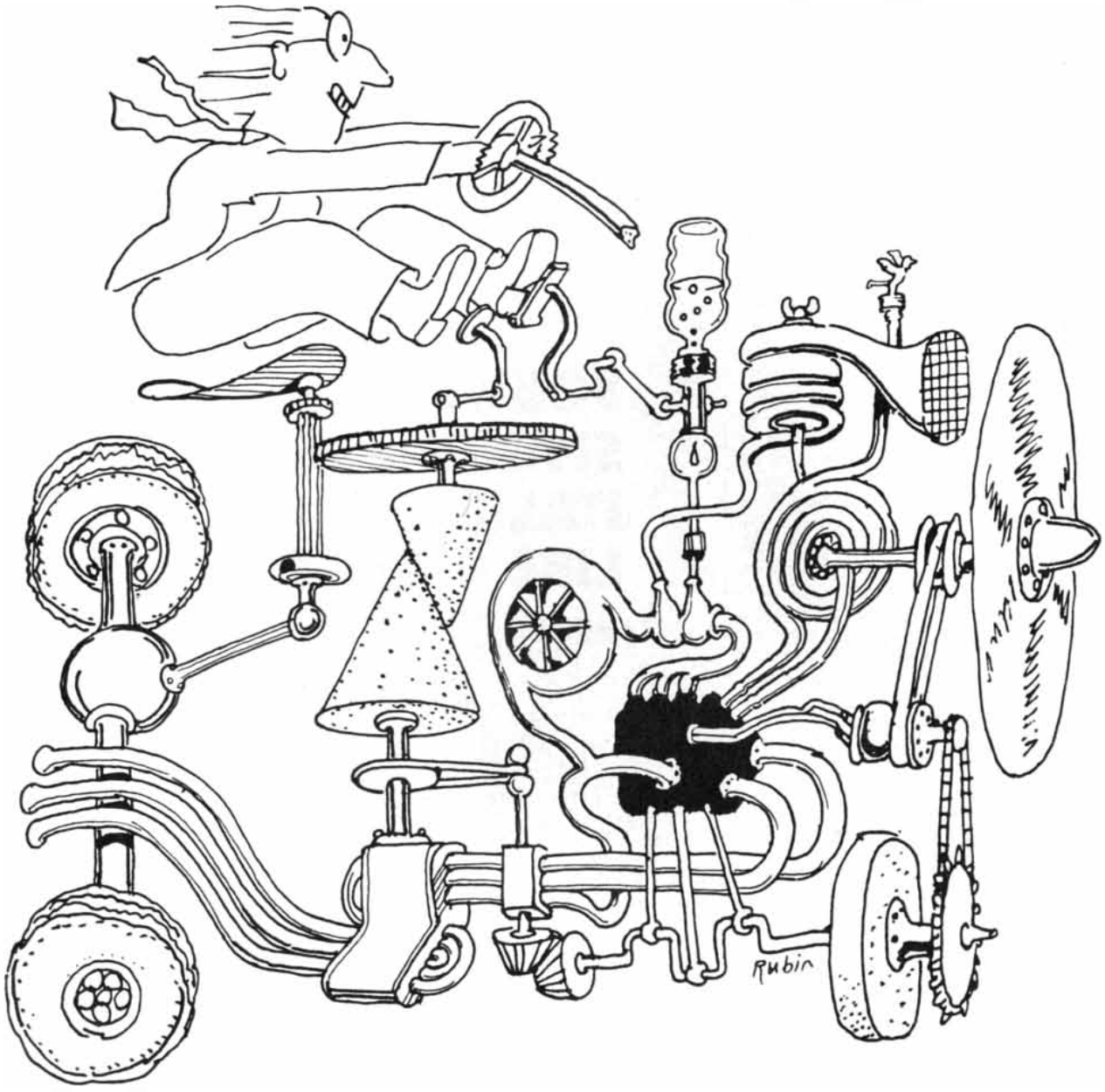

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If you're not sure how we can help you, we suggest you first take a look at your energy bills, or your EPA requirements, or whatever else you're working against. Then write us for more information. Just take the time you'd normally spend at the gas pump and send a letter off to our President, Jack Teske. You can reach him at The Garrett Corporation, Dept. 1, P.O. Box 92248, Los Angeles, California 90009.

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in the 1820's, confirm the earlier data from burials in middens and caves.

The age curve is shown over a span of time; it is a welcome fact that medical care and increased food supply have restored the old high value. In 1948 there were no old people; in 1973 several people in the sample were older than 80. It appears that much of this success in adaptation, by the crude but intuitively appealing measure of life span, arises from the fact that the elderly Aleuts could win most of their own food, by fishing easily accessible places on beach, bay and stream, and by collecting shellfish when the tide was out. The feedback loop closed; the old people then played a valuable part in society. They acted as skilled midwives and physicians, as bearers of knowledge in a nonliterary culture and as tutors of children in hunting skills, from coastwise piloting to travel by small kayak.

But the Aleuts in the Pribilofs, 200 miles north, where the Russians resettled some of the Fox Island people to harvest the fur seal, were not so long-lived. The oldest man there in 1889 was 66. The Pribilofs offer no reefs or streams; they are fine for seals but not for Aleuts. No, it is not, as has been suggested, the high polar flux of cosmic rays that can explain Aleut longevity by mutation; it is the accessibility of reefs and streams that gave their old people a key advantage; since they could just about feed themselves, they were well worth a small cost to the younger hunters. "Indeed, the persistence of the Aleuts over 9,000 years may be attributed to the functions that old persons play."

BIOLOGICAL STRUCTURES, by W. Krommenhoek, J. Sebus and G. J. van Esch. University Park Press, Baltimore, Md. ($16.50). Crisp from title to careful index, *Biological Structures* is a collection of photographs with well-keyed marginal annotations that opens a view, at every relevant scale, on life's geometry. Such a view is not novel to the general reader in science; this magazine and nearly every textbook put the images forward. There is no dearth, either, of well-made compilations, surveying every particular animate geography from wood fibers to the human skeleton. What this rather elegant presentation offers is a compact catholicity. Its multidisciplinary Dutch compilers, pooling their knowledge and their slide files, have assembled 140 pages of pictures, beginning with the intricate tracery of modern electron microscopy of ultrastructure, then proceeding to an optical (and scanning electron micrograph) look at the microscopic forms of seed plants, to the tissues of the mammalian body (classical histology), to the day-by-day development of a mouse embryo through sections, to the radiography of the human body in life, the shadowy bulk of our bones and organs. It is an album satisfying more the peruser than the casual page turner. The plant micrographs and most of the tissue pictures are in painterly color, not the colors given by the brush but those added by the ingenious and patient microstainer, whose palette encodes a deal of chemical meaning. These color patterns are showy enough to stop even a reader on the run; the cover reproduces a fine stem section of that invaluable symbiont of human society, stained vascular bundles of the monocot wheat.

A few of the best-known distinctions within biology can serve as a sample of what the compilation makes clear. Only a few pages separate the well-labeled section of a liver cell—with its double-membrane-enclosed nuclear sphere, its ribosome-studded infolded membranes and its intricate septate mitochondria—from a bacterial cell. That prokaryote bacterium is magnified 10 times more than the mammalian cell, and yet within the small cell of ancient lineage little internal differentiation is to be seen: there are no organelles. The hereditary material lies strewn in a fibrous skein. All the higher plants display a structure manifestly built on a unified principle of chemical technology: bundles of tubes and support rods, now fanning out, now joining up. Dicots show a firmer architectural hand.

The mammalian organism is clearly displayed as a tour de force of indefatigable corrugation. First the entire small intestine is packed in like a tangle of hose, then fine accordion pleats come into view, then we see the Turkish-towel texture of the villi and proceed on down to the microvilli, the micron-size fingers that enlarge 30-fold the external surface of the exposed end of each individual cell. It is a pictorial tale of an epic struggle for surface. Three X-ray plates follow up a fresh leg fracture: after eight weeks the callus of bone has formed, and 17 years later the bone is strongly welded but a little awry. A fine spread in color, this time created not by dyestuff but by the noninvasive colors of wave interference in the phase-contrast microscope, presents the choreography of living chromosomes in mitosis. The act of division in an amoeba is literally tense: a scanning electron micrograph shows two newly formed daughter cells pulling taut the last thin thread of cytoplasm that had joined them.

VOLCANOES OF THE EARTH, by Fred M. Bullard. University of Texas Press ($29.95). The dark tower of ash over the truncated cone of Mount St. Helens is the image of the year. Just about every bookstore and substantial newsstand already offers a couple of quickie illustrated paperbacks that summarize the events. Their photography in color and in black and white is in general superb and well reproduced; the camera was taken close up by helicopter and hiker and was knowingly directed at the volcano, its environs, ash fall and ruin. The photoengravers and printers are deft craftsmen. The images are worthy documents, and many are works of art. Ours is the land and the epoch of the quick image. The text of the books, the hasty product of unprepared writers more at home among the small alarums and trivialities of the local press, are quite the reverse. Mixing error and sentiment, getting the facts from handouts generally a little wrong (Krakatoa being confused with Tambora is a typical example), innocent of graphs and scales, the authors make such a botch that these columns will not mention particular titles. The books are easy to find, worth the money for the images alone but to be read at your own risk.

*Volcanoes of the Earth,* on the other hand, is a good general volume on volcanoes, their muster, their types, their origins, their geological context and their effects. It is the work of a senior volcanologist who was able to revise his original edition of 20 years ago to meet the improved state of geological knowledge. Professor Bullard, 50 years a student of active volcanoes at first hand from Iceland to New Zealand, published the revision in late 1976. His book nonetheless remains a lively and accessible guide for the general reader. In this edition he includes a thoughtful chapter on plate tectonics, the theory which provides the only general understanding of volcanism. The chapter is charming to read, with its note of residual skepticism. The book offers useful diagrams, maps and tables in plenty, cogent and apt to the textual setting, and many splendid photographs, some in color. The text and illustrations that explain how the sharply angular glass particles of volcanic ash form through the explosive disintegration of the gassy pumice from acidic lavas clarify a dozen long newspaper stories we have all puzzled over; the stuff is scouring powder, "as in Old Dutch Cleanser." It is a useful reminder of what the engine mechanics have been up against.

There is a summary, but no one-by-one lists, assigning more than 500 active volcanoes to geographic locations by country. World-map endpapers plot only about a third of them; the editors might have worked a little harder. Is Mount St. Helens listed as active? You bet it is, along with the six other eminences in the Cascades, from Baker to Lassen, for which eruptions are confirmed within the past century or two. "Any eruption in historic time, regardless of how remote, is certainly in the 'present' if considered as a part of geologic time." Professor Bullard reads the depths, not the headlines.

A future President should be announced with more than a cigar.

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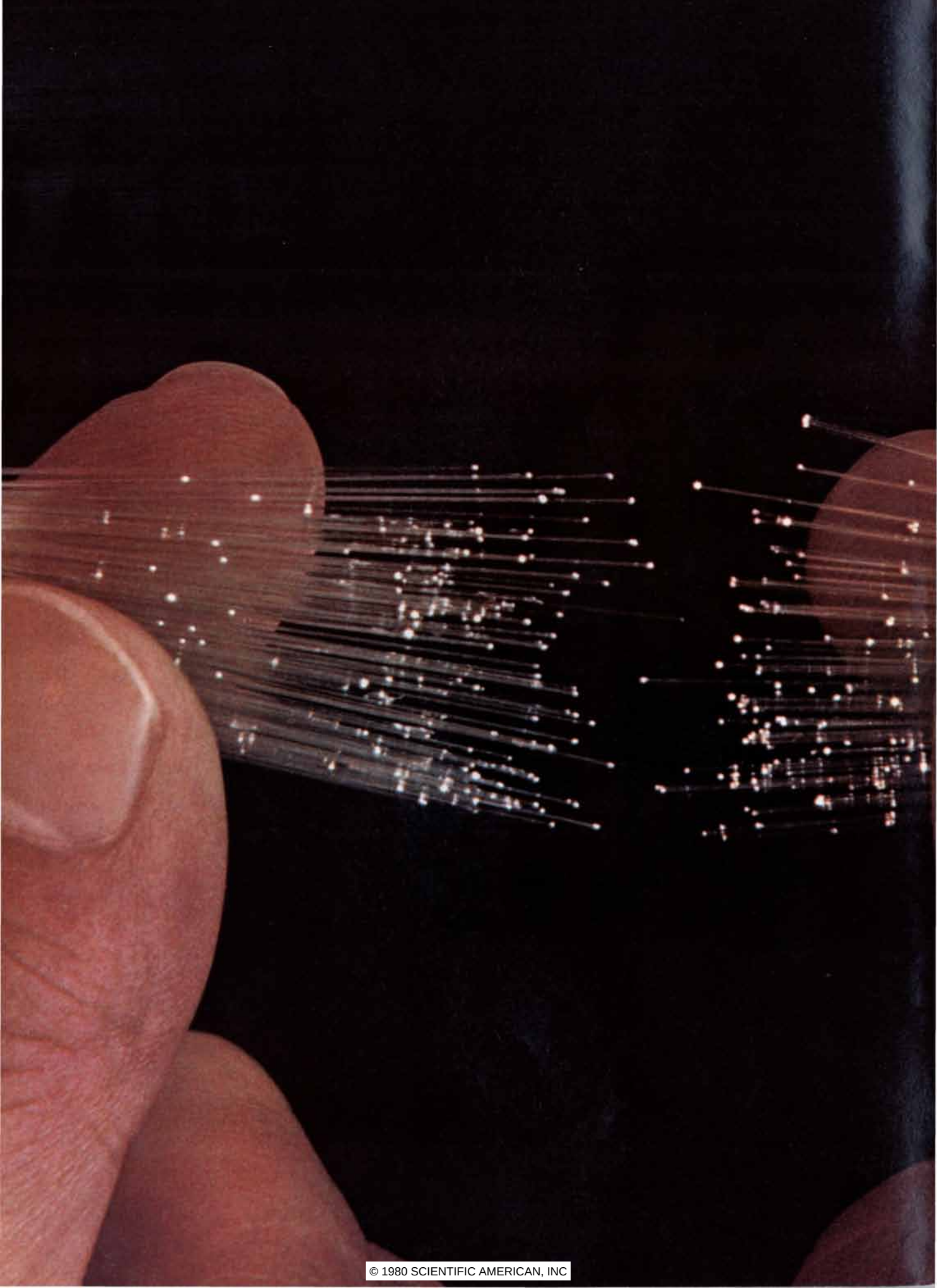

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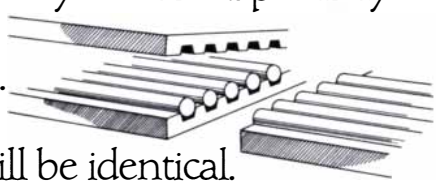

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**Consumer Orientation**
No. 9 in a Series
**Subject:** The Race Track as Proving Ground

9

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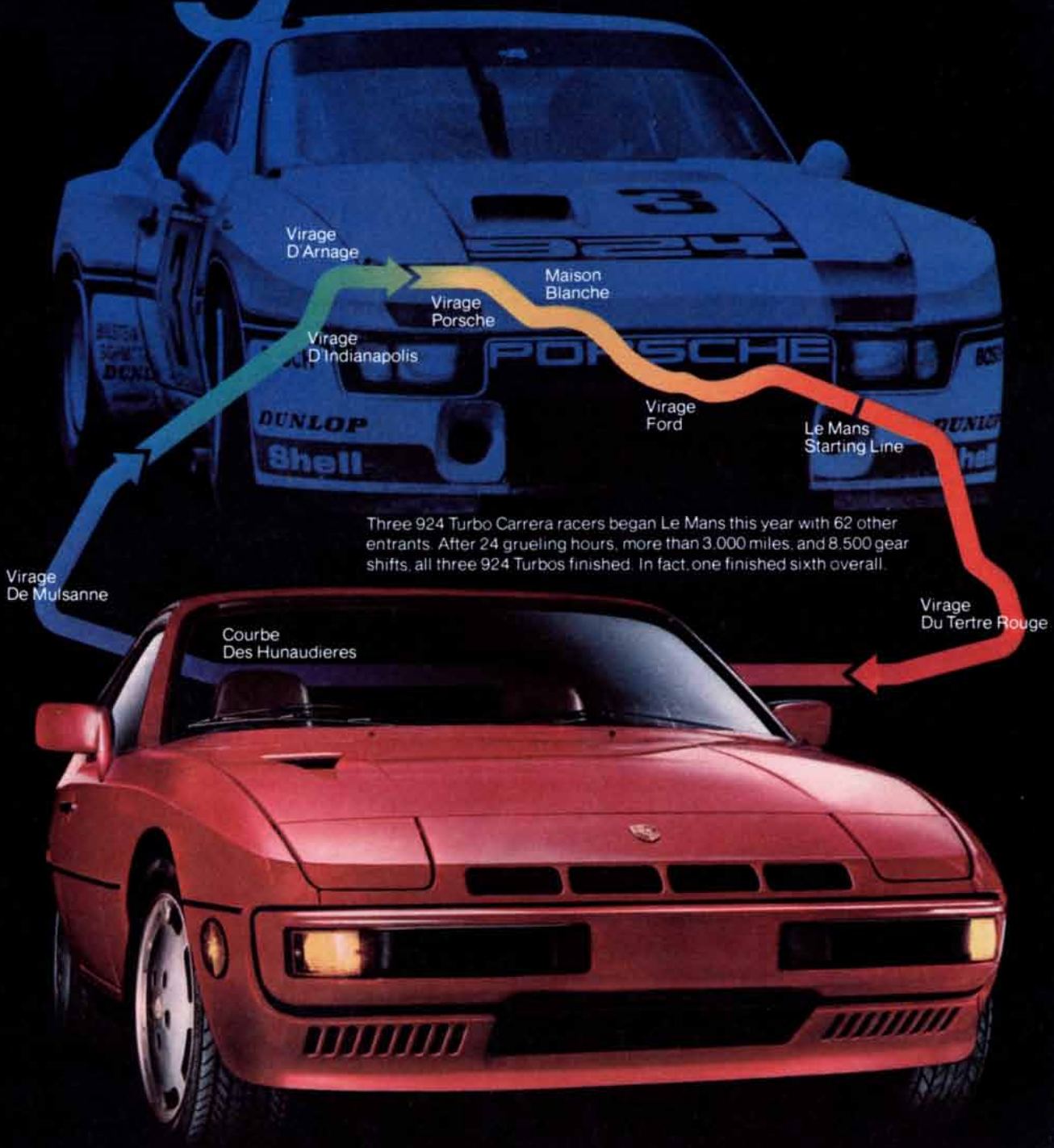


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# The Rise and Fall of Ischemic Heart Disease

*In the U.S. the death rates attributed to heart attack and other results of the obstruction of the arteries that nourish the heart have fallen since the 1960's. Why they have is not understood*

by Reuel A. Stallones

Whenever a drastic difference is found in the frequency of a disease from one time to another or between disparate cultures or in different geographic areas, a special opportunity is created for research into the causes of the disease. Epidemiologists refer to these opportunities as natural experiments because they are untainted by the intervention of an experimenter. The recent history of heart attack and other conditions embraced by the term ischemic heart disease presents evidence that the inhabitants of the U.S. are all participants in just such an experiment, conducted on a grander scale than any experimenter could have devised. For more than 30 years ischemic heart disease has been the single greatest cause of death in the U.S. Of 1.9 million deaths in 1976, for example, some 650,000, or nearly a third of the total, were attributed to ischemic heart disease specifically. Without fanfare, however, the mortality rates for ischemic heart disease reached a peak in the mid-1960's and have steadily declined since then, for a total reduction that has exceeded 25 percent.

The terms ischemic heart disease, coronary heart disease and arteriosclerotic heart disease are more or less synonymous; they denote the clinical manifestations of atherosclerosis, the obstruction of the flow of blood through the arterial network, when the vessels that are obstructed are the coronary arteries, which nourish the muscle of the heart. Although the factors that determine the progression of atherosclerosis are not fully understood, the process is known to involve the growth of a mass called an atheroma in the inner layers of the arterial wall. In its early stages the mass contains smooth-muscle cells and cholesterol; later its structure is complicated by the growth of fibrous tissue and by deposits of calcium. Atherosclerosis may begin early in life, even in childhood. It progresses slowly over decades, thickening the walls of the arteries and restricting the flow of blood.

Eventually an atheroma may completely block a coronary artery, thereby depriving a segment of heart muscle of its supply of blood in the medical crisis known as a myocardial infarction, or heart attack. An atheroma also promotes the clotting of blood in an artery; hence a clot may produce a sudden myocardial infarction long before the atheroma is large enough to do so. The likelihood of a heart attack is therefore determined by two processes, the slow course of atherosclerosis and the rapid, unstable clotting of blood. Acute myocardial infarction is often fatal; in about a third of all the cases in the U.S. the afflicted person dies before receiving medical attention. Those who survive are at high risk of subsequent attacks; they may be permanently disabled, and ultimately they may die of congestive heart failure. In spite of advances both in knowledge of atherosclerosis and in medical care for the victims of ischemic heart disease, the brightest prospects for the future lie in the effective prevention of the disease. Plainly a sustained decline in the death rate for ischemic heart disease commands attention and calls for explanation.

Mortality data for the U.S. are derived from death certificates that have been coded for cause in accord with the International Classification of Diseases. Data in this form are available only since 1900, and for the first three decades of this century they are available only for states that had a registration method of sufficient quality to warrant admission to the system. The coding has been revised at approximately 10-year intervals to reflect the evolution of medical concepts of diseases and their causes. All these circumstances sharply limit the comparability of data over long periods of time, and so interpretations must be offered with more than the usual caution.

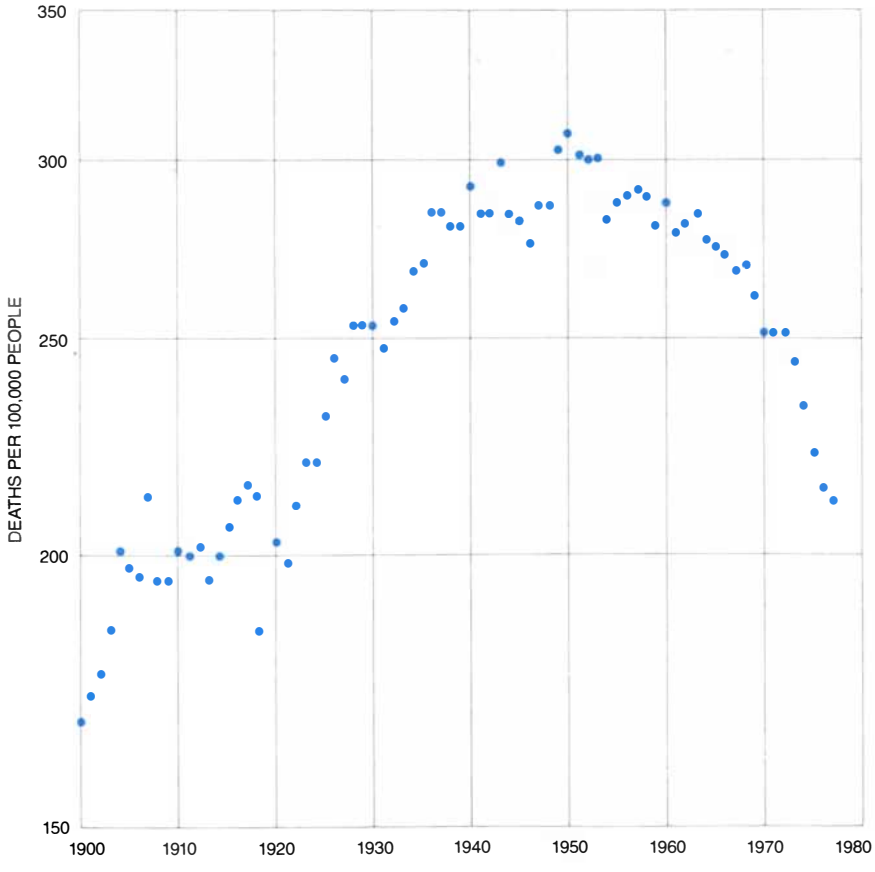
The changes in medical terminology preclude the direct examination of long-term trends in the mortality from ischemic heart disease, but the broader category "diseases of the heart" has reflected the changing patterns in spite of its lack of specificity. Between 1900 and 1920 the death rates attributed to diseases of the heart were relatively stable. An abrupt change came in 1920, when an upward trend was established that continued for 30 years. The abruptness of the change was accentuated by a deficit of deaths in 1919, the year that followed the excessive mortality of the influenza pandemic of that time. Moreover, a detailed analysis of heart-disease mortality by Theodore D. Woolsey and Iwao M. Moriyama of the U.S. Public Health Service demonstrates that in about 1920 the admission of southern and western states to the death-registration area added young people to the population base. This too accentuated the apparent break in the slope of the curve.

An examination of the deaths by 10-

year age groups shows, however, that the change in slope was characteristic of the mid-adult years. The death rates for diseases of the heart among people younger than 35 decreased steadily throughout the first half of the century, and the death rates increased steadily for people older than 75. If the change in slope were due to vagaries in the reporting or the classification of the deaths, then the reason for the change to be so highly selective for the age groups between 35 and 75 is obscure. Terence W. Anderson of the University of Toronto presented additional evidence that the change was not artifactual when he computed the ratios of the male to the female death rates attributed to diseases of the heart and showed that from 1920 onward the ratios increased sharply. To put it another way, the male and the female death rates diverged as they both increased between 1920 and 1950 because the death rates for males grew faster. A change in the rates by gender is no more likely to be adventitious than is a change in the rates for a particular age group.

Within the diversity of diseases that constitute the category of diseases of the heart, only one diagnosis, angina pectoris, showed an increase coincident in time with the one for the broader category. Angina pectoris means pain in the chest, and it results from the inadequate flow of blood to the heart. The pain itself is not considered now to be a likely cause of death, but in 1912, when James B. Herrick alerted the medical profession to a lethal disease marked by occlusion of the coronary arteries, he called the condition angina pectoris.

In 1930 a new rubric, diseases of the coronary arteries, was introduced. Apparently it replaced angina pectoris as the designation of choice for the lethal disease, which continued to rise rapidly through the 1930's and 1940's. In 1949 diseases of the coronary arteries disappeared from the classification system. It was absorbed into a more modern term, arteriosclerotic heart disease, which in turn gave way (in 1968) to ischemic heart disease. The time trends in this century for other forms of heart disease show no other plausible candidate to account for the overall increase in diseases of the heart. Ischemic heart disease can therefore be traced backward and downward in a logically consistent chain to the sudden change in mortality that marked the year 1920.



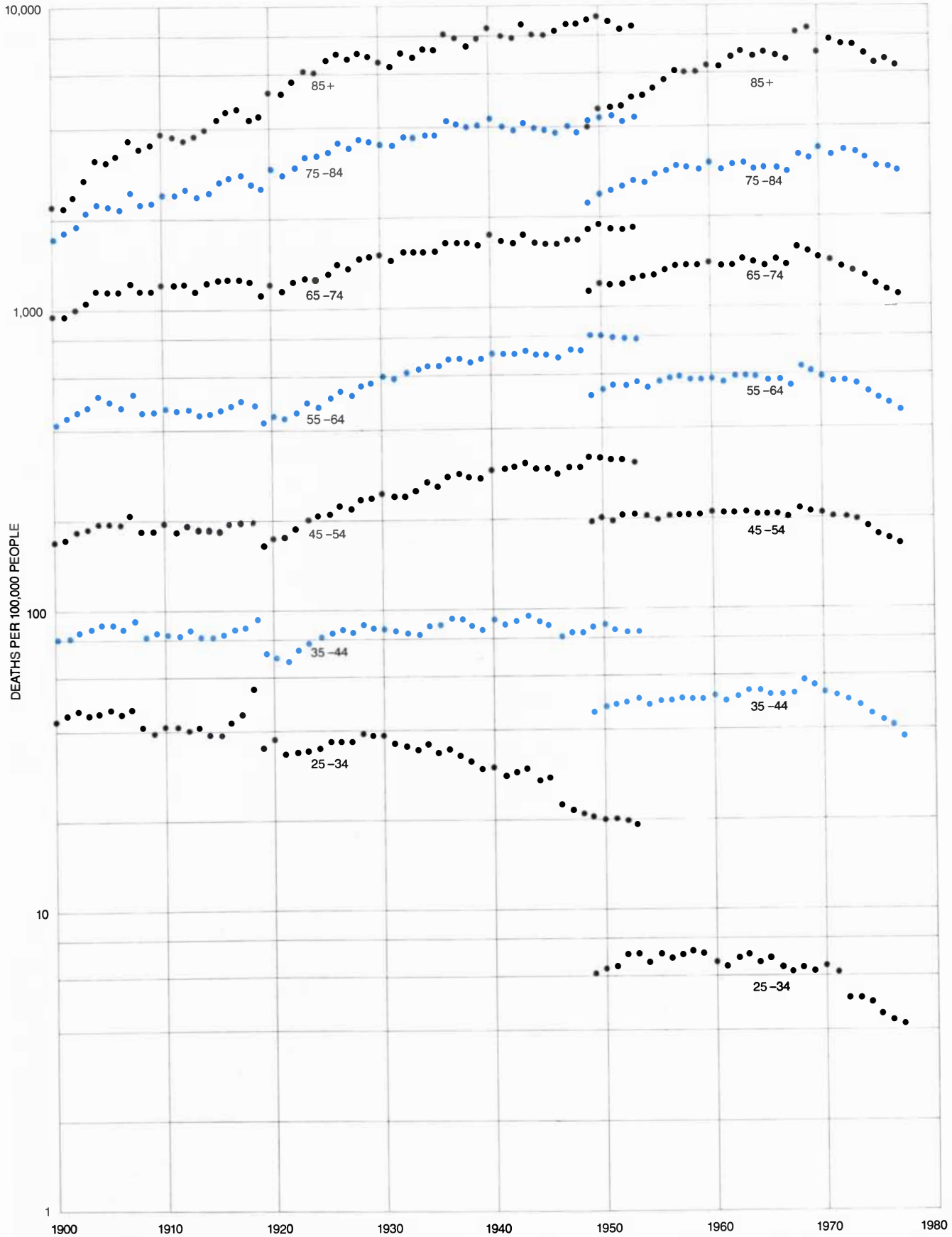

**TIME TREND OF U.S. MORTALITY due to diseases of the heart shows a steep increase in the death rates from the 1920's to the 1950's and then an equally steep decrease that began in the 1960's. The rates have been scaled to fit the distribution of ages in the U.S. population according to the census of 1940. In this way the death rates for different years can be compared in spite of the changes in age structure in the past 80 years. The vertical scale is logarithmic.**

The mortality rates for ischemic heart disease reached their peak in the mid-1960's, and by 1970 a declining trend was well established. The interpretation of the data for these years is mildly complicated by the 1968 revision of the system for coding the causes of death. One result of the revision was the transfer of a substantial number of deaths from hypertensive diseases into ischemic heart disease. Nevertheless, the decreasing trend of ischemic heart disease has continued through 1978, the most recent year for which information is available. Indeed, the rate of decrease appears to have accelerated since 1973. In the 1968 revision the category of ischemic heart disease was divided into two major subgroups, acute myocardial infarction and chronic ischemic heart disease, with remarkable results: acute myocardial infarction has fallen since 1968, whereas chronic ischemic heart disease has shown no consistent decline.

Parenthetically, the decrease in the risk of death from acute myocardial infarction for women is sharply at odds with the popular supposition that the redefinition of women's roles in American society (in particular their appearance in large number in executive offices around the country) will result in a redistribution in their pattern of illness. Increases in peptic ulcer and in myocardial infarction are projected, and sometimes cited. Since the mortality from peptic ulcer is decreasing as steeply as the mortality from myocardial infarction, the thesis appears to be contradicted by the observations.

The natural experiment involving the incidence of ischemic heart disease in the U.S. is signaled by marked variation in the geographic distribution of the disease as well as the changes over time. Before 1950 a geographic pattern for the mortality from ischemic heart disease was established in which the death rates were highest along the eastern and western seaboards (particularly toward the Northeast) and lowest on the Great Plains. A number of investigators sought to determine whether these differences were biologically genuine or were instead the result of variations in customs of diagnosis or in the availability and quality of medical care. The general conclusion was that although the data were shaky, the basic pattern could not be explained away as artifact.

The geographic pattern for 1950 persisted through 1960, but some important trends began to emerge. The states with the highest death rates in 1950 had the smallest increase in the decade that followed. The result was a relative shift of ischemic heart disease toward the Southeast. An analysis of the data for California by Nemat O. Borhani and H. H. Hechter of the University of California at Davis shows that between




**U.S. MORTALITY BY AGE GROUP** is plotted for diseases of the heart (1900–1953), arteriosclerotic heart disease (1949–67) and ischemic heart disease (1968–77). The last two diagnoses both signify the obstruction of the arteries that nourish the heart. Through 1950 the death rates increased steadily for the old and decreased steadily for the young. The change in the trend of the death rates that came in 1920 affected the people whose ages were in between. In contrast, the recent decline in the death rates has affected all age groups.

1950 and 1969 the death rates for ischemic heart disease in that state actually decreased by about 20 percent for white males and 25 percent for white females. The peak mortality in California came in about 1955.

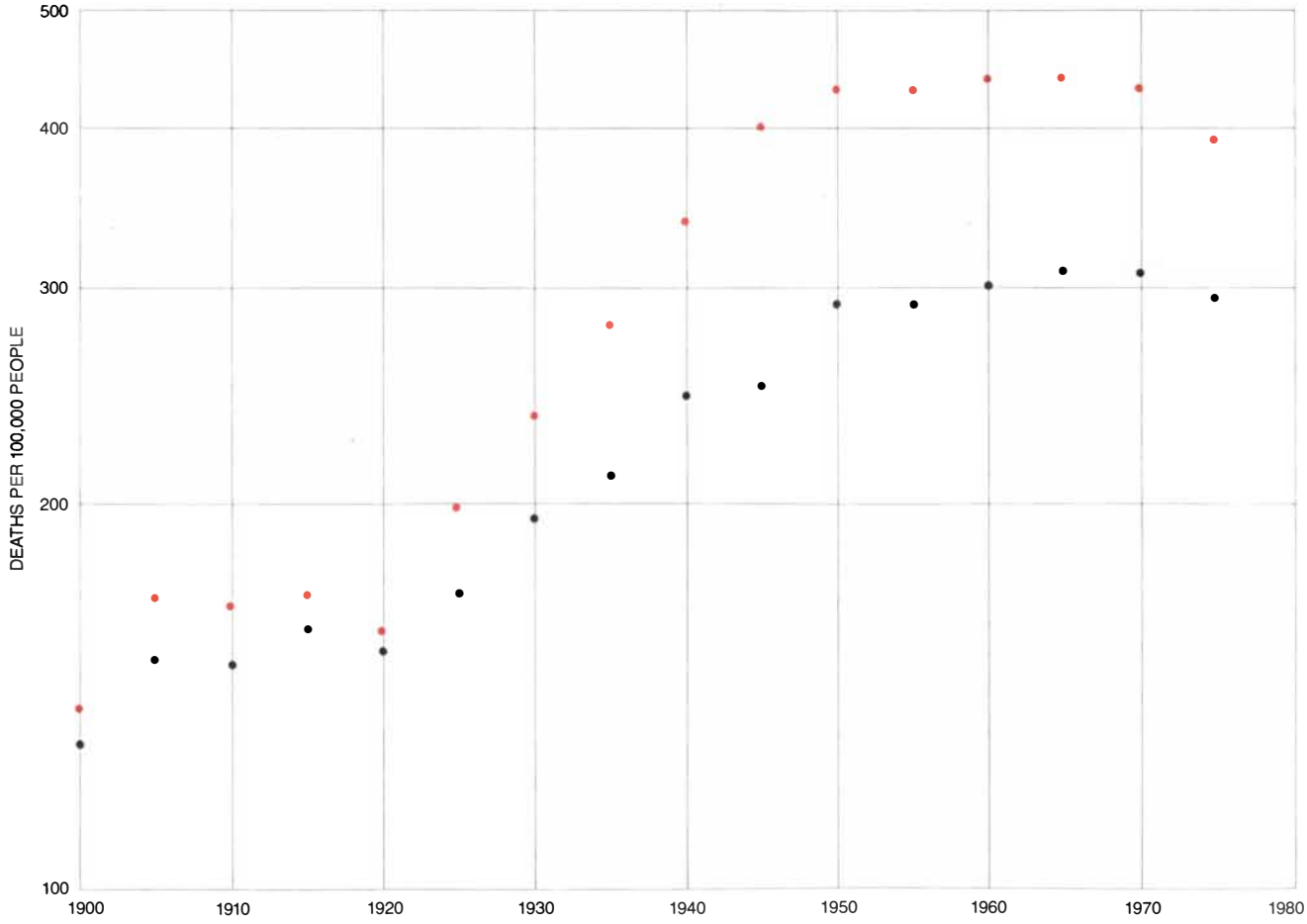
In retrospect, therefore, one can see that California gave the earliest manifestation of a decline in ischemic heart disease that extended to other parts of the U.S. in the 1960's and 1970's. By 1970 ischemic heart disease was heavily concentrated east of the Mississippi. This was primarily owing to the geographic distribution of acute myocardial infarction. Chronic ischemic heart disease was dissociated from acute myocardial infarction in geographic pattern as well as in the national time trend.

At this point some of the conundrums that have appeared repeatedly in research on the epidemiology of ischemic heart disease should be mentioned. In a number of population-based studies the factors most consistently predictive of ischemic heart disease have been blood pressure, the blood-serum concentration of cholesterol and cigarette smoking, together with a strong selection for males and an increased risk with increasing age. In the U.S., however, the associations with cigarette smoking, serum cholesterol and male gender fade among people over 65 years old. Moreover, in countries with a very low mortality rate from ischemic heart disease a male preponderance is not evident at any age. Related to this point are the international comparisons of morbidity and mortality directed by Ancel Keys of the University of Minnesota, which failed to show an association of ischemic heart disease with cigarette smoking or with serum cholesterol in those communities where the frequency of the disease was low.

These epidemiological observations are consistent with the hypothesis that occlusive disease of the coronary arteries is resolvable into two components that are partially differentiated in the current system of disease classification as acute myocardial infarction and chronic ischemic heart disease. According to this hypothesis, the rise and fall of the mortality for ischemic heart disease and the marked differences in the incidence of the disease in different regions of the U.S. are best understood as being primarily due to trends in the incidence of acute myocardial infarction, a condition strongly associated with both cigarette smoking and serum cholesterol and having a special affinity for males. Chronic ischemic heart disease may have varied to a lesser degree, but its history cannot be traced clearly through the confusion of diagnoses applied to the deaths due to chronic heart disease.

The rise and fall of ischemic heart disease affords a special opportunity to link changes in the factors that appear to determine the risk of the disease in individuals to the sweeping changes in the frequency of the disease in the population at large. For any single factor to account neatly for the overall trend it should meet certain well-defined conditions.

If its effect was immediate, it should have appeared in about 1920, increased through the 1930's and 1940's and then begun to disappear in the mid-1960's. An immediate link is likely only if the causative factor affects the most labile component of the occlusive process, namely clot formation. If the causative factor is presumed to stimulate the de-




**U.S. MORTALITY BY GENDER** is plotted for diseases of the heart. The death rates for males are in color and those for females are in black. The upward trend that began in 1920 was markedly greater for males. This is evidence that the increase was not fortuitous.

velopment of atherosclerosis, then a latent period of at least 20 years must be subtracted from the critical years in the trend of mortality in order to derive the trend of the causative factor.

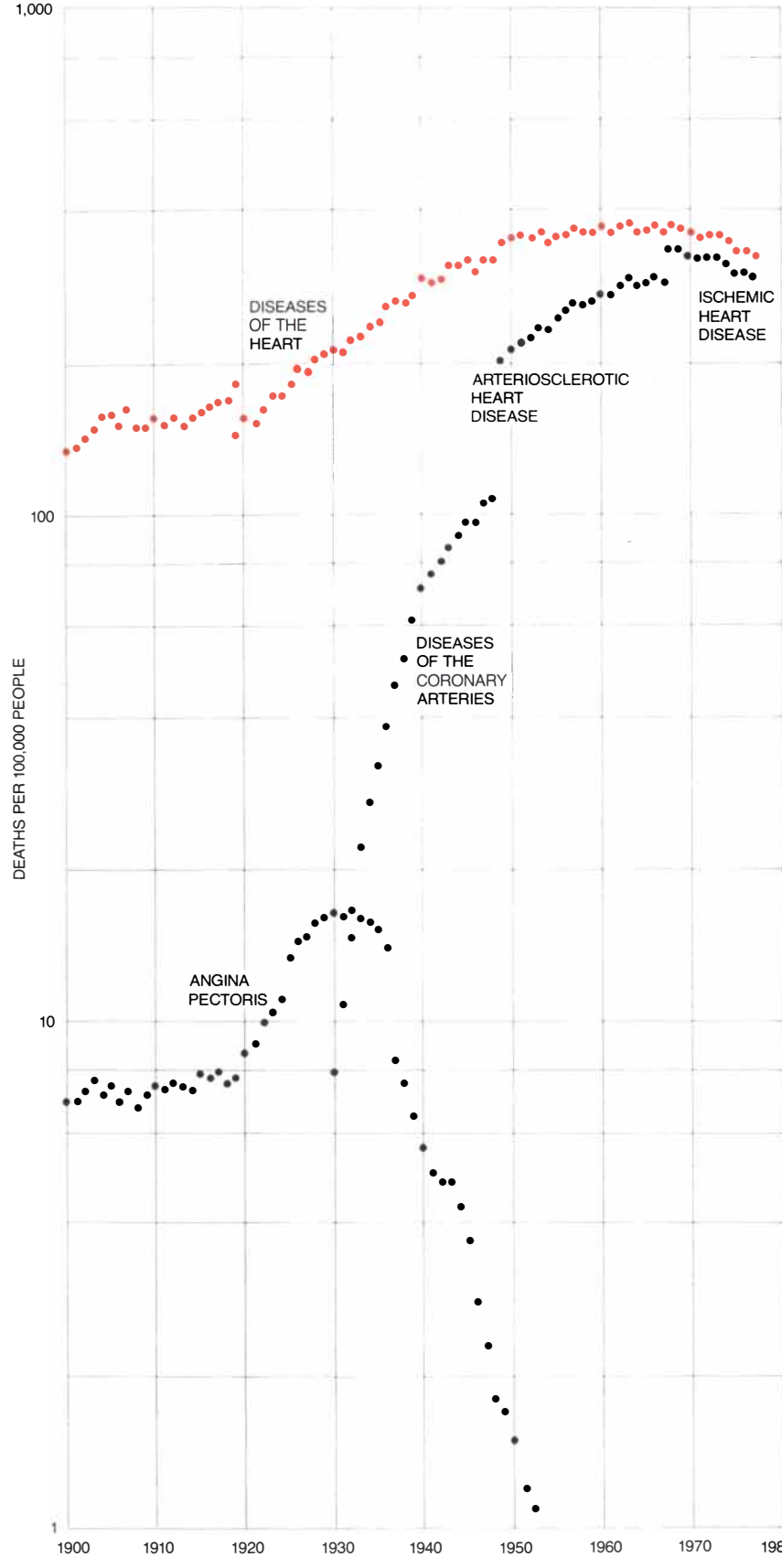
At its inception the causative factor should have affected men and women at about the same time, but the effect on men should have been notably greater, and it should have been greatest on people in their mid-adult years. After 1968 the death rates for acute myocardial infarction declined in equal proportion for men and women and also for younger and older adults; that is, the force of mortality has been constant for these age- and gender-specific categories. The implication is plain: if the decrease in mortality in one of these groups is due to the decrease in the intensity of some single causative factor, that factor should show an equal decrease for each of the other groups.

Finally, the causative factor should have begun to decrease in California a decade before it decreased in the northeastern states, and a decade after that it should still be strong in the southeastern states. If a single factor fails to meet all these criteria, some combinations of factors might be considered, although the argument must thereby be weakened and made more complex.

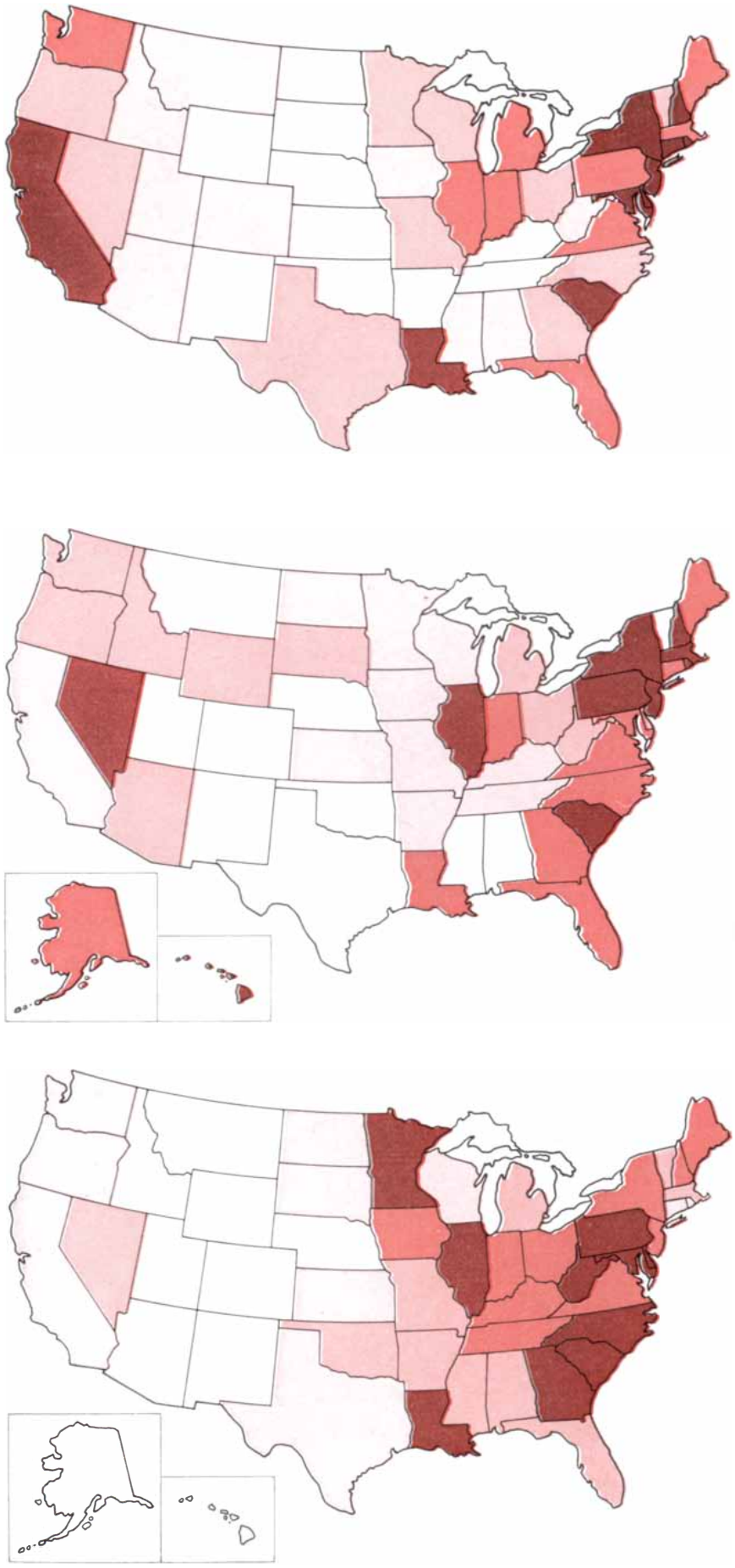
The evidence is strong that a diet high in fat, and particularly saturated fat, increases the concentration of serum cholesterol. In the controlled environment of the hospital the intentional alteration of serum cholesterol by manipulation of the diet has been fully documented, and epidemiological observations in many environments around the world have related low-fat diets to low mean cholesterol levels with comfortable consistency. (Low-fat diets in those communities, however, are usually found to be linked with strenuous physical activity.)

Certainly dietary customs in the U.S. have changed in important ways. In recent years saturated fats have been replaced to a considerable degree by unsaturated fats, and data are available to support the contention that serum-cholesterol values for large population groups decreased from the 1960's to the 1970's. And yet if recent dietary changes have caused the mortality rates to fall, surely the deprivations of the depression years should have left a similar mark on the curve. Moreover, the concentration of serum cholesterol is not associated with the risk of ischemic heart disease in older people, yet people over 65 have shown the same proportional decrease in the death rate as younger adults.

There the matter rests for now. Some evidence supports the argument that the decline in the death rates for ischemic heart disease could be due, at least in part, to decreasing cholesterol, and this could be due, at least in part, to changes




**SUCCESSION OF DIAGNOSTIC TERMS within "diseases of the heart" includes four whose death rates (*black dots*) appear to form a sequence. Beginning in 1920 the attribution of deaths to the first term, angina pectoris (literally "pain in the chest"), increased notably. The newest term in the sequence is ischemic heart disease. The death rates have not been adjusted for age.**



in fat ingestion. Diet, however, does not provide a satisfactory explanation for the rise in ischemic heart disease in 1920. The death rates for ischemic heart disease did not track dietary changes in the ensuing 40 years, and the recent decline in mortality is not fully consonant with the changes in diet or in serum cholesterol.

Cigarette smoking spread through American culture after World War I, coinciding with the increase in ischemic heart disease, and during the past 15 years or so smoking has decreased. On the assumption that a major portion of the harmful effects of cigarette smoking has little or no latency, so that the risk of ischemic heart disease rises and falls almost immediately with changes in cigarette consumption, the correlation looks quite good.

The decline in cigarette smoking has been much more pronounced, however, in middle-aged men than in middle-aged women, a difference that is not at all in accord with the equivalence in the decline in mortality for the genders. Moreover, the lack of association for older people between ischemic heart disease and smoking as well as serum cholesterol raises the question of how a reduction in smoking could effect a decrease in risk for this age group. Little information is available about regional variations in cigarette smoking, but a concordance between such variation and the geographic pattern of the mortality from ischemic heart disease also does not seem likely.

Even though high blood pressure is known to be associated with an increased risk of myocardial infarction, the death rates for hypertensive disease have decreased in log-linear fashion since 1950, whereas those for ischemic heart disease increased, reached a peak and then began to decline. Programs for the detection and treatment of hypertension have become far more effective in the past decade, but the forces responsible for the rise and fall of ischemic heart disease must be operating quite independently, and with much greater effect.

In an interval of about 20 years Americans changed from a nation of walkers

**GEOGRAPHIC PATTERNS in the death rates for ischemic heart disease are demonstrated by maps of the U.S. for 1950 (*top*), 1960 (*middle*) and 1969–71 (*bottom*). In each map the 10 states in which the death rates for white males 55 through 64 years old were greatest are shown in dark color, the 10 states in which the death rates were smallest in white. States with intermediate death rates are shown in three intermediate shades of color. California's drop in death rates from 1950 to 1960 antedated by a decade the trend that spread through the nation. By 1971 ischemic heart disease was concentrated in the eastern U.S.**

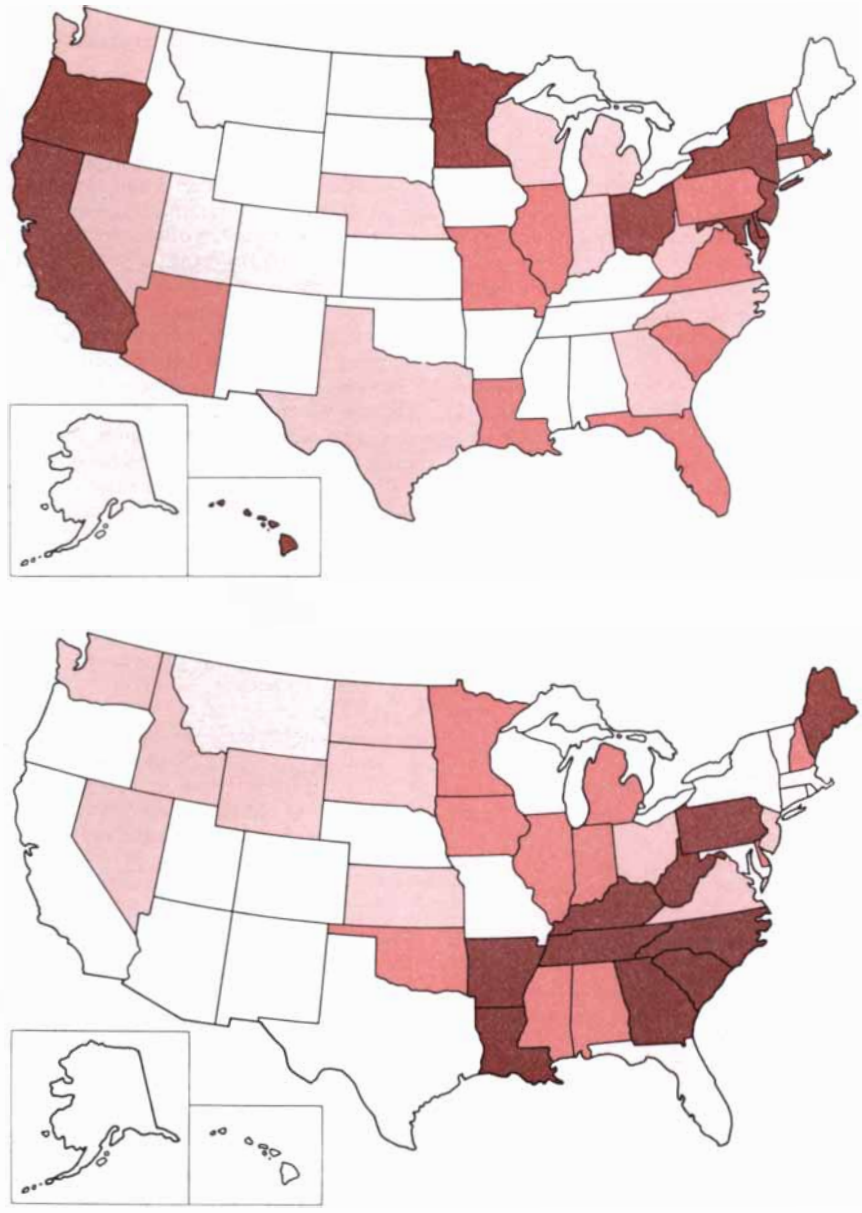
to a culture dependent on automobiles, and the beginning of that interval coincides well with the rise in ischemic heart disease. Concurrently the flow of cheap fuel reduced the caloric expenditure of people at work to some small fraction of its previous value. Almost no one now spends his life at hard labor as our grandparents understood it; we are taller, heavier and probably stronger, but we are not inured to the daylong expenditure of effort in walking and working that was expected of most people in the 19th century. Yet if an increasingly sedentary way of life is invoked to account for the increase in ischemic heart disease, the decrease is left unexplained. The national mania for recreational jogging has not spread to large numbers of upper-middle-aged men and women, both black and white, whose death rates are falling as rapidly as those of younger people.

Although arguments are heard about the effectiveness of specialized treatment facilities for ischemic heart disease, it is unlikely that these treatments have had a major effect on population mortality data, because the mortality rates for a large population are quite insensitive to such influences. It is just as unlikely that the benefits of a treatment would accrue nearly equally to males and females and whites and nonwhites across a broad age span, or that an effective treatment would have been introduced in California 10 years before it appeared in states such as New York and Massachusetts. Any residual doubt on this issue could be laid to rest if the morbidity rates for ischemic heart disease in a large population were known. Stated quite simply, if the incidence of the disease is declining in parallel with the mortality, the treatment of the disease is of no consequence in explaining the decline. Unfortunately, but almost predictably, the evidence is equivocal.

In summary, four major variables are known to be associated with the risk of ischemic heart disease in individuals. Among the four, hypertension does not fit the trend of the mortality from ischemic heart disease at all; physical activity fits only the rising curve, serum cholesterol fits only the falling curve and only cigarette smoking fits both. In no case is the fit as precise as one would like. This raises doubt that any of the factors is a fully satisfactory explanation for the variation in mortality.

Much more could be clarified by the use of existing data. The nomenclature for diseases has been relatively stable since 1949, a period that includes a significant part of the increase in ischemic heart disease and all of its decline. Samples of death certificates for this period should be recoded according to the classification system adopted in 1968 in order to delineate the apparent dissociation between acute myocardial infarction and chronic ischemic heart disease. In the same set of data, attention to occupation and other indexes of social status would provide important information, and detailed analyses of the shifting geographic patterns would be particularly useful.

We now have strong assurance that programs based on our present knowledge can reduce the risk of death from ischemic heart disease. Unfortunately these programs require people to stop doing certain things they like to do, such as smoking cigarettes or eating whatever they want to, or to do things they do not want to do, such as taking antihypertensive drugs or exercising strenuously. If the individual characteristics and habits now known to influence the frequency of the disease do not contain sufficient information to fully explain the epidemiological patterns in time and in space, and the evidence presented here suggests that they do not, then we may direct our attention to more general environmental factors in a search for more effective and more acceptable means of prevention.



**GEOGRAPHIC PATTERNS FOR TWO COMPONENTS of ischemic heart disease are shown for 1969–71. The upper map displays the death rates for chronic ischemic heart disease. The lower map displays the death rates for acute myocardial infarction: the sudden blockage of a coronary artery. Again dark color marks the 10 states in which death rates were greatest for white males from 55 through 64, and white marks the 10 states in which rates were smallest. Acute myocardial infarcts account for southeastern concentration of ischemic heart disease.**

# Gene Amplification and Drug Resistance

*Experiments on the development of drug resistance in cultured mammalian cells serve as a laboratory model of the mechanism whereby duplicate genes are created in the course of evolution*

by Robert T. Schimke

As living organisms have evolved from simple forms to more complex ones the genome (the organism's complete set of genes) has become larger in terms of both the amount of the genetic material DNA and the number of genes. This evolutionary phenomenon is thought to result largely from gene amplification, the process whereby a small part of the genome, representing one or more genes, is duplicated locally within a chromosome. The newly emerging techniques of molecular biology involving artificially recombinant DNA are uncovering numerous examples of the phenomenon. Certain genes have been found to be present in multiple copies (sometimes as many as 400 copies per cell), and the identical genes are often grouped together in a chromosome in what have come to be called gene clusters. In other cases the amplified genes have undergone mutations in their basic chemical constituents, with the result that the enzymes or other types of proteins they code for are slightly altered. Sets of similar genes of this type are referred to as multigene families.

Amplified genes may be closely linked on a single chromosome, or they may be present on different chromosomes. Thus amplified genes are capable of translocating, or moving from one chromosome to another. These three fundamental genetic processes—amplification, mutation and translocation—can occur repeatedly in successive generations of cells; hence they can lead over evolutionary time to more complex genomes and ultimately to more complex organisms.

Although such processes have been at work throughout the course of evolution, the frequency of their occurrence and the molecular and biochemical mechanisms involved have not been investigated thoroughly. Obviously one cannot study in the laboratory processes that occur infrequently over millions of years. In the past few years, however, several groups of experimenters, including my colleagues and me at Stanford University, have been examining the mechanism whereby mammalian cells grown in laboratory culture develop resistance to certain drugs, a process that can be shown to involve gene amplification. This phenomenon accordingly serves as an experimental model for learning about gene amplification as it operates in evolution; in addition it provides a means for learning how individual cells, multicellular tissues such as tumors and entire organisms become resistant to various drugs, including insecticides and antibiotics. One of the most surprising findings to emerge from the investigation so far is the high frequency with which gene amplifications are observed in cultured mammalian cells, a fact that suggests there is far greater potential for change in the genome than had been suspected.

In our laboratory we have been examining specifically the mechanism whereby cultured mouse and hamster cells become resistant to the drug methotrexate, a chemotherapeutic agent used in the treatment of human cancer. Methotrexate is an analogue of the vitamin folic acid (also known as vitamin $B_6$). The drug kills cancer cells by binding tightly to the enzyme dihydrofolate reductase at the same site where the normal substrate, dihydrofolate, would bind. The binding of methotrexate blocks the conversion of dihydrofolate into tetrahydrofolate inside the cells. Tetrahydrofolate is needed in metabolism for the generation of key precursor molecules in the synthesis of DNA and proteins, so that the cells are prevented from growing and therefore die.

Methotrexate has long been a standard drug for the treatment of various forms of cancer, and it has been established that these cancers can become resistant to the drug. Because of this problem investigators have over the past two decades studied a variety of possible mechanisms for the development of resistance to methotrexate in cultured animal cells. Three mechanisms have been identified. One is an alteration in the enzyme dihydrofolate reductase, presumably resulting from a mutation in the cells' DNA, such that the normal high affinity of methotrexate for the enzyme is lost; in this case the enzyme would not be inhibited. The second possible mechanism is an alteration, again presumably a mutation, in a surface-membrane protein that is involved in the transport of methotrexate into the cells; here the cells would no longer take up the drug and the enzyme again would not be inhibited. The third possibility is an increase in the total amount of dihydrofolate reductase in the cells; although here the enzyme would be inhibited at any given concentration of methotrexate in the growth medium, there would be an excess of the enzyme with respect to the concentration of the drug in the cells, and therefore some of the enzyme would be free (in the sense of not being inhibited) to carry out the conversion of dihydrofolate into tetrahydrofolate. It is this last mechanism that we have been studying.

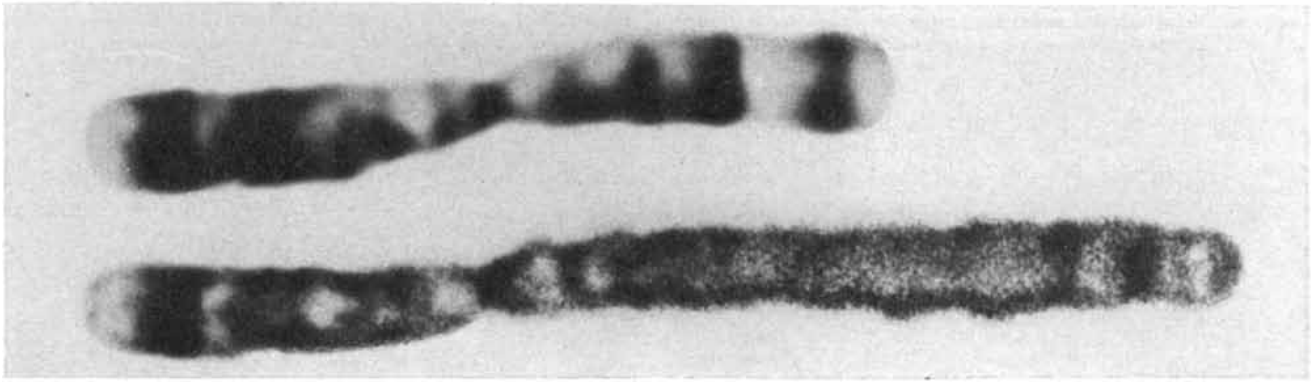
We obtain methotrexate-resistant cells with high levels of dihydrofolate reductase by a procedure called stepwise selection. If one grows cells in the presence of a low concentration of methotrexate, virtually all the cells are killed. Occasionally, however, some cells (approximately one in every 100,000 of the cells we have been working with) survive and will grow. These cells are thereafter resistant to a low concentration of methotrexate, and they have an elevated level of dihydrofolate reductase. If such cells are now grown in the presence of a somewhat higher concentration of methotrexate, again the majority of the cells will be killed, but some will survive and grow; they will be even more resistant to the drug, and they will have still more elevated levels of the enzyme. By continuing the process

through additional incremental selections in progressively higher concentrations of methotrexate, one eventually gets cells that are highly resistant to methotrexate and also contain a very high level of dihydrofolate reductase.

It is important to realize that this procedure is equivalent to a Darwinian selection process, inasmuch as most of the cells are killed at each step along the way. The selection pressure in this case is far greater than would ever be expected in normal evolutionary processes in mammals (although perhaps a comparable selection pressure is attained when insects are exposed to a massive application of insecticide). The experimental procedure is akin to a natural selection process in which a population of 10 million organisms is reduced to 100, which later grow back to 10 million, which in turn are reduced to 100, and so on through many generations.

The level of dihydrofolate reductase in the selected cells can be as much as 400 times higher than it is in normal methotrexate-sensitive cells. Indeed, this single enzyme can constitute as much as 5 percent of all the protein synthesized by such cells. This conclusion is

**CHROMOSOMES from the cells of two different cell lines, one drug-sensitive, or normal (*left*), and the other drug-resistant (*right*), are compared in this pair of photomicrographs. Both cell lines were derived from ovary tissue of the Chinese hamster. The drug-resistant cells, which are comparatively invulnerable to the powerful anticancer drug methotrexate, were propagated by a stepwise selection method that is believed to involve the amplification, or localized duplication, of genes coding for dihydrofolate reductase, an enzyme that is needed for cell growth and is specifically inhibited by the presence of methotrexate in the growth medium. The location of the amplified genes coding for the enzyme was determined by first exposing both chromosome spreads to radioactively labeled single-strand DNA molecules whose deoxyribonucleotide base sequence is complementary to that of the chromosomal DNA segments containing the gene for the enzyme. The two kinds of DNA form hybrid double-strand molecules at the matching sites on the chromosomes, thereby fixing the radioactive label to them. Following the hybridization step the microscope slides bearing the chromosome spreads were washed to remove most of the nonhybridized radioactive complementary DNA. The slides were then coated with a photographic emulsion, and the energy of the radiation from the slides was just enough to expose the emulsion at the exact positions where the labeled complementary DNA was fixed (*black spots*). In the case of the chromosomes from the drug-sensitive cells there is no evidence of the localization of the genes coding for the enzyme. In the case of the chromosomes from the drug-resistant cells, in contrast, the radioactive label indicating the location of the amplified genes coding for the dihydrofolate reductase enzyme is clearly concentrated in a single region on the long arm of one of the chromosomes, which is designated the No. 2 chromosome (because it is the second-largest chromosome in this cell line).**



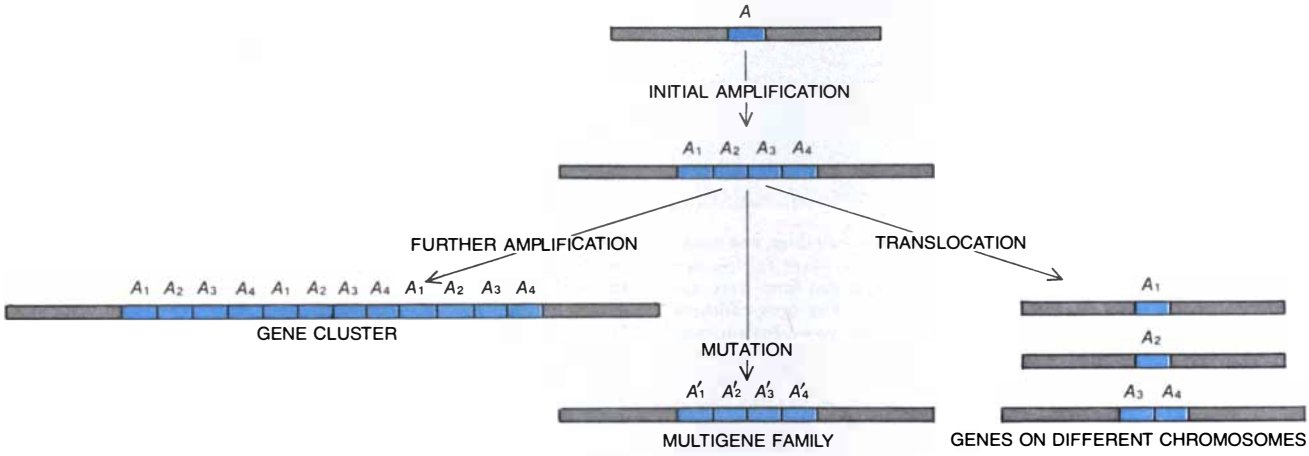
**NO. 2 CHROMOSOMES from a drug-sensitive cell (*top*) and a stably drug-resistant cell (*bottom*) are compared. The chromosomes, both of which are from Chinese-hamster ovary cells, were stained in such a way as to bring out their characteristic banding pattern. The most striking difference between the two chromosomes is the expanded region on the long arm of the one from the drug-resistant cell. It is this region, known as a homogeneous staining region (because it does not have the bands typical of normal chromosomes), that is thought to harbor the approximately 150 amplified genes coding for the dihydrofolate reductase enzyme in the drug-resistant cell line.**

supported by tests based on the two-dimensional electrophoretic separation of cell proteins in gels, a technique that distinguishes proteins in one direction on the basis of size and in the other direction on the basis of net electric charge. Relying on this technique, which is capable of separating as many as 1,000 different cellular proteins, we have observed only one major difference in the two-dimensional pattern of cellular proteins between the methotrexate-sensitive cells and the methotrexate-resistant ones. The difference is in the amount of dihydrofolate reductase in the two kinds of cells.

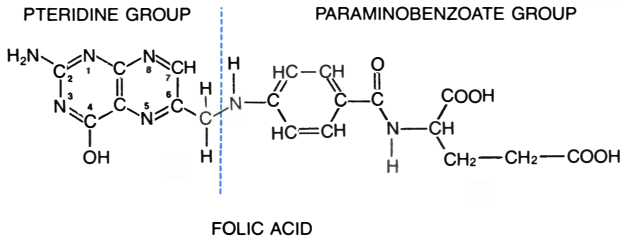
Our conclusion that the elevated enzyme content in methotrexate-resistant cells results from gene amplification is based on a series of studies that have taken advantage of many of the latest techniques of molecular biology. Such experiments would not have been possible as recently as 10 years ago. First we obtained purified samples of messenger RNA carrying the information required for the synthesis of dihydrofolate reductase from cells with a high level of the enzyme. With the purified messenger RNA we next synthesized radioactively labeled DNA that is complementary to the RNA. This step depends on the enzyme reverse transcriptase, which is obtained from certain RNA-containing tumor viruses. (It was for the discovery of this enzyme that Howard M. Temin of the University of Wisconsin and David Baltimore of the Massachusetts Institute of Technology were awarded the Nobel prize for physiology or medicine in 1975.)

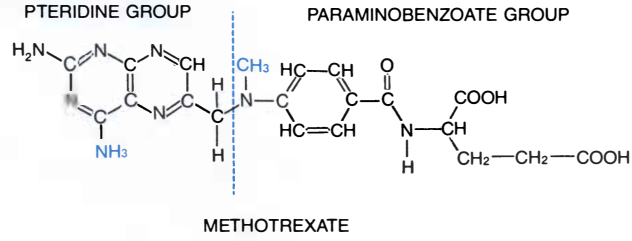
In the reaction involving reverse transcriptase the RNA serves as a template for the synthesis of a single strand of DNA with a sequence of deoxyribonucleotide bases that is complementary to the sequence of ribonucleotide bases of the RNA. Because of the complementarity of the nucleotide bases of the two kinds of nucleic acid, the paired molecules will bind tightly to each other to form an RNA-DNA hybrid. The messenger RNA responsible for specifying a given protein has a unique linear sequence of nucleotide bases; hence the hybridization of complementary DNA with the sequence for dihydrofolate reductase can be used to detect and measure the amount of messenger RNA coding for the enzyme. Similarly, the complementary DNA for dihydrofolate reductase can hybridize specifically to the deoxyribonucleotide sequences in the cellular DNA that normally code for dihydrofolate reductase (in other words, the actual genes coding for that enzyme). Thus the hybridization test can also be used to identify and measure the number of genes coding for dihydrofolate reductase in the cell's genome.

It is fairly easy to detect complementary RNA-DNA or DNA-DNA hybrids with the aid of another enzyme, called $S_1$ nuclease, which destroys any single-strand molecule of RNA or DNA but does not affect a molecule of complementary DNA when it is hybridized with either cellular RNA or cellular DNA. What is actually measured in an experiment of this kind is the amount of




**GENE AMPLIFICATION plays an important role in evolution by increasing both the total amount of genetic material (DNA) and the number of individual genes in the chromosomes of each cell. In this schematic diagram, for example, gene *A* is a segment of chromosomal DNA that incorporates a specific sequence of deoxyribonucleotide bases coding for the synthesis of a certain protein. The initial amplification of this gene results in four identical copies of the same base sequence, arrayed in succession in an expanded region of the chromosome. The four duplicate genes, designated $A_1$, $A_2$, $A_3$ and $A_4$, may in turn be amplified further, yielding multiple gene clusters consisting of as many as 400 copies of the same gene. Alternatively, each of the original set of four amplified genes may independently undergo a mutation in its base sequence, leading to the synthesis of slightly altered proteins; sets of related but different genes of this type ($A_1'$, $A_2'$, $A_3'$, $A_4'$) are called multigene families. The four original amplified genes may also move from one chromosome to another (translocation). The fundamental genetic processes of amplification, mutation and translocation can lead ultimately to more complex organisms.**



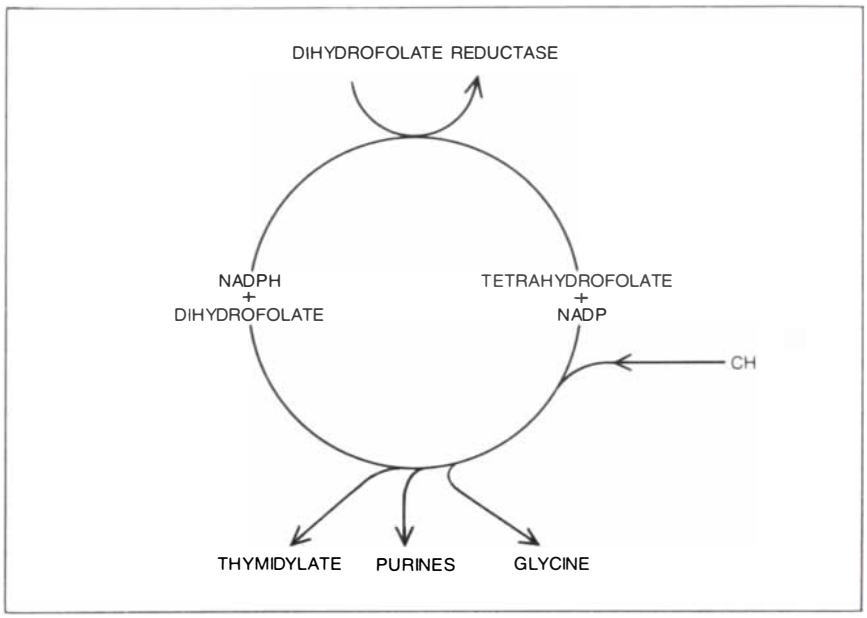

**METHOTREXATE, the drug utilized by the author and his colleagues at Stanford University for their study of the development of drug resistance in cultured mammalian cells, is an analogue of folic acid (vitamin $B_6$). The drug differs from the vitamin in having an amino group ($-NH_3$) instead of a hydroxyl group (–OH) at the No. 4 position of the molecule's first pteridine ring and a methyl group ($-CH_3$) instead of a hydrogen atom (H) attached to a nitrogen atom in the paraminobenzoate portion of the molecule. The substitutions are shown in color at the right. Methotrexate has long been administered as a chemotherapeutic agent in the treatment of human cancer.**

radioactivity present in the RNA-DNA or DNA-DNA hybrid. (The radioactivity is present in the complementary DNA because this molecule was synthesized from radioactively labeled building blocks called deoxyribonucleoside triphosphates.)

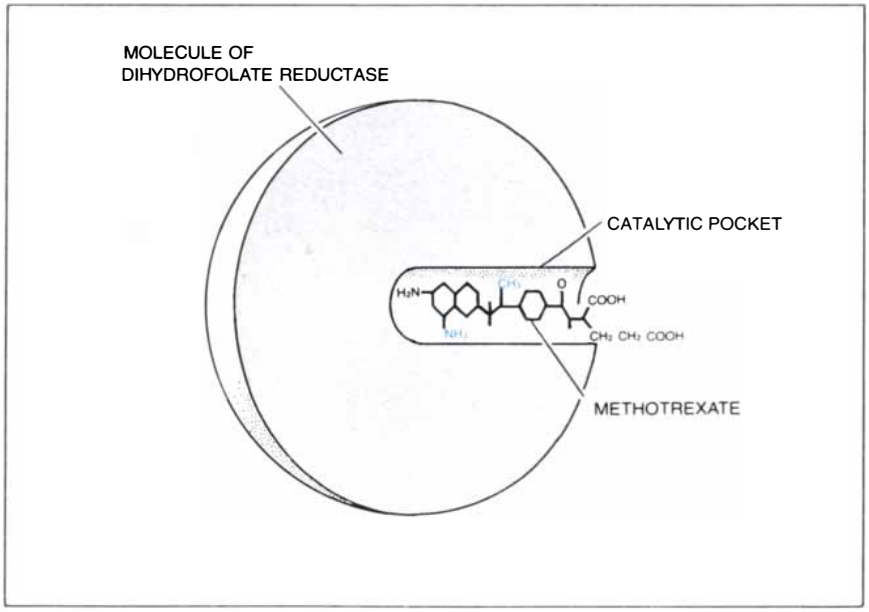
To measure the number of gene copies the cellular DNA is broken into small pieces, the double strands are denatured (separated into single strands) by boiling, and a small amount of the radioactively labeled complementary DNA is added to the mixture under experimental conditions in which the complementary DNA can now hybridize with any DNA with which it has complementary nucleotide sequences. At varying times samples of the reaction mixture are digested with $S_1$ enzyme, and the radioactivity that is resistant to digestion (that is, the radioactivity sequestered in a hybrid) is recorded. Obviously the more DNA sequences there are that can react with the complementary DNA, the more rapid will be the rate of hybridization. Hence by measuring the rate of hybridization of radioactive complementary DNA coding for dihydrofolate reductase with either RNA or DNA from cells with differing levels of the enzyme, one can determine both the amount of messenger RNA and the number of genes.

Basically what we have found through the nucleic acid hybridization technique I have described is that an increased level of dihydrofolate reductase in selected cells results from a comparably increased level of specific messenger RNA, and that this increase in turn is the result of an increase in the number of dihydrofolate reductase genes in the cells. In short, the process is one of gene amplification. It is a selective amplification because the total amount of DNA per cell does not increase significantly. We have examined a number of cultured cell lines derived from both mouse and hamster tissues, and in all cases we have found that there is a good correlation between the increase in the enzyme level and the number of gene copies.

Although our studies were the first to show conclusively that gene amplification operates under experimental conditions in mammalian cells, the phenomenon had been known for some time in bacteria. About 10 years ago, for example, William R. Folk and Paul Berg of Stanford were studying a laboratory strain of the common intestinal bacterium *Escherichia coli* that required the amino acid glycine for growth. Although the bacterium could not synthesize this particular amino acid, it would grow perfectly well when glycine was added to the growth medium. From this bacterial strain Folk and Berg obtained a mutant strain that grew poorly in the




**IN THE METABOLISM OF THE CELL folic acid is involved in the set of chemical reactions whereby the transfer of a single-carbon group (–CH) generates key precursor molecules in the synthesis of nucleic acids and proteins; examples include thymidylate (needed for DNA synthesis), various purines (for DNA and RNA synthesis) and glycine (for protein synthesis). The active form of folic acid involved in these one-carbon transfer reactions is tetrahydrofolate, a reduced form of the acid in which there are four extra hydrogen atoms in the second pteridine ring (*at positions Nos.* 5, 6, 7 *and* 8). When the one-carbon group is transferred to the precursor, the tetrahydrofolate is converted into the dihydrofolate form (by the removal of two hydrogen atoms). A key to the process is the enzyme dihydrofolate reductase, which converts dihydrofolate into tetrahydrofolate with the assistance of another important intermediate in cell metabolism, the reduced form of nicotinamide adenine dinucleotide phosphate, or NADPH.**



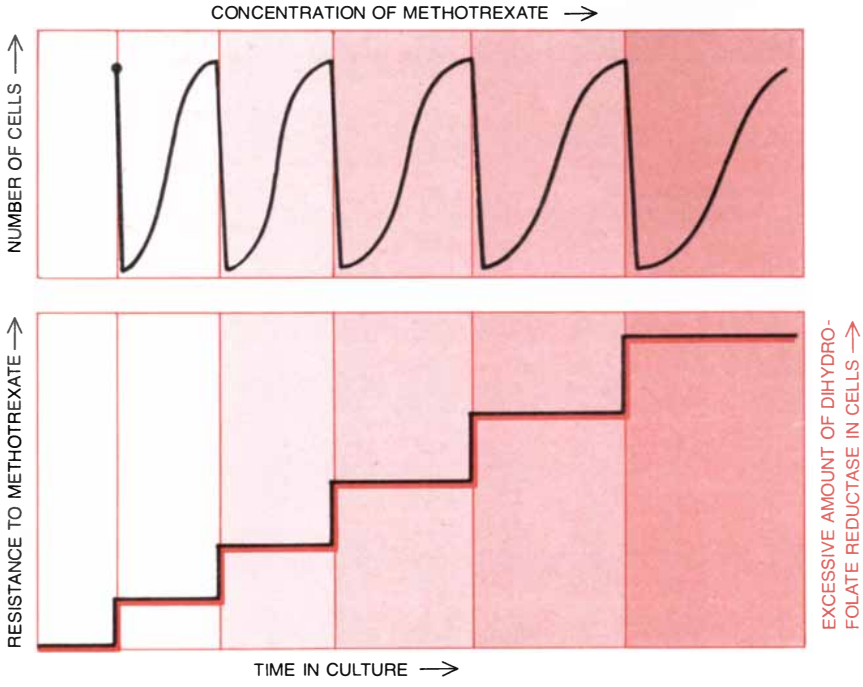

**DIHYDROFOLATE REDUCTASE is a comparatively small enzyme, consisting of 187 amino acids, that is folded into a roughly spherical structure resembling a bowling ball with a single finger hole. The hole is the catalytic pocket where the dihydrofolate and NADPH molecules normally bind in such a way that two hydrogen atoms can be transferred from the NADPH to the dihydrofolate, thereby generating tetrahydrofolate. The drug methotrexate kills cancer cells by specifically inhibiting dihydrofolate reductase; because its structure is very similar to that of dihydrofolate the methotrexate molecule binds to the catalytic pocket of the enzyme at the same site where the dihydrofolate molecule would. The binding of methotrexate to the pocket is much tighter, however, and as a result the drug effectively prevents the reduction of dihydrofolate to tetrahydrofolate. The inhibition of the catalytic action of dihydrofolate reductase by methotrexate blocks the growth of the cell and hence leads ultimately to its death.**

presence of glycine. They found that the mutation affected the ability of a specific enzyme, glycyl transfer-RNA synthetase, to catalyze the first step in converting glycine into protein; the enzyme, they observed, had a poor affinity for glycine.

Subsequently Folk and Berg looked for derivatives of the mutant bacterial strain that could grow faster in a medium containing small amounts of glycine. They obtained such bacteria readily, and they found that the bacteria had more of the defective enzyme rather than an additional change in the enzyme itself. They concluded that the DNA sequence coding for the defective enzyme had been amplified. Thus the mutant bacteria were limited in their ability to grow rapidly because of the defective enzyme, and the bacteria that were selected were those that had amplified this DNA sequence, yielding cells that could grow more rapidly.

John R. Roth of the University of Utah has since undertaken a study of the amplification of genes coding for the amino acid histidine in the closely related bacterium *Salmonella typhimurium*. He concludes that random gene duplications are frequent in this organism too, but that they are generally unstable and are detected only when the bacteria are maintained under growth conditions selecting for the retention of a specific amplified gene.

Our working hypothesis for explaining the amplification of dihydrofolate reductase genes in cultured mammalian cells is based on an analogy with the amplifications observed in bacteria. We propose that DNA sequences (containing specific genes) in cultured cells are being amplified continually, and that these amplifications potentially involve any DNA sequence. They are generally unstable, however, and hence they usually pass undetected. If, on the other hand, the cells are placed in a situation where those few cells with amplified genes coding for a specific protein have a selective survival advantage or a selective growth advantage, then the comparatively rare amplification event will be detected. In particular the presence of methotrexate in the growth medium gives those rare cells with amplified dihydrofolate reductase genes a selective growth advantage, and as a result the amplification event is detected.




**STEPWISE SELECTION is the experimental procedure employed by the author's group for progressively increasing the resistance of cultured mammalian cells to methotrexate by raising the level of dihydrofolate reductase in the cells. The cells are grown initially in a low concentration of methotrexate, which has the effect of killing as many as 99.999 percent of them. A few cells survive and grow, however, and they are by definition resistant to the specified low concentration of methotrexate; when such cells are assayed for enzyme activity, they are found to have higher levels of dihydrofolate reductase. These cells are then allowed to multiply until their population is roughly equivalent to that of the original cells, whereupon the concentration of methotrexate in the growth medium is abruptly increased, again killing most of the cells. The surviving cells in turn begin to grow; they have an even higher level of the enzyme and hence a greater resistance to the drug. The selection process is continued through a number of further increments of methotrexate in the growth medium (represented here by progressively darker shades of color), and at each step the surviving cells are found to have higher levels of dihydrofolate reductase. The resistance to the drug in this case results from the fact that there is always enough enzyme left in the cells to convert dihydrofolate into tetrahydrofolate.**

We believe the initial amplification event involves a comparatively small number of copies of the gene coding for dihydrofolate reductase. These genes can later undergo further amplification, leading to the selection of still greater resistance to methotrexate. This interpretation explains the need for stepwise selection to obtain eventually a high level of drug resistance and a large number of amplified genes. Any attempt to select initially for high methotrexate resistance would not result in the detection of such cells, since the gene-amplification phenomenon operates in multiple steps.

The phenomenon of gene amplification for drug resistance is not limited to methotrexate. George R. Stark and his colleagues at Stanford have been studying the development of resistance of cultured hamster cells to a highly specific inhibitor of an enzyme that is vital for the synthesis of nucleic acid precursors. (The name of the enzyme is aspartyltranscarbamylase.) By stepwise selection they have obtained cells that are highly drug-resistant, and they have shown by techniques similar to those we employed that the gene for this enzyme is amplified as much as a hundredfold.

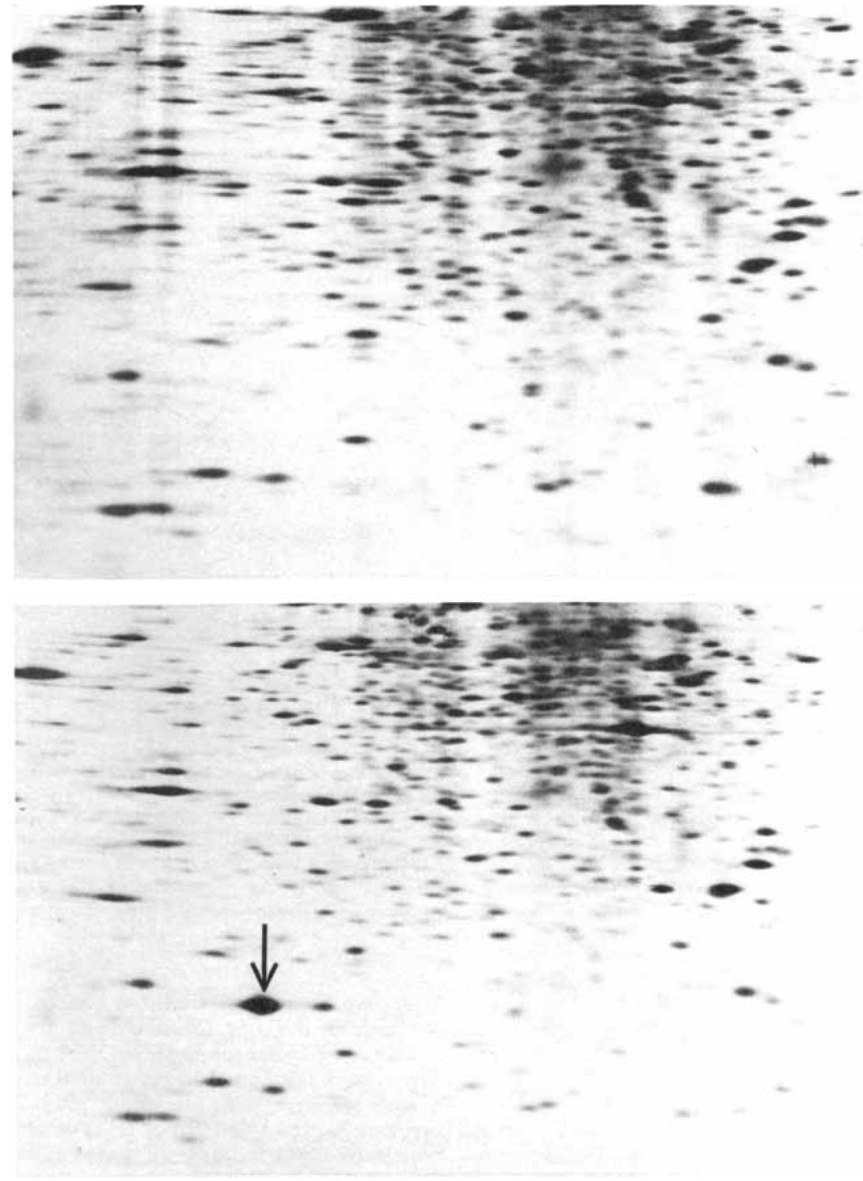
These two examples of selection for drug resistance are analogous in several respects. First, the drug in both cases is highly specific: essentially it inhibits only a single enzyme that is necessary for the cells to grow. Second, a high level of drug resistance and a correspondingly large number of duplicate genes are obtained in both cases by stepwise selection. Third, drug resistance in both cases results from an increase in a specific protein that, when present in sufficient quantity, overcomes the inhibitory effects of the drug. There are additional examples of stepwise selection for resistance to various compounds and drugs in mammalian cells resulting from elevated levels of specific enzymes, and it is likely that at least some of them will also turn out to involve gene amplification.

One of our early observations that was quite perplexing at the time was that in some cell lines the resistance to methotrexate and the elevated enzyme level were not stable. When we took cells that had been grown continuously in the presence of methotrexate for many months and then grew them in a medium that did not contain the drug, the high drug resistance and the excessive enzyme level both diminished progressively. In as short a time as 20 cell doublings (about 20 days) some cell lines lost half of their enzyme content; eventually the cells lost most of their excessive amount of enzyme and their resistance to methotrexate. In other cell lines, however, a high drug resistance and a high enzyme level were maintained in spite of the absence of methotrexate in the growth medium. The sta-

bility or instability of a particular cell line appears to be independent not only of the type of cell (mouse or hamster) but also of the absolute magnitude of the excessive enzyme level attained at the end of the stepwise selection procedure. In fact, the same source of drug-sensitive cells can be selected to obtain both stable and unstable cell lines. In all cases, however, the number of amplified genes is linked to the relative enzyme level. Evidently the amplified genes can be present in either a stable state or an unstable one.

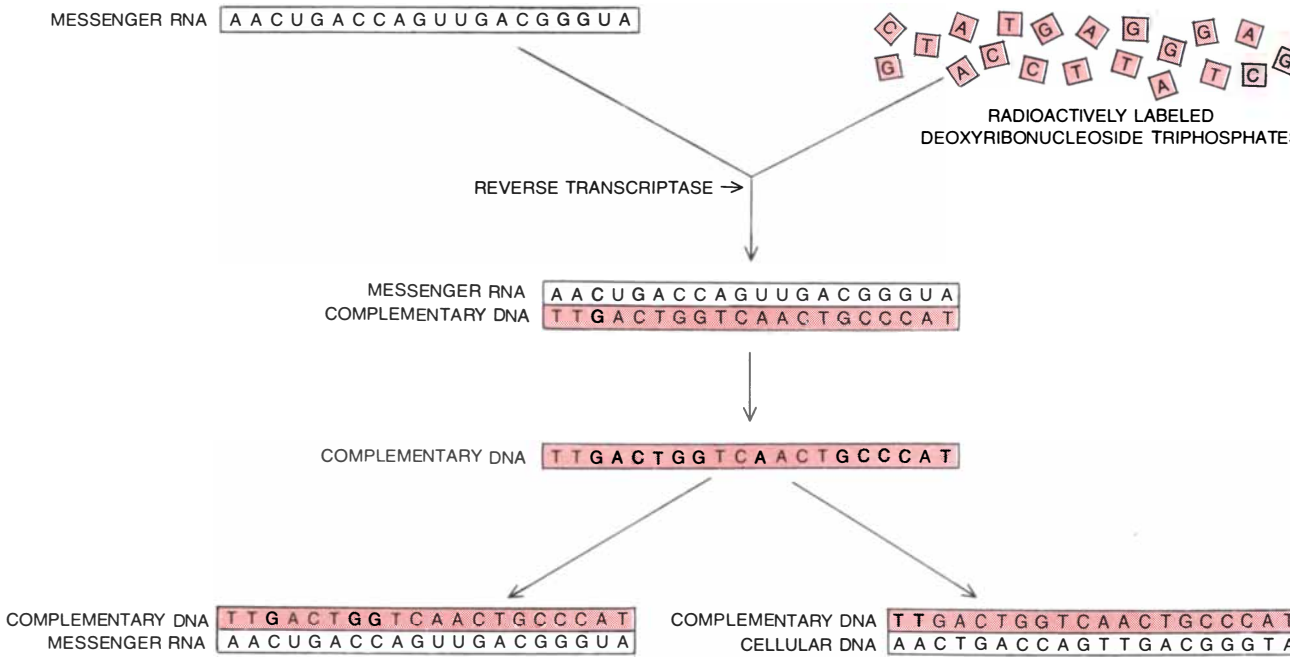
What is the mechanism responsible for the variable stability of methotrexate resistance in different cell lines? The search for an answer to this question leads one away from molecular biology and into the study of the structure of chromosomes. Two of our collaborators, Lawrence A. Chasin and Gail Urlaub of Columbia University, pursued the problem in that direction. Working with a methotrexate-resistant cell line selected from the ovary of the Chinese hamster, they found that a specific chromosome in the drug-resistant cells was quite different from the corresponding chromosome in drug-sensitive cells derived from the same tissue. The difference was an expanded region in the long arm of the No. 2 chromosome of the drug-resistant cells (designated No. 2 because it is the second-largest chromosome); otherwise the chromosomes in both types of cells were quite similar. This particular chromosomal region is known as a homogeneous staining region, since it does not have the banding pattern characteristic of chromosomes. (Several years earlier June L. Biedler of the Sloan-Kettering Institute for Cancer Research had described such expanded regions of a specific chromosome in several methotrexate-resistant cell lines derived from the lung tissue of the Chinese hamster; she had even suggested that they constituted regions of gene amplification!)

Working with the nucleic acid hybridization techniques described above, we determined that the drug-resistant cell line studied by Chasin and Urlaub had approximately 150 copies of the dihydrofolate reductase gene. The question was: Where were the genes that were coding for the enzyme? In order to find these genes we proceeded to hybridize radioactive DNA complementary to messenger RNA for the enzyme with chromosomal DNA from both drug-resistant and drug-sensitive cells. The cell samples were prepared in such a way that the chromosomal DNA was exposed first, so that it could form a hybrid with the complementary DNA. (As this experiment shows, complementary DNA can be used not only to determine the number of duplicate genes but also to locate gene sequences on chromosomes.)



**CELLULAR PROTEINS ARE DISTINGUISHED by the technique of two-dimensional gel electrophoresis, which separates proteins in one direction on the basis of size (vertical axis) and in the other direction on the basis of net electric charge (horizontal axis). In this particular application of the technique only one major difference is observed in the two-dimensional pattern of spots corresponding to cellular proteins between a sample of methotrexate-sensitive cells (*top*) and a sample of methotrexate-resistant cells (*bottom*). The single difference, indicated by the arrow, is in the spot signifying the amount of dihydrofolate reductase in the two kinds of cells. Both cell lines were derived from the same source of mouse cells. The proteins were first labeled with radioactive methionine, and the resulting radioactivity of the spots was recorded by placing a photographic film over the gel and then developing the film. The darkness of each spot is a measure of the relative amount of each protein in the cells. The drug-resistant cells clearly contain much more dihydrofolate reductase than the drug-sensitive cells.**

The radioactivity of the complementary DNA was detected by a method pioneered several years ago by Mary Lou Pardue of M.I.T. A photographic emulsion was placed on the microscope slide, and the developed silver grains in the exposed emulsion were examined visually with a microscope. In every case we found that the developed silver grains were concentrated in the homogeneous staining region of the No. 2 chromosome, indicating that the amplified genes were indeed localized in this particular part of the chromosome. In a later experiment, done in collaboration with Joseph R. Bertino of the Yale University School of Medicine, we showed that a mouse-tissue cell line with 400 amplified genes has a comparable homogeneous staining region on a single chromosome and that the genes coding for dihydrofolate reductase are localized there. (Only one of the two paired chromosomes turns out to have the expanded region.) From these studies and others we have concluded that the stable

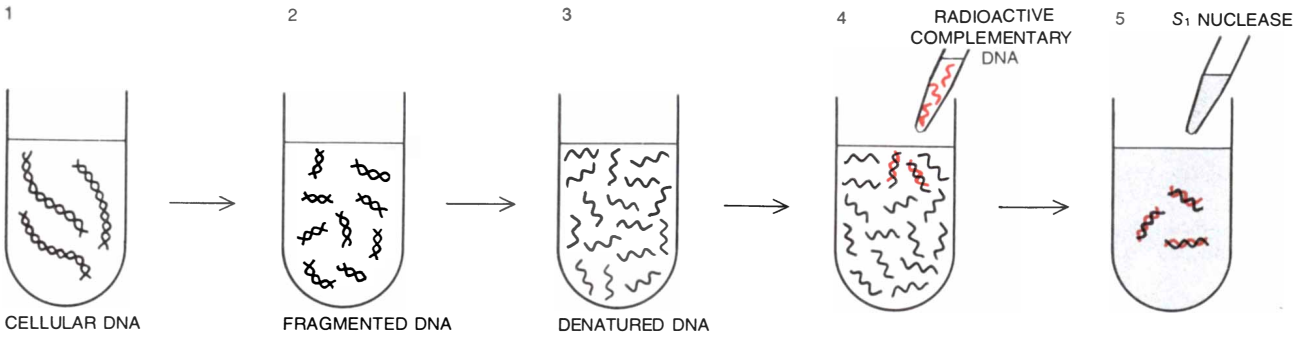



**HYBRIDIZATION OF NUCLEIC ACIDS, a comparatively new technique in molecular biology, was adopted by the author and his colleagues for their demonstration that the phenomenon of gene amplification is responsible for the elevated level of the enzyme dihydrofolate reductase observed in methotrexate-resistant mammalian cells. The hybridization technique in this case begins with the isolation of purified samples of messenger RNA carrying the information needed for the synthesis of dihydrofolate reductase. (The RNA samples are obtained from cells with a high level of the enzyme.) With the aid of another enzyme, reverse transcriptase, the messenger RNA is next made to serve as the template for the synthesis of a single strand of DNA with a sequence of deoxyribonucleotide bases that is complementary to the sequence of ribonucleotide bases of the RNA. The complementary DNA is synthesized from radioactively labeled building blocks, deoxyribonucleoside triphosphates, and as a result it becomes highly radioactive. Since the radioactively labeled strand of complementary DNA carries the specific base sequence coding for dihydrofolate reductase, it can be used in subsequent hybridization tests to detect and measure the amount of cellular DNA (or messenger RNA) coding for the same enzyme. In short, the hybridization technique makes it possible to determine the actual number of genes coding for dihydrofolate reductase in the drug-resistant cell line.**

amplification of genes in cultured mammalian cells is related to the localization of the genes in a specific region of a single chromosome.

Where are the amplified genes in the unstable cell lines? Recently we have found that all our unstable cell lines contain, in addition to the normal set of chromosomes, small extrachromosomal DNA elements called double minute chromosomes. By purifying these extrachromosomal DNA segments we have shown that they contain the amplified genes for dihydrofolate reductase. Extrachromosomal DNA of this type is not found in either methotrexate-sensitive cells or stable methotrexate-resistant cells (that is, cells in which the amplified genes are chromosomal). The number of such extrachromosomal DNA segments present in the nucleus of a cell, we discovered, is proportional to the number of amplified genes. In some instances there are as many as 100 of the extrachromosomal DNA elements per nucleus. Furthermore, when unstable drug-resistant cells lose their resistance to methotrexate (and therefore their amplified genes for drug resistance), the cells also lose their extrachromosomal DNA elements.

The extrachromosomal DNA segments in question here are like chromosomes in that they contain genes and are associated with certain proteins. Moreover, like normal chromosomes, they can replicate during the period when DNA is synthesized in cells. They dif-




**HYBRIDS ARE DETECTED with the help of another enzyme, $S_1$ nuclease, which destroys any single-strand nucleic acid molecule but does not affect double-strand molecules, such as hybrids of complementary DNA with either cellular RNA or cellular DNA. The cellular DNA (*1*) is first broken into small pieces (*2*). The DNA fragments are next denatured (broken into single strands) by boiling (*3*), and a small amount of radioactive complementary DNA is added to the mixture (*4*). After the complementary DNA has had a chance to hybridize with any RNA or DNA with which it has complementary nucleotide sequences, samples of the reaction mixture are subjected to the $S_1$ nuclease, which digests the single-strand molecules, leaving behind only the radioactive hybrids, which are then recorded (*5*).**

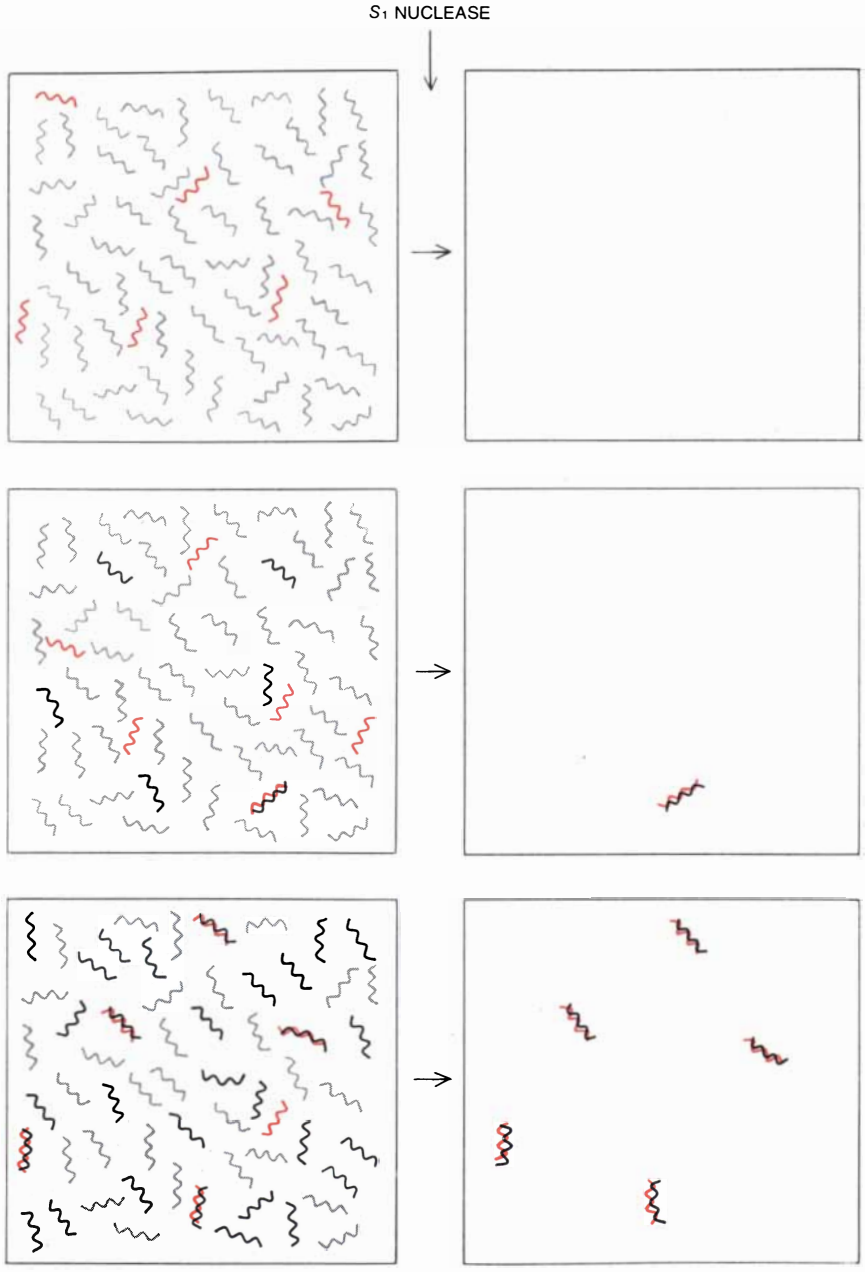
fer significantly from normal chromosomes, however, in that they do not have centromeres, the chromosomal structures to which a thread of protein, the spindle fiber, is attached at metaphase. (Metaphase is the period in the cell cycle following DNA synthesis when the newly replicated set of chromosomes is distributed equally to the daughter cells.) The presence of the spindle fiber ensures that the duplicated normal chromosomes segregate (distribute equally) into the daughter cells during mitosis (cell division). Because the extrachromosomal DNA segments do not have centromeres the spindle fibers do not attach to them, and therefore the segments are not necessarily distributed equally at mitosis.

The distinctive features of these extrachromosomal DNA segments mean that they are susceptible to two processes that can lead ultimately to their disappearance from a cell. First, since they can be distributed unequally between the daughter cells, some daughter cells will gain genes and others will lose them. Cells that have more genes for dihydrofolate reductase are known to grow slower than cells that have fewer such genes, when both types of cells are grown in the absence of methotrexate. Thus over a long period of growth in the absence of methotrexate those cells that can grow a little faster and divide a little more often (that is, those cells with fewer copies of the gene for dihydrofolate reductase) will eventually become dominant in the population. The net result will be that the cell population as a whole will gradually lose genes coding for the enzyme.

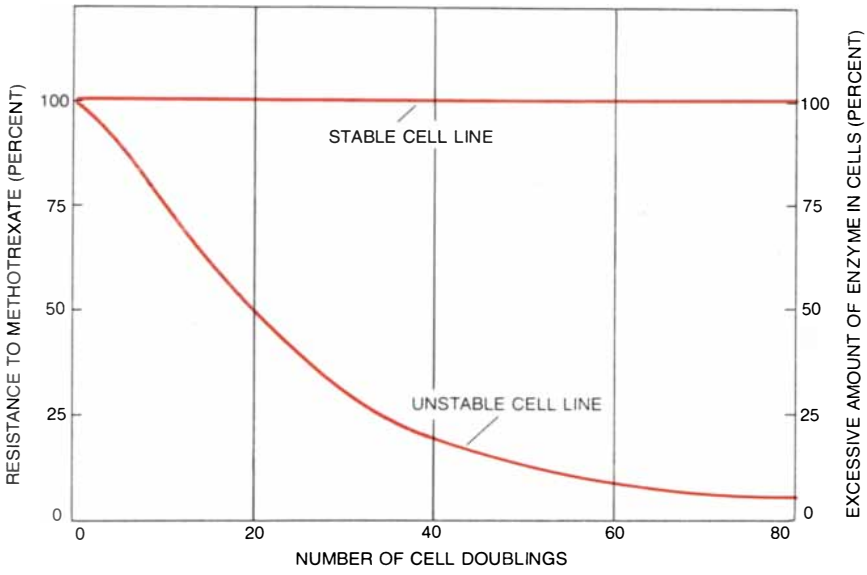
A second consequence of the fact that the extrachromosomal DNA segments lack attachments for spindle fibers arises from another phenomenon that takes place during the replication of normal chromosomes in the cells. The chromosomes of all higher organisms are surrounded by a membrane that separates the nucleus of the cell from the cytoplasm. When the cell divides, the nucleus must divide in two. At that time the nuclear membrane disaggregates to allow the chromosomes to be distributed into the nuclei of the two new daughter cells. Following segregation of the chromosomes the nuclear membrane reassembles around the segregated chromosomes.

At the time of reassembly of the nuclear membrane there is the possibility that some (or all) of the extrachromosomal DNA segments will be surrounded by nuclear-membrane material to form minute entities known as micronuclei. According to J. Albert Levan and his colleagues at the University of Göteborg, such micronuclei, which are separate from the nucleus containing the chromosomes, can be extruded into the cytoplasm and can eventually leave the cell. Extrachromosomal amplified genes can therefore be unstable. In contrast, when amplified genes are incorporated into chromosomes that undergo the normal segregation events of mitosis, they are retained in the cells and are therefore stable.

The possibility that daughter cells may not have the same number of genes coding for dihydrofolate reductase and the same excessive enzyme level as their parents (or their sisters) means cell lines that are unstably drug-resistant would constitute a population of cells with differing enzyme levels. How can one determine the amount of the enzyme in an individual cell? Bertino, who worked with us in 1978 while he was on sabbatical leave from Yale, suggested then that a derivative of methotrexate, first synthesized by John Whiteley and his colleagues at the Scripps Clinic and Research Foundation, might be useful for measuring the amount of dihydrofolate



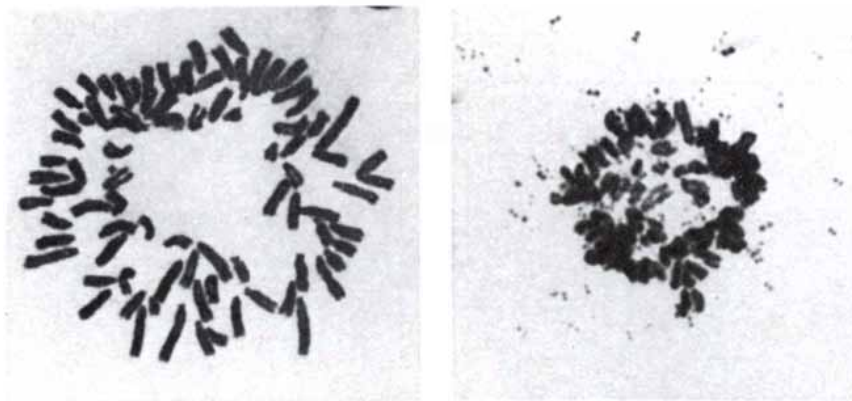

**NUMBER OF GENES coding for dihydrofolate reductase is determined by measuring the rate of hybridization of complementary DNA for the enzyme with either RNA or DNA from cells with differing levels of the enzyme. In this demonstration of the procedure a small but constant amount of the radioactive complementary DNA (*color*) has been added to three different cell mixtures, and the radioactivity of the samples is measured after a certain fixed interval. In the sample at top there are no complementary cellular nucleotide sequences, and accordingly no evidence of hybridization is detected. In the sample at middle a small number of complementary sequences (*black*) are present, and the measured rate of hybridization is low. In the sample at bottom there are many such sequences, and hence the rate of hybridization is high.**




**STABILITY OF DRUG RESISTANCE in cultured mammalian cells turns out to be quite variable. In this case two different methotrexate-resistant cell lines were grown continuously in the presence of the drug for many months. They were then grown in a medium that did not contain the drug. One of the cell lines, represented by the bottom curve, rapidly lost all resistance to the drug; the cells in this unstable line were also observed to lose most of their excessive amount of the dihydrofolate reductase enzyme. The other cell line, represented by the top curve, maintained a stable high level of drug resistance and a high enzyme level. Drug resistance and enzyme level were measured at various cell-doubling intervals as a percentage of the corresponding values for control cells, which were allowed to continue their growth in the presence of methotrexate. On the average such cells double once every 24 hours or so. The stability or instability of a particular cell line appears to be independent not only of the type of cell but also of the absolute enzyme level attained at the beginning of the test period. In this case both drug-resistant cell lines were selected from the same source of drug-sensitive mouse cells.**

reductase in individual cells. We found that this particular methotrexate derivative, which has a molecule of the fluorescent dye fluorescein attached to it, binds tightly to dihydrofolate reductase in living cells. Hence the amount of fluorescence per cell can in principle be used as a measure of the enzyme content per cell.

We were fortunate in this regard in having access to the fluorescence-activated cell sorter, a versatile experimental tool developed by Leonard A. Herzenberg and his colleagues at Stanford. Basically the device consists of a glass capillary tube down which a suspension of dissociated cells, "tagged" with the fluorescent dye, is made to flow. A laser shines a fine shaft of light across the capillary, and the fluorescence excited in individual cells by the laser light is detected. This information can then be used to sort the cells by electrically charging the liquid droplets containing the tagged cells in such a way that they are deflected by a downstream electric field into separate containers [see "Fluorescence-activated Cell Sorting," by Leonard A. Herzenberg, Richard G. Sweet and Leonore A. Herzenberg; SCIENTIFIC AMERICAN, March, 1976]. For our purpose the fluorescence per cell is a direct indicator of the amount of dihydrofolate reductase in the cell and also the number of genes present. This technique has become a powerful aid for studying variations in the number of amplified genes in populations of cells with unstable drug resistance.



**EXTRACHROMOSOMAL DNA ELEMENTS, known as double minute chromosomes, are visible as small paired dots in the photomicrograph at the right, which shows a typical chromosome spread of a drug-resistant cell obtained from an unstably methotrexate-resistant cell line derived from a sarcoma, or malignant connective-tissue tumor, of a mouse. The photomicrograph at the left shows the chromosomes of a drug-sensitive cell from the same cell line; no evidence of the extrachromosomal DNA elements can be seen in it. Both pictures were made as the cells were going through metaphase, the period in cell division when the newly replicated set of chromosomes is distributed equally to the daughter cells; the chromosomes are aligned in the normal fashion just before being pulled apart by the attached spindle-fiber apparatus. The extrachromosomal elements are spread over the field of view, however, and hence they are not aligned in a way that would allow their equal segregation into daughter cells. As a result they would presumably be distributed unequally to the daughter cells at cell division.**

All the experiments described up to this point have dealt with cell lines that have undergone multiple steps of selection; furthermore, the cells have been studied only after growth in the presence of methotrexate for comparatively long periods. With the fluorescence-activated cell sorter we have investigated populations of Chinese-hamster ovary cells in the early stages of gene amplification. When we study such cells after several incremental steps of selection (that is, stages of gene amplification), we find the population is extremely heterogeneous in terms of the number of genes; the heterogeneity is demonstrated by the fact that there is a wide range of fluorescence in the cell population. When we look at individual nuclei from these cells, we find the number of extrachromosomal DNA segments varies markedly among cells. We have made similar observations with cell lines from mouse tissues.

It seems clear that if extrachromosomal DNA segments containing the gene coding for dihydrofolate reductase are being generated in these cell lines, and if these genes can be distributed unequally between daughter cells, then the attainment of progressively higher levels of drug resistance can be a fairly rapid process, because one can repeatedly select for those cells that have more genes segregated into one of the two daughter cells at each cell division. A curious (and perhaps important) aspect of this phase of our work is the finding that the generation of cells with unstable drug resistance is a far more frequent event in the early stages of the selection process than the generation of cells with stable drug resistance.

What happens to the progeny of individual cells with a high but unstable number of amplified genes when these cells are grown in the absence of metho-

trexate? We are able to separate individual cells of this type with the fluorescence-activated cell sorter. The cells are then grown for many generations in a medium that lacks methotrexate. Finally, we determine the distribution of progeny cells with respect to the number of amplified genes they contain. What we find is that the progeny of different individual cells behave quite differently. The progeny of some of the cells lose all their amplified genes, with the result that they revert to the status of drug-sensitive cells. Other cells yield a heterogeneous population of progeny, with varying amounts of enzyme per cell. The observation that individual cells generate progeny with different numbers of amplified genes is a predictable consequence of the finding that the genes coding for dihydrofolate reductase are present in extrachromosomal DNA segments. Such genes can be distributed unequally between the daughter cells, or they can be lost entirely.

How common is the phenomenon of gene amplification in nature? I have already discussed the possible relevance of our experimental studies to the natural evolution of multigene families and to the random selection events observed in bacteria. There is also good evidence that gene amplification operates in higher organisms in two other situations, both involving the genes that code for ribosomal RNA. This form of RNA, unlike messenger RNA, does not participate directly in the synthesis of proteins; instead it reacts with specific proteins to form ribosomes, the particles that are an essential part of the cellular machinery devoted to protein synthesis. In the eggs of certain amphibians there is a developmental stage before fertilization in which the genes coding for ribosomes are amplified enormously, multiplying as many as 10,000 times. The excess genes are not associated with the chromosomes of the egg cell. During this particular stage in the developmental process there is a rapid synthesis of ribosomes, which are stored by the cell in an inactive form pending their mobilization for protein synthesis after fertilization.

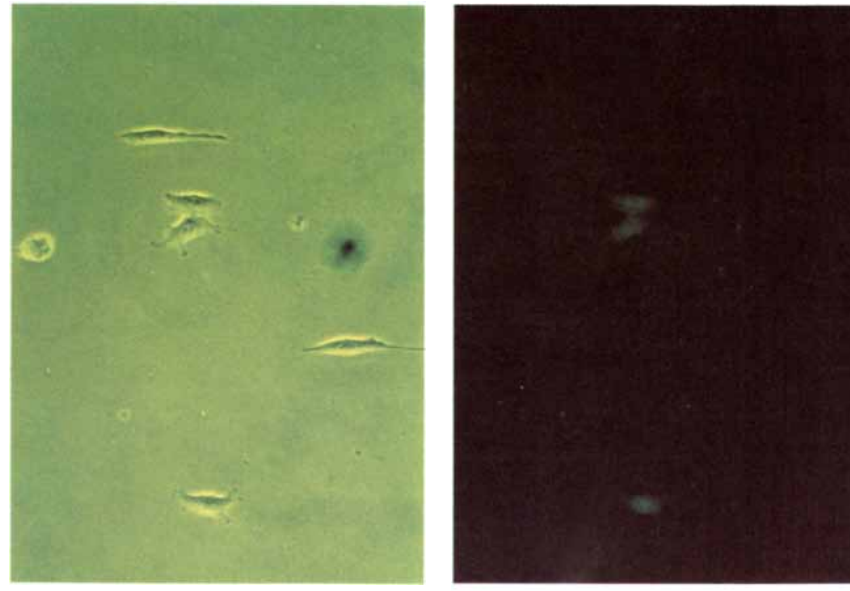
Another example of gene amplification in nature involves the amplification of genes coding for ribosomes in *Drosophila melanogaster,* the common fruit fly, a process studied intensively some 35 years ago by A. H. Sturtevant at the California Institute of Technology. Certain male fruit flies are partially deficient in their ability to synthesize proteins because one of their chromosomes contains very few genes coding for ribosomes. When these flies are mated with normal females, some of the offspring are normal; the normal complement of ribosomal genes observed in these offspring evidently results from a compensatory amplification of ribosomal genes derived from the chromosomes of the normal female.

In both of these examples the amplification process appears to be directed by the requirement of the organism for large numbers of genes coding for ribosomes. In the case of the amphibian egg the amplification is developmentally regulated and operates in all the eggs at a time when there is a need for the rapid synthesis of large numbers of ribosomes. In the case of the fruit fly the additional ribosomal genes are similarly required for the synthesis of ribosomes necessary for the generation of nondefective offspring. Other examples exist, and no doubt additional ones will be discovered in the future.

The gene amplification for methotrexate resistance we have reported in cultured mammalian cells differs in several respects from the gene amplification for ribosome synthesis in that the latter process seems to be a comparatively rare event requiring selection for its detection. Nevertheless, the characteristics of stepwise selection and variable drug-resistance stability in association with an elevated enzyme level have been reported in some instances involving the acquisition of antibiotic resistance in bacteria and insecticide resistance in insects. Hence gene amplification may be commoner among organisms than had been thought and may underlie various forms of drug resistance in nature.

Clearly our findings raise more questions than they answer. For example, does gene amplification operate in normal cells in intact animals or only in cultured cells? Is some of the resistance to methotrexate and other chemotherapeutic drugs for human cancer a result of gene amplification? Is there a possibility that certain drugs, such as methotrexate, may affect more basic metabolic functions, for example the replication of DNA, and thereby facilitate gene amplification? It is in the nature of research that the answers to one set of questions lead to more questions. Recently homogeneous staining regions and double minute chromosomes have been detected in cultured cell lines derived from human tumors. Why are they present in these cells, which have not been subjected to any selection procedure for drug resistance? Is the reason related to their being cancer cells?

The past few years of progress in the study of the molecular structure of genes in higher organisms have shown that there is much more potential for changes in the DNA content and chromosome structure of mammalian cells than had been thought. The evidence comes not only from our studies of gene amplification but also from studies of the recombination of DNA segments coding for the synthesis of antibodies and from studies showing the existence of transposable DNA sequences in higher organisms. The results of such studies have forced new ways of thinking about normal development, evolution and the mechanism by which cells become malignant. Only time and more experimentation will tell where this line of inquiry is likely to lead.



**FLUORESCENCE of drug-resistant cultured mammalian cells can be made to serve as a measure of the amount of dihydrofolate reductase in the cells. For this purpose molecules of the fluorescent dye fluorescein are first attached to methotrexate molecules in such a way that the binding of the drug to the enzyme is not altered. The ordinary phase-contrast photomicrograph at the left shows a mixture of methotrexate-sensitive and methotrexate-resistant cells. The photomicrograph at the right was made with a special fluorescence microscope after the cells had been incubated with the fluorescein-tagged methotrexate molecules. Only the drug-resistant cells (that is, those with a high level of the enzyme) are observed to fluoresce intensely.**

# The Discovery of a Gravitational Lens

*A recently discovered pair of quasars turns out to be not a pair at all but two images of a single quasar formed by a gravitational lens: an elliptical galaxy halfway between the quasar and our own galaxy*

by Frederic H. Chaffee, Jr.

Quasars are thought to be the most distant and luminous objects in the universe, and they have taxed the understanding of astronomers ever since their discovery. In March of last year two quasars were discovered that seemed to be closer together and more similar in their spectra than any other two of the some 1,500 known quasars. Eight months of theoretical work and intensive investigation with the largest optical and radio telescopes has demonstrated that these "twin" quasars are not two distinct objects at all. Rather, they are a single object whose light has been split into two images by the gravitational field of a galaxy between the quasar and our galaxy: a kind of optical illusion on a cosmic scale. That the mystery of the twin quasars was solved in such a short time is almost unprecedented in a field where many questions take years of painstaking analysis to answer.

According to Einstein's general theory of relativity, the gravitational field of a massive object can bend a ray of electromagnetic radiation in the direction of the object. The phenomenon has been observed numerous times when rays of visible light and radio waves from distant objects pass near the sun. The twin quasars go beyond this phenomenon in showing that a massive body can act as a gravitational lens, creating multiple images of an object as an optical lens does.

Quasars in general have been a puzzle since their discovery 20 years ago revealed that they are receding from us at very high velocities, some approaching the velocity of light. The speed of recession of any object can be measured from its spectrum. Just as the tone of a train whistle changes depending on whether it is approaching or receding from someone standing near the tracks (the most familiar example of the Doppler effect), so does the apparent wavelength of light change depending on the source of the light. Therefore if a galaxy is receding from the observer, its light is "red-shifted" with respect to him by an amount that is directly proportional to its speed of recession.

The spectra of most galaxies are found to be red-shifted, indicating that the galaxies are receding from us. Furthermore, those galaxies whose distances can be independently estimated have red shifts directly proportional to their distance. It is this phenomenon that leads to the concept of the expanding universe. Astronomers have turned the argument around to suggest that the velocity of recession of any object can be used to estimate its distance, even when no direct measurement of the distance is possible. It follows that the many quasars with red shifts larger than the red shift of any other known object in the universe must be the most distant objects in the universe. That we can see quasars at all at such distances in turn implies they are also the brightest objects in the universe.

It is the brightness of the quasars that has led some astronomers to question whether the red shifts of these objects are really the result of simple recession. More exotic physical phenomena can also give rise to red shifts, and if one of them were responsible for the observed red shifts of quasars, at least there would not be the problem of explaining how a comparatively tiny source can generate 100 times more radiation than the brightest galaxy known. Nevertheless, the bulk of the data on quasars points to the original interpretatin of the red shifts, namely that quasars are the most luminous and the remotest of objects.

The 1,500 known quasars are uniformly distributed throughout the sky. One quasar is found on the average almost every 30 square degrees, a patch of sky about the size of the bowl of the Big Dipper. It therefore came as a surprise when Dennis Walsh of the Jodrell Bank radio-astronomy observatory, Robert F. Carswell of the University of Cambridge and Ray J. Weymann of the University of Arizona discovered two quasars separated by only six seconds of arc, an angular distance only a three-hundredth the diameter of the full moon. The two quasars have been officially designated 0957 + 561 A, B, the numbers giving their astronomical coordinates and the letters indicating the presence of two sources at those coordinates. They have come to be known simply as "the twins."

The photograph of the twins on page 73, made in the 1950's with the 1.2-meter Schmidt telescope on Palomar Mountain, shows two starlike images of nearly equal brightness: roughly 20,000 times fainter than the faintest star that can be seen without a telescope. How close together the objects appear in the sky is indicated by the fact that they are fused in the photograph to form one slightly elongated image. It is nonetheless clear that the elongated image consists of two distinct smaller images.

On March 29 of last year Walsh, Carswell and Weymann, working with the 2.1-meter telescope at the Kitt Peak National Observatory and the 2.3-meter telescope of the University of Arizona, obtained spectra indicating that each of the two images is the image of a quasar. For each of the twins they measured a red shift of 1.4, which means the twins are receding at a speed of 70.7 percent of the speed of light, a very high velocity but by no means an exceptional one for a quasar. It was not the recessional velocity of the twins but the details of their spectra that first startled the investigators and then perplexed the entire astronomical community.

The spectra of quasars are characterized by broad lines emitted by atoms that have been stripped of at least one electron by the intense radiation field to which they are subjected. Many such emission lines are possible, and each quasar has its unique collection of them. What is remarkable about the twins is the similarity of their spectra. Not only

do they have the same set of emission lines but also the strength of any particular line in one spectrum is the same as that of the same line in the other. Moreover, the discoverers found all the lines had the same red shift within the accuracy with which they could make the measurements.

Like many other quasars, the twins also have in their spectra sharp absorption lines that probably arise in cool gas lying between the quasar and our galaxy. The red shift of these absorption lines usually differs from that of the broad emission lines, and in some quasars the absorption lines show more than one red shift, indicating that the radiation has passed through a corresponding number of clouds.

Walsh, Carswell and Weymann found that the absorption lines in the spectrum of quasar A all have the same red shift, indicating that the radiation passes through only one intervening cloud. The red shift of the absorption lines (70.1 percent of the speed of light) is close to the red shift of the emission lines (70.7 percent), suggesting that the intervening cloud is close to the quasar itself. Furthermore, the absorption lines in the spectrum of quasar B have the same red shift as the absorption lines in the spectrum of quasar A to within an experimental uncertainty of 150 kilometers per second. The cloud is receding from us at 210,000 kilometers per second, so

**TWIN QUASARS 0957 + 561 A, B are the two multicolored ellipses tilted to the right and lined up vertically in the center of this false-color computer-graphic display of radio emission from the region. The colors black, green, red, yellow, dark blue, light blue, purple and white correspond respectively to areas of increasing intensity of radio emission with a wavelength of six centimeters. Opponents of the gravitational-lens explanation of the twins were troubled by the absence of an image of the deflecting galaxy between the twins and by the absence near the southern twin (*bottom*) of an image of the multicolored radio blobs to the left of the northern twin (*top*). The data for the display were gathered by the National Radio Astronomy Observatory's Very Large Array instrument. The observation was made by Perry E. Greenfield and Bernard F. Burke of Massachusetts Institute of Technology and David H. Roberts of Brandeis University.**

**VERY LARGE ARRAY (VLA) that produced the display on the preceding page is a *Y*-shaped collection of 27 dish antennas near Socorro, N.M. Each of the dishes is 25 meters in diameter.**

**MULTIPLE-MIRROR TELESCOPE (MMT) on Mount Hopkins in Arizona was used to make measurements of the twins' red shift. Each of the six mirrors is 1.8 meters in diameter.**

that a difference of 150 kilometers per second would be small indeed. The situation is analogous to two automobiles driving side by side on a freeway, one at 50 miles per hour and the other at 50.04. To someone at the side of the road the speeds of the two automobiles would be indistinguishable. It is therefore no exaggeration to say that the twins are more similar to each other in the characteristics of both their emission lines and their absorption lines than are the most similar of any pair of quasars chosen from among all other known quasars, and it is their striking similarity that demanded explanation.

It is well known that there are binary stars that travel in orbit around each other. Could the twins simply be the first example of a binary quasar? Clearly they are physically related, and if they are a binary quasar, the similarities in their spectra could arise naturally from the fact that the twins originated and evolved in the same cosmic environment. What further explanation might be necessary?

It is precisely this kind of question that would draw the battle lines in the astronomical community over the interpretation of the twins, and it must be considered carefully. The evidence against the binary-quasar hypothesis rests chiefly on the interpretation of the absorption lines, particularly on the similarity of the red shifts of the absorption lines.

The nature of the clouds responsible for the absorption lines in the spectra of quasars is still debated in the astronomical community, with opinions divided among three hypotheses. The first hypothesis attributes the cloud to matter that was ejected from the quasar in a violent explosion. The second assumes that the cloud is one of many isolated conglomerations of primordial matter scattered throughout space by the big bang. The third suggests that the cloud is a "halo" of gas surrounding an ordinary galaxy that is part of a cluster of galaxies either including the quasar or lying along the line of sight between the quasar and our galaxy. All three hypotheses have consequences far beyond the interpretation of the twins, but I shall limit myself to the consequences regarding the twins.

Only the first hypothesis needs to be examined in detail, because one of its flaws in explaining the twins is also a flaw of the other two hypotheses. Suppose the cloud around the twins resulted from the violent ejection of matter from one of them, say quasar A, at some time in the past. (The analysis would be the same if the material had been ejected by quasar B.) The top illustration on page 74 shows the current geometrical relations between the quasars and the cloud, which is shown as an expanding spherical shell with an expansion veloci-

ty $v$. The component of $v$ toward us where the line of sight to quasar A intersects it is equal to the difference between the velocity represented by the red shift of the emission lines of quasar A (the velocity of the quasar with respect to our galaxy) and the velocity represented by the shift of the absorption lines of quasar A (the velocity of the shell with respect to our galaxy). Similarly, the component of the expansion velocity of the shell toward the earth where the line of sight to quasar B intersects the shell is the difference between the velocity represented by the emission lines of quasar B and that represented by the absorption lines of quasar B.

The calculation of velocity from a measurement of the red shift yields only the component of the velocity of the object along the line of sight. This means that in the top illustration on the next page the cloud velocity measured toward quasar A is equal to the cloud expansion velocity $v$; the cloud velocity measured toward quasar B should be somewhat less than $v$. From the distance to the quasars inferred from their red shift their separation can be calculated to be 200,000 light-years, nearly three times the diameter of a typical galaxy. With that value and the difference between the absorption-line red shifts toward A and B (which the original observations showed could not exceed 150 kilometers per second) the minimum radius of the cloud can be calculated to be 575,000 light-years.

This distance, combined with the measured strength of the absorption lines, makes it possible to calculate that the minimum mass of the shell is $10^{12}$ times the mass of the sun, or 10 times the mass of our entire galaxy. The energy required to eject such a massive shell at the measured velocity is unbelievably large: $10^{61}$ ergs, or the energy of $10^{28}$ suns expelled in one violent explosion. This ludicrous number immediately casts doubt on the hypothesis that the twins are separate quasars.

Nevertheless, adherents of the binary-quasar hypothesis have argued that absurd values for the energy and the mass of the cloud hold only if the cloud is a complete spherical shell. Suppose a small jet of material was ejected toward our galaxy by one of the quasars. It would expand to form a cloudlet through which the twin quasars would be seen. In that case only a comparatively small amount of material would be involved, and the energy of ejection would be much less than $10^{61}$ ergs.

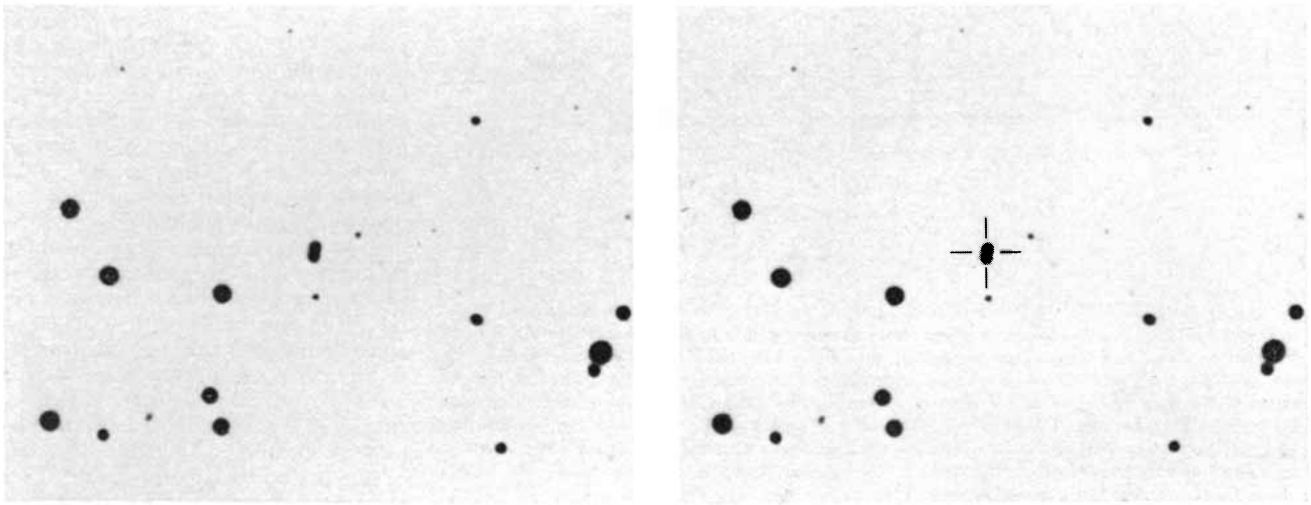
The similarity of the absorption-line velocities, however, presents other problems for the binary-quasar hypothesis, regardless of which hypothesis for the origin of the absorbing cloud is correct. If the twins are really separate quasars, our line of sight to them will penetrate the clouds at two points 200,000 light-years apart. If there is any differential motion in the cloud (rotational motion being the most likely kind), it should manifest itself as a slight difference in the absorption-line red shifts of the twins.

It is nonetheless possible that a cloud of the proposed size could be rotating at a reasonable rate and still show a velocity difference of less than 150 kilometers per second for two points separated by 200,000 light-years. Yet if better measurements were to reveal the velocity difference as being any smaller, the difficulties in interpreting the twins as separate quasars will increase. That is why the next step in the study of the twins was to try to improve the quality of the spectra and to measure the difference in the absorption-line velocities more accurately.

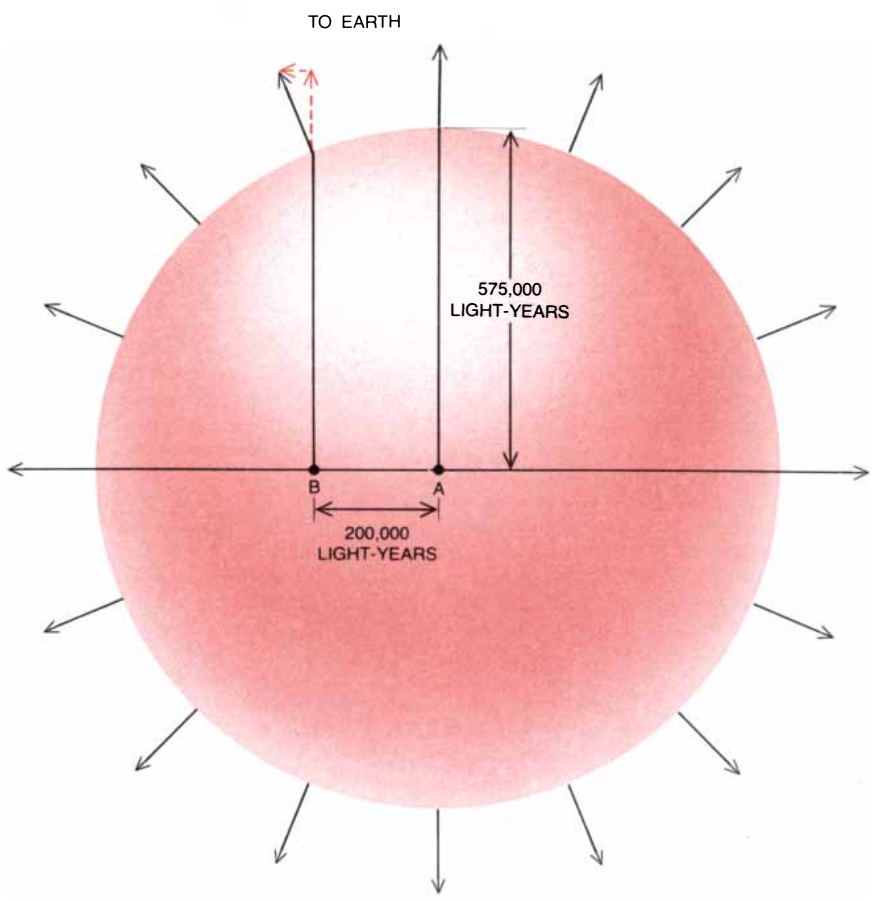
What I have described above was the situation three weeks after the twins were discovered. At that time Walsh, Carswell and Weymann joined Marc Davis of the Harvard College Observatory, Nathaniel P. Carleton of the Smithsonian Astrophysical Observatory and me in trying to increase the precision of the red-shift measurements. Since the twins are extremely faint, more precise measurements called for a larger telescope and longer exposure times. Fortunately the new multiple-mirror telescope (MMT) of the Smithsonian Astrophysical Observatory and the University of Arizona had just been completed. This instrument combines the light rays gathered by six 1.8-meter telescopes joined in a single structure, so that it is equivalent to a single-mirror telescope with a diameter of 4.5 meters.

On the nights of April 20, 21 and 22 of last year we mounted a spectrograph at the focal plane of the MMT and trained the telescope on the twins. Although the MMT had never been used with a spectrograph before, the results were excellent. The measured spectra were of such high quality that we could confidently conclude that the absorption-line velocities of the quasars did not differ by more than 15 kilometers per second. This made the twins 10 times more alike than the original Kitt Peak measurements had had them. The extremely small velocity difference rules out the possibility that the similar absorption lines originate with a complete shell ejected from a quasar. The radius, the mass and the formation energy of the ejected shell, which had already strained the limits of credibility, would now be even larger.

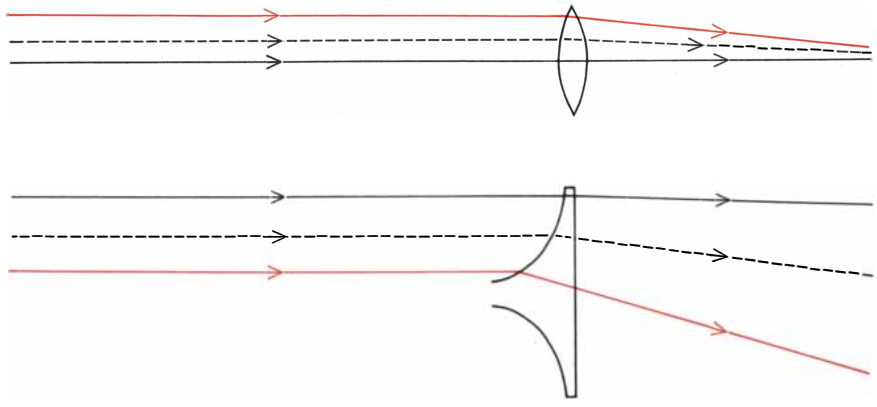
Even if the ejected material were only a cloudlet expanding toward the earth, the small velocity difference measured by the MMT is less than what would be



**FUSED IMAGE OF THE TWIN QUASARS** appears in these two negative prints of a photograph made in the early 1950's with the 1.2-meter Schmidt telescope on Palomar Mountain. The position of the fused image is marked on the print at the right. The image is fused because of the motion of the earth's atmosphere; if the telescope had been above the atmosphere, it could have resolved objects 60 times closer together than the twins. The photograph indicates the difficulty of examining the space between the twins with optical instruments.




**BINARY-QUASAR HYPOTHESIS, which maintains that the twins are not dual images of a single quasar but are actually two quasars, runs into difficulty when one considers the geometrical relations between the two hypothetical quasars and an expanding shell of gas that was ejected with velocity *v* from one of them at some time in the past. (The expanding shell is necessary to account for the similarity of the absorption lines in the spectra of the twins.) The geometrical relations lead to impossibly large values for mass of the shell and energy to eject it.**



**OPTICAL MODEL OF A POINT-MASS LENS is developed in these two diagrams. At the top is an ordinary positive lens where the closer the light passes to the center, the less it is bent. In a point-mass gravitational lens the light does the opposite: the closer it passes to the center, the more it is bent. At the bottom is an optical analogue of a gravitational lens. The lens has the shape of the base and stem of a wineglass. (To be strictly analogous to a point-mass deflector the stem would have to extend to infinity and become increasingly narrow.) Indeed, a real wineglass can be used to demonstrate the focusing properties of a gravitational lens. If a dot is drawn on a sheet of paper and viewed with one eye through the base of a wineglass held a few inches above the paper, the dot is invisible and its image is displaced from the actual position of the dot. When the dot, the lens and the eye all lie precisely in a straight line, the image of the dot is a ring. Similarly, if a quasar, a deflecting mass and the earth were aligned perfectly, the image of the quasar as it was seen from the earth would be a bright ring. If the wineglass is moved to the right or the left, the ring image breaks down into two sliverlike images. An imperfect alignment of the quasar, the lens and the earth would give rise to twin images of the quasar.**

expected if the cloudlet were rotating. It is of course conceivable that the cloudlet is being seen with its plane of rotation perpendicular to the line of sight to the twins. In this case the cloudlet would show no motion toward or away from the observer, so that the red shift would not be affected. Then the actual velocity difference would always be smaller than the measured difference, regardless of the precision of the spectral measurements.

Clearly this explanation requires two exceptional circumstances. First, the cloudlet has to be ejected toward the observer rather than in some other direction. Second, nature has had to conspire to orient the rotation of the cloudlet precisely in such a way that it cannot be detected. Although it is not inconceivable that the cloudlet could have this orientation, the explanation struck many investigators as being somewhat ad hoc. That is why Walsh, Carswell and Weymann now made the radical proposal that the twins are actually gravitational-lens images of a single object.

That a massive object can bend a ray of light passing close to it (or more accurately that the space around the massive object is warped by the object's presence) follows directly from the general theory of relativity, which deals with the interaction of space-time and gravity. In fact, one of the classic corroborative tests of general relativity—the correctly predicted amount of observed change in the apparent positions of distant stars seen near the sun's edge during a total eclipse of the sun—is a manifestation of the same phenomenon that under different conditions can split the images of distant objects.

As early as 1937 Fritz Zwicky of the California Institute of Technology had suggested that some galaxies (or "nebulae," as many astronomers then called them) at different distances might appear to overlap in the sky. He concluded: "The gravitational fields of a number of 'foreground' nebulae may therefore be expected to deflect the light coming to us from certain background nebulae. The observation of such gravitational-lens effects promises to furnish us with the simplest and most accurate determination of nebular masses."

Einstein recognized the possibility that the image of a distant star could be split by the gravitational field of an intervening one, but in a 1937 article he concluded that "there is no great chance of observing this phenomenon." In the wake of this dampening comment the subject of gravitational lenses remained largely unexplored until the discovery of quasars a quarter of a century later. Here were objects bright enough to be seen sufficiently far away for their light, on its way to the solar system, to have a good chance of passing close to some massive object that would deflect the

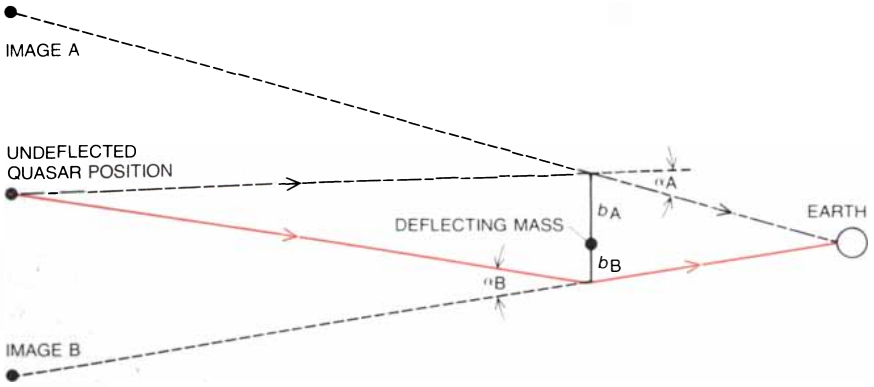
light in accordance with the predictions of general relativity. A single star would not be massive enough to produce any measurable splitting, but an entire galaxy or a black hole would be.

The deflecting object is called a gravitational lens because under certain conditions it directs more light from a distant source toward the solar system than would arrive in the absence of the object. Therefore the object can focus light as a lens does. It has even been proposed that gravitational lenses might explain the fundamental puzzle of all quasars: their enormous energy output. If quasars are simply images of more familiar objects, their apparent brightness might be explained by an intervening gravitational lens. Such an explanation, however, runs into substantial difficulties. There is only a remote probability of finding each of the 1,500 quasars properly lined up with intervening massive objects. And even if the quasars were so aligned, the galaxies that serve as the deflecting lenses should be seen on photographs of all the nearest quasars. Galaxies seldom appear in such photographs. The ultimate speculative leap is to maintain that the lenses do not show up in photographs because they are not galaxies but black holes.

Because of its speculative nature the subject of gravitational lenses has had the odor of witchcraft for the notoriously conservative astronomical community. As a result Walsh, Carswell and Weymann were painfully careful to examine every possible conventional explanation of the twins before they turned to the gravitational-lens hypothesis. No one likes to lose credibility by turning out to be wrong.

How does a gravitational lens of mass $M$ split the light of a quasar? Suppose the light passes a distance $b$ on both sides of a point-mass deflector, as is shown in the illustration on this page. In that case the angle $\alpha$ through which the beam is bent is given by Einstein's formula $\alpha = 4GM/c^2b$, where $G$ is the constant of gravitational force and $c$ is the velocity of light. Consequently the more massive the lens is and the closer the light passes to it, the more the light is bent. There is one path of light on one side of the lens and one path on the opposite side that will be bent directly toward the observer. The observer, of course, does not see the light bend, and to him it appears to have traveled in a straight line not from the actual position of the quasar but from two other points in the sky. The alignment of the quasar, the lens and the observer is critical if two images are to result. To make images of the same brightness the lens should be halfway between them.

The most direct test of the gravitational-lens hypothesis is to photograph the area of the sky between the quasars and see whether a faint galaxy can be detected in it. This test is hard to carry out because it is difficult enough to distinguish two quasar images in the Palomar photograph on page 73 without having to detect some faint object between them. The images are blurred chiefly because of the motion of the earth's atmosphere above the telescope. If there were a faint galaxy between the twins, it could be photographed only on a night of exceptional "seeing." On June 15 of last year Mark T. Adams and Todd A. Boroson of the University of Arizona made photographs of the twins with the four-meter telescope on Kitt Peak, but the results were inconclusive. After this attempt optical astronomers had to suspend their efforts because the twins had moved too close to the sun and would not reappear in the night sky until November.




**POINT MASS acting as a gravitational lens is shown in this highly schematic drawing. Rays of light (or radio waves) from a quasar passing a certain distance to one side or another of a massive deflector will be bent toward the observer. Their true paths are shown as solid lines. Because the observer does not see the rays bend he perceives them as having traveled to him in a straight line. As a result he sees two images of the quasar displaced from the quasar's actual position. Angle $\alpha$ by which a ray is bent is equal to $4GM/c^2b$, where $G$ is the gravitational constant, $M$ the mass of the deflector, $c$ the speed of light and $b$ the distance between ray and mass.**

The radio astronomers who were studying the twins, however, were able to continue their work because radio waves from the sun are not intense enough to interfere with such observations, and the earth's atmosphere does not significantly scatter radio waves, as it does those of visible light. The radio observations, which continued through the summer, were particularly important because the deflection of electromagnetic radiation by gravity is independent of wavelength; therefore if the gravitational-lens hypothesis were correct, the twins would have to appear double not only at optical wavelengths but also at radio ones. A radio picture of the twins might also reveal the presence of an intervening massive object capable of acting as a gravitational lens.

The ability of a telescope to resolve objects that appear close together is directly proportional to its diameter and inversely proportional to the wavelength at which it operates. If it were not for imperfect seeing, the 1.2-meter Schmidt telescope with which the photograph of the twins on page 73 was made could have resolved two objects as close together as .1 second of arc, or 60 times closer together than the twins actually appear to be. At radio wavelengths the effect of seeing is negligible, and so radio telescopes perform at the resolution predicted by theory. Radio wavelengths, however, are typically 100,000 times longer than optical wavelengths, so that a radio telescope the size of the 1.2-meter Schmidt optical telescope would barely be able to resolve two objects separated by 10,000 arc seconds. Indeed, a radio telescope of that size would fuse two objects at opposite ends of the bowl of the Big Dipper.

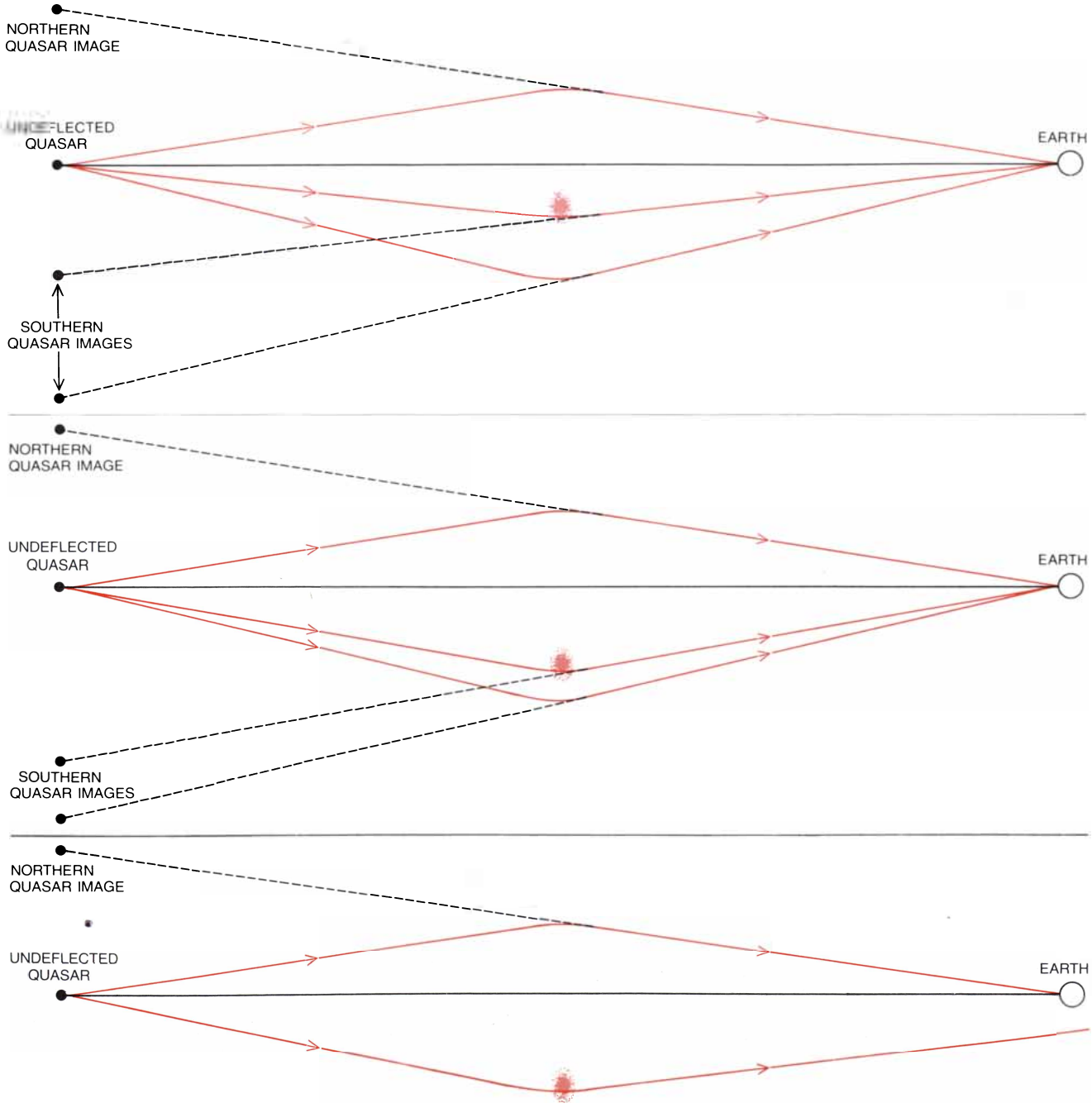
Over the past seven years the National Radio Astronomy Observatory has upgraded the traditionally poor resolving power of radio telescopes by developing the Very Large Array (VLA), a collection of 27 antennas, each 25 meters in diameter, laid out in the shape of the letter $Y$ near Socorro, N.M. The instrument, which in effect is a telescope with a diameter of 27 kilometers, can resolve objects separated by as little as .6 arc second. This resolution, which is 200 times better than that of any other radio telescope, rivals the resolution of the best optical instruments.

On June 23 and 24 of last year David H. Roberts, Perry E. Greenfield and Bernard F. Burke of the Massachusetts Institute of Technology obtained 42 minutes of data on the twin quasars with the VLA. At that time only 14 of the 27 VLA antennas were operating, but the data made it possible to achieve a resolution of .8 arc second, 7.5 times better than the resolution of the optical photograph on page 73 in which the twins can barely be seen as two distinct images. At first the radio picture seemed to support the gravitational-lens hypothesis because it revealed two radio images of roughly equal brightness corresponding to the two optical ones. But

the picture provided the first look at the space between the twins, and at radio wavelengths there was no convincing evidence of emission from an object halfway between them. This in itself did not rule out the gravitational-lens hypothesis. An elliptical galaxy, which optical astronomers had suggested was the most likely candidate for the lens, is often a weak source of radio waves. In other words, an elliptical galaxy could be halfway between the quasar images but might be too faint to be detected at radio wavelengths.

What troubled the proponents of the gravitational-lens hypothesis most were two blobs of radio emission just to the northeast of the northern quasar image. If a gravitational lens had doubled the quasar image, it should do the same for other images in the immediate vicinity. Why was there no image of the northeast blobs near the southern quasar image? It is possible that the blobs are simply a clump of radio emission much closer to the solar system than either the quasar or the lens is. In that case no second image of the blobs would be expected. Such a coincidental alignment with the twins, however, is unlikely. Therefore the absence of any radio image of either of the northeast blobs near the southern quasar image led the M.I.T. workers to conclude that the twins are not images generated by a gravitational lens but are two distinct quasars, one of which happens to have two blobs of radio emission associated with it.

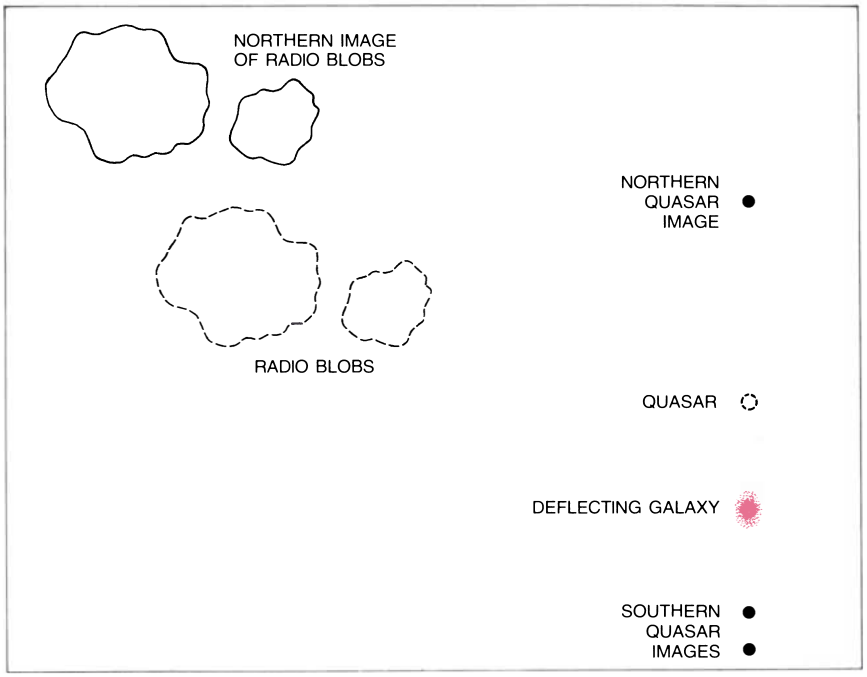
The conflicting interpretations were clearly drawn. On one side were the optical astronomers who supported the




**EXTENDED MASS such as an elliptical galaxy is shown acting as a gravitational lens in three situations that represent an increasing misalignment of the quasar, the lens and the earth. Unlike a point mass, an extended mass can create three gravitational-lens images. When the alignment is almost perfect (*top*), three images are created. As the galaxy is displaced from the line joining the quasar and the earth (*middle*) two of the images become faint and approach each other. As the galaxy is displaced still further (*bottom*) two of the images vanish.**

gravitational-lens hypothesis because any conventional explanation leads to preposterous conclusions about the energy, mass and orientation of the ejected cloud. On the other were the radio astronomers who favored a conventional explanation and avoided the absurdly large values by having one of the quasars eject only a small cloudlet directly toward our galaxy with a rotation in the plane of the sky. The radio astronomers cited the absence of a second image of the northeast blobs as sufficient evidence to rule out the gravitational-lens hypothesis.

When the twins reappeared in the night sky in November, many optical astronomers were poised to observe them, but it was Alan N. Stockton of the University of Hawaii at Manoa and a group from the Hale Observatories who would ultimately solve the riddle of the twins. Stockton thought that the most promising approach was the direct one of making a photograph of the space between the twins. In spite of the difficulties of this approach and the inconclusive results of Adams and Boroson, Stockton had an important advantage. The 2.2-meter telescope with which he does his research is at one of the world's best observing sites: atop the 4,200-meter peak of Mauna Kea on the island of Hawaii. The seeing on Mauna Kea is excellent. If there was any chance of spotting a galaxy between the twins, it would require such conditions.




**FINAL PICTURE of the twins is presented in a highly schematic manner. The "real" quasar (*shown in broken outline*) is a single optical point source with two extended blobs of radio emission (*also in broken outline*) to one side. About halfway between the quasar and our galaxy is an elliptical galaxy displaced about three seconds of arc from the line connecting the undeflected quasar and the earth. The elliptical galaxy forms three images of the distant quasar, one deflected above the "actual" position of the quasar and two deflected below the actual position to lie nearly on top of each other. The line connecting either of the radio blobs and the earth passes far enough away from the galaxy for only one image of either of them to be formed; this single image is displaced upward and to the left of its real position. Therefore none of the objects shown in broken outline is "seen" in any photograph of the sky, only the images in solid outline.**

The group at the Hale Observatories, consisting of Peter Young, James E. Gunn, Jerome Kristian, J. Beverley Oke and James A. Westphal, also decided on the direct approach. In addition to the five-meter (200-inch) telescope and extensive knowledge of the theory of gravitational lenses the group had access to the best available charge-coupled device (CCD): the new solid-state detector that will probably replace the photographic plate as the astronomer's chief recording medium. The advantage of the CCD is that in one exposure it can record the images of objects of vastly different brightnesses and still allow the relative brightness of each object to be determined. (Such a determination cannot be made from a photographic plate because of the effects of saturation.)

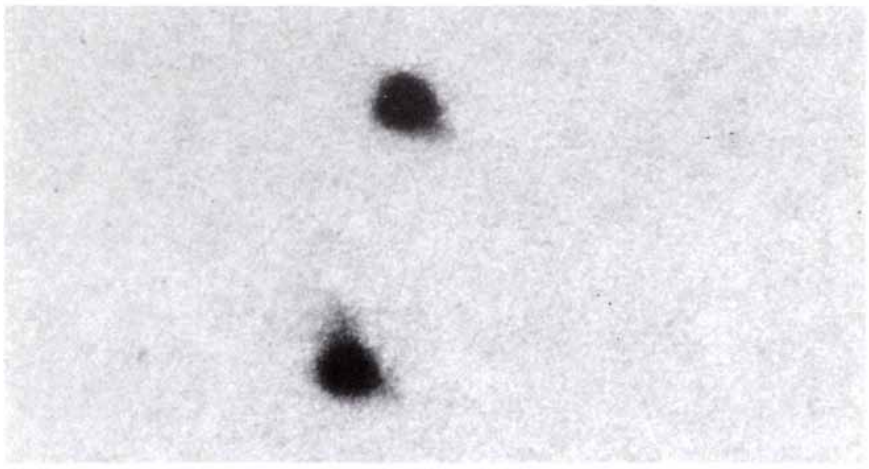
On November 15 of last year the Hale group made a two-hour CCD exposure of the twin quasars. Subsequent analysis of the exposure showed that the southern image was elongated to the north by one arc second and that the northern image had the circular shape characteristic of a single object.

On November 28 Stockton, unaware of the Hale results, made a series of one-minute photographic exposures under superb seeing conditions. His photographs turned up a small patch of fuzz to the north of the southern image. The fuzz appeared to be a jet of material emerging from the southern twin. The Hale astronomers were quick to recognize that their elongated image and Stockton's jetlike fuzz were the same object. Stockton's photographs had resolved the southern twin and the adjacent fuzz, whereas the Hale photographs had not. Nevertheless, the Hale astronomers realized that there was a faint galaxy between the quasar images that was much closer to the southern image than to the northern one. In fact, the image of the galaxy is almost coincident with the southern quasar image, and so the spectrum of the southern image is undoubtedly contaminated by the light of the much fainter galaxy. A close study of the results revealed a spectrum of the galaxy superimposed on the spectrum of the southern image. The Hale observers concluded that the galaxy has a red shift of .4, indicating that it lies about halfway between the quasar and our galaxy.

The news of the results spread quickly through the astronomical community, but excitement was tempered by nagging questions. The proponents of the gravitational-lens hypothesis had thought that for the lens to create dual images of almost equal brightness it would have to be almost exactly on the line of sight to the quasar. Moreover, it should appear to be halfway between the twin images. If the galaxy really is a gravitational lens, why is it closer to the southern image than to the northern one? And where are the images of the northeast radio blobs?

The Hale astronomers responded to these two questions convincingly. They pointed out it was being assumed that the gravitational lens was a point mass, such as a black hole might be. The imaging properties would be quite different if the lens were an extended mass such as a galaxy. The questions would not have arisen at all if those who had been trying to explain the twins as gravitational-lens images had used assumptions appropriate to an extended mass.

The Hale astronomers worked out the imaging characteristics of an extended mass in rigorous mathematical detail. They found the most important difference between a point lens and an extended-mass lens is that the point lens exactly produces two images and the extended-mass lens can produce one image or as many as three images or even more. They suggested that the galaxy actually does produce three images of the twins. Two of the images are so close together that they cannot be resolved, and their combined light is what we see as the single southern quasar. The northern quasar is the third image formed by the galaxy. This explains how the southern image can appear to be almost as bright as the northern one in spite of its be-



**SMALL PATCH OF FUZZ to the north of the southern twin showed up in this negative print of a photograph made with the 2.2-meter telescope on Mauna Kea on Hawaii. The fuzz is a poorly resolved image of the faint galaxy that is the gravitational lens responsible for the twin images. The photograph was made by Alan N. Stockton of the University of Hawaii at Manoa.**

ing nearly coincident with the deflecting galaxy. Moreover, the northeast radio blobs are poorly aligned with the deflecting galaxy, so that only one image of them could be formed.

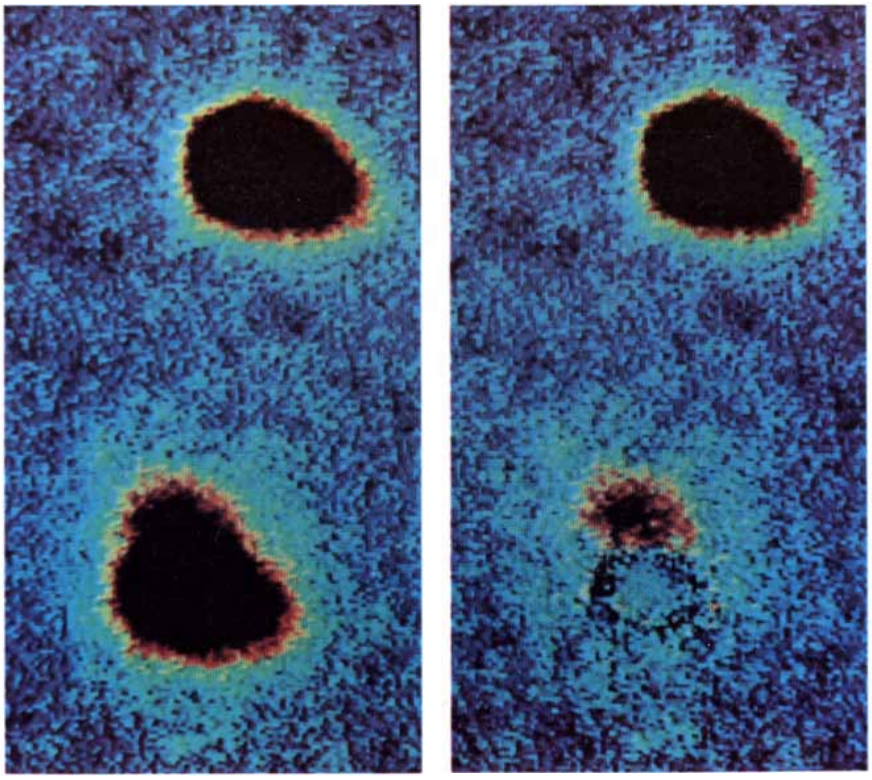
The final picture of the twin quasars is shown in the illustration on the preceding page. The real quasar is a single optical point with two extended blobs of radio emission to the northeast. About halfway between the quasars and our galaxy lies an elliptical galaxy displaced about three arc seconds south of a line connecting the undeflected quasar and the solar system. The galaxy forms three images of the distant quasar, one of which is deflected north of the actual position of the quasar and two of which are deflected south so that they lie almost on top of each other. Once astronomers recognized that the gravitational lens was not a point mass but an extended one they were able to account for both the relative brightnesses of the twins and the single image of the extended radio blobs.

I have, to be sure, somewhat simplified the final picture. The Hale astronomers showed that depending on how the mass in the deflecting galaxy is distributed the three images of the quasar might be different from what I have described. For example, one mass distribution would make the third optical image coincident with the galaxy itself, and so observers would see only the other two images. Moreover, it is not just one elliptical galaxy that deflects the light of the quasar. The galaxy turns out to be the brightest member of a cluster of some 60 galaxies that lie halfway to the quasar.

None of these complications detracts from the significance of 0957 + 561 A, B. As the first case of gravitational-lens imaging the twins should help to dispel stubborn pockets of resistance in the astronomical community to the concept that quasars are distant objects. The evidence is irrefutable that the quasar 0957 + 561 is much farther away from us than the deflecting galaxy is. In other words, the quasar cannot be within our galaxy or close to it but must be at a "cosmological" distance.

Other issues of a cosmological character will undoubtedly be clarified when additional cases of gravitational-lens imaging are discovered. Indeed, this past spring the first triple quasar, PG 115 + 08, was discovered with the MMT by a group headed by Weymann and David W. Latham of the Center for Astrophysics of the Harvard College Observatory and the Smithsonian Astrophysical Observatory. The triplet, which has yet to be studied in detail, is presumably three images (and possibly more) of a distant quasar whose radiation has been deflected by a gravitational lens.

So ends the early history of the twin quasars. In the short eight months since their discovery they have elicited one of the most intensive investigations ever concentrated on a single celestial object. They have provided certain evidence that gravitational imaging actually occurs in nature and that the general theory of relativity can be applied to the explanation of phenomena millions of light-years away as well as of those within the solar system. Finally, the twin quasars prove that although at one time, in Einstein's words, there seemed to be "no great chance of observing [the] phenomenon," advances in technology and the persistence of individual astronomers improved the odds to the point of success.



**DEFLECTING GALAXY shows up in false-color processing of Mauna Kea photographs. Display at the left was generated by a computer program that summed and color-coded many images of the twins. Elongation of both the northern twin and the southern one in the direction of four o'clock is an artifact of imperfect alignment of the telescope optics. Stockton adjusted the northern image so that it had the same brightness as the southern one. Display at the right was made by subtracting the adjusted northern image (*top*) from the unadjusted southern one (*bottom*). What remains is an image of a galaxy one arc second north of the southern twin.**

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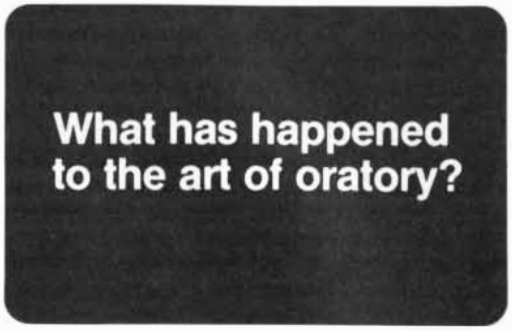


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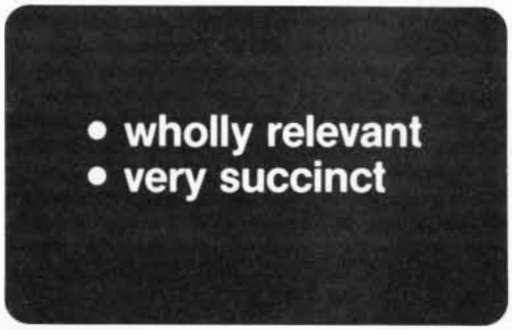


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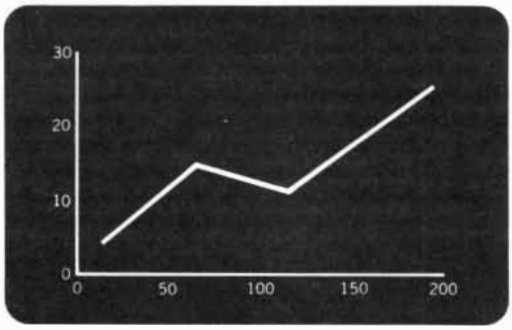


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# SCIENCE AND THE CITIZEN

## *Running against Darwin*

The theory of evolution through natural selection advanced by Charles Darwin in 1859 has become the organizing principle of modern biology, but in recent years it has been under attack by proponents of "scientific creationism," who repudiate geological evidence for a world billions of years old, fossil evidence for the gradual appearance of new species and biological evidence for the evolution of man from lower primates. The present objective of creationists is "equal time": a requirement that public-school courses and textbooks dealing with the origin of life present the creationist view as an alternative to evolution. The drive for equal time has been waged in state legislatures (unsuccessfully so far) and before state and local school boards (with some success), but until this year it had not figured in a presidential campaign. William Jennings Bryan is remembered for his championship of creationism at the Scopes trial, but in his three runs for president he campaigned against the Eastern financial establishment, not Darwinism.

Creationism and the equal-time issue entered the 1980 presidential campaign on August 22, when Ronald Reagan addressed a "national affairs briefing" held in Dallas by a politically oriented evangelical Christian organization called the Roundtable. At a news conference before his speech Reagan was asked if he thought the theory of evolution should be taught in the public schools. He answered: "Well, it *is* a theory. It is a scientific theory *only.* And it has, in recent years, been challenged in the world of science... and is not believed in the scientific community to be as infallible as it once was believed. But, if it *was* going to be taught for schools, then I would think that also the biblical theory of creation—which is not theory, but the biblical story of creation—should also be taught."

Reagan was also asked if he himself believed in the theory of evolution. "I have a great many questions about it," he answered. "I think that recent discoveries down through the years have pointed out great flaws in it."

A few days later John B. Anderson was asked if he thought public schools "should teach the biblical theory of creation." He answered: "No, no... we have to have separation of church and state." If parents want their children instructed "in a particular doctrinal view," he said, then "there are Sunday schools for that purpose, there are church schools, there are parochial schools, there are Christian day schools, and I think that's the proper place for that kind of instruction." Did Anderson himself believe "in the infallibility and absolute truth of the Bible"? He answered that although he believes in the Bible as the revealed word of God, the Scriptures "are subject to interpretation and I do not have to believe, for example, that the seven days that are spoken of in Genesis as having accounted for the creation of the universe represent seven 24-hour days.... I can interpret that in the light of contemporary history and contemporary experience."

President Carter, asked for his views on the matter, said: "The scientific evidence that the earth was formed about four-and-a-half billion years ago and that life developed over this period of time is convincing. I believe that responsible science and religion work hand in hand to provide important answers concerning our existence on the earth. My own personal faith leads me to believe that God is in control of the ongoing processes of creation. Insofar as the school curriculum is concerned, state and local school boards should exercise that responsibility in a manner consistent with the Constitutional mandate of separation of church and state."

## *Later, Longer, Fewer*

In assessing the future trend of the human population, the growth rate in the Peoples' Republic of China is crucial, because that single nation includes a fourth of the world's four billion people. The Chinese government calculates that the rate of population increase in China has been halved in recent years. It was 23.4 per 1,000 in 1971 and 12.1 per 1,000 in 1978. The intent of the Chinese is to reduce the rate to five per 1,000 in 1985 and then to zero by the end of the century.

Some details regarding the methods of the Chinese have recently been reported by H. Yuan Tien of Ohio State University, who writes in *International Family Planning Perspectives.* Tien examined records of fertility and contraception in four places in Sichuan province. Such records are kept by local workers and volunteers throughout China. The records include a charting of the menstrual cycle for every woman of childbearing age and a further record for each married woman of her means of contraception and the birth date of each of her children. The collation of the data furnishes guidance to population planners in the central government. Tien observes that the keeping of the records also helps to "maintain reproductive discipline throughout the whole of China."

The effort to stop the growth of the Chinese population appears to rely on exhortation, local systems of rewards and penalties and the availability of contraceptive techniques and abortion. The exhortation is exemplified by the slogan *Wan, xi, shao* (Later, longer, fewer). "Every couple," Tien reports, "is exhorted to marry late, to space their births at long intervals and to have few children." The rewards and penalties are exemplified by a set of 29 regulations recently announced in Guangdong province. According to these, an only child receives free nursery care or free medical care, whereas on the birth of a third child (or of a second child less than four years after the birth of the first) the parents' salaries are reduced.

In response to the national effort the women in the four places studied by Tien are deferring marriage, but only by a few years. For women 23 or older "marriage is almost universal." Although all forms of contraception are available (birth-control pills, intrauterine devices, condoms and male and female sterilization), the newly married do not use them. Hence "most women conceive soon after marriage." Almost no marriage stays childless by choice, and the government does not expect it.

The married women evidently wish to adhere to a slogan of the 1970's: "One is not too few, two is good, three is too many." Tien's data show that of the women now using the pill 70.7 percent have had one or two children. The rest have had more. For women now using IUD's the corresponding statistic is 72.4 percent. Sterilized women tend to be older than the users of the pill or an IUD, and many of them "had already had two, three or four children before reaching their 30th birthday." Similarly, "the data show that more than 80 percent of vasectomized men had fathered three or more children."

The data on sterilization thus suggest a "relatively low effectiveness of contraceptive use." Instead it is abortion that has taken "a major part in keeping fertility within bounds." In Chengdu, the capital of Sichuan, Tien finds that the number of abortions "has grown more or less steadily" through the 1970's, and "in the most recent year, 1979, between January and June, 58 percent of all pregnancies were terminated by abortion." The abortion rate in Beijing (Peking) municipality is reported to be similar.

Tien notes a recent change in the interpretation of "fewer." In the past two years "the notion of 'shao' was changed first to 'one is best,' and then to 'one is enough.'" This suggests the national strategy. If all births after the second could be prevented, the annual rate of population growth would be reduced to seven per 1,000; the prevention of some of the second births would then reduce

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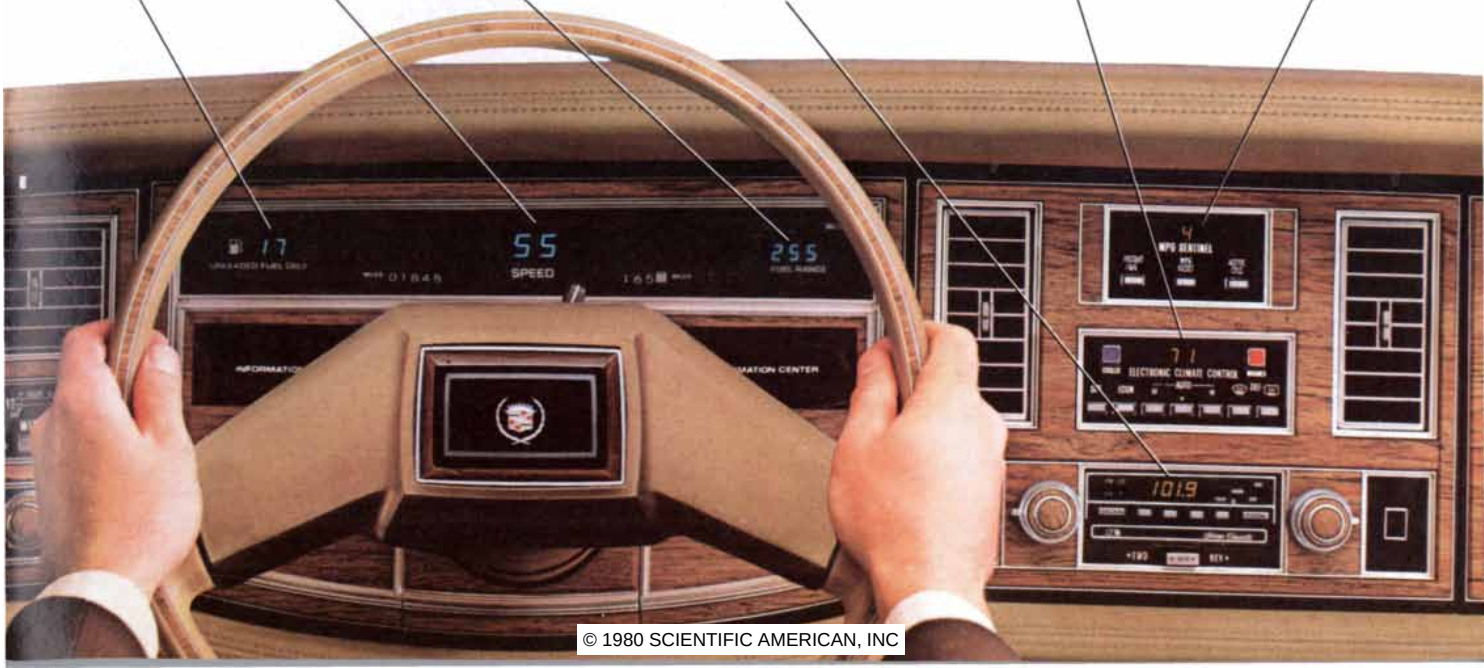


the rate to five. Tien considers this goal attainable by 1985, but apparently it will require "tremendous increases in the number of induced abortions and sterilizations." In the first issue of the new journal *Renkuo Yanjiu* (*Population Research*) three Chinese investigators (who are quoted by Tien) cite "a pressing need to strengthen information and education in the scientific knowledge of contraception."

### *Quarkprints*

The quark has now been missing in action for 17 years. It is the ultimate constituent of the proton, the neutron, the pion and a host of other particles, but a quark by itself has not yet been unequivocally identified. Indeed, there is reason to suspect that quarks are permanent prisoners in the particles they compose and that they will never be seen. The quest continues nonetheless. A new search is about to get under way, employing a novel method based on a printing technology.

What is striking about the quark model is its comprehensiveness. The particles made up of quarks comprise the particle family of hadrons, and more than 200 are known. Just five kinds of quark can account for the internal structure of all of them. Each hadron is composed either of three quarks or of a quark and an antiquark. The properties of the hadron are established by its constituent quarks. For example, the proton has one unit of electric charge because it consists of two "up" quarks, each with a charge of $+2/3$, and one "down" quark, with a charge of $-1/3$.

Although the quark model constitutes an impressive simplification of nature, it was not clear initially whether the quarks were real objects or mere theoretical constructs for bringing order to an unwieldy number of hadrons. In 1963, when the concept of quarks was introduced, there was no direct evidence of their existence, and they had several peculiar properties. For example, the quarks seemed to violate the exclusion principle, the quantum-mechanical equivalent of the intuitive notion that no two things can be in the same place at the same time. Moreover, not all physicists viewed the idea of fractionally charged quarks as a comforting explanation of the proton's one-unit charge. They were disturbed by the fact that all other known particles have a charge that is an integral multiple of the proton's charge.

A preponderance of experimental evidence and theoretical arguments has by now convinced most physicists that quarks are real. Experiments in the late 1960's in which high-energy electrons were scattered by protons revealed the presence of a substructure within the proton. More recent experiments at the Fermi National Accelerator Laboratory

near Chicago have provided evidence that quarks and antiquarks carrying a fractional charge exist inside the pion. On the theoretical front, the quarks have been reconciled with the exclusion principle by the introduction of a new physical property called color.

The idea that quarks are permanently imprisoned in hadrons has become more than an ad hoc explanation of the failure to observe a quark in isolation. It has helped to account for the properties of the strong interaction that binds the quarks together to form hadrons. For now, however, the various confinement theories cannot be tested directly, and so the hunt for the free quark has not been abandoned.

The new search that is now about to be undertaken was conceived by Greg Hirsch and Ray Hagstrom of the Lawrence Berkeley Laboratory of the University of California. It promises to be cheaper and simpler than the methods tried up to now, and to cover more territory.

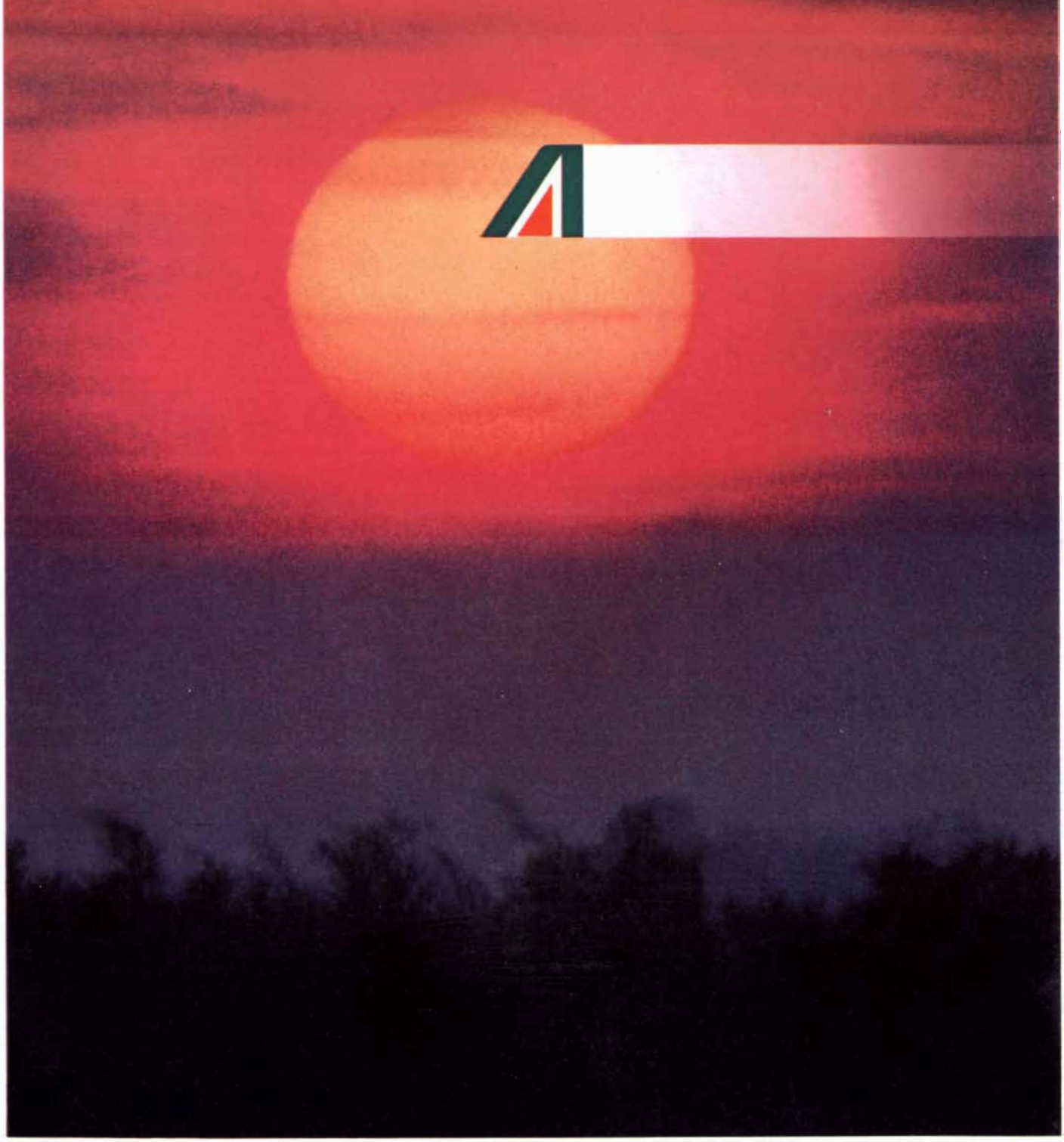
All quark searches try to detect the elusive particle by its fractional charge. Most of the searches have been modeled on the famous oil-drop experiment with which Robert A. Millikan measured the charge of the electron in 1923. Millikan suspended drops of oil in the electric field set up between two charged plates. He compared the drift speed of the drops when the field was on and when it was off and was able to conclude that the electric charge on a drop is always an integral multiple of the charge of the electron.

The most successful adaptation of the Millikan oil-drop experiment to the search for the quark has been done by a group of investigators headed by William M. Fairbank of Stanford University. These workers levitate microscopic spheres of the metal niobium in a magnetic field. An electric field is then applied, so that if a sphere carries an electric charge, the sphere will be accelerated. The next step is to try to neutralize the charge of the sphere by judiciously shooting electrons or positrons at it. (The positron is the particle with the same mass as the electron but the opposite charge.) If a sphere's charge cannot be brought to zero, the sphere presumably has not an integral charge but a fractional one. Such a result would suggest that somewhere in the material of the sphere there is a free quark.

Although the technique of Fairbank's group is easy to describe, it is quite difficult to execute. The magnetic force supporting the sphere is a billion times stronger than the applied electric force, so that great technical ingenuity is required even to detect the sphere's charge. Fairbank and his collaborators have reported detecting six lone quarks, but no one has been able to reproduce the results.

The new approach suggested by Hirsch and Hagstrom offers a welcome independent check on the Fairbank result. Their method is based not on the Millikan oil-drop experiment but on the technology called ink-jet printing. In this form of printing a stream of ink squirted from a nozzle is broken up into small drops, each of which is independently given an electric charge. The drops can be steered by an electric field to various positions on a piece of paper, so that an array of drops forms a letter of the alphabet.

It was after reading an article on ink-jet printing in SCIENTIFIC AMERICAN that Hirsch and Hagstrom devised their technique of searching for quarks. (The article, by Larry Kuhn and Robert A. Myers of the International Business Machines Corporation, appeared in April, 1979.) Small drops of a conductive liquid such as mercury are to pass through an electric field as they fall about 10 feet in air. The field deflects each drop by an amount proportional to its charge, so that the stream of drops spreads out like a fan. Since electric charge is quantized, the fan will not be solid but will resemble the fingers of a hand, with each finger corresponding to a particular integral charge. If a drop carries a lone quark, the drop will have a fractional charge



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If free quarks exist, it is already evident they are quite rare. One advantage of the ink-jet technique is that it can sift through a comparatively large volume of matter quickly. Each second several thousand drops will move through the apparatus, so that several grams of mercury could be examined in a day. The total amount of matter studied in all the previous quark searches comes to only a few milligrams.

### *Steady Stream*

Industrial microbiology is an ancient art that has recently acquired a new glamour. The biochemical capabilities of microorganisms such as yeasts and molds have long been exploited in making bread, beer, wine, cheese and many other foods; they have also been applied to the manufacture of medicines and a few other products. Now there is the prospect of genetically modifying the microorganisms to extend the range of their talents. By this means, for example, bacteria can be induced to synthesize human hormones. Genetic engineering is not all that is needed, however, for the development of a biochemical technology. Engineering of a commoner kind must provide the optimum conditions for the activities of the microorganisms. Up to now most biological processing has been done by a comparatively simple batch method. There is much to be gained by converting to a continuous-flow system.

The brewery can be taken as a model of the batch process. In a large vat raw materials and nutrients are mixed with a culture of microorganisms, which grow and reproduce while carrying out the desired chemical conversion. When the process is complete, the vat is emptied and a new batch is started. The system works exceedingly well in breweries, but it has certain drawbacks when more elaborate biological processes are considered. Controlling the chemistry of such a complex mixture can be difficult. What may prove to be most detrimental of all is that when a batch is completed, the microorganisms are lost. Where the organisms themselves are difficult to prepare the loss can be costly; moreover, in some products (such as antibiotics) contamination with other microorganisms is unacceptable.

The prototypical process of continuous flow is that of an oil refinery. There the raw material is pumped into one end of a reactor column and the product is withdrawn in a continuous stream from the other end. Stages in the processing are easily segregated, with the product of one reactor serving as the feedstock for the next.

In adapting biological processes to the continuous-flow method it turns out that the most pressing need is for a means of anchoring the microorganisms to a solid substrate. They must be bathed in the liquid that flows through the reactor, but they must not be washed out with it. The method of attachment must not impair the biochemical activity of the cells. Methods of immobilizing cells for biochemical reactors were reviewed by P. Dunnill of University College London in a discussion of industrial microbiology organized last year by the Royal Society of London. His assessment of the technology has now been published in the society's *Philosophical Transactions*.

There is one major biological industry that has long employed the continuous-flow method, namely sewage treatment. In the commonest method of treatment sewage trickles through a bed of stones, where bacteria and other microorganisms decompose the organic matter. The bacteria are bound to the stones by a layer of slime.

Most other applications of industrial microbiology demand a more carefully selected culture. One process for which an immobilized-cell technology has been developed is the manufacture of sweeteners from starch. Starch is a polymer of the sugar glucose, and it can be made sweet by converting some of the glucose into fructose. The reaction is catalyzed by enzymes secreted by several bacterial species. In a method em-

ployed by the British company Imperial Chemical Industries Ltd. the conversion is carried out by bacteria of the genus *Arthrobacter*. The bacteria are compressed into dry cylindrical pellets, which fill a column reactor.

The Tanabe Seiyaku Company of Japan has devised an immobilized-cell procedure for converting fumaric acid into L-aspartic acid. The conversion is accomplished by cells of the bacterium *Escherichia coli*. The cells are first suspended in a solution of acrylamide, which is polymerized to form a gel of polyacrylamide. The gel is a permeable solid matrix that traps the bacteria but allows the feedstock and nutrient broth free access to them. The biological activity of the entrapped cells declines, but only slowly: the half-life is about 120 days.

Bacteria enmeshed in polymer gels have also been employed in smaller-scale laboratory projects. For example, cells of *Arthrobacter simplex* fixed in this way have dehydrogenated the steroid cortisol, and mutant cells of the bacterial species *Pseudomonas putida* have oxidized benzene. In these experiments it was found that the reaction rate did not decline initially; on the contrary, it increased steadily for up to about 30 days. The explanation of the increase is that the cells reproduce in the pores of the gel. When the reaction rate does eventually fall off, it is because overcrowding in the rigid matrix causes some of the cells to implode.

Many of the chemical transformations mediated by microorganisms are actually catalyzed by a single enzyme. One alternative to immobilized-cell methods, therefore, is to extract and purify the enzymes and attach the molecules to a solid substrate. The partial conversion of glucose into fructose is done on a large industrial scale by such fixed enzymes. A continuous-flow fructose plant operated by the A. E. Staley Company has a capacity of some 450,000 tons per year.

Ultimately even the brewer's art might be transformed by immobilized-cell or immobilized-enzyme technology. It has been found that yeast cells can survive in a gel at a concentration of a billion cells per milliliter. When such a yeast-loaded gel is installed in a continuous-flow reactor and supplied with the appropriate nutrients, the output stream is 10 percent ethyl alcohol.

### *Path between the Seas*

For many years the government of Israel has considered a plan to build a canal from the Mediterranean Sea to the Dead Sea, taking advantage of the 400-meter difference in elevation to generate electricity in a hydroelectric plant. This would also have restored the Dead Sea's evaporation equilibrium, which was disturbed by the loss of some 50 percent

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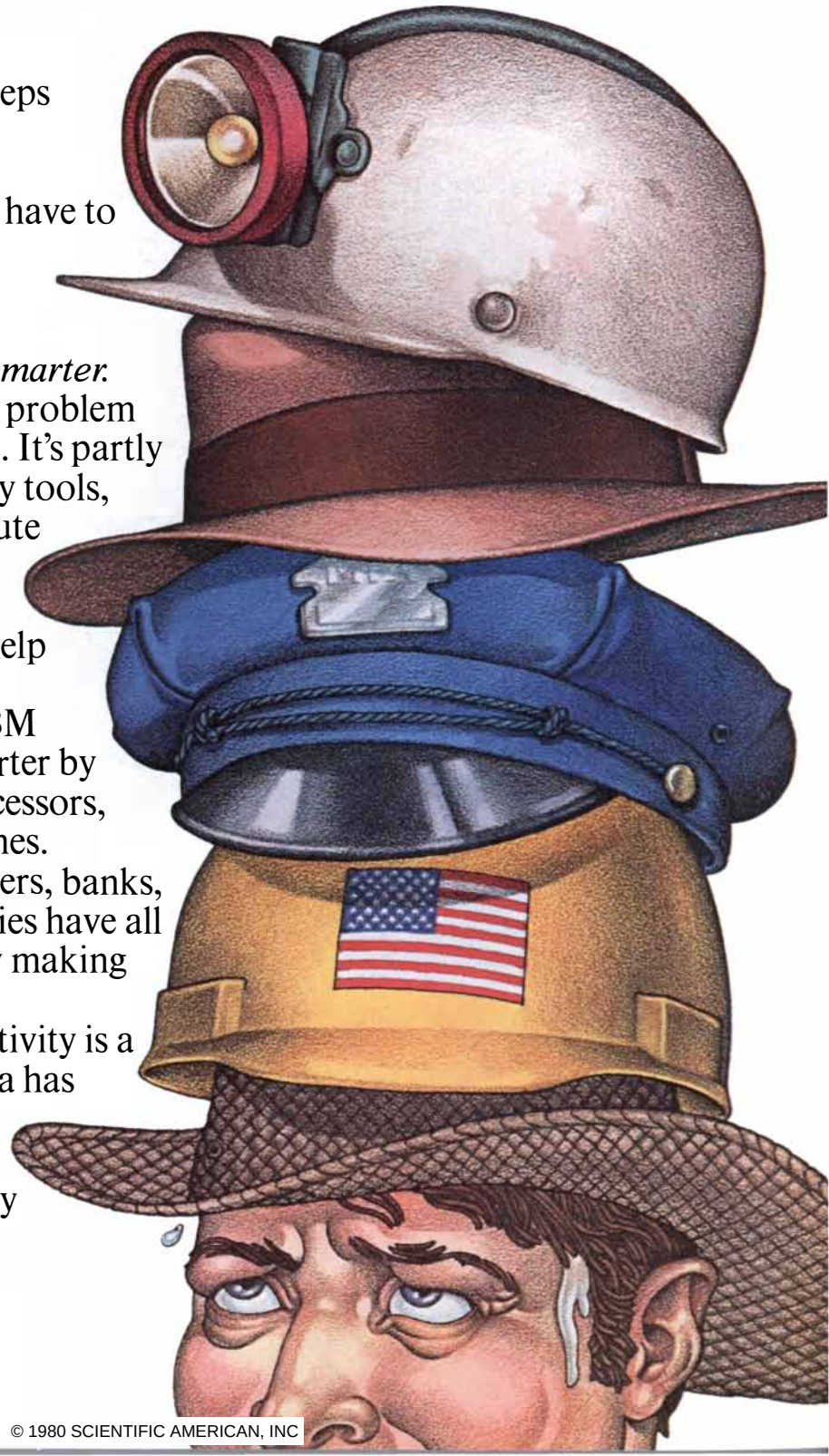


of the supply coming from the Jordan River, its only feeder. The Jordan's waters were diverted to the Negev in the 1950's and have been a key factor in Israel's agriculture. The level of the Dead Sea is expected to drop after 1983 with the completion of Jordan's diversion of the Yarmukh, the main affluence of the Jordan River. Until as recently as 1975 the economics of the project were deemed to be unfavorable. This year, however, a working group appointed by the government in 1978 and headed by the well-known physicist Yuval Ne'eman reported that with rising oil prices the balance had tipped in favor of the canal. On the basis of that report the government has now decided to go ahead.

Under the present plan the canal will run approximately 70 miles in a curving path from Deir el Balah on the Mediterranean southeasterly to an area south of Beersheba and thence northeasterly to the Dead Sea near Masada. The cost, including the hydroelectric plant, is estimated to be about $680 million. Assuming such an investment, Ne'eman says, the electricity generated would pay for the project in less than 30 years.

The idea of a canal between the seas was put forward in the 19th century by British colonialists, who proposed it as a barrier to a Russian thrust toward the Suez Canal. The hydroelectric plan was favored by Theodor Herzl, a founder of the Zionist movement, as part of his vision for the development of the prospective state of Israel. Today the project is seen in Israel as an integral part of planning for the country's energy requirements.

Notwithstanding the government's approval, a start on the construction of the canal may have to await the resolution of certain problems. One is that the first stage of the planned route from the Mediterranean crosses the Gaza Strip, an area of contention between Israel and Egypt. The route may have to be shifted. Moreover, there is concern in Jordan (with which Israel shares control of the Dead Sea) that the influx of Mediterranean water would change the chemistry of the Dead Sea and threaten Jordanian potash plants on the east bank.

## *The Jukes Redeemed*

In the endless debate over nature v. nurture the favorite traditional citation of those who viewed heredity as the dominant influence in human affairs was the lamentable history of the Jukes family, the descendants of five sisters in the Finger Lakes region of New York in the second half of the 19th century. In the annals of American eugenics the New York Jukes rank with the New Jersey Kallikaks as standard examples of hereditary degeneration. It now appears that the sordid reputation of the Jukes family stems exclusively from a systematic distortion of the Jukes case histories; the compiler of the case histories, Richard L. Dugdale, did not blame the troubles of the Jukes on their genes. Indeed, he suggested that altered nurture could provide a cure for the Jukes's condition. Dugdale called for social reform: "The correction," he wrote, "is change of environment."

How was Dugdale the environmentalist posthumously converted to a hereditarian? Elof Axel Carlson of the State University of New York at Stony Brook traces the process in *BioScience*. Dugdale, an enthusiastic young penal reformer, first published his study of the Jukes (a pseudonym of his invention) in a report to the New York State Prison Association in 1874. The report was subsequently issued in five editions, three of them published as books for the general public. Dugdale died in 1883; the distortion of his views began with his obituary in *The New York Times*. Mistakenly stating that "every member of [the Jukes family] was a criminal of greater or less degree," the notice concluded that "the whole question of crime and pauperism rests strictly and fundamentally on a physiological basis."

The next notable distorter was David Starr Jordan, who was then the president of Indiana University. Jordan was an ichthyologist and a disciple of the British eugenicist Francis Galton. In *Footnotes to Evolution,* published 15 years after Dugdale's death, Jordan selectively cited the Jukes study to support his own opinions. "Dugdale has shown," he wrote, "that parasitism, pauperism, prostitution and crime reappear generation after generation." He concluded that "every family of Jukes... which enters at Castle Garden [the immigration depot in New York City] carries with it the germs of pauperism and crime." Jordan went on to become the first president of Stanford University.

Less prominent than Jordan but his equal as a muddier of Dugdale's views was C. B. Davenport of Cold Spring Harbor, N.Y. In 1913 Davenport described the Jukes as "families of defectives and criminals that can be traced back to a single ancestor" and pointed out that the "Jukes's protoplasm has been multiplied and dispersed during the subsequent years and is still marching on." Davenport was not reluctant to embellish. The Jukes sister whom Dugdale named "Margaret" escaped his attention, although Jordan had called her "the mother of criminals." To "Ada," however, Davenport attributed the preponderance of criminal Jukes, to "Bell" the sexually immoral Jukes and to "Effie" the Jukes paupers. As the single ancestor responsible for the family's misfortunes Davenport cited "Max," "a good-natured, lazy sot, without doubt of defective mentality."

In 1916 A. H. Estabrook of the Carnegie Institution of Washington came on Dugdale's manuscript and notes and undertook to bring the Jukes family record up to date. By then there were more than 2,000 Jukes descendants, about half of whom were still living at the time of Estabrook's study. He characterized 600 of these Jukes as "feebleminded and epileptic" and said he found among them "83 alcoholics" and "41 criminals." He noted with regret that "there are now only three in custodial care."

By the early years of the 20th century the hereditarian interpretation of the Jukes studies had become established as an argument supporting the view that poverty, crime and a variety of other social problems are the result of inborn tendencies. The program of the eugenicists to rid the population of supposedly bad genes was soon given legal force in discriminatory immigration laws and compulsory sterilization of the indigent and the insane. Dugdale's proposed remedies had been quite different: he had recommended improved health care, remedial education for the underprivileged, penal reform and assistance to poor families. Not all of his ideas have yet been given a fair trial.

# Carbohydrates

*Sugars and chains of sugar units are the most abundant constituent of living matter. New carbohydrates are still being discovered, as are new roles for them in normal biological processes and disease*

by Nathan Sharon

The four major classes of compounds essential to life are nucleic acids, proteins, lipids and carbohydrates. Over the past 30 years the first three classes have received much attention from chemists and biologists, whereas during most of that time the carbohydrates were largely neglected, partly in the belief that their chemistry and biology had been fully worked out. In the past decade, however, research on carbohydrates has been revived and is now expanding rapidly. As a result of many new developments carbohydrate research is today broad and diverse.

The study of carbohydrates and their derivatives has greatly enriched chemistry, particularly with respect to the role of molecular shape and conformation in chemical reactions. Recent carbohydrate investigations have played a decisive role in the characterization of various antibiotics and antitumor agents. Such studies have led to the discovery of new biosynthetic reactions and enzymic control mechanisms and are contributing significantly to the understanding of many fundamental biological processes, for example the interaction of cells with their environment and with other cells. As a result revolutionary new methods for combating bacterial and viral infections and for targeting drugs on diseased cells and organs are being envisioned. Carbohydrate research has also provided a basis for recognizing the enzyme deficiency underlying several genetic disorders and has led to the hope that they can be treated effectively. A common theme behind many of the recent findings, which is also a powerful driving force in carbohydrate research, is the realization that monosaccharides (the basic units of carbohydrates) can serve, as nucleotides and amino acids do, as code words in the molecular language of life, so that the specificity of many natural compounds is written in monosaccharides.

Carbohydrates are sugars or (like starch and cellulose) chains of sugars. To most people sugar is the common household foodstuff, which to the chemist is sucrose. Chemically the molecule of sucrose consists of two monosaccharides, or simple sugars, glucose and fructose, that are hooked together; it is thus a disaccharide. More than 200 different monosaccharides have been found in nature, all of which are chemically related to glucose or fructose. As a rule they are white crystalline solids that dissolve readily in water. Some of them have not been obtained in amounts sufficient for testing their sweetness, but they are still called sugars, as are the monosaccharides that are found to be not sweet.

Glucose is the best-known monosaccharide; indeed, it has probably been investigated more thoroughly than any other organic compound. It was undoubtedly known to the ancients because of its occurrence in granulated honey and wine must. References to grape sugar, which is glucose, are to be found in Moorish writings of the 12th century. In 1747 the German pharmacist Andreas Marggraf, whose isolation of pure sucrose from sugar beets is an example of the chemical art of the time at its best, wrote of isolating from raisins "eine Art Zucker" (a type of sugar) different from cane sugar; it was what is now called glucose. The action of acids on starch was shown to produce a sweet syrup from which a crystalline sugar was isolated by Constantine Kirchoff in 1811. Later workers established that the sugar in grapes is identical with the sugar found in honey, in the urine of diabetics and in acid hydrolysates of starch and cellulose. The French chemist Jean Baptiste André Dumas gave it the name glucose in 1838. The structure of glucose and of several other monosaccharides, including fructose, galactose and mannose, was established by about 1900, mainly by the brilliant work of the German chemist Emil Fischer, who thereby laid the foundations of carbohydrate chemistry.

Monosaccharides rarely exist as such in nature. They are found in the form of various derivatives, from which they can be liberated by hydrolysis with aqueous mineral acids or with enzymes. The most abundant of the derivatives are polysaccharides, which are made up of sugar units formed into giant molecules that can consist of as many as 26,000 monosaccharides (as in cellulose from the alga *Valonia*). Sugars also occur frequently as oligosaccharides, which are compounds made up of from two to 10 monosaccharides. Sugars are frequently found in combination with other natural substances.

## The "Water of Carbon"

The name carbohydrate was originally assigned to compounds thought to be hydrates of carbon, that is, to consist of carbon, hydrogen and oxygen in the general formula $C_n(H_2O)_n$. Indeed, glucose and other simple sugars such as galactose, mannose and fructose do have the general formula $C_6H_{12}O_6$. They are typical hexose monosaccharides, meaning that they have six carbon atoms. With the accumulation of more data the definition has been modified and broadened to encompass numerous compounds with little or no resemblance to the original "water of carbon." Carbohydrates now include polyhydroxy aldehydes, ketones, alcohols, acids and amines, their simple derivatives and the products formed by the condensation of these different compounds through glycosidic linkages (essentially oxygen bridges) into oligomers (oligosaccharides) and polymers (polysaccharides).

Much of the current interest in carbohydrates is focused on such substances as glycoproteins and glycolipids, complex carbohydrates in which sugars are linked respectively to proteins and lipids. They are termed glycoconjugates. It should also be noted that in the excitement about nucleic acids a simple fact is being forgotten: they too are complex carbohydrates, since monosaccharides are among their major constituents (ribose in RNA and deoxyribose in DNA).

Carbohydrates are the most abundant group of biological compounds on the earth, and the most abundant carbohydrate is cellulose, a polymer of glucose; it is the major structural material of plants. Another abundant carbohydrate

**CELL-SURFACE ROLE** of a carbohydrate, mannose, is indicated in this scanning electron micrograph made by Fredric Silverblatt and Craig Kuehn of the Veterans Administration Hospital in Sepulveda, Calif. Cells from tissue on the inside of the human cheek occupy the background of the micrograph; the white cylindrical objects are *Escherichia coli* bacteria. The mannose, which is on the cell membrane, is not visible, but it is causing the *E. coli* to adhere to the tissue surface. Such adherence to surfaces is the first step in a bacterial infection.

is chitin, a polymer of acetylglucosamine; it is the major organic component of the exoskeleton of arthropods such as insects, crabs and lobsters, which make up the largest class of organisms, comprising some 900,000 species (more than are found in all other families and classes together). It has been estimated that millions of tons of chitin are formed yearly by a single species of crab!

Carbohydrates are also the fuel of life, being the main source of energy for living organisms and the central pathway of energy storage and supply for most cells. They are the major products through which the energy of the sun is harnessed and converted into a form that can be utilized by living organisms. According to rough estimates, more than 100 billion tons of carbohydrates are formed each year on the earth from carbon dioxide and water by the process of photosynthesis. Polymers of glucose, such as the starches and the glycogens, are the mediums for the storage of energy in plants and animals respectively. Coal, peat and petroleum were probably formed from carbohydrates by microbiological and chemical processes.

Carbohydrates comprise only about 1 percent of the human body; proteins comprise 15 percent, fatty substances 15 percent and inorganic substances 5 percent (the rest being water). Nevertheless, carbohydrates are important constituents of the human diet, accounting for a high percentage of the calories consumed. Thus some 40 percent of the calorie intake of Americans (and some 50 percent of that of Britons and Israelis) is in the form of carbohydrates: glucose, fructose, lactose (milk sugar, a disaccharide of glucose and galactose), sucrose and starch.

Sucrose is a major food sugar. Its world production rose from eight million tons in 1900 to nearly 88 million in 1977. No other human food has shown an increase in production on this order in the same period. The amount of sucrose produced by a country is an index of its average income. In the richer countries, such as the U.S., Britain, Australia and Sweden, the annual consumption is between 40 and 50 kilograms of sucrose per person, whereas in the poorer ones, such as India, Pakistan and China, it is five kilograms or less. It has often been suggested that the high sucrose diet may have detrimental effects on the health of people in developed countries, being responsible to some extent for the increase in such diseases as diabetes, obesity and dental cavities.

Carbohydrates are the raw materials for industries of great economic importance, such as wood pulp and paper, textile fibers and pharmaceuticals. The principal industrial carbohydrate is undoubtedly cellulose: its worldwide use is estimated at 800 million tons per year. Polysaccharides with gelling properties, such as agar, pectic acid and carrageenans, are important in the food and cosmetic industries.

## Research Difficulties

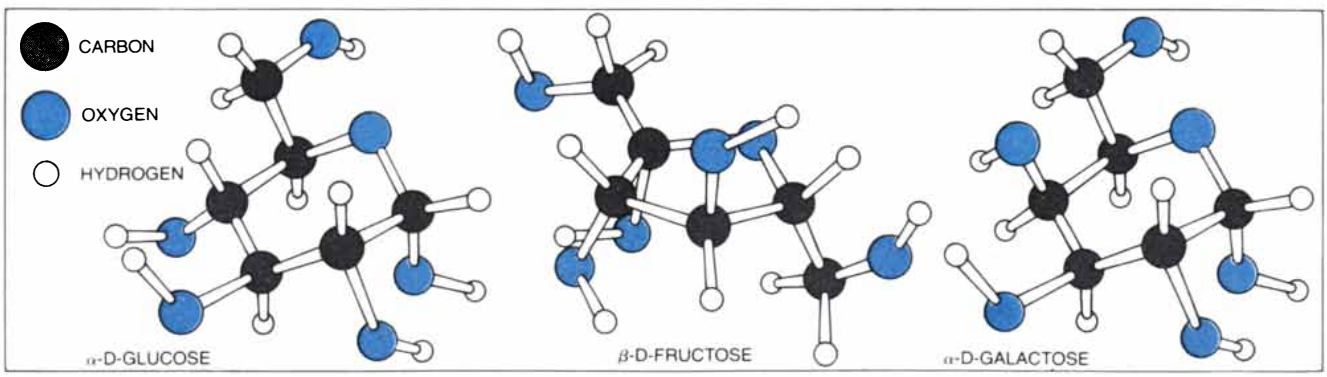
The major polysaccharides I have mentioned—cellulose, starch, glycogen and chitin—are relatively simple polymers: they are homopolymers, made up of one type of monomer (glucose or acetylglucosamine). This seeming simplicity, perhaps even dullness, of structure is probably one of the reasons carbohydrates seemed to lack interest.

Another important reason chemists tended to shy away from the study of carbohydrates stemmed from the many chemical problems encountered in dealing with these materials. Sugars are multifunctional compounds with several hydroxyl (–OH) groups, usually four or five in the hexose sugars, most of which are of approximately equal chemical reactivity. The manipulation of a single selected hydroxyl group is often a serious problem to this day. Blocking one hydroxyl group or leaving one free can be achieved only with great difficulty and requires the careful design and execution of a complex series of reactions. The synthesis of a disaccharide is therefore a considerable achievement; trisaccharides have rarely been synthesized, and there are only a few reports on the synthesis of higher saccharides.

By way of contrast, in protein chemistry peptides made up of dozens of amino acids can readily be synthesized, not only manually but also by automatic methods. At least three proteins, insulin (made up of 51 amino acids), ribonuclease (124) and lysozyme (129), have been synthesized. One reason for the relative ease of such syntheses is that the number of steps involved in the preparation of a peptide is considerably less than the number required for the synthesis of an oligosaccharide of similar size. It is even more important that a far larger number of isomeric oligosaccharides (the same in composition but different in structure) than of oligopeptides can be obtained from a given number of corresponding monomers.

An added complication for the chemist is that whereas proteins and nucleic acids are linear polymers, polysaccharides are commonly branched. This characteristic greatly increases the number of possible structures and therefore the difficulties of studying polysaccharides. Luckily for carbohydrate chemists many of the possible structures are apparently not formed in nature.

The recent revival of interest in carbohydrates can be ascribed primarily to the introduction of much improved methods. Carbohydrate chemists in the first half of this century had to rely almost exclusively on carefully controlled chemical transformations and on optical measurements (chiefly polarimetry) in the investigation of the structures of monosaccharides and their derivatives. Work at that time was further limited by the lack of good separation techniques and by the need of a substantial quantity (a gram or more) of material for many of the experiments. The advent of chromatography in its various forms and of powerful instrumental analytical methods, such as nuclear-magnetic-resonance spectroscopy (requiring only milligrams of material), mass spectrometry (requiring only micrograms) and X-ray-




**THREE MONOSACCHARIDES are (*left to right*) glucose, fructose and galactose. Carbohydrates being sugars or chains of sugars, monosaccharides are the basic units of the chains. Glucose, fructose, galactose and many other simple sugars fit the original definition of carbohydrates as hydrates of carbon, consisting of carbon, hydrogen and oxygen in the general formula $C_n(H_2O)_n$. With glucose, fructose and galactose the formula is $C_6H_{12}O_6$; they are hexoses: they have six carbon atoms. More than 200 monosaccharides have been found.**

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diffraction analysis, and the availability of highly specific enzymes acting on carbohydrates have given rise to a complete transformation in the approach to the problem of carbohydrate structure. Moreover, combinations of these techniques can provide information faster, more conveniently, in greater detail and with smaller quantities of material than was formerly possible. Maurice Stacey of the University of Birmingham has observed that ascertaining the constitution of a new carbohydrate would have taken three years in the 1930's but can now be done in less than three weeks.

## New and Unusual Saccharides

One result of the introduction of the powerful new techniques was the discovery of many new saccharides, both simple and complex. In recent years the number of rare sugars isolated from natural sources has increased rapidly. They have provided the carbohydrate chemist with new and challenging problems of structural determination and synthesis. I shall illustrate this state of affairs with examples from an area in which I have been active, the amino sugars: sugars in which one or more hydroxyls are replaced by an amino group.

In 1875 a young physician named George Ledderhose was working during the summer semester in the laboratory of Friedrich Wöhler in Göttingen when Ledderhose's uncle, Felix Hoppe-Seyler, a noted physiological chemist, invited him to dinner. At his uncle's suggestion he took the remains of the lobster they had eaten back to the laboratory, where he found that the claws and the shell dissolved in hot concentrated hydrochloric acid and that on evaporation the solution yielded characteristic crystals. He soon identified the crystalline compound as a new nitrogen-containing sugar, which he named *glycosamin*.

During the next 20 years much evidence was gathered to indicate that the new sugar has a structure derived by the replacement of the hydroxyl group attached to carbon No. 2 in the glucose molecule by an amino group. With the synthesis, which was still not definitive, of the amino sugar by Emil Fischer and H. Leuchs in 1903 the problem of its structure appeared to have been solved. The structure of glucosamine was unequivocally established, however, only in 1939, when Norman Haworth achieved an unambiguous synthesis that proved Fischer was correct in assigning the "gluco" structure to the amino sugar. A second amino sugar, galactosamine, was isolated in 1914 by P. A. Levene and Frederick B. La Forge at the Rockefeller Institute for Medical Research from acid hydrolysates of cartilage, tendon and aorta, but its structure was firmly established only in 1945, again attesting to the enormous difficulties such substances present. At the time that was thought to be the end of the amino-sugar story. By 1960, however, some 20 new amino sugars had been discovered. The number is now over 60.

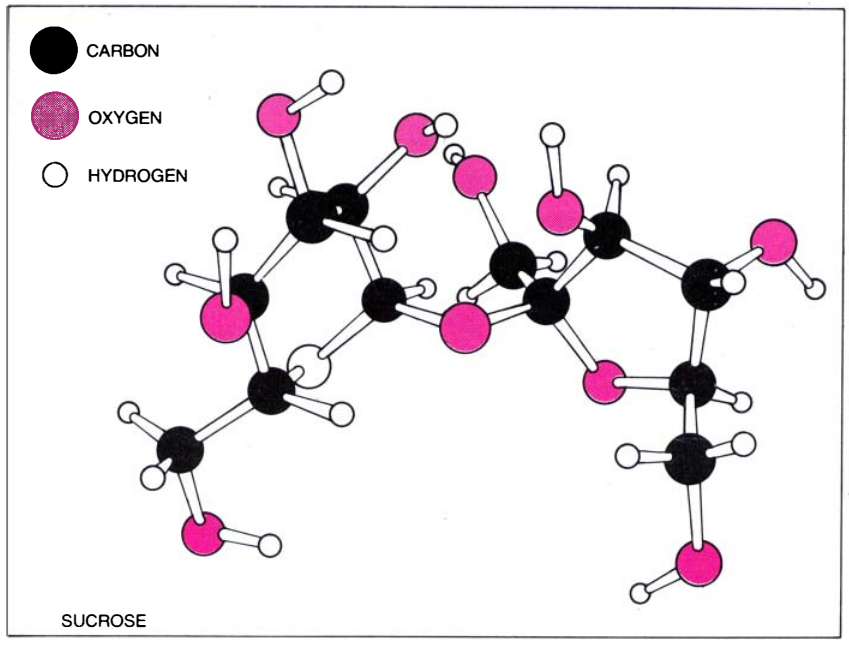
The first of the "new" amino sugars, found in 1946, was *N*-methyl-L-glucosamine, a constituent of the antibiotic streptomycin. Soon many other new amino sugars were identified in antibiotic substances. Indeed, some antibiotics have an oligosaccharide-like structure. They include the streptomycins, the neomycins and other aminoglycoside antibiotics such as the kanamycins and the paromomycins, all of which are employed clinically against bacterial infections. Another aminoglycoside antibiotic is puromycin, a well-known inhibitor of protein synthesis. The potent and clinically useful antitumor agents daunomycin and adriamycin, which have proved to be effective in the treatment of acute leukemia, are also aminoglycosides; they contain the rare 3-amino sugar daunosamine.

To learn more about the mode of action of these antibiotics and to improve on them it is imperative to synthesize analogues with different amino-sugar constituents, because it is known that structural features of the sugar components often exert a decisive influence on the pharmacological properties of the antibiotics. This objective has given strong impetus to the development of new methods of synthetic-amino-sugar chemistry and has opened the way to the preparation of new and improved antibiotics that are remarkably effective against microorganisms resistant to the natural aminoglycoside antibiotics. In no case, however, are the monosaccharide constituents alone effective in vitro in killing bacteria or in inhibiting the growth of tumors.

Interestingly enough, several disaccharides such as trehalosamine are active against bacteria. Herbert A. Blough and Robert L. Giuntoli of the University of Pennsylvania School of Medicine reported last year that the monosaccharide 2-deoxyglucose applied to the site of an infection is highly effective in the treatment of genital herpes infection, a widespread form of venereal disease caused by the herpes simplex virus, for which no cure had been available. The sugar is believed to interfere with the synthesis of glycoprotein in the virus by virtue of its similarity to mannose, an important constituent of the viral glycoproteins.

New amino sugars and other types of sugar have been isolated in recent years not only from antibiotics but also from other sources, in particular from the polysaccharides of bacteria. One of the most important is the 3-lactic-acid ether of glucosamine, known as muramic acid. This amino sugar, which is limited to bacteria, was isolated for the first time by R. E. Strange and F. A. Dark in Britain in 1956. (For a while it was nicknamed the strange and dark compound.) Its acetylated derivative, acetylmuramic acid, and acetylglucosamine form the polysaccharide backbone of the peptidoglycan in the wall of the bacterial cell.

Another new sugar is ribitol, a reduction product of ribose. It is a constituent of the teichoic acids, which were discovered by James Baddiley in Britain in the 1950's. Teichoic acids are polymers of ribitol phosphate or glycerol phosphate found in Gram-positive bacteria. In the cell wall of these organisms they act as




**STRUCTURE OF SUCROSE is depicted. Sucrose is common household sugar. It is a disaccharide: it consists of two monosaccharide molecules (glucose and fructose) joined together.**

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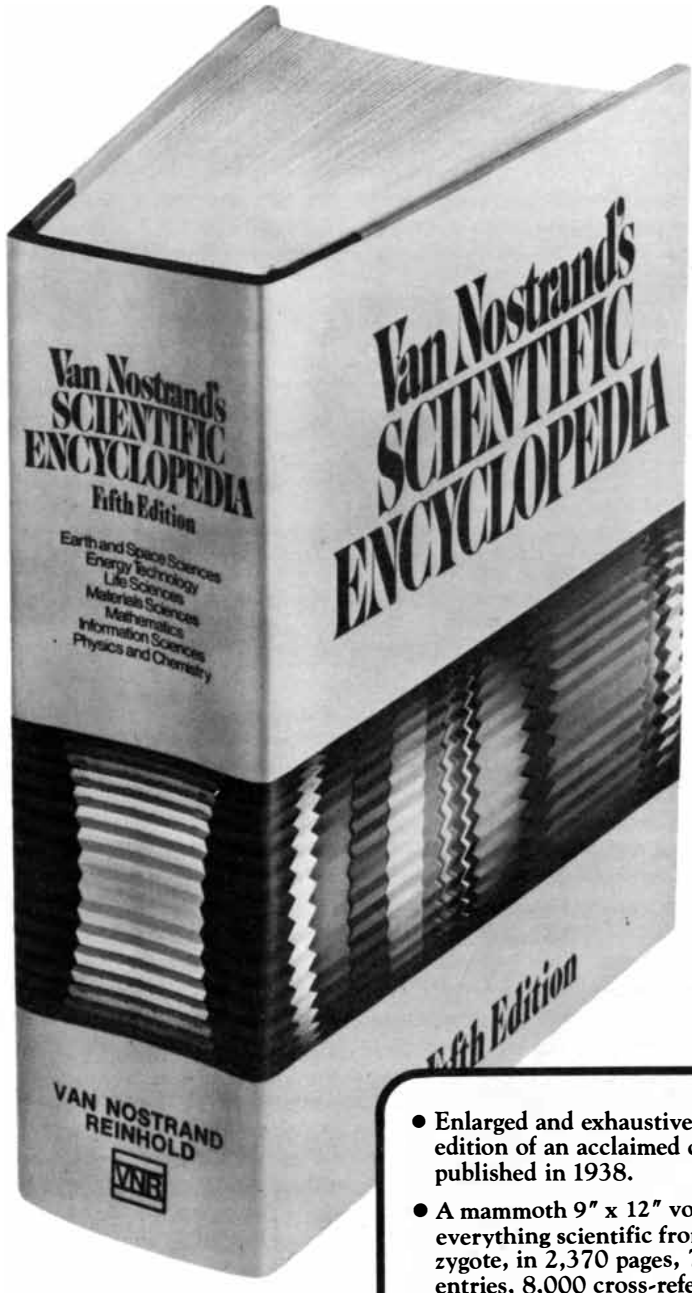


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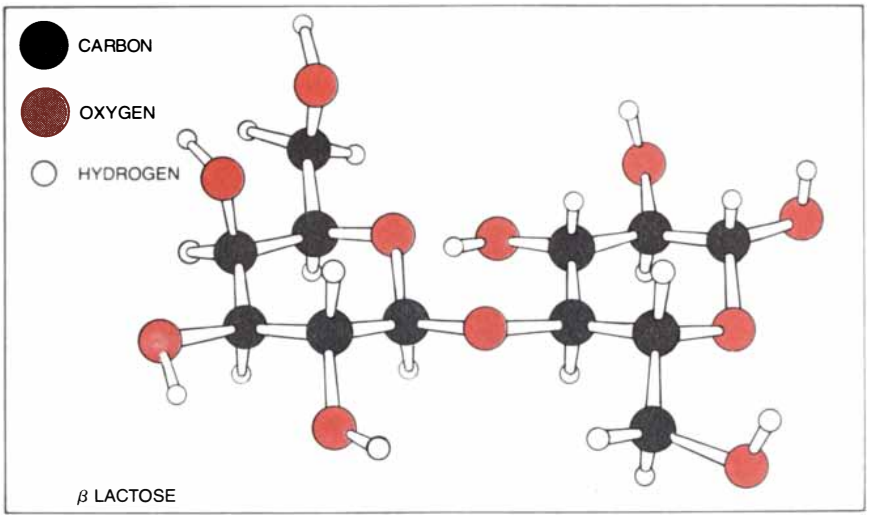
immunological determinants and as receptors of bacteriophages, that is, viruses that infect bacteria.

An important sugar of unusual structure is neuraminic acid, the parent compound of the sialic acids, which are ubiquitous in nature except for plants. Neuraminic acid is a nine-carbon sugar acid with an amino group in its molecule. Today 20 sialic acids are known, most of which were discovered during the past decade by Roland Schauer of the University of Kiel. They are among the major constituents of mucins, such as those secreted by the respiratory and urogenital tracts, and are also found in the eye socket. By virtue of their negative charge they impart to the mucin molecules an extended rodlike structure. They are therefore responsible for the high viscosity of the mucins. Only because of the mucins' sialic acid can they act as lubricants for the rotation of the eyeball, preventing the cornea from drying out and protecting it from damage by grains of dust.

In the oral cavity and the gastrointestinal tract the viscous glycoproteins incorporating sialic acid envelop foods, making them slippery and protecting the tender mucous surfaces from mechanical damage. In the cervical canal of the uterus a highly viscous plug of mucin keeps bacteria out of the uterine cavity and hence out of the abdominal cavity. This viscous barrier is lowered at the time of ovulation to admit spermatozoa. Glycoproteins rich in sialic acid that are secreted by mucous glands of the vagina also lubricate both coitus and childbirth.

A rare diamino sugar, the first of its kind, that I have been studying for the past 20 years is bacillosamine. I discovered it in a polysaccharide of *Bacillus licheniformis* in 1958 while I was working in the laboratory of Roger W. Jeanloz at the Massachusetts General Hospital. Only recently, through the joint efforts of a number of co-workers, were we able to establish its structure. We then went on to synthesize the corresponding galactose derivative in the belief that it too must occur in nature. To our great satisfaction 2,4-diamino 2,4,-6-trideoxygalactose was identified last year in natural products by workers in Stockholm and Tokyo.

A major breakthrough, which opened new horizons in biochemistry and had an immediate impact on medicine, was the discovery of sugar nucleotides and their manifold roles as intermediates in the biosynthesis of monosaccharides, oligosaccharides and polysaccharides and of complex carbohydrates. The first sugar nucleotide, uridine diphosphate glucose (UDP-glucose), was discovered by Luis F. Leloir and his co-workers in Argentina in 1949; for this discovery Leloir received a Nobel prize in 1970. At about the same time that Leloir described UDP-glucose James T. Park and Marvin J. Johnson of the University of Wisconsin observed the accumulation of similar compounds in *Staphylococcus aureus* bacteria that had been exposed to penicillin.




**LACTOSE is a disaccharide consisting of glucose linked with galactose. It is the sugar of milk and therefore (with such other sugars as glucose, fructose and sucrose) is one of the carbohydrates making up a large part (40 percent in the U.S.) of the calorie intake in the human diet.**

More than 100 different sugar nucleotides have now been identified. Most of them have the general structure of nucleoside diphospho sugar with any of the five nucleosides: adenosine, guanosine, cytidine, uridine and deoxythymidine. The sugar exhibits a large variety of structures, some of which are extremely rare.

## Biosynthetic Intermediates

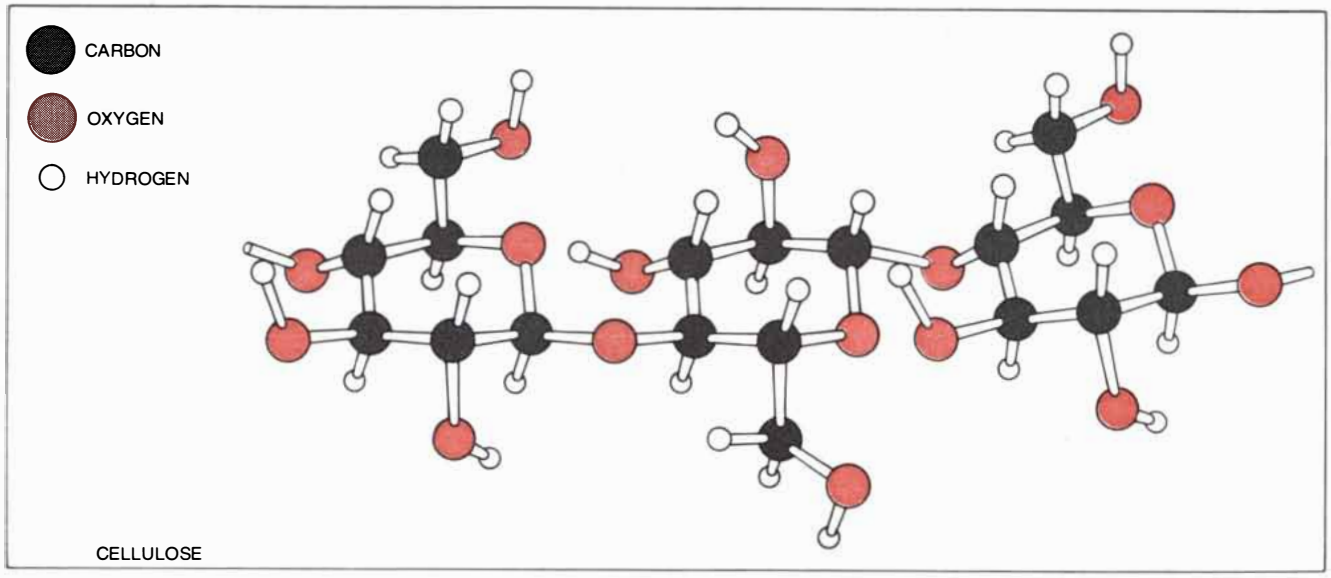
The nucleoside can be considered as a handle that holds the sugar in a form ready for transformation into other sugars or for transfer to suitable acceptors. UDP-glucose is the sugar nucleotide most commonly found in biological materials and is the starting compound for the formation of numerous other sugars. In many organisms it is converted into UDP-galactose, which is the source of galactose for the formation of lactose. UDP-glucose is also the donor of glucose for the synthesis of glucosides (for example phenyl-$\beta$-glucoside), oligosaccharides (such as sucrose and trehalose), polysaccharides (including starch and glycogen) and other glucose-containing compounds.

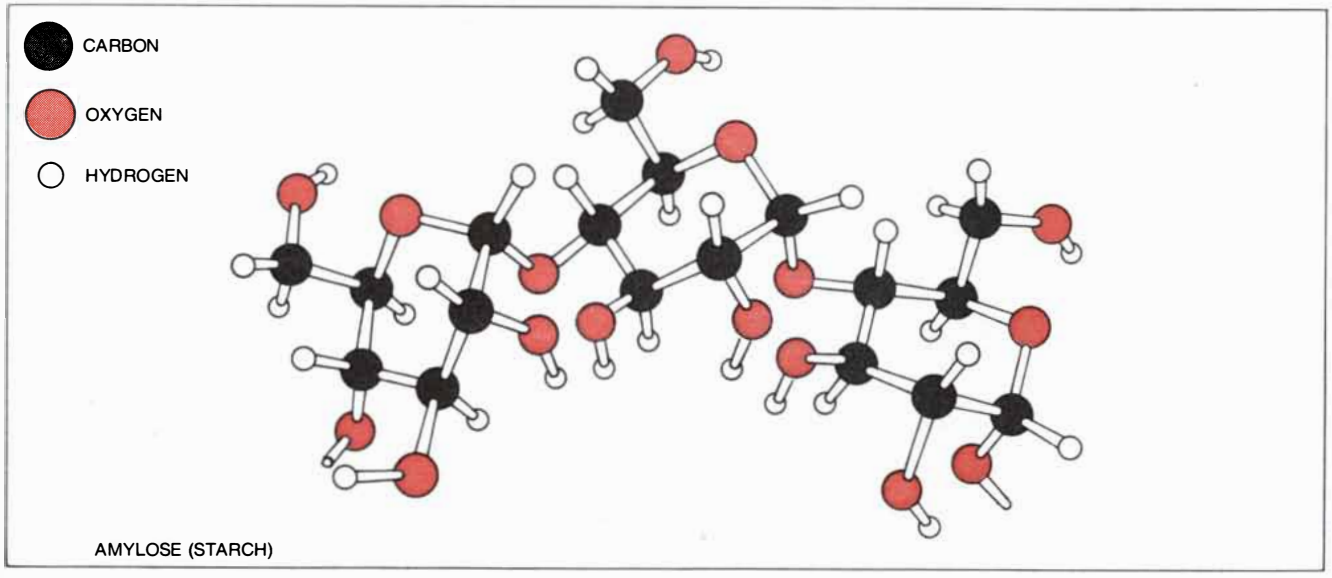
The discovery of sugar nucleotides led not only to the understanding of the biosynthesis of unusual monosaccharides and of complex saccharides but also to the discovery in 1965 by Phillips W. Robbins of the Massachusetts Institute of Technology and by Jack L. Strominger of the University of Wisconsin School of Medicine of a new type of activated sugars: the lipid-linked sugars. They are sugar derivatives linked by a monophosphate or diphosphate bridge to polyprenols, long-chain unsaturated lipids. One example of such a lipid is bactoprenol, which in the form of its sugar diphospho derivative is an intermediate in the biosynthesis of bacterial lipopolysaccharides and peptidoglycan.

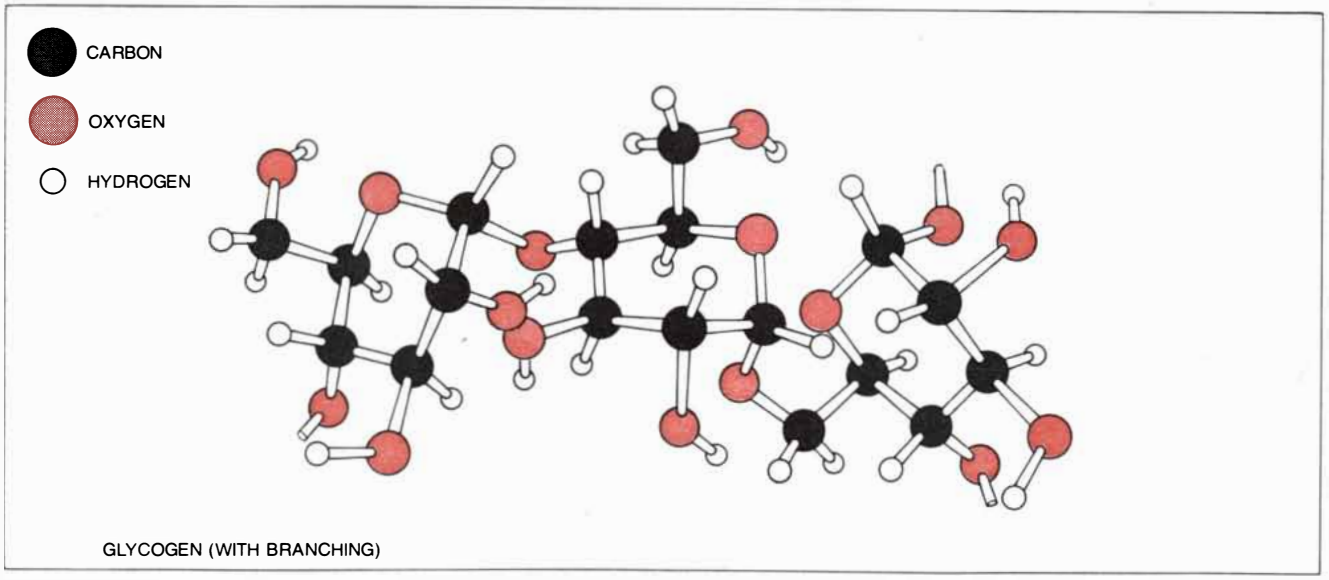
In 1970 Leloir demonstrated for the first time that similar compounds, the dolichol phosphates, participate in the biosynthesis of glycoproteins by animal cells. In bacteria the lipid-linked intermediates, which are hydrophobic (water-repelling), serve for the transport of activated sugars or oligosaccharides from the cytoplasm of the cell through the lipid-rich cell membrane to the cell surface, where polysaccharides such as the cell-wall peptidoglycan are laid down. In animals the role of these intermediates remains to be established.

As a result of investigations of the participation of the lipid-linked sugars in the biosynthesis of complex carbohydrates, new mechanisms for the assembly of biological polymers have been discovered. For example, with proteins and simple polysaccharides (such as glycogen) the biosynthesis proceeds by the addition of a single monomeric unit, in its activated form, to the growing polymer chain, whereas in complex carbohydrates the mechanism is often different. In the synthesis of the cell-wall peptidoglycan a peptide derivative of the disaccharide acetylglucosamine-acetylmuramic acid is first synthesized on the lipid carrier. This repeating unit is subsequently polymerized and is only then attached to a polymeric acceptor. A similar mechanism operates in the biosynthesis of bacterial lipopolysaccharides, except that the repeating unit consists of a trisaccharide of mannose, rhamnose and galactose.

In the biosynthesis of the carbohydrate units of glycoproteins linked to the amino acid asparagine an oligosaccharide consisting of two residues of acetylglucosamine, nine of mannose and three




**THREE POLYSACCHARIDES** are (*from the top*) **cellulose, starch and glycogen. They are homopolymers, meaning that they are made up of one type of monomer. In each of the polysaccharides depicted the monomer is glucose. The individuality of these polysaccharides and others arises from the length of the polymer chain (which in cellulose may run to several thousand units), the type of linkage between the sugar units and the occurrence of branches. Three basic units of each polysaccharide are shown here. Cellulose is a major structural component in plants. Starch and glycogen serve respectively in plants and animals for the storage of the energy that is derived from food.**

of glucose is first assembled on a lipid carrier by a complex sequence of reactions in which both sugar nucleotides and lipid-linked sugars participate. The preassembled oligosaccharide is transferred en bloc to specific asparagine residues on the growing polypeptide chain and is then "processed" to its mature, final form. This processing includes the removal by special glycosidases of the glucose and most of the mannose and their replacement by tails consisting of sialic acid, galactose and acetylglucosamine (as has been found in many serum glycoproteins and in certain viral glycoproteins). The replacement proceeds by the stepwise addition of the individual sugars from the corresponding sugar nucleotides; for example, acetylglucosamine is added by transfer from UDP-acetylglucosamine and galactose from UDP-galactose.

Research on sugar nucleotides in relation to the biosynthesis of bacterial-cell-wall peptidoglycan has led to the clarification of the mechanism of action of penicillin, which is still the most useful antibiotic. The unique effectiveness of penicillin results from the fact that peptidoglycan is not found in any organisms other than bacteria. It is therefore an excellent target for selective chemotherapeutic agents that kill the bacteria without affecting their host.

### Genetic Diseases

A completely different reason for the new wave of interest in carbohydrates stems from the fact that many of the hereditary or genetic diseases of man for which the molecular basis has been established are defects of carbohydrate metabolism, mostly of complex saccharides. One of the diseases is galactosemia, a rare familial defect in galactose metabolism caused by the lack of a single enzyme: galactose phosphate uridyl transferase. Because of the absence of this enzyme afflicted infants cannot utilize galactose or galactose-containing compounds, in particular lactose. Breast-feeding literally poisons such infants. The galactose, which is ordinarily converted into glucose and eventually into energy, accumulates in the infant's blood in the poisonous form of galactose phosphate, causing severe neural retardation and often early death.

Mainly as a result of the efforts of Herman M. Kalckar and his collaborators at the National Institute of Arthritis and Metabolic Disorders in the late 1950's the diagnosis of galactosemia can be made before the disease is far advanced. The procedure tests for the presence of the enzymes that metabolize galactose. If one of the enzymes is missing and the infant is given a diet free of galactose, all symptoms of galactosemia disappear and development becomes normal.

Most other genetic defects of carbo-

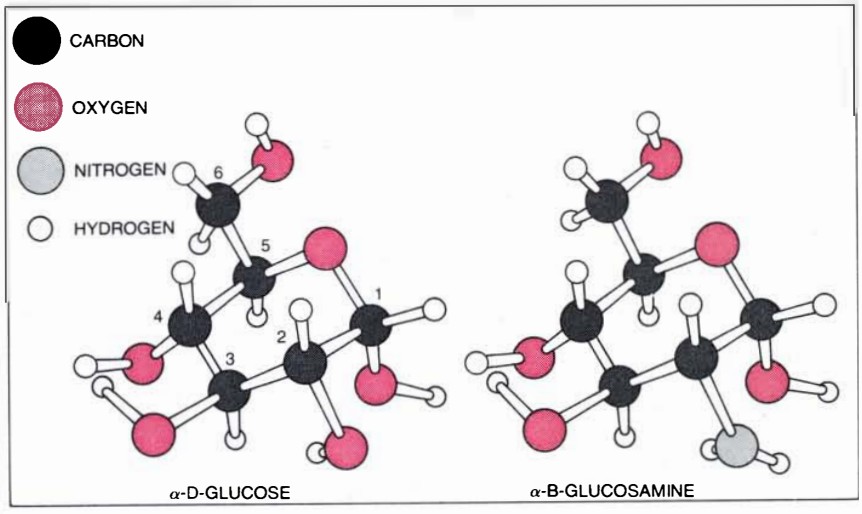
hydrate metabolism cause mental retardation and often early death. The best-characterized among them are the mucopolysaccharidoses: disorders of mucopolysaccharide metabolism, such as Hurler's syndrome and Hunter's syndrome, and disorders of glycolipid metabolism, such as Tay-Sachs disease, which occurs at a relatively high incidence (one birth in 3,000 births) among Ashkenazi (eastern European) Jews. In most of these diseases the missing enzyme normally functions to degrade complex saccharides.

In the mucopolysaccharidoses large quantities of complex carbohydrates (the mucopolysaccharides) accumulate in the lysosomes, the subcellular organelles where large molecules are normally broken down. Increased quantities of mucopolysaccharides are also secreted in the patient's urine. Cells taken from the skin of a patient and grown in tissue culture also accumulate mucopolysaccharides. In the early 1970's Elizabeth F. Neufeld of the National Institute of Arthritis, Metabolism, and Digestive Diseases found that this accumulation can be prevented by providing the cells with the missing polysaccharide-degrading enzymes. Unfortunately attempts to treat patients by administering the appropriate enzymes have not yet been successful.

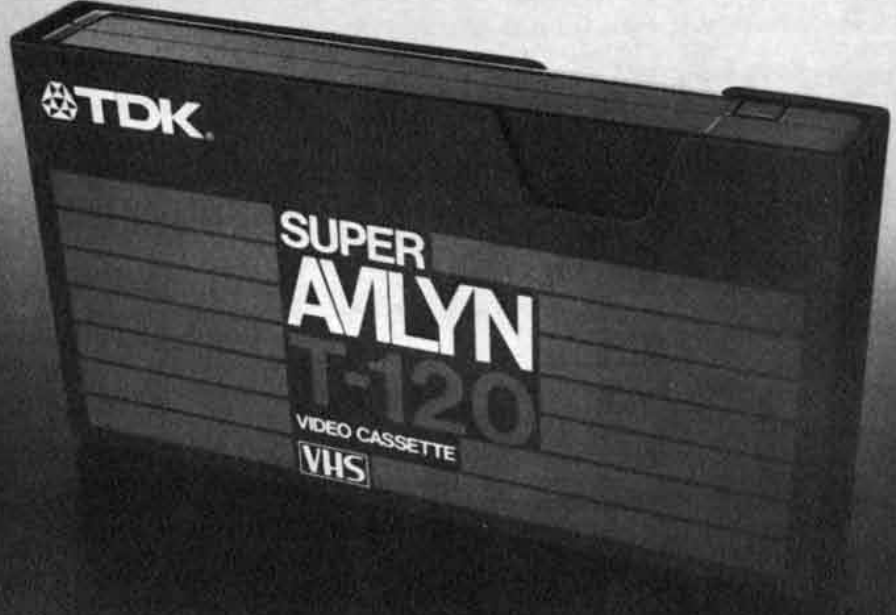
A disease that is well known to be closely linked with sugar metabolism is diabetes. Although diabetes has now been shown to be a family of different disorders, all diabetics have one thing in common: abnormally high levels of glucose in the blood. Moreover, in nearly all diabetics similar complications develop, including heart disease, blindness, cataracts, blood-vessel damage, nerve disorders and kidney damage. Is the high blood sugar by itself the cause of diabetic complications? Many investigators tend to believe that it is and that tight control of blood sugar can prevent, arrest and possibly even reverse the progress of these complications.

To understand what high blood sugar does biochemists and physicians are asking how glucose damages cells at the molecular level. One possible mechanism is that glucose combines with proteins in the body, altering their configuration and their function. Evidence of how this process might occur was recently obtained by a number of groups, including Anthony Cerami and Ronald Koenig and their associates at Rockefeller University and H. Franklin Bunn, Kenneth H. Gabbay and Paul M. Gallop at the Harvard Medical School. These investigators found that glucose attaches itself, in a process not requiring enzymes, to the hemoglobin molecules of diabetic patients, thereby altering the electric charge and biochemical properties of the hemoglobin.

The idea that glucose can combine with amino acids and proteins is not new. For a while it was the subject of considerable research by biochemists and food chemists. Aharon Katzir-Katchalsky studied this reaction at the Hebrew University of Jerusalem for his doctoral degree, which he was awarded in 1938, and I continued on the same subject with him for my Ph.D. degree (also from Hebrew University) in 1950–53. Food chemists had long known that the interaction of glucose and food proteins, a reaction known as nonenzymatic browning because it proceeds without enzymes and turns the protein brown, causes a decrease in the digestibility and nutritive value of protein. Hematologists found some years ago that about 5 percent of the hemoglobin molecules of normal people contain nonenzymatical-




**AMINO SUGAR is glucosamine, a constituent of lobster shell, glycoprotein and the cell wall of fungi. In amino sugars one or more hydroxyl (–OH) groups of the sugar molecule are replaced by an amino, or nitrogen-containing, group. Here the amino group replaces the hydroxyl group on carbon No. 2 of the glucose molecule. More than 60 amino sugars are now known.**

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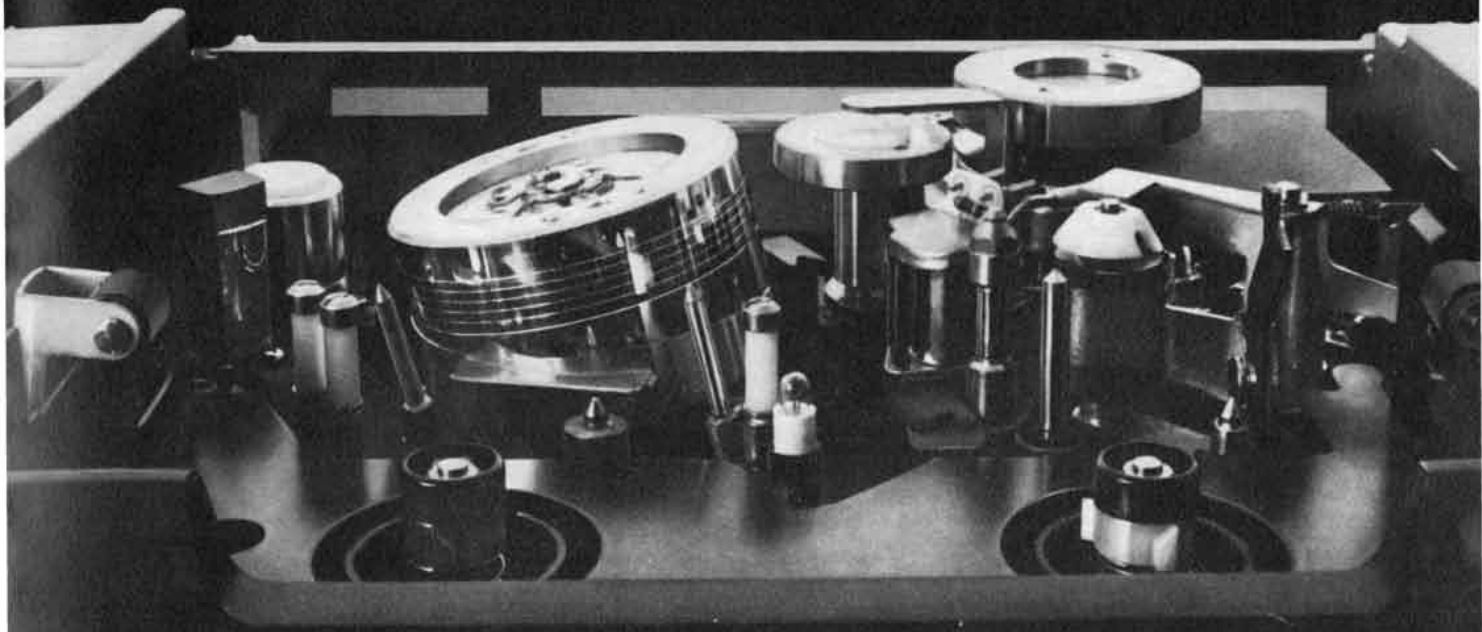


ly bound sugars. This attachment of sugar molecules to proteins is a slow process and does not normally happen to any great extent with proteins that are rapidly broken down and resynthesized. Few sugar molecules are expected to attach themselves even to relatively stable proteins such as hemoglobin. Diabetics, however, have so much glucose in their blood that their level of glucosylated hemoglobin molecules is two or three times higher than the norm. Attempts are now being made to exploit this finding clinically.

Red blood cells and their hemoglobin have a lifetime of about 120 days. Once glucose has become attached to the hemoglobin it comes off slowly, so that the amount of glucosylated hemoglobin in the blood of a patient acts as an indicator for the total blood-sugar concentration over the preceding few weeks. It is hence a better index than anything now available of how well controlled the patient's blood glucose has been over such a period.

Since glucose attaches to hemoglobin, it almost certainly attaches to other proteins in the same way and may therefore change their properties and biological functions. The process may be particularly damaging to proteins that are slow to be replaced, such as those in the lining of blood vessels and in the insulating material around nerve cells. Cerami has recently demonstrated that a high concentration of glucose leads to the glucosylation of proteins of the eye lens, both in vitro and in vivo, and to a subsequent opacity of the protein matrix, mimicking the opacity seen in diabetic cataracts.

## Biological Markers

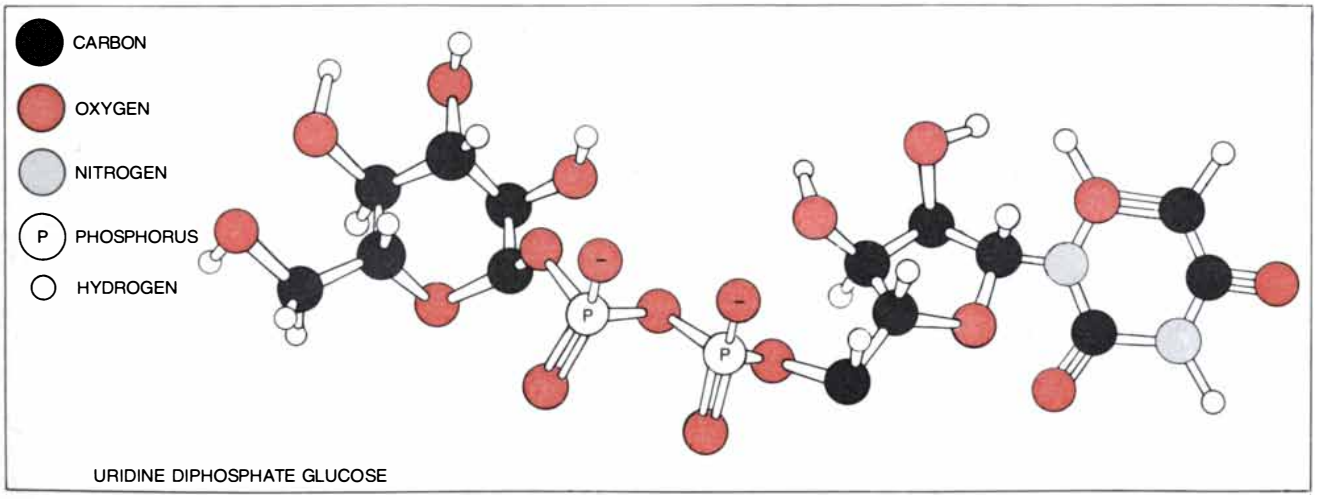
Until recently it was not recognized that nature can employ sugars for the synthesis of highly specific compounds that can act as carriers of biological information. This capability arises from the fact that a large number of structures can be formed from a small number of monomers. In other words, monosaccharides can serve as letters in a vocabulary of biological specificity, where the words are formed by variations in the nature of the sugars present, the type of linkage and the presence or absence of branch points. It is now known that the specificity of many natural polymers is written in terms of sugars, not amino acids or nucleotides. This idea is not entirely novel, but it has only recently become well established.

In the 1920's it was still believed that the specific information in biological polymers was carried only by proteins. Between 1925 and 1937 Oswald T. Avery of the Rockefeller Institute, together with Michael Heidelberger and Walther F. Goebel, demonstrated that pure polysaccharides can carry specific immunological messages as antigens: substances that stimulate the production of an antibody specific to themselves. Thus the highly purified Type III pneumococcus "specific soluble substance" was an antigen even though it did not have any of the properties of a protein. This substance was shown to be polysaccharide, consisting of repeating units of cellobiuronic acid (a disaccharide of glucose and glucuronic acid).

The chemical basis of the antigenicity of polysaccharides was thoroughly clarified through the application of highly sophisticated techniques developed by Heidelberger and Elvin A. Kabat of the Columbia University College of Physicians and Surgeons, Walter T. J. Morgan of the Lister Institute of Preventive Medicine in London and many others. Today it is well established that carbohydrates are ideally suited for the formation of specificity determinants that can be recognized by complementary structures, which presumably are carbohydrate-binding proteins, on other cells or molecules.

The first indication that sugars serve as specificity determinants came from the discovery in 1941 by George K. Hirst in New York and by Ronald Hare in Toronto that the influenza virus caused red blood cells to agglutinate, or clump. The molecular basis of this phenomenon was for a time obscure. Mainly as a result of the efforts of Alfred Gottschalk in Australia it was shown that the influenza virus binds to the red blood cell through sialic acid units on the cell surface. If the sialic acid is removed from the cell surface by the enzyme neuraminidase, the influenza virus will no longer bind to the cell.

The role of carbohydrates in recognition has been best demonstrated in the control of the lifetime of glycoproteins in the circulatory system and their uptake into the liver and of the uptake of lysosomal enzymes by cells. As often happens, these exciting discoveries originated with an unexpected observation, this one made in 1966 by G. Gilbert Ashwell of the National Institute of Arthritis, Metabolism, and Digestive Diseases and by Anatol G. Morell of the Albert Einstein College of Medicine in the course of an effort to understand the biological role of ceruloplasmin, a copper-transport protein found in the blood serum of man and other animals. When Ashwell and Morell removed sialic acid from rabbit ceruloplasmin and reinjected the modified ceruloplasmin into the animals, it almost completely disappeared from the circulatory system within 15 minutes. This was in striking contrast to the native glycoprotein, almost all of which remained in circulation after the same length of time. Further work has shown that with many serum glycoproteins the removal of terminal sialic acid units to expose the un-



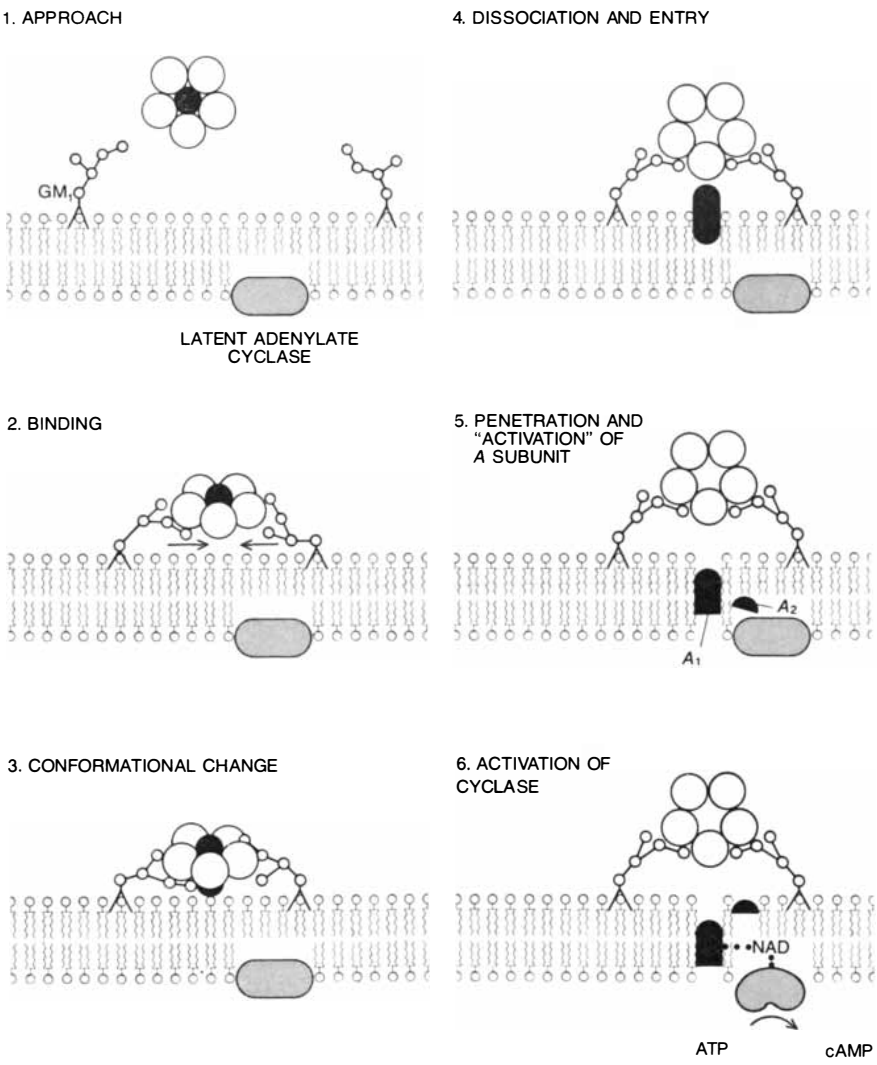

**SUGAR NUCLEOTIDE, the first of more than 100 that have been found, is uridine diphosphate glucose (UDP-glucose). It is the starting compound for the biosynthesis of numerous other sugars. The general structure is that of a sugar in association with a nucleoside (adenosine, guanosine, cytidine, uridine or deoxythymidine) and phosphorus in the form of phosphate. Here it is glucose, uridine and two phosphate groups. The nucleotide holds the sugar in an activated form for transformation to other sugars or transfer to acceptors.**

derlying galactose units results in the rapid removal of the modified glycoproteins from the circulatory system of experimental animals and their uptake by the parenchymal cells of the liver. The surface of such a cell contains a receptor specific for the binding of glycoproteins that lack sialic acid.

Galactose hence serves as a recognition marker that determines the survival time of many serum glycoproteins in the circulatory system of man, the rabbit and the mouse. In bird and reptile species the recognition marker appears to be primarily acetylglucosamine. Clearance systems in which fucose and mannose are the markers have also been found.

A particularly interesting marker is mannose-6-phosphate, a sugar derivative that has recently been shown to act mainly in directing the intracellular traffic of glycoprotein enzymes normally present in lysosomes. This finding had its origins in Neufeld's discovery that the enzyme deficiencies in cells from patients afflicted by mucopolysaccharidoses such as Hurler's and Hunter's syndromes can be corrected by providing the cells with the missing enzymes. In 1974 she showed further that uptake into the cells depended on the presence in the enzymes of a carbohydrate-recognition marker. In 1977 William S. Sly of the Washington University School of Medicine and Arnold Kaplan of the Saint Louis University School of Medicine identified the recognition marker as a phosphorylated sugar unit: mannose-6-phosphate. The function of the marker is apparently to prevent the secretion of the enzymes from the cells and to direct them into the lysosomes. When the enzymes are supplied from the outside, it is this recognition signal that promotes their binding to the cell surface; without binding they cannot enter the cells and reach the lysosomes.

By the covalent (electron-sharing) attachment of carbohydrates to proteins or by a modification of the sugars in glycoproteins it may thereby be possible to control the proteins' lifetime in the circulation and to direct them to the liver and perhaps also to other organs, as well as into lysosomes. Such techniques will have far-reaching uses for enzyme-replacement therapy in cases of genetic disease and also for delivering drugs accurately into target organs and cells.




**ACTION OF GLYCOLIPID in binding the toxin of cholera bacteria is indicated. A glycolipid is a compound in which a sugar is linked to a lipid; here it is the ganglioside, or acidic glycolipid, known as $GM_1$, which is found in the plasma membrane of cells. A cholera toxin, consisting of one *A* subunit (*black*) and five *B* subunits (*white*), approaches the plasma membrane of an intestinal mucosal cell (*1*), is bound by the $GM_1$ (*2*) and as a result is changed in conformation (*3*) in such a way that the *A* subunit is dissociated from the toxin and enters the membrane (*4*). There the *A* subunit becomes activated (*5*) so that it is able to activate the adenylate cyclase system of the cell (*6*). The activation of the cyclase system causes the cell to secrete excess quantities of fluid, giving rise (as large numbers of cells become overactive) to the huge losses of liquid that often cause dehydration and death in cholera. If $GM_1$ is administered to the patient so that much of it is not associated with cells, it can bind the cholera toxin and inhibit the toxin's effect. Other gangliosides evidently inhibit similarly the action of other toxins.**

## Other Biological Roles

Sugars on cell surfaces also appear to determine the life span of circulating cells and their distribution in the body. This role was originally demonstrated in 1964 by Bertram M. Gesner and Victor Ginsburg of the National Institute of Arthritis, Metabolism, and Digestive Diseases. They found that radioactively labeled rat lymphocytes migrated to the spleen when they were reinjected into the animal. If before reinjection the sugar fucose was removed from the surface of the cells by treatment with a specific glycosidase, the lymphocytes migrated to the liver instead, as if the fucose on the lymphocytes served as a "ZIP" code directing them where to go.

Old red blood cells have less sialic acid on their surface than young ones, and so it has been postulated that the decrease of sialic acid is the signal responsible for the removal of the older red blood cells from the circulatory system. This hypothesis seemed to be further substantiated by the finding that when red blood cells are taken out of the circulation, and when the sialic acid is removed from their surface and they are reinjected into the blood, their life span is extremely short: only a couple of days out of the normal lifetime of 120. In spite of these striking correlations there is considerable doubt whether the removal of sialic acid and the exposure of galactose units on the surface of the red blood cell are responsible for the removal of senescent red cells from the blood under physiological conditions in vivo.

The well-known *ABO* blood-group system was first described by Karl Landsteiner of the Rockefeller Institute in 1900, but it was not until 1953 that Walter Morgan and Winifred Watkins of the Lister Institute demonstrated that the specificity of the major blood types is determined by sugars. For example, the difference between the blood types *A* and *B* lies in a single sugar unit that

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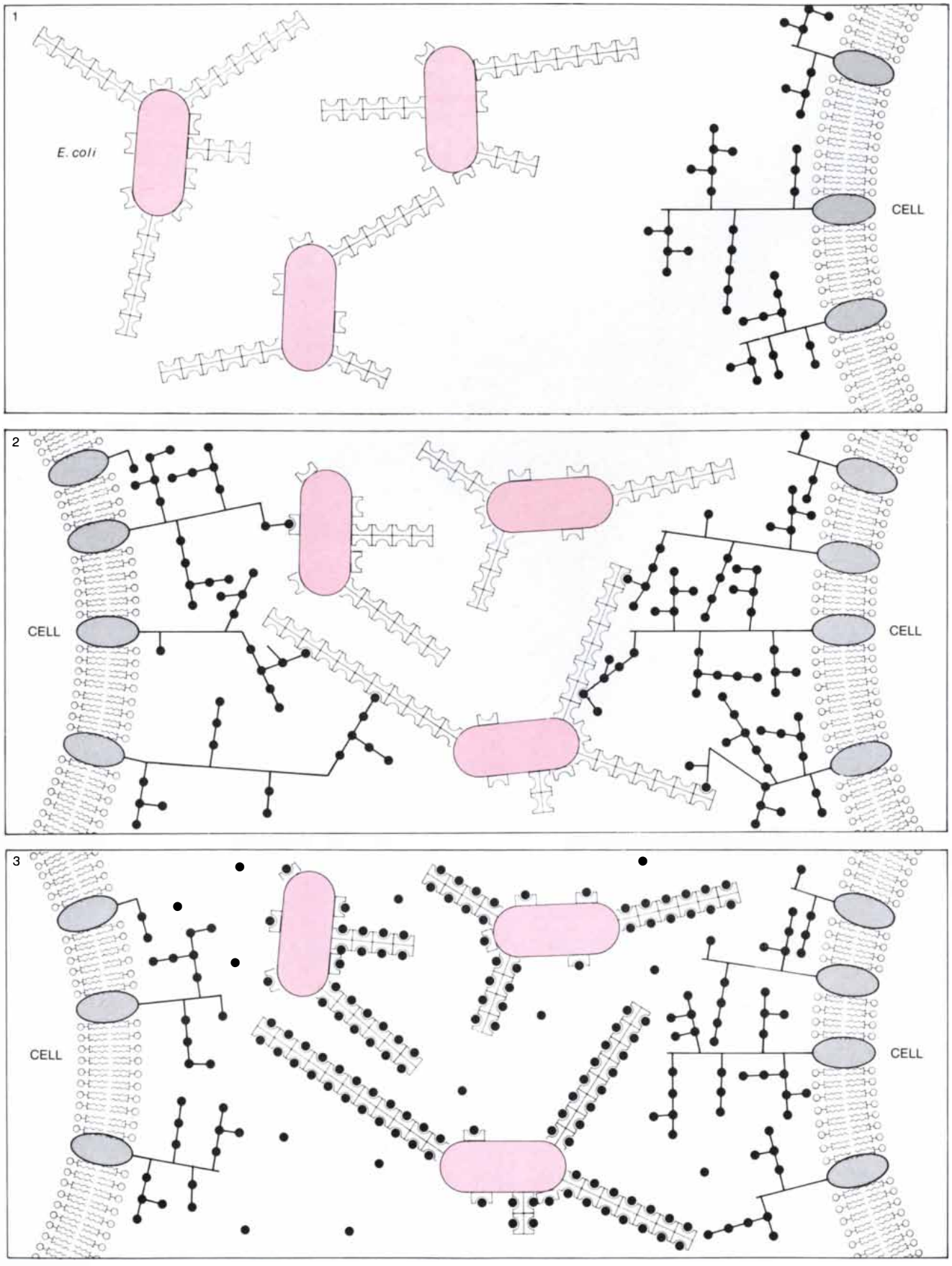
*Figures are for comparison. Your results may differ due to driving speed, weather conditions and trip length. Actual highway mileage will be less. California mileage will be different. • Jeep Corporation, a subsidiary of American Motors Corporation.




**MECHANISM OF ATTACHMENT** of *E. coli* to a cell membrane, as is shown in the micrograph on page 91, and its inhibition by free mannose is portrayed schematically. Bacteria approach a cell membrane (*1*) in which a glycoprotein is embedded. Here mannose (*black dots*), which is part of the glycoprotein, is recognized by binding sites on the *E. coli*. As a result the bacteria adhere to the host surface (*2*), initiating an infection. If free mannose is available, however, it binds to the bacteria first (*3*) and prevents them from attaching to the cell.

sticks out from the end of a carbohydrate chain of a glycoprotein or glycolipid on the surface of the red blood cell. In blood type *A* the determinant is acetylgalactosamine, in blood type *B* it is galactose. The two monosaccharides differ by only a small group of atoms, but that little difference is sometimes a matter of life and death, since using the wrong type of blood in a transfusion can have fatal results.

The enzymatic removal by specific glycosidases of $\alpha$-linked acetylgalactosamine from type *A* red blood cells or of $\alpha$-linked galactose from type *B* red blood cells will convert both into type *O* cells. An effective conversion can, for example, be carried out by purified $\alpha$-galactosidase from coffee beans or soybeans, as was demonstrated in our laboratory by Noam Harpaz and Harold Flowers. Such a conversion may be useful clinically when type *O* cells of rare subtypes are needed for transfusion.

The sugars that determine the specificity of substances in the *ABO* blood group are distributed in the biological world in forms similar to those found in human beings. The substances are therefore also present in different mammals. Hence the red blood cells of the dog, the pig and the rabbit are invariably of type *B* and in some cases may also belong to type *A*. The *ABO* blood-group substances are present in birds and amphibians and even in plants and bacteria.

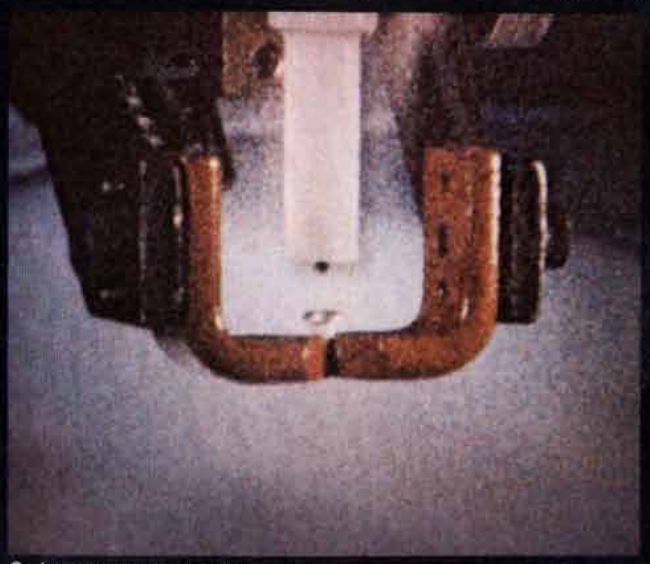
Tamio Yamakawa of the University of Tokyo has recently suggested that dogs may possess a blood-group system specified by the sialic acid in red-blood-cell glycolipids. Whereas all European dogs so far examined have glycolipids that incorporate acetylneuraminic acid, Yamakawa and his co-workers have shown that representative Japanese dogs such as the Kishu and Shiba breeds often have glycolylneuraminic acid instead and that this occurrence is genetically determined. Akita and Hokkaido dogs from northern Japan seem to be exceptional in having only acetylneuraminic acid in their red-blood-cell glycolipids. The origin of the Japanese dog is still controversial, but since the glycolylneuraminic acid glycolipid is inherited as a dominant trait, the findings suggest that the origins of the Akita and Hokkaido breeds are different from those of other Japanese dogs and that the Akita and Hokkaido breeds are related to European dogs.

Several toxins of bacteria and plants are now known to recognize carbohydrate structures present in various classes of cell-surface molecules. Included are the cholera toxin and possibly the tetanus toxin, which bind to certain glycolipids of the ganglioside type. Gangliosides are unique acidic glycolipids that are selectively concentrated in the plasma membrane of cells.

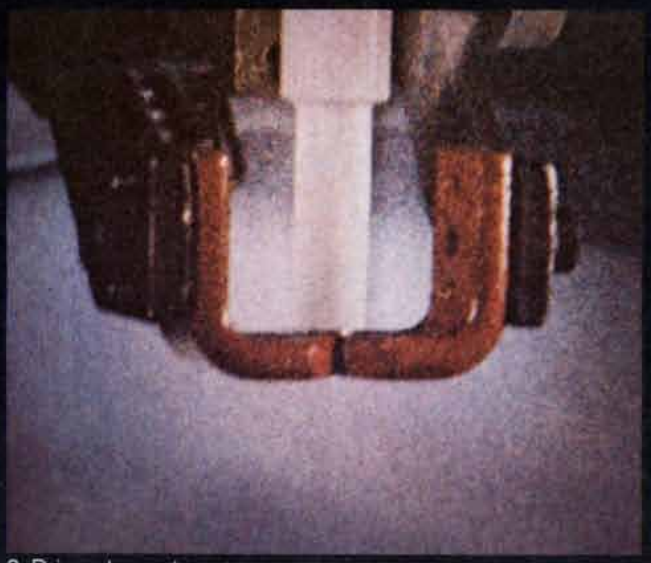
W. E. van Heyningen of the University of Oxford showed in 1971 that gangli-

Automatic screw machine filmed at 300 frames/second. Images photographed while projected on analyzer.
*Problem:* Determine why screw was not being inserted into part (misalignment, vibration, lack of vacuum, premature release by jaws?).

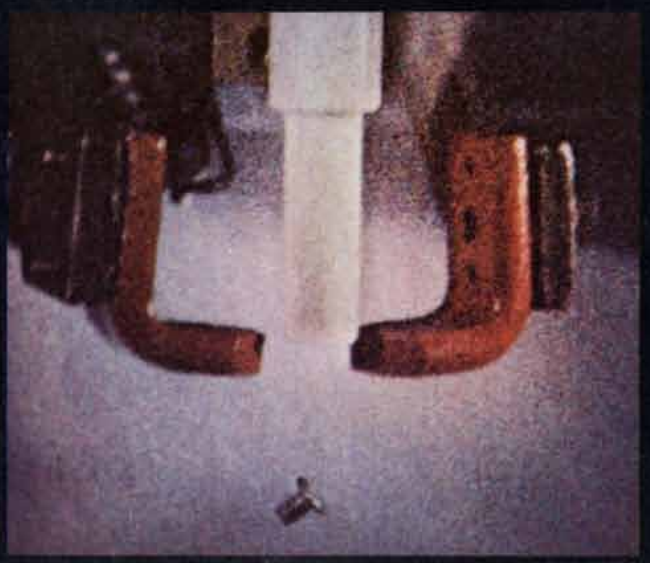
1. Sequence starts. Jaws pick up screw.



2. Jaws move to driver.



3. Driver drops down to accept screw.



4. Jaws open and screw falls because of insufficient vacuum.

5. Driver moves to part to insert now missing screw.

6. Driver returns. Cycle complete in less than 5 seconds. Problem identified in minutes.

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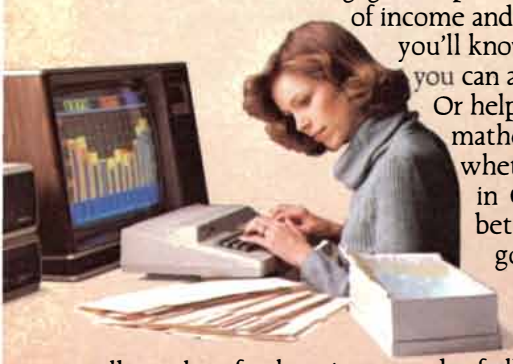

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ATARI 400™

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computer doesn't have to move on to someone else, in order to save time. It waits for your child to answer the question correctly.

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osides of the brain bound cholera toxin and blocked its physiological effect. Later work by van Heyningen, by Lars Svennerholm and Jan Holmgren of the University of Göteborg and by Pedro Cuatrecasas of the Johns Hopkins University School of Medicine showed that the ganglioside $GM_1$ is the most effective inhibitor. A close correlation was found between the $GM_1$ content of intestinal mucosal cells from different species and the amount of cholera toxin that was bound. There is also considerable evidence that specific gangliosides can inhibit the action of tetanus toxin and botulinum toxin. The existence on cells of specific carbohydrates showing a strong affinity with the toxins of virulent organisms such as cholera and diphtheria is of great medical importance, since it may be possible to protect against these diseases by the administration of suitable gangliosides.

The cell-surface sugars of gangliosides serve for the attachment of other biologically active molecules. Prominent among them is the potent antiviral agent interferon. The incubation of gangliosides with interferon will inhibit interferon's antiviral activity. Moreover, mouse cells that do not respond to treatment with interferon become responsive after the incorporation of gangliosides into their surface membrane. These results indicate that gangliosides and interferon can interact at the cell surface and that these complex carbohydrates may have a function in the antiviral activity of interferon.

## Cell Recognition

Cell-surface sugars serve as receptors for various other physiological and nonphysiological agents. Among them are lectins, which in binding to cells often give rise to agglutination. If they bind to lymphocytes, they induce cell growth and division, a phenomenon known as mitogenic stimulation.

Pronounced changes in cell-surface sugars are observed during the development and differentiation of cells and on the transformation of normal cells into malignant ones. Many of the changes were originally detected with the aid of lectins. In particular the finding during the 1960's that malignant cells are much more readily agglutinated by lectins (such as wheat-germ agglutinin, concanavalin A and soybean agglutinin) than their normal counterparts focused the attention of many investigators on cell-surface sugars. The excitement over these findings is waning, however, because it has proved to be extremely difficult to identify the structural changes that take place on the surface when normal cells become malignant. It has also not been possible to gain any insight into the physiological meaning of these changes. Moreover, the increased agglutination by lectins is not a property

# THE LEADING EDGE

## #1 in a series of reports on new technology from Xerox

*About a year ago, Xerox introduced the Ethernet network—a pioneering new development that makes it possible to link different office machines into a single network that's reliable, flexible and easily expandable.*

*The following are some notes explaining the technological underpinnings of this development. They are contributed by Xerox research scientist David Boggs.*

The Ethernet system was designed to meet several rather ambitious objectives.

First, it had to allow many users within a given organization to access the same data. Next, it had to allow the organization the economies that come from resource sharing; that is, if several people could share the same information processing equipment, it would cut down on the amount and expense of hardware needed. In addition, the resulting network had to be flexible; users had to be able to change components easily so the network could grow smoothly as new capability was needed. Finally, it had to have maximum reliability—a system based on the notion of shared information would look pretty silly if users couldn't get at the information because the network was broken.

### Collision Detection

The Ethernet network uses a coaxial cable to connect various pieces of information equipment. Information travels over the cable in packets which are sent from one machine to another.

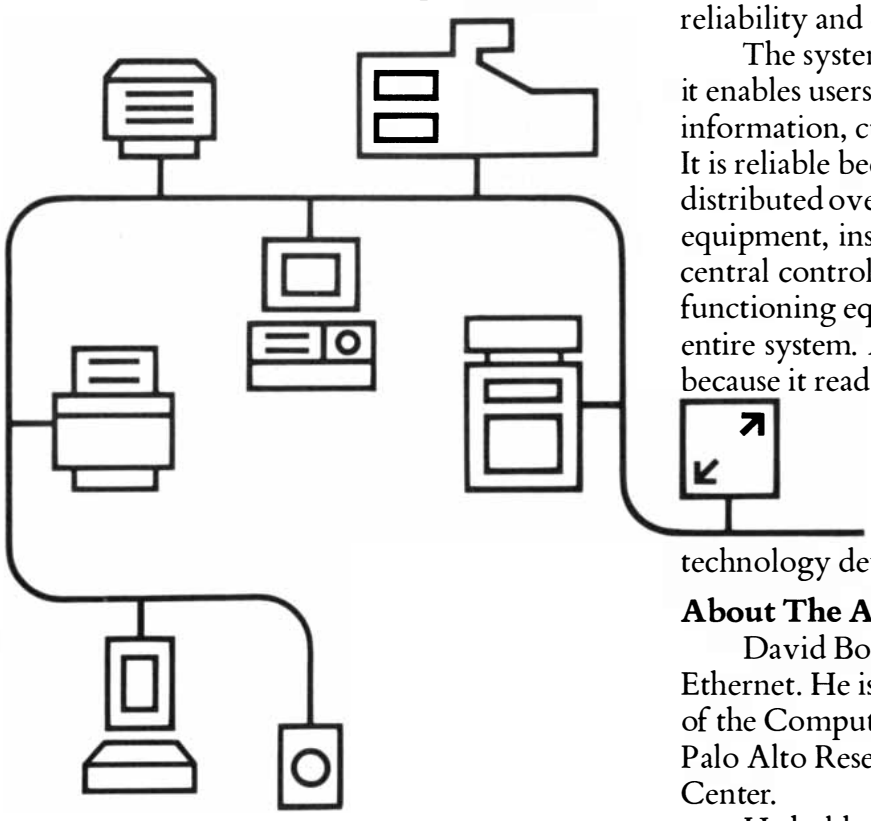
A key problem in any system of this type is how to control access to the cable: what are the rules determining when a piece of equipment can talk? Ethernet's method resembles the unwritten rules used by people at a party to decide who gets to tell the next story.

While someone is speaking, everyone else waits. When the current speaker stops, those who want to say something pause, and then launch into their speeches. If they *collide* with each other (hear someone else talking, too), they all stop and wait to start up again. Eventually one pauses the shortest time and starts talking so soon that everyone else hears him and waits.

When a piece of equipment wants to use the Ethernet cable, it listens first to hear if any other station is talking. When it hears silence on the cable, the station starts talking, but it also listens. If it hears other stations sending too, it stops, as do the other stations. Then it waits a

random amount of time, on the order of microseconds, and tries again. The more times a station collides, the longer, on the average, it waits before trying again.

In the technical literature, this technique is called carrier-sense multiple-access with collision detection. It is a modification of a method developed by researchers at the University of Hawaii and further refined by my colleague Dr. Robert Metcalfe. As long as the interval during which stations elbow each other for control of the cable is short relative to the interval during which the winner uses the cable, it is very efficient. Just as important, it requires no central



control—there is no distinguished station to break or become overloaded.

## The System

With the foregoing problems solved, Ethernet was ready for introduction. It consists of a few relatively simple components:

Ether. This is the cable referred to earlier. Since it consists of just copper and plastic, its reliability is high and its cost is low.

Transceivers. These are small boxes that insert and extract bits of information as they pass by on the cable.

Controllers. These are large scale integrated circuit chips which enable all sorts of equipment, from communicating typewriters to mainframe computers, regardless of the manufacturer, to connect to the Ethernet.

The resulting system is not only fast (transmitting millions of bits of information per second), it's essentially modular in design. It's largely because of this modularity that Ethernet succeeds in meeting its objectives of economy, reliability and expandability.

The system is economical simply because it enables users to share both equipment and information, cutting down on hardware costs. It is reliable because control of the system is distributed over many pieces of communicating equipment, instead of being vested in a single central controller where a single piece of malfunctioning equipment can immobilize an entire system. And Ethernet is expandable because it readily accepts new pieces of information processing equipment. This enables an organization to plug in new machines gradually, as its needs dictate, or as technology develops new and better ones.

## About The Author

David Boggs is one of the inventors of Ethernet. He is a member of the research staff of the Computer Science Laboratory at Xerox's Palo Alto Research Center.

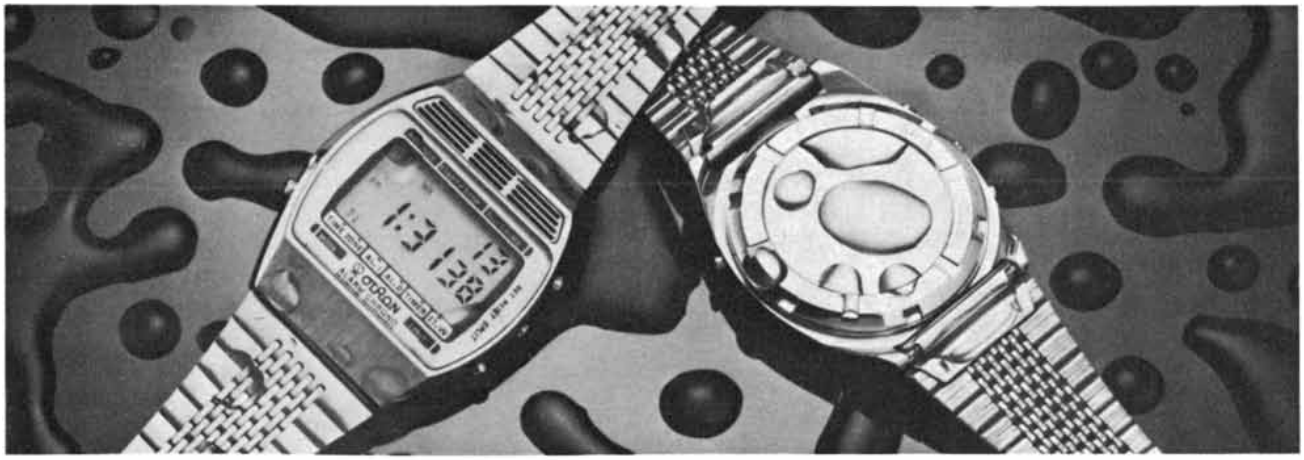
He holds a Bachelor's degree in Electrical Engineering from Princeton University and a Master's degree from Stanford University, where he is currently pursuing a Ph.D.

shared by all malignant cells, so that the early hopes of employing lectins to identify and perhaps to attack such cells selectively have faded.

Cell-surface sugars participate in fertilization in mammals, sea urchins, protozoa and algae. Cellular association in slime molds is mediated by the interaction of carbohydrate-binding proteins on one cell with specific oligosaccharide receptors on another cell. Thus differentiation in slime molds from a vegetative (single cell) form to a cohesive (aggregated) form is accompanied by the appearance of both cell-surface lectins and specific glycoproteins. Moreover, simple sugars such as galactose and acetylgalactosamine inhibit the aggregation of cells in this system.

In recent years it has been demonstrated that cell-surface saccharides act as receptors not only for viruses but also for bacteria. This finding is probably the best-documented example of a specific cell-cell interaction mediated by carbohydrates. It is a phenomenon of great importance, since the adherence of bacteria to tissue surfaces is the initial event in a bacterial infection. Work done in our laboratory and elsewhere has demonstrated that bacteria such as *Escherichia coli* and *Salmonella typhimurium* adhere to epithelial cells and to scavenging white blood cells through units of mannose on the surface of such cells. This carbohydrate-specific interaction is mediated by a mannose-specific lectin present on the surface of the bacteria. The lectin has been isolated from *E. coli* by Yuval Eshdat of our department. In collaboration with David Mirelman of our department and Moshe Aronson and Itzhak Ofek of Tel Aviv University we have also found that colonization of the urinary tract of mice infected with *E. coli* can be markedly diminished by the administration of methyl $\alpha$-mannoside, a sugar that effectively inhibits the mannose-specific adherence of the bacteria to epithelial cells. Further studies of the sugars on cell surfaces that act as receptors for bacteria may lead to the design of improved inhibitors of adherence. Such inhibitors might serve to prevent bacterial infection by blocking its first step, the adherence of the invading organism to the epithelial surfaces of the host.

To sum up, carbohydrates are found in wide variety, and many of them are extremely complex. They perform numerous tasks in living organisms; most important, like nucleic acids and proteins, they seem to serve as informational molecules. Determining more about these compounds and establishing in detail their chemical structure and conformation will not only result in a deeper understanding of what life is but also make it possible to combat more effectively various diseases, such as those caused by genetic defects or infectious agents.



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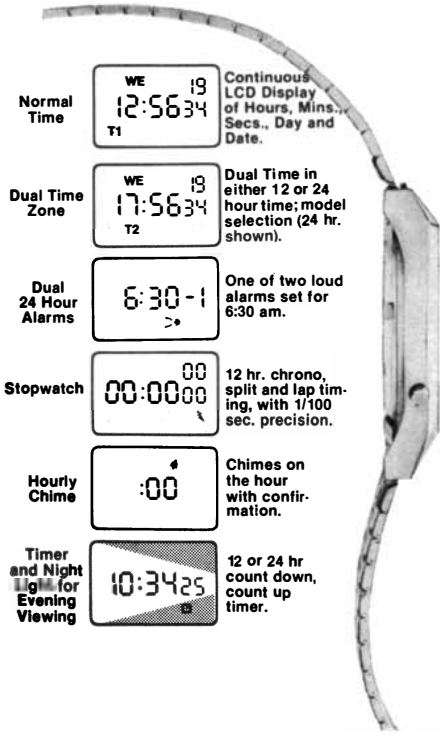
Olympos Electronic now wants the world to know its name and genius. We feel lucky to be selected to bring this story to you.




Olympos Electronic Co. is now introducing products into this country under its own trade name—Otron. We are introducing one of the first Otron products into the U.S.

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# The Vestibular Apparatus

*Balance and orientation depend on two organs of the inner ear: the semicircular canals and the otolith receptors. The system is "multimodal" in that it also requires inputs from other senses*

by Donald E. Parker

If a cat is dropped upside down, it will land right side up on all fours. If a newborn infant is tilted backward, its eyes will roll downward so that its gaze remains fixed. If the reader shakes his head rapidly from side to side as he reads this article, the print nonetheless stands still. Each of these effects represents a compensation for a disturbance to balance or orientation, and each is controlled in part by the sensory apparatus in the vestibule of the inner ear.

The exact role of the vestibular apparatus is only partly understood. Unlike the apparatus of the other major senses, it cannot, for example, "see" or "hear"; it responds to accelerations of the head, but the individual cannot readily describe sensations associated with it as he can sights or sounds. The study of vestibular sensations is difficult because the vestibular apparatus is only one source of information for a system of balance and orientation that is "multimodal": the system also receives input from the eyes and from somatic receptors (sensors in the skin and the joints). Moreover, the multimodal system of balance and orientation is adaptable: if the vestibular apparatus itself is damaged, the system can learn to function without it. For all these reasons it is difficult to trace a response to any one source of information in this triad of sources: vestibular, visual and somatic.

Experiments to be conducted in the manned satellite Spacelab will test the ability of astronauts to balance and orient themselves under conditions of weightlessness and therefore will offer a new opportunity for studying the elusive vestibular apparatus. Such experiments may also help to explain why motion sickness appears to be intimately related to the functioning of the vestibular apparatus.

The vestibular apparatus is shared by vertebrate animals from fishes and amphibians to birds and man. At the core of the apparatus are the vestibular receptors of the inner ear. When the head is accelerated in a particular direction, within the receptor a fluid or a gelatinous mass covered with tiny crystals tends to remain stationary with respect to the ground. Projecting into the fluid or the gelatinous mass are cilia: ultrafine hairs anchored to the rest of the head. As the head is displaced the hairs are deflected in the opposite direction, much as the bristles of a brush bend backward when the brush is moved across a surface. This bending initiates impulses in adjoining nerve cells, and the impulses are transmitted to the brain. There decisions are made to excite reflex movements of eye, neck, limb or body muscles, and nerve cells that mediate the perception of motion and of orientation in space are activated.

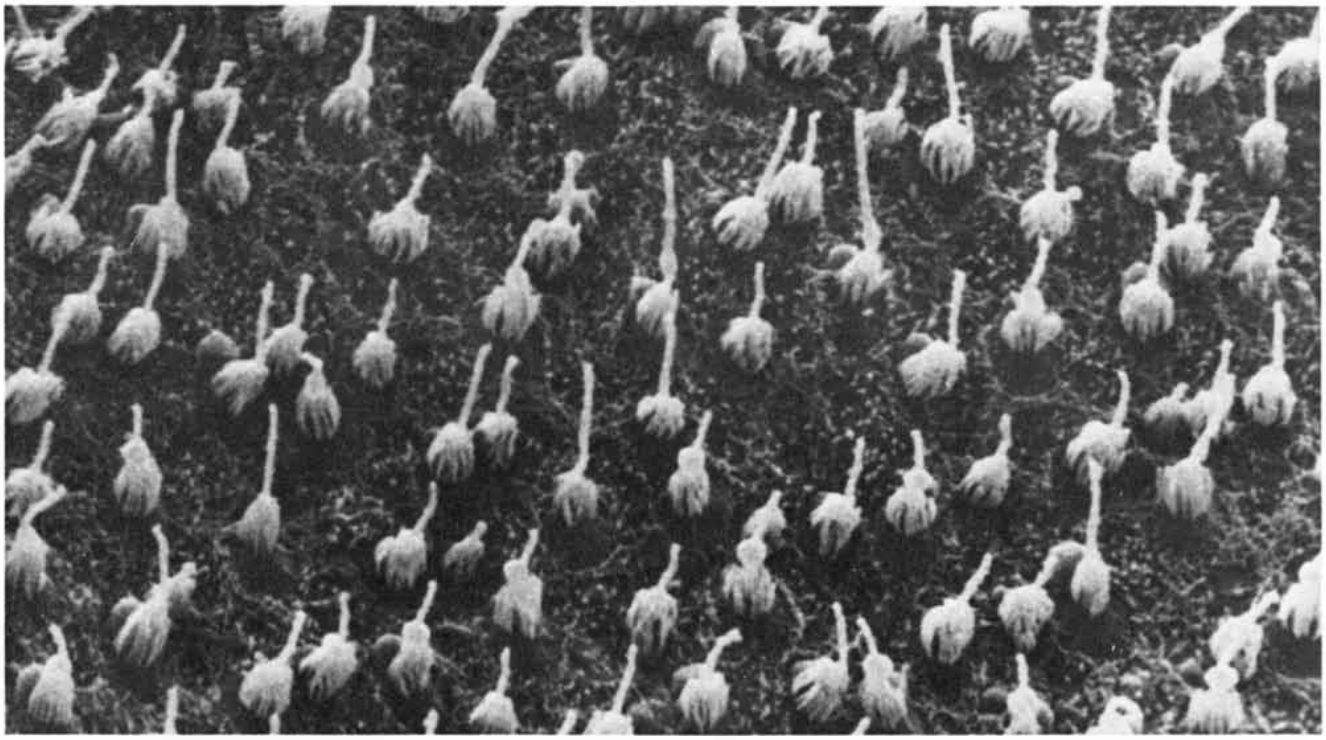
The vestibular receptors are within the inner ear's membranous labyrinth, a series of fluid-filled sacs and tubes suspended in the convoluted space in the temporal bone called the bony labyrinth. There are two kinds of receptors: the otolith (or statolith) organs, which respond to linear accelerations, and the semicircular canals, which respond to angular accelerations. Linear accelerations include the action of gravity and are defined as a change in the velocity of an object traveling in a straight line. (Gravitational attraction is equivalent to accelerating an object upward at 980 centimeters per second squared.) Angular acceleration results from circular motion and is measured by the change in rate of rotation, a quantity often given in degrees per second squared.

The otolith organs are two similar sac-like structures in the ear called the utricle and the saccule. Each organ has a patch of hairs known as the macula; in the utricle the patch is approximately horizontal in the upright head, and in the saccule it is approximately vertical. In the utricle the hairs project upward into the gelatinous otolith membrane and in the saccule they project sideways. Loosely attached to the surface of the membrane are the otoconia, calcium carbonate crystals that have a density of 2.95 grams per cubic centimeter, almost three times the density of water. The crystals act as an inertial mass that strongly resists the application of external forces. Therefore when the head moves in response to a linear acceleration, the crystals in the utricle or the saccule tend to stand still as the patch of hair slides under the gelatinous membrane, bending the hairs backward. For example, when a cat is dropped, the saccular receptor detects a change in acceleration the instant the animal starts falling and signals the leg muscles to extend in preparation for landing. In either of the otolith organs the bending of the hairs triggers the nerve impulses that relay the information to the brain.

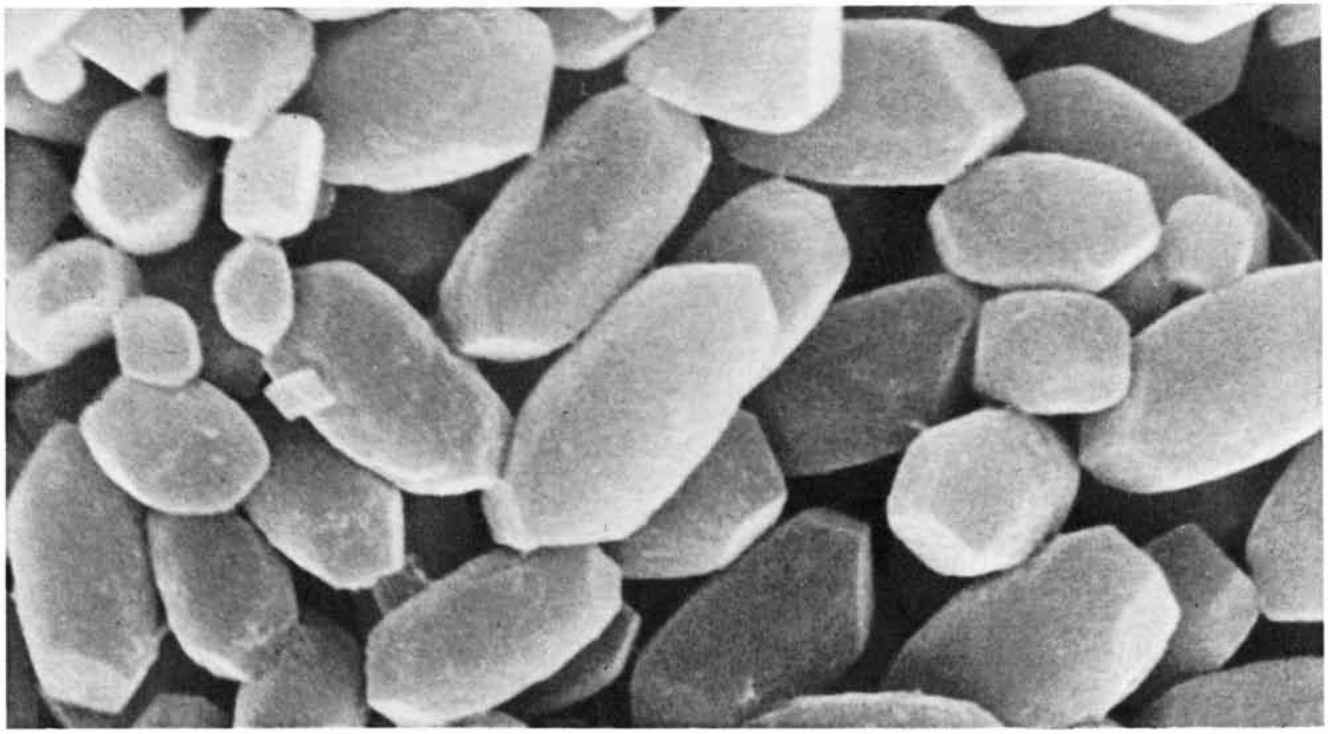
The three semicircular canals, the organs that detect angular acceleration, lie in three planes like those defined by the $x$, $y$ and $z$ axes in a three-dimensional graph. Depending on the plane of rotation of the head, one canal, two canals or all three are affected. Each canal has a bulge, the ampulla, that contains a patch of hair cells embedded in a crest-shaped surface, the crista. As in the otolith organs, the hairs project into a gelatinous membrane called the cupula. Where in the otolith organs the inertial mass is provided by the otoconia crystals, in the semicircular canals it is provided by a fluid, the endolymph. When the head rotates, the fluid tends to remain at rest and the cupula, along with the hairs protruding into it, is displaced in the opposite direction.

The movement of hairs in either the otolith organs or the semicircular canals sets off nerve impulses by changing the electric potential of the adjoining nerve cells. Each of these neurons, like other neurons, has an axon, a long fiber that is negatively charged inside and positively charged outside. The difference between the two levels of charge is the cell's electric potential; a neuron in its resting state has a potential of about 70 millivolts. Most of the vestibular neurons emit a steady stream of impulses.

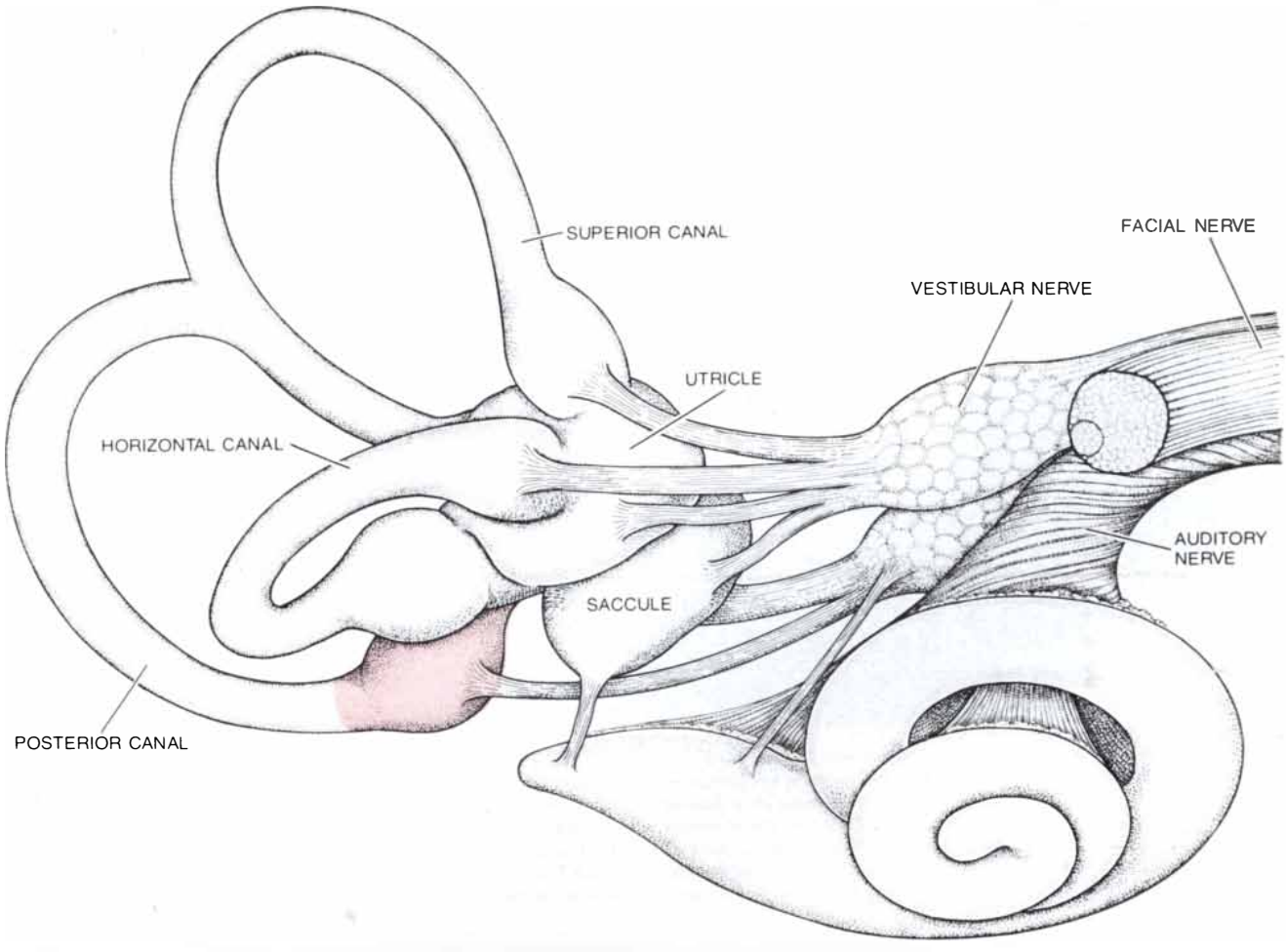
When vestibular hairs move in a particular direction, they make the inside of the axons of the neighboring neurons more negative and in so doing increase



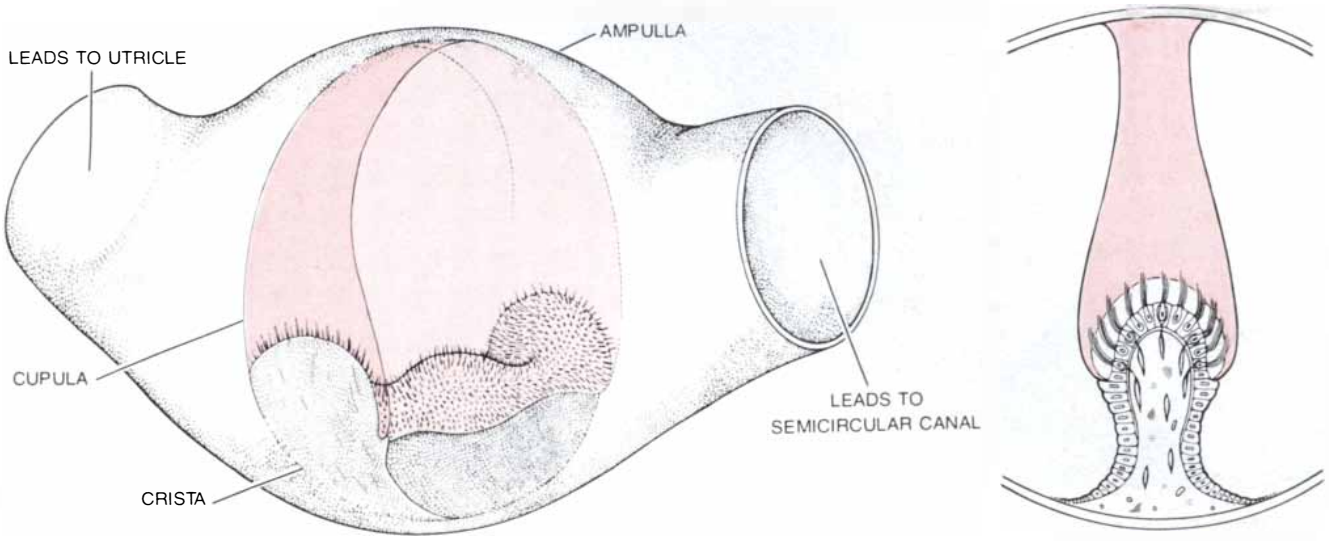
**ULTRAFINE HAIRS** cover the surface of an otolith receptor in the vestibule of the inner ear. Otolith hairs respond to linear accelerations of the head. This scanning electron micrograph, which enlarges the structures some 5,000 diameters, shows the surface of the utricular organ, one of the two otolith receptors in each ear. Each bundle of hairs consists of many small hairs, the stereocilia, and one longer hair, the kinocilium. The function of the kinocilium is not well understood. The hairs project upward into a gelatinous membrane that has been removed for the purposes of the micrograph. Surrounding the hairs in the micrograph is the remnant of a spongelike surface, the filamentous base, that cushions the gelatinous membrane. The scanning electron micrograph, which was made by Dean E. Hillman of the New York University Medical Center, shows the utricle in the inner ear of a frog; a human utricle is similar in both function and appearance.



**OTOCONIA CRYSTALS** function as an inertial mass within the otolith receptors. These dense crystals of calcium carbonate rest on a gelatinous membrane not visible in this scanning electron micrograph of a human utricle; the crystals are enlarged some 5,000 diameters. A linear acceleration of the head carries along with it the hairs embedded in the surface of the otolith receptors; the otoconia crystals resist the acceleration and tend to hold the gelatinous membrane stationary. As a result hairs protruding into the membrane from the otolith surface are bent in a direction opposite to the direction of acceleration. Nerve cells at the base of hairs transmit this information to the central nervous system. The scanning electron micrograph was made by Muriel D. Ross of the University of Michigan Medical School.




**VESTIBULAR APPARATUS consists of a series of fluid-filled sacs and ducts. In this drawing of the human vestibular apparatus the three semicircular canals are at the left; clockwise from the top they are the superior, the horizontal and the posterior canal. They are oriented in the three dimensions of space and respond to angular accelerations of the head. In the center of the drawing are the two otolith receptors: the utricle (*top*) and the saccule. The fluid known as endolymph fills the apparatus; in the semicircular canals the endolymph functions as an inertial mass analogous to the otoconia crystals in the otolith receptors. Each semicircular canal has a bulge, the ampulla, one of which is shown in color; it is enlarged in the illustration on page 125. At the lower right in the drawing is the cochlea.**




**BULGE OF THE SEMICIRCULAR CANAL, the ampulla, is shown in transparent full view (*left*) and in cross section (*right*). Hairs anchored in a crest-shaped surface, the crista, project into a gelatinous flap called the cupula (*color*). The endolymph flows through the canal but is blocked by the flap. When the head is accelerated in the plane of the canal, the fluid remains stationary as the canal, including the gelatinous flap, rotates in the direction in which the head has been accelerated. The flap and the hairs protruding into it are therefore bent in the opposite direction. The bending of the hairs stimulates the transmission of impulses by nerve cells at base of hair cells.**

the potential. The neurons are said to be hyperpolarized, and they emit impulses less frequently. When the hairs move in the opposite direction, the opposite happens: the inside of the axons becomes less negative. The neurons are depolarized, and because of the lowered potential they transmit impulses at a higher rate.

Several investigators, notably Cesar Fernandez and Jay M. Goldberg of the University of Chicago, have isolated a second class of neurons in the vestibular system. These cells respond not so much to the displacement of the hairs as to changes in the displacement. After a period of sustained bending (constant acceleration) they no longer transmit impulses regularly. These neurons may alert the brain that a change has occurred and indicate the rate of the change.

The nerve pathways that connect the vestibular apparatus with the brain and the spinal cord are complex and not as well traced as those of the other sensory systems. It is known, however, that all vestibular nerve signals travel initially to either one of two destinations: the brain stem, just above the spinal cord, or the cerebellum, in the rear of the brain.

The vestibular nerve fibers that reach the brain stem terminate at any one of four different nerve-cell groups called the vestibular nuclei: the superior, Deiters' (or lateral), medial and descending (or inferior) nuclei. These cell groups also receive input from visual and somatic sensors, particularly receptors in the neck muscles that indicate the angle of inclination of the head. This information is coordinated in the vestibular nuclei, and a neural signal is sent to the eye muscles or to the spinal cord, where it excites a reflex contraction of neck, limb or body muscles. There may be many neurons in the pathway from the receptor to the spinal cord or as few as two. In the latter case one axon extends from the receptor to the vestibular nuclei and the other reaches from there all the way down the spinal cord, giving it a length of 30 centimeters or more.

In the cerebellum vestibular, visual and somatic inputs arrive in the region called the vestibulocerebellum. The reticular formation, a collection of cells in the brain stem, also receives information from visual and somatic receptors (but not vestibular ones) and communicates with the vestibular nuclei elsewhere in the brain stem. The exact function of the cerebellum and reticular formation in balance and orientation has not yet been determined.

Since the systems that receive information from the vestibular receptors are multimodal, also receiving information from visual and somatic sources, it is hard to isolate a pure vestibular input.

# Physician, did you miss any of these significant developments in medical science?

- **The isolation of coxsackievirus B4 from the damaged pancreatic cells of a 10-year-old boy who died of diabetic ketoacidosis adds to the growing evidence that implicates viruses in some forms of insulin-dependent diabetes mellitus (IDDM).**

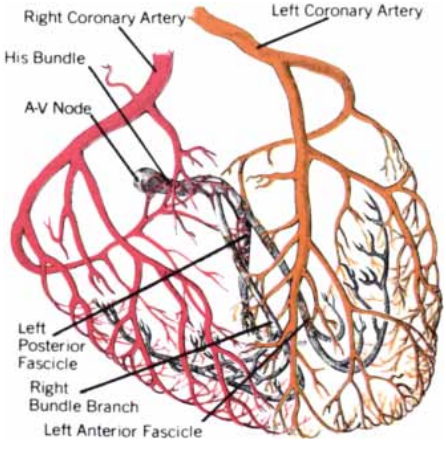
- ***Campylobacter fetus* subsp. *jejuni* causes at least as much acute gastroenteritis as does *Shigella* or *Salmonella;* the culturing and antimicrobial therapy for *C. fetus* subsp. *jejuni* differs from that for the other two bacteria.**

- **Miconazole shows great promise in patients with disseminated and meningeal coccidioidomycosis who do not respond to or cannot tolerate amphotericin B.**

- **Pittsburgh pneumonia agent (PPA) and atypical *Legionella*-like organisms (ALLO) are particularly dangerous in immunosuppressed patients.**

- **Lithium batteries for pacemakers have made mercury-zinc cells virtually obsolete; they can power a unit for 8 to 20 years. Microcircuitry has revolutionized the therapeutic and diagnostic potential of these devices.**

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.




**Branches of the right and left coronary arteries supply blood to the AV node and intraventricular conduction system.**

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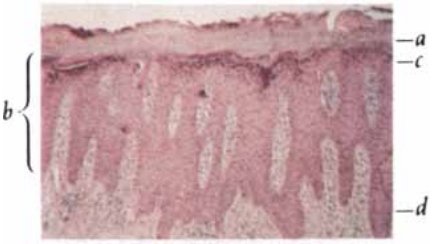


**Histopathologic changes in psoriasis.**

**Extensive psoriasis (top) cleared completely (bottom) after four weeks of treatment with anthralin.**

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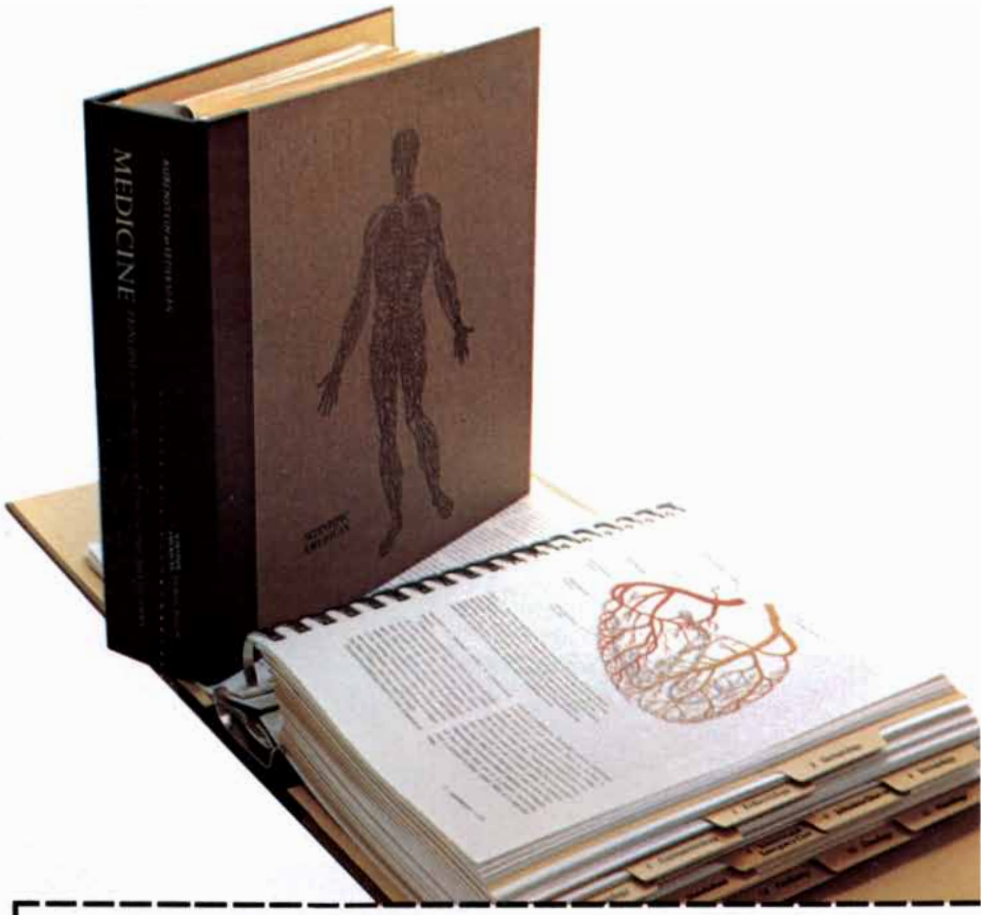


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18

# WHAT'S NEWS IN PATENTS?

## A continuing series on progress by GE inventors.

Last year, General Electric inventors were awarded over 600 patents, adding to GE's unsurpassed total of over fifty thousand U.S. patents, past and present. Here, GE reports on some recent patents—and on the inventors who won them.

### Brisken & Smith: New weapon against heart disease.

A patient can hold his breath, but he can't stop his heart.

That's why early ultrasonic scanners could not always be used successfully to diagnose heart disease. They were not fast enough to show images of the heart in motion without blurring.

But recently, GE researchers have succeeded in bringing the heart into better focus. The latest improvement comes from Dr. Axel F. Brisken and Dr. L. Scott Smith. They've been awarded Patent Number 4,211,948—"Front Surface Matched Piezoelectric Ultrasonic Transducer Array With Wide Field of View."

Their invention is a transducer array that actually transmits and receives the ultrasound better. This increased sensitivity results from better impedance matching. One way to do that is the addition of acoustic layers of glass and plastic to the conventional ceramic sensors. Result: sharper images.

With real-time imaging, ultrasonic scanners could play a significant role in the battle against heart disease.

### Milton Rickert: More from less.

"Less is more." That famous principle applies to productivity as much as it does to design. Using less energy, less expensive materials and less costly processes are clear paths to more productivity.

Consider one simple example: Milton Rickert's new process. This GE chemist's latest patent is Number 4,181,773—"Process for Rendering Surfaces Permanently Water Wettable and Novel Products Thus Produced."

The products referred to include refrigerator components: evaporators and cooling coils. Presently, these are made of anodized aluminum and joined by brazing.

Rickert's invention replaces the anodizing process with a less expensive one. The aluminum is given an organic coating, which is formed by electrodeposition, then cured and partially hydrolyzed. Processing costs are reduced. Instead of the energy-intensive brazing process, simple adhesives can now be used to join parts.

This process was developed to provide a gain in productivity, and these days, a gain in productivity is a nice kind of progress.

### Kurt Hedel: Lightening the load.

Everybody knows that in aircraft design, lighter is better.

Recent advances in microelectronics have made possible dramatic reductions in weight of on-board computers and communications equipment.

But significant reductions in the weight of on-board power systems have not been possible. Until now.

GE's Kurt Hedel has developed a unique voltage converter that's considerably smaller and lighter. He's been awarded Patent Number 4,195,333 "DC to DC Voltage Converter."

Hedel's invention basically consists of splitting a conventional converter circuit in two to produce two series of equal pulses that are 180 degrees out of phase. The pulses are then recombined. This cancels most of the "noise" or interference voltages and currents that are an inherent part of the conversion process.

With less "noise," much smaller input and output filters are needed. This actually reduces the overall size and weight by as much as 30 percent. That's progress.

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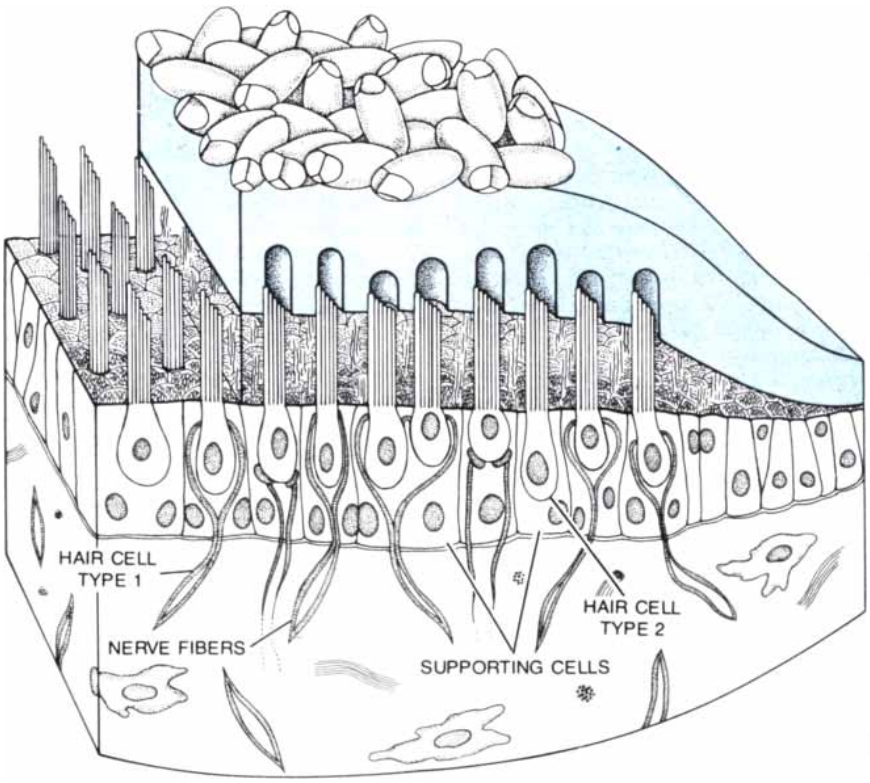
GENERAL ELECTRIC




**OTOLITH RECEPTOR has bundles of hairs that project into a gelatinous membrane (*color*). The kinocilium, the longest hair in each bundle, is attached to the side of an opening in the membrane; the shorter stereocilia extend into the opening and do not make contact. Otoconia crystals rest on top of the membrane; the membrane in turn rests on a spongelike surface, the filamentous base. Under the base is a layer of cells. Near the top of this layer are the hair cells; separating the hair cells and extending to the bottom of the layer are supporting cells. Attached to the hair cells are the threadlike nerve fibers that transmit impulses to the central nervous system. Curvature of the bottom layer of tissue corresponds to inside wall of utricle and saccule.**

Two of the simplest and least equivocal demonstrations of vestibular input have to do with the "functional" system that acts to stabilize the eyes. Functional systems can involve several sensory organs and central-nervous-system pathways in compensating for disturbances to balance or visual orientation. Such disturbances may be caused by the environment, as when an external force displaces the head or the eyes, or may be initiated by the organism itself, as in a voluntary turning of the head or movement of the eyes.

One demonstration is based on a voluntary disturbance. Hold your hand about 12 inches in front of your face with the palm toward you. Fix your gaze on it as you shake your head from side to side at a rate of about three times per second. If your vestibular system is working normally, the creases in your palm should appear distinct; this indicates that the semicircular canals are signaling the oculomotor muscles to rotate your eyes in the direction opposite to that in which your head has rotated. If you now hold your head still and shake your hand at the same rate, your palm will probably appear blurred. This simple demonstration illustrates that eye-position control is better when information from the vestibular receptors is available than it is when only visual information is available.

The other demonstration of vestibular compensation for disturbance is the involuntary "doll eyes" reflex of human infants. This reflex is controlled primarily by the otolith organs. Here a newborn infant is held upright so that its gaze is straight ahead. If its body is slowly tilted backward or to the side, its eyes will roll in their sockets in the reverse direction in order to maintain their original orientation in space. The reflex gradually disappears during the first month following birth as eye orientation becomes increasingly dominated by visual stimuli.

One of the first quantitative studies of a multimodal system of compensation was done on fish by the late Erich von Holst of the Max Planck Institute for Behavioral Physiology at Seewiesen in West Germany. He demonstrated that the orientation of a fish in water depends on two factors: light and acceleration. In the fish's natural environment it will swim horizontally in response to overhead illumination and the vertical acceleration of gravity. When

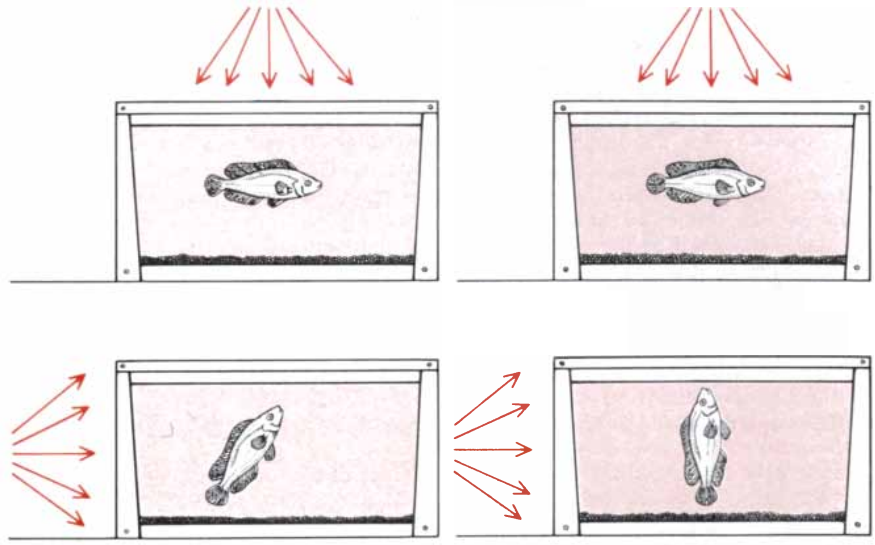
von Holst disturbed these parameters by changing the direction of the illumination or changing the linear acceleration by rapidly rotating the fish tank, he found that the fish adopted a compromise position taking the changed light and acceleration into account.

For example, when under normal gravitational conditions von Holst illuminated the fish from the rear rather than from above, the fish tilted itself upward at an angle to the light falling on its back and gravity pulling at its belly. When a fish from which the otolith receptors had been surgically removed was subjected to the same conditions, it responded only to the horizontal light source and so swam straight upward. By varying the parameters of light and acceleration von Holst was able to determine the relative extent to which vestibular and visual stimuli were responsible for the fish's orientation. The fish swam at an angle predicted by the sum of the sine of the angle of the light and the sine of the angle of linear acceleration.

Compensation for a disturbance to the system of balance and orientation may involve a change in the orientation of a receptor, as it does in the doll-eyes reflex. This kind of compensation has been called external compensation. In human beings the ability to adjust the orientation of posture and of the eyes is limited, and some form of internal compensation must originate in the brain rather than in the adjustment of receptors. In our laboratory at Miami University we have recently undertaken research on multimodal internal compensation for visual disturbances in human beings. One mode of compensation is for head tilt; for example, a door frame continues to appear vertical whether your head is upright or tilted toward your shoulder. When you tilt your head, the image of the door frame falls on a set of retinal receptors different from the set it falls on when your head is upright. Your perception of the door frame must somehow be compensated for in order to make the frame appear vertical.

The process of internal compensation has been theoretically modeled with a biological control system called a "mesh" or "feedforward" system by Horst Mittelstaedt of the Max Planck Institute for Behavioral Physiology and Norbert Bischof of the California Institute of Technology. According to this model, inputs from vestibular, visual and somatic receptors are collected in the brain and integrated, each input having been assigned a particular weight in the final determination of compensation. My colleagues and I have done experiments to test this hypothesis.

Each of our experimental subjects was placed in a dark environment and asked to orient a luminous line along some axis of his body. The subjects' settings of the luminous line were recorded as two sets of parameters were varied, each corresponding to one of two sources of compensation information: vestibular and somatic. To vary the input from his otolith organ the subject undertook to set the luminous line while he was either seated upright or lying hori-



**MULTIMODAL COMPENSATION for disturbances to orientation was demonstrated in an experiment with a fish, the wrasse (*Crenilabrus*). Normally the fish (*top left*) orients itself horizontally in response to two modes of input: overhead illumination and the downward pull of gravity. When the fish is illuminated from the rear (*bottom left*), its orientation is disturbed and it takes up a compromise position: it tilts itself in response partly to the horizontal illumination and partly to the vertical acceleration. A fish whose otolith receptors have been surgically removed (*top right*) cannot perceive gravitational acceleration and so orients itself solely with respect to the overhead illumination. When the same fish is illuminated from the rear (*bottom right*), it orients itself vertically, showing that it is responding only to illumination. This experiment was done by Erich von Holst of the Max Planck Institute for Behavioral Physiology.**

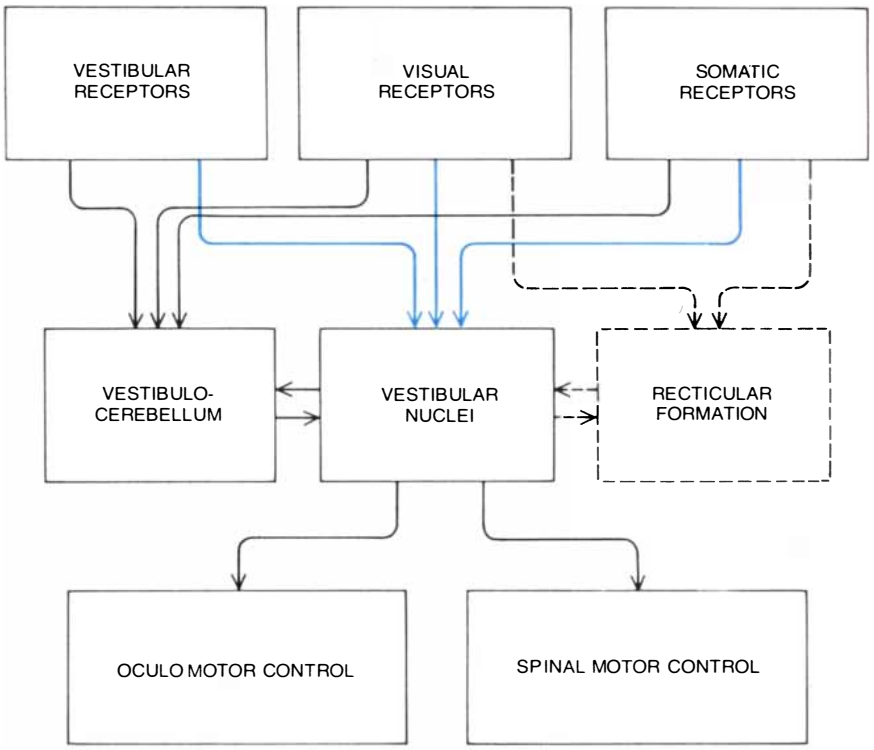
zontally on a board. To vary the input from his neck receptors he undertook to set the line with his head either aligned with his body or tilted 30 degrees toward his shoulder. By varying these conditions in many different combinations we hoped to determine the relative weight of the two inputs in compensating for the disturbance to the normal orientation of the eyes.

When the subjects were in the upright position, information from both otolith and neck receptors was available to compensate for head tilt. When they were lying horizontally, however, the otolith receptors no longer indicated head tilt because every position in the new plane of movement responded equally to gravity. We predicted that the compensation would be nearly complete when both sources of information were present but incomplete when in the horizontal subject only neck-receptor signals were available. Our experimental observations supported these predictions. We have adapted a biological-control-system feedforward network to account for the integration of the two stimuli in the brain.

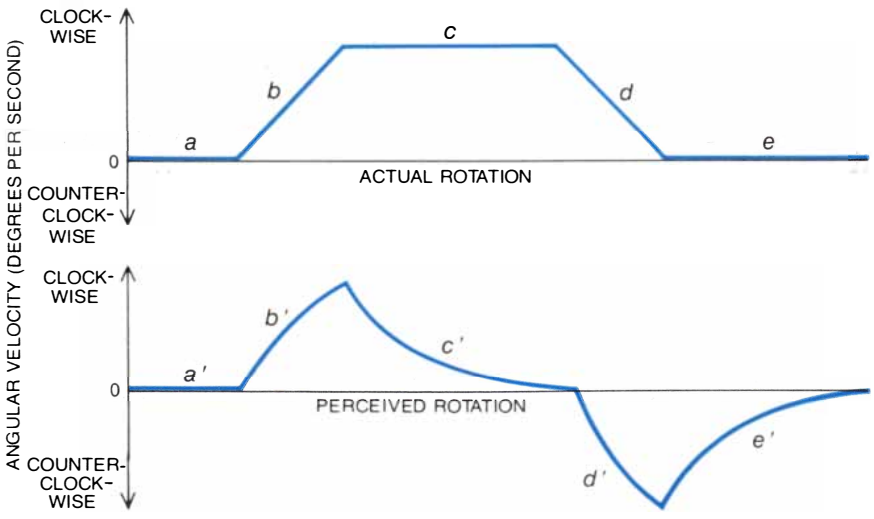
Another factor that has made it difficult to determine the contribution of the vestibular apparatus to spatial orientation is the capacity of an animal or a human being for adaptation. If accident or disease distorts the signals from some sensory receptor, normal perception and response usually return after an initial period of confusion. A classic experimental technique for studying adaptation is to disturb the subject's visual input by having him wear goggles that change normal visual relations for a substantial period of time. In normal vision when you rapidly turn your head to see an object, your eyes turn first to meet the object; the head then follows, and the eyes must turn back in the opposite direction in order to avoid overshooting the target.

When a subject wore goggles that reversed images laterally, he could not at first correlate his eye and head movements. After a period of adjustment, however, he was able to do so readily. A similar adaptive capability has been exhibited by animals and human beings with a defect in the vestibular apparatus. Adaptation, like compensation, is thought to be accomplished somewhere in the central nervous system.

Adaptation occurs whenever balance or orientation stimuli are rearranged over a prolonged period. Temporary rearrangement, such as that produced when an individual receives conflicting information from vestibular, visual and somatic receptors, can disorient the individual. For example, laboratory subjects who had been blindfolded were made to perceive that they were stationary when they were actually rotating and to perceive that they were rotating in a particular direction when they were



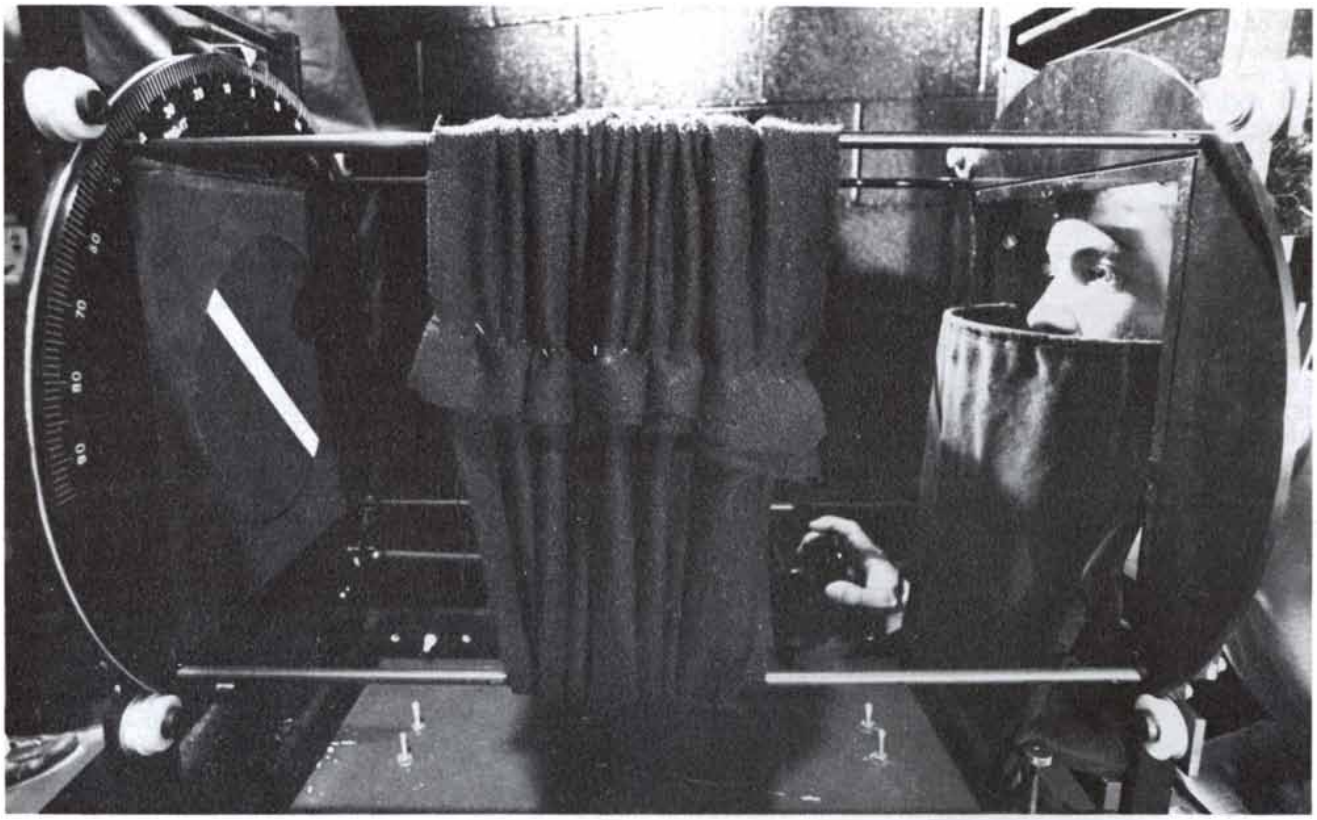

**NERVE-SIGNAL PATHWAYS of the balance and orientation system are outlined. At the top are three modes of input: the vestibular, visual and somatic (skin and joint) receptors. They transmit impulses to three processing units of the central nervous system: the vestibulocerebellum (a region of the cerebellum to the rear of the brain), the vestibular nuclei (a group of nerve cells in the brain stem, just above the spinal cord) and the reticular formation (another group of nerve cells in the brain stem, shown as a broken-line box because its function is not clear). After the information has been processed the vestibular nuclei transmit signals to either of two outputs: the oculomotor control and the spinal motor control. Oculomotor control coordinates the movements of the eyes; the spinal motor control is responsible for contraction of neck, limb and body muscles. Secondary pathways to the thalamus and cerebral cortex may be activated when stimulation of the vestibular apparatus gives rise to sensations of motion and orientation.**



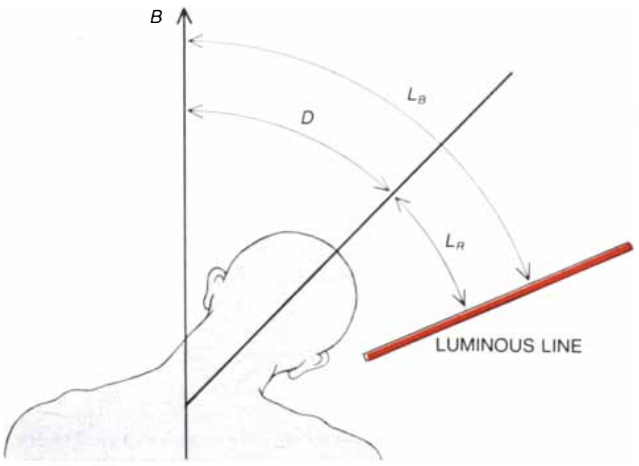

**ROTATION ILLUSION arises when a human subject rotated on a platform is deprived of visual input. A graph of the actual rotation (*top*) shows that from a stationary position (*a*) the blindfolded subject was rotated clockwise at increasing velocity (*b*) and then at a constant velocity (*c*). Thereafter the velocity was decreased (*d*) until the platform was again stationary (*e*). A graph of how the subject perceived his rotation is at the bottom. During the time that he was stationary (*a'*) and that his velocity was increasing (*b'*) he interpreted his motion correctly. After a period of rotating at constant velocity, however, he perceived himself to be slowing down and finally not to be turning at all (*c'*). When the velocity of rotation was decreased, the subject imagined himself to be turning counterclockwise (*d'*); immediately after the rotation had stopped he continued to feel as if he were rotating counterclockwise but slowing down (*e'*). Only after a substantial period without rotation did he perceive himself to be stationary again.**

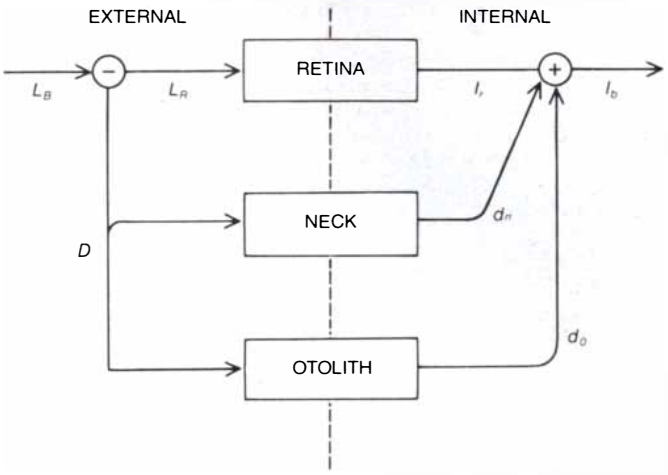
actually spinning in the opposite one. When the blindfold was removed in the course of the experiment, visual stimuli dominated signals from the semicircular canals, and after a brief period of confusion the subjects could interpret their motion correctly. This demonstrates very rapid adaptation or what might be called vestibular suppression.

In these experiments the subjects were put on a platform and rotated from a stationary position to a certain level of angular velocity. The velocity was held constant for one to two minutes and then decreased until the subjects were again stationary. At the beginning of the rotation the subjects were able to report the direction in which they were turning correctly. After a period of rotating at constant velocity they no longer perceived themselves to be turning at



**LABORATORY APPARATUS was used to test the ability of subjects to orient a luminous line along the axis of their head or of their body. The subject at the right operates a hand lever to rotate the line; in an actual experiment the curtain at the center would be drawn and the subject would be working in the dark. Subject did the experiment in two positions, sitting upright and lying horizontally on a board, with his head either aligned with his body, tilted 30 degrees toward his left shoulder or tilted 30 degrees toward his right shoulder.**




**BIOLOGICAL-CONTROL-SYSTEM MODEL suggests how subjects in one of the luminous-line experiments compensated for the tilting of the head. The subject (*drawing at left*) was required to estimate the angle of the luminous line ($L_B$) with respect to the axis of his body ($B$). When a disturbance to balance and orientation was introduced by the subject's tilting his head toward his shoulder ($D$), the orientation of the line on the retina ($L_R$) was altered. In order to estimate $L_B$ the subject had in effect to add $L_R$ and $D$. The biological-control-system model (*drawing at right*) represents the luminous line as $B$ and the tilt of the head as $D$. Neck and otolith receptors generate nerve signals that indicate the amount of tilt ($d_n$, $d_o$). These signals are added to the signal produced by the luminous line on the retina ($l_r$) to provide an estimate in the central nervous system of the orientation of the line with respect to axis of the subject's body ($l_b$).**

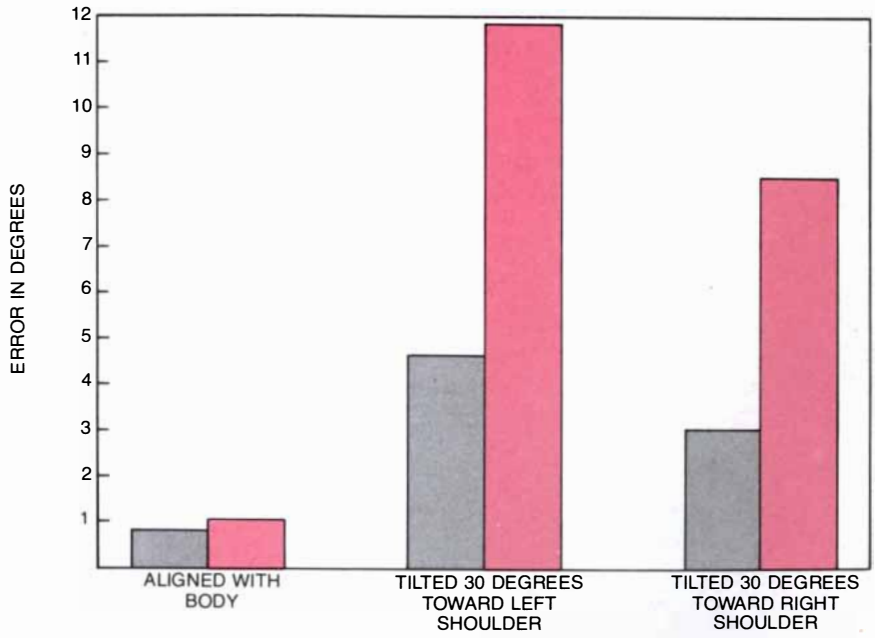
all. Then when the angular velocity was decreased, they sensed themselves to be turning in the opposite direction.

These misperceptions are in accord with the physical properties of the semicircular canals. Since the canals respond to angular acceleration and not to angular velocity, the individual cannot distinguish between moving at constant velocity and not moving at all. After a period of rotation at a constant velocity the semicircular canals no longer signal rotation. Since a speeding up in the clockwise direction produces the same reaction as a slowing down in the counterclockwise direction, the subject assumes that he has stopped rotating and then has started rotating in the opposite direction. Similar illusions with respect to linear motion have been experienced by airplane passengers flying through clouds. Although the plane is moving at a constant velocity, the passenger cannot see the ground or feel any acceleration and so perceives he is stationary.

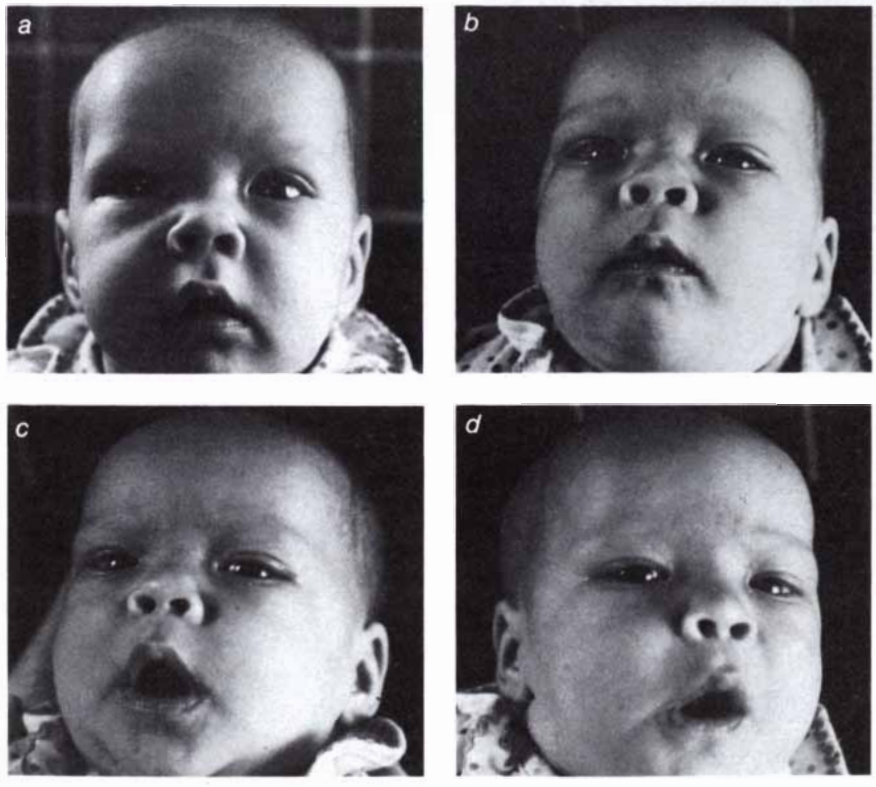
Weightlessness in an orbiting space laboratory would create a stimulus rearrangement analogous to that created by image-reversing lenses. Consider the case of an astronaut who tilts his head toward his shoulder. Visual and somatic input would be the same as they are on the ground, and the input of the semicircular canals would be the same while he is moving his head. In the absence of gravity, however, the otolith receptors would not indicate that any tilt had taken place. Input to the astronaut's spatial-orientation system has been rearranged.

Stimulus rearrangement resulting from weightlessness offers a prime opportunity for studying the vestibular system. Spacelab missions will make this research possible. Spacelabs are reusable modules that will be carried into orbit for a period of seven to 21 days and then returned to the ground by the Space Shuttle. After the initial missions, currently scheduled to begin in 1982, most of the Spacelab flights will be dedicated to particular disciplines. Vestibular investigations will be included with the life-sciences missions to be flown at intervals of 12 to 18 months beginning in 1984. Experiments will be undertaken by several groups of investigators from around the world both with a view to gaining a better understanding of the vestibular system and in the expectation that this basic research will help investigators and physicians to solve the practical problem of motion sickness in space.

One experiment I have proposed with Millard F. Reschke and Jerry L. Homick of the Johnson Space Center will evaluate differences in motion perception associated with adaptation to weightlessness. Astronauts who have been blindfolded will be moved back and forth in a sled on a straight track inside the Spacelab module and will indicate their perceived motion by operat-




**INCOMPLETE COMPENSATION for a disturbance to orientation is shown in this chart of performance in the luminous-line experiment. When the subject's head was aligned with his body, he was able to orient the line with an average accuracy of one degree with respect to the body axis whether his body was upright (*gray bar at left*) or horizontal (*colored bar at left*). By tilting his head he introduced a disturbance to orientation, and his performance deteriorated. When he was seated vertically, information from both neck and otolith receptors was available to compensate for the head tilt; his undercompensation remained less than five degrees (*gray bars in middle and at right*). When he was horizontal, the otolith receptors no longer indicated head tilt because every position in the new plane of movement responded equally to gravity, and the undercompensation ranged up to 12 degrees (*colored bars in middle and at right*).**




**"DOLL EYES" REFLEX in human infants demonstrates a vestibular compensation for a disturbance to orientation. Here an infant is held upright so that its gaze is straight ahead (*a*). If its body is tilted backward (*b*), its eyes will roll downward in order to maintain their original orientation in space. If the infant's body is slowly rotated to the right (*c*) or to the left (*d*), its eyes will roll in their sockets in the reverse direction. These reflexes are controlled primarily by the otolith receptors and gradually decline in the course of the first month following birth as the visual receptors assume a greater role in the preservation of orientation and balance.**

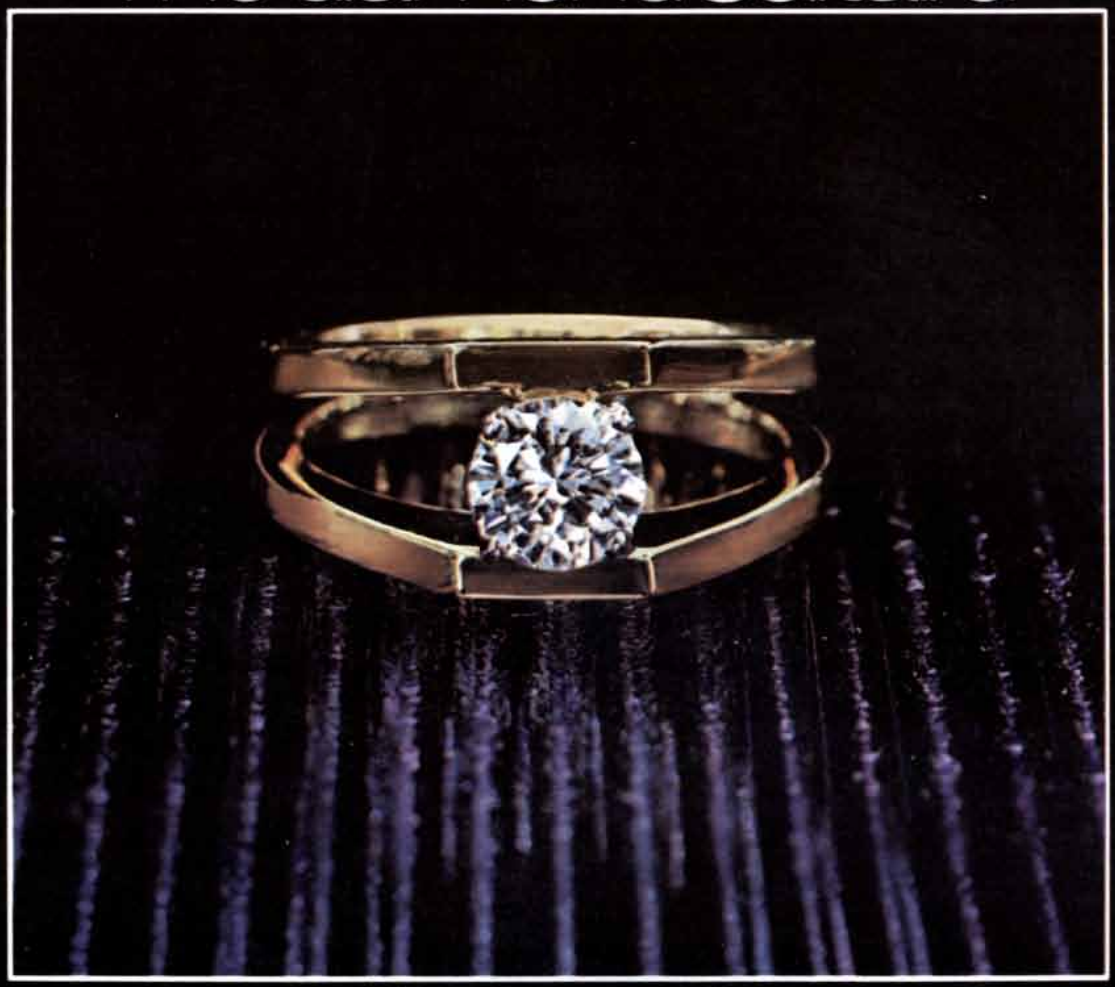
ing a joystick. One of our models predicts that astronauts will at first perceive their motion to be parabolic, almost as if they were riding on a playground swing (although that path is actually semicircular). After a period of adaptation to weightlessness they will correctly interpret their motion as being linear. Immediately on their return to the ground they will perceive the same motion as being parabolic but in the direction opposite to the one they experienced in space. After they have been on the ground for an extended period they will once again perceive their motion on the sled to be linear.

This experiment may demonstrate the human capacity for adapting to rearranged sensory stimuli. When people in the normal terrestrial environment are accelerated back and forth in a sled on a track, they feel a horizontal acceleration but are usually unaware of the omnipresent vertical acceleration of gravity. Actually they are being exposed to a rotating linear acceleration that is the sum of the changing horizontal acceleration and the constant vertical one. Their brain somehow interprets the rotating acceleration as motion in a straight line. In other words, the sensation of linear motion is a construct.

With the astronauts' initial exposure to weightlessness the only acceleration stimulus to their otolith receptors will be the one arising from the experimental sled; the absence of gravity will seem to their brain almost like a force pulling in the opposite direction, producing the sensation of traveling in a parabolic trajectory. After the astronauts adapt to weightlessness their motion will once again appear linear because they will no longer expect to feel a force pulling them toward the seat of the sled. On their return to the ground, however, gravity will exert what seems to be an unnatural force pulling them downward, and until their nervous system readapts to the normal terrestrial environment they will perceive their motion on the sled to be a parabola pointed in a direction opposite to the one they had imagined in space.

The experience of weightlessness will also be examined with respect to a multimodal system that compensates for disturbance to orientation. The biological-control-system model for head tilt derived from the luminous-line experiments in our laboratory suggests that visual compensation depends on weighted signals from otolith and neck receptors when the subject is upright on the ground. A study of Skylab astronauts by Ashton Graybiel and the late Earl F. Miller II of the Pensacola Naval Air Station and Homick has shown that the astronauts' ability to orient themselves with respect to a luminous rod was not disturbed by the absence of gravity. Building on this observation, Reschke,

# The diamond solitaire.



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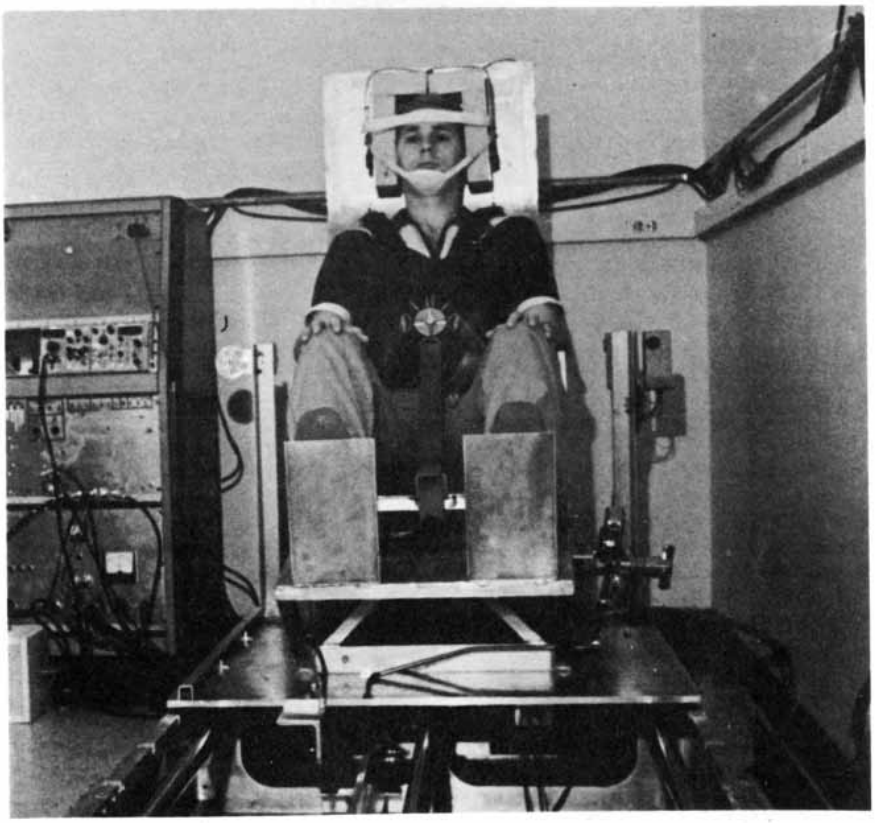
Homick and I have developed a Spacelab experiment to evaluate changes in the weighting of neck-receptor signals during compensation for the absence of otolith information in a zero-gravity environment.

We have proposed that the astronauts repeat at intervals of 24 to 48 hours throughout the mission the luminous-line experiments already done in the laboratory. Our model predicts that under conditions of zero gravity weighting given to compensatory neck-receptor signals will increase and performance in aligning the rod will become increasingly accurate as the astronauts adapt to a rearrangement of orientation stimuli in which otolith signals are absent. According to the model, after returning to the ground the astronauts may overcompensate in performing the same task.

Another line of inquiry that will be pursued in early Spacelab missions is the investigation of space motion sickness. Fourteen out of 34, or 41 percent, of the astronauts on the Apollo and Skylab missions experienced symptoms of motion sickness (typically pallor, cold sweating, nausea and vomiting) in the initial period of weightlessness. (Apollo refers to the manned moon landings; Skylab was an orbiting research laboratory employed in missions undertaken in 1973 and 1974.) Motion sickness may significantly impede performance by astronauts during Spacelab missions and has been identified by the National Aeronautics and Space Administration as a major problem to be addressed on the initial flights.

The available evidence suggests that the motion sickness experienced under conditions of zero gravity may be associated with the vestibular apparatus. Graybiel examined the reactions of subjects with a defective vestibular system to parabolic flight in high-speed aircraft. In such flight the aircraft climbs and descends on a parabolic trajectory. At the beginning of the trajectory the occupants of the aircraft feel a linear acceleration, at the top they feel no gravity for as long as 30 seconds and at the end they feel another linear acceleration. This sequence usually results in motion-sickness symptoms in individuals who have a normal vestibular system. Graybiel's subjects with a defective vestibular system did not report such symptoms.

Among investigators interested in the vestibular system the prevailing explanation for space motion sickness, as for terrestrial motion sickness, is sensory mismatch: the disparity between orientation inputs received from different receptors. For example, a person who is at sea during a storm and remains in his cabin receives visual information that his body is fixed with regard to a stable,



**SLED APPARATUS similar to this one will be used in Spacelab, a reusable orbiting module, to test astronauts' adaptation to weightlessness. Astronauts who have been blindfolded will be moved back and forth in the sled; they will indicate perceived motion by operating a joystick.**

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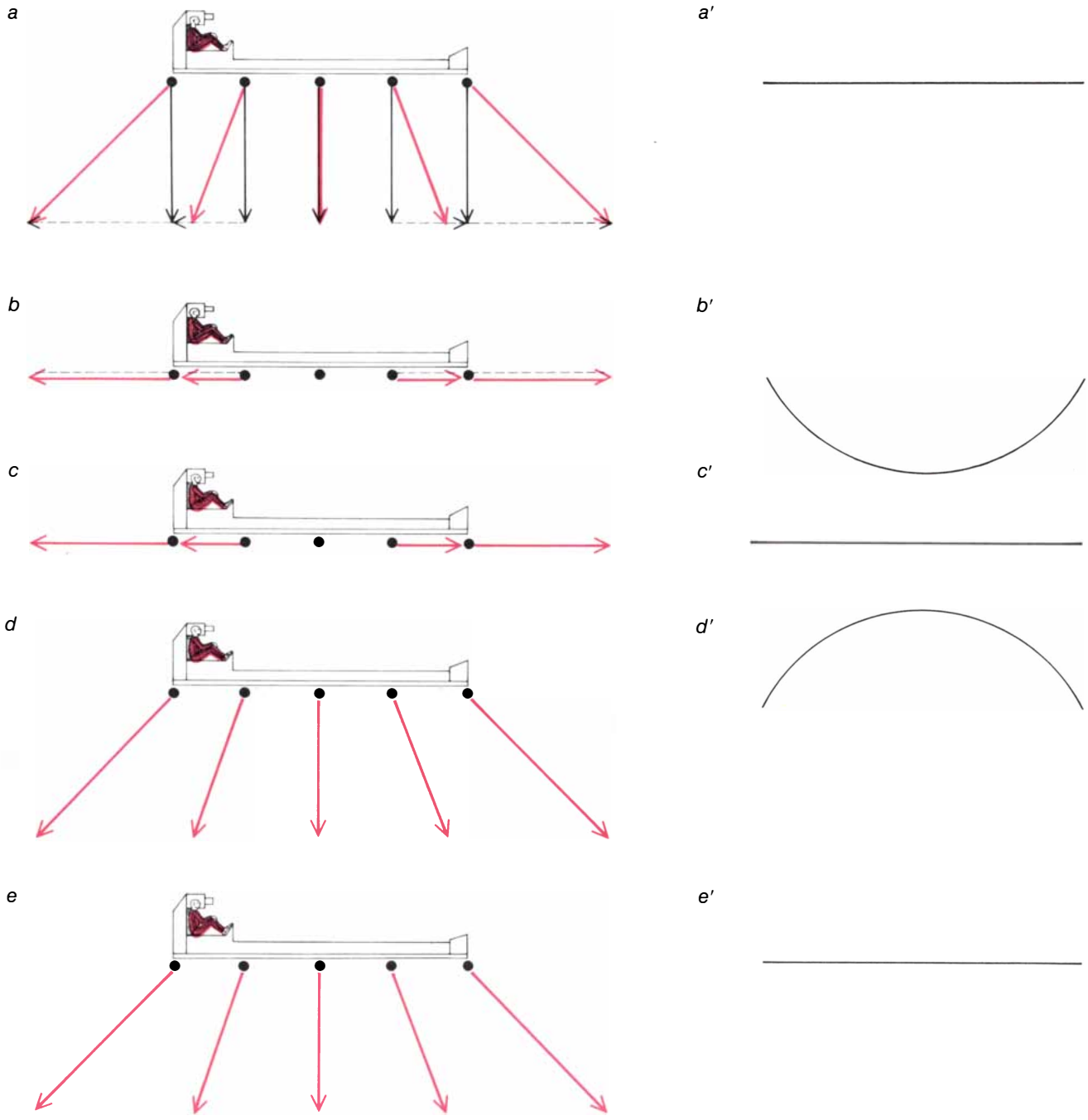
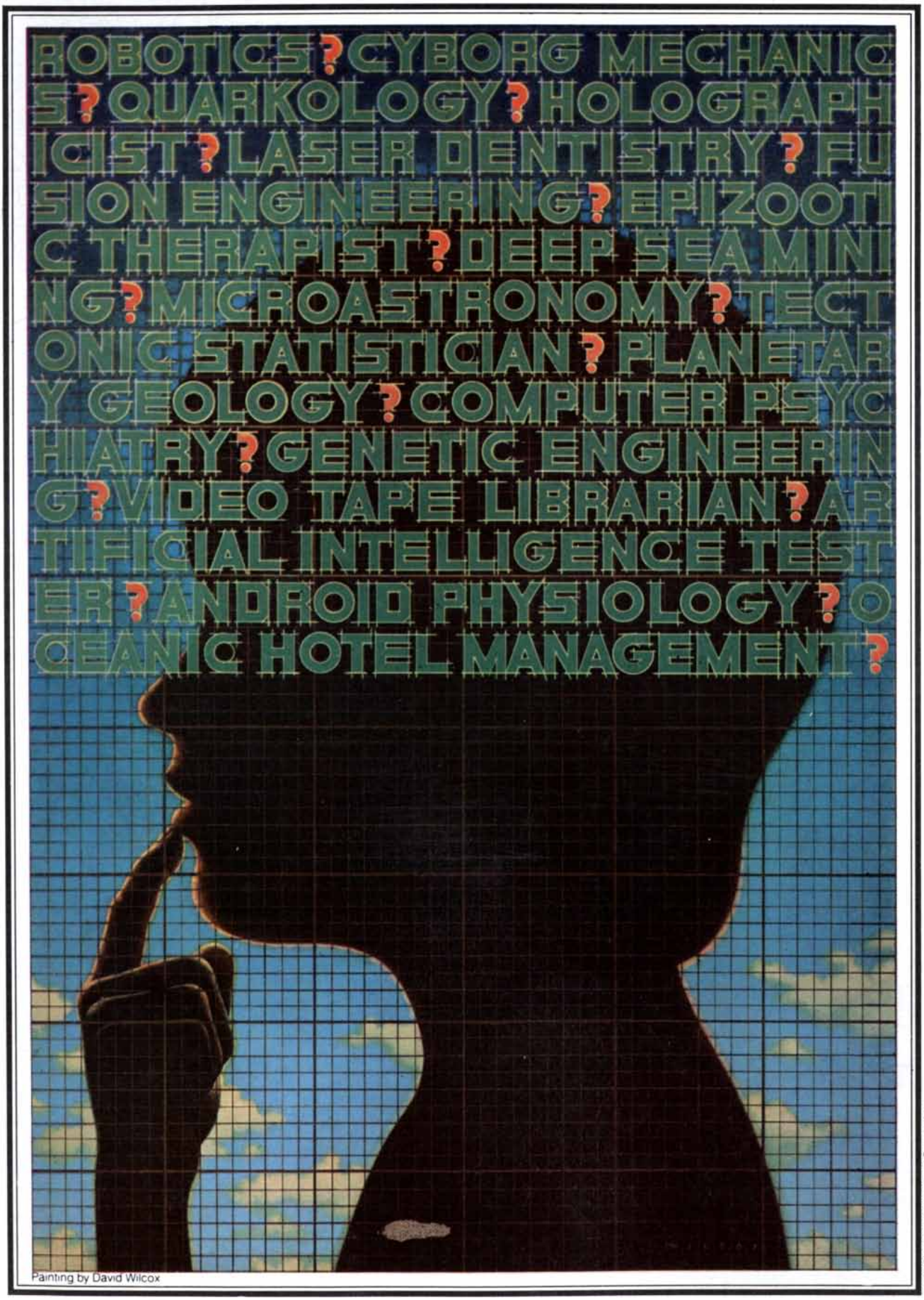



**MOTION ILLUSION** may be experienced by astronauts who have been oscillated on a sled apparatus during a Spacelab flight. This experiment will demonstrate the human capacity for adapting to the rearranged sensory input arising from weightlessness. The left-hand column shows the acceleration experienced by the astronauts at several points along the track during the five stages of the flight. The top diagram (*a*) illustrates the acceleration that will affect the astronauts before lift-off; the same acceleration affects them at other times when they are on the ground (*d*, *e*). The acceleration produced by the sled (*broken-line arrow*) will be greatest at the ends of the track; at the center of the track the astronauts will undergo no horizontal acceleration. Gravity (*black arrow*) provides a constant downward pull equivalent to accelerating an object in a weightless environment at 980 centimeters per second squared; the astronauts' acceleration due to gravity is therefore the same at all points on the track. The total acceleration (*colored arrow*) is the sum of the horizontal and vertical accelerations. Astronauts oscillated on the track while they are on the ground are thus exposed to a rotating linear acceleration. In space, where gravity is absent, astronauts experience only the horizontal acceleration produced by the track (*b*, *c*). The right-hand column shows the astronauts' perception of their motion (as predicted by the author) during the same five stages of the flight. Before lift-off the astronauts will correctly perceive their motion to be linear (*a′*). Their initial exposure to weightlessness will produce the sensation of traveling in a parabolic trajectory (*b′*). After the astronauts adapt to a zero-gravity environment their motion will again appear to be linear (*c′*). On returning to the ground they will perceive themselves to be traveling in a parabola oriented in the direction opposite to the one they will have imagined in space (*d′*). After an extended period on the ground they will again recognize their motion as being linear (*e′*). Changes in the perceived motion should demonstrate the capacity of the central nervous system for adapting to rearranged sensory stimuli.

nonaccelerating environment (the cabin). As the ship is tossed by the storm, input provided by the vestibular apparatus is at variance with the visual information, and motion sickness may result. Because of the sensory rearrangement produced by weightlessness a similar mismatch should arise during space flight.

Experiments performed on a programmable rotating chair in Skylab suggest a more critical contribution of the otolith receptors to motion sickness than had been recognized previously. Graybiel and his colleagues examined the motion-sickness symptoms elicited by cross-coupled angular accelerations. Cross-coupling can take place when the semicircular canals move in and out of the plane of rotation of the entire body; Graybiel's experiment duplicated this effect when an astronaut moved his head through prescribed angles while he was rotating in the chair at a constant velocity. On the ground cross-coupled angular accelerations usually give rise to motion sickness and disturbances in spatial orientation. Suprisingly, the Skylab astronauts indicated that they felt few if any motion sickness symptoms even after extended exposure to cross-coupled angular accelerations while weightless. Although these results are not fully understood, they suggest that the terrestrial motion sickness produced by head movement during rotation may originate in a conflict between information from the otolith organs and information from the semicircular canals. In space, where the otolith organs are not responding to gravity, this sensory mismatch may be greatly reduced.

The sensory-mismatch hypothesis may not be adequate to explain all reported cases of space motion sickness. One of the Skylab astronauts was so insensitive to sensory mismatch in preflight training that he was given the nickname Lead Ear. At the beginning of a Skylab flight, however, he experienced severe motion sickness for several days. In response to observations such as this one several workers have proposed that space motion sickness might be associated with a change in vestibular stimuli caused by the large shifts of body fluids that occur when an astronaut enters a zero-gravity environment. In the absence of gravity the muscles of the legs tend to force fluids upward into the torso and the head. As a result of these shifts astronauts tend to develop thin "chicken legs," a puffy face, a continuous nasal discharge and possibly an alteration of fluid balance in the labyrinth. Data supporting a fluid-shift explanation of space motion sickness may emerge from experiments to be performed on the Spacelab flights. Indeed, the Spacelab era promises to be one of excitement in all areas of vestibular research.




Painting by David Wilcox

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What this means, as a practical matter, is that one of the major "jobs" in the future will be learning itself. What we now call "work" may be redefined to include a strong component of *learning*. Learning will never stop. Because those people who stop learning will stop working.

But what can we do now to prepare for this new and unpredictable way of life?

We must give our children nothing less than the ability to think, the ability to absorb facts quickly and then structure them into a useful discipline. Creativity, chance-taking and insight will be at a premium along with adaptability to rapid change.

It's the kind of thinking which educators have been *attempting* to teach at least since the time of Socrates.

How then will our children, instead of just learning today's "lessons," learn to be experts at continuous learning? From our teachers? But who will teach the teachers this new way of looking at things?

For a number of reasons, educational systems tend to become institutionalized: because of the expensive commitment to physical plant, previous training, established curricula and lack of discretionary funds for experimentation. Now, suddenly, they must de-institutionalize to meet a rapidly compressing future. What can we do?

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# Superconductors in Electric-Power Technology

*The exploitation of materials that carry current without loss has had to await the creation of superconductors that also withstand high current densities and strong magnetic fields*

by T. H. Geballe and J. K. Hulm

The technological promise of superconducting materials has been obvious since superconductivity was discovered 70 years ago. A wire that offers no resistance to the flow of a steady electric current suggests the possibility of generating electric power with an efficiency approaching 100 percent and of transmitting it great distances without loss. Why, then, are superconductors not found everywhere in the power network? Indeed, why is it that not one superconducting generator or transmission line has yet entered commercial service?

One problem is the need for refrigeration. Superconductivity is observed only at temperatures close to absolute zero, and so liquid helium is required as a coolant. The need for cryogenic apparatus effectively excludes superconductors from certain small-scale applications, such as ordinary house wiring. In a large electric-generating plant, however, cooling would represent only a minor cost and inconvenience.

Until the 1960's there was a more serious impediment to the adoption of superconducting power technology: the known superconductors tended to be quenched, or restored to the normal resistive state, if they were exposed to a strong magnetic field or if they were forced to carry a high density of electric current. Large electrical machines, such as dynamos, almost invariably require a strong magnetic field and a high current density for efficient operation.

A number of unusual superconducting alloys and compounds have now been found to retain their superconductivity even when exposed to extremely high field strengths and current densities. The materials also have the highest-known temperatures of transition to the superconducting state, although helium cooling is still needed. With the introduction of these alloys and compounds the most fundamental barriers to the creation of a superconducting power system have been overcome. The remaining problems are technological and economic rather than physical.

The new high-field, high-current superconductors offer two main advantages in electrical technology: they can carry large electric currents without loss of energy through resistive heating, and they can operate in very strong magnetic fields. Both of these properties are of value, but it is probably through their combination in a single material that the greatest benefits are achieved. In order to explain why this is so we shall briefly examine the history of electric-power technology.

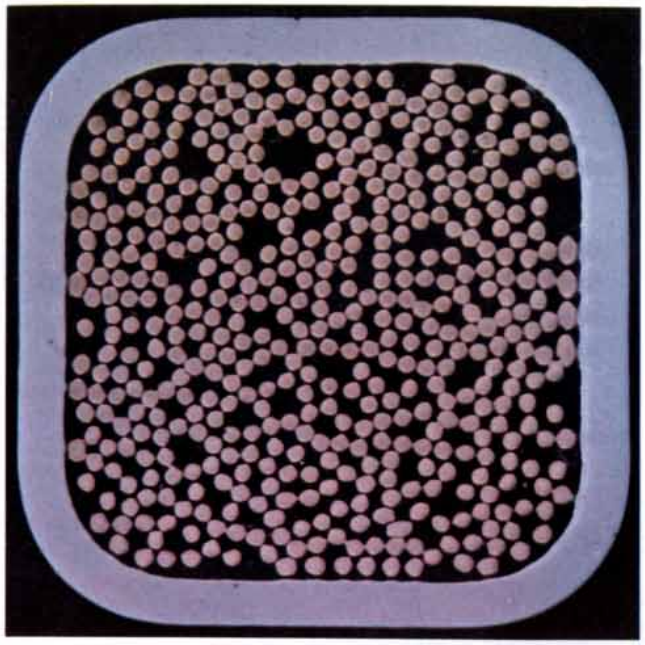
Two important early developments were the invention of the electrochemical battery in 1800 by Alessandro Volta and the discovery in 1819 by Hans Christian Oersted that electric current flowing in a wire gives rise to a local magnetic field. By 1830 Michael Faraday, Joseph Henry and others had found that the magnetic field generated in this way could be enhanced by winding the conductor into a coil or helix around an iron core. Such electromagnets became the central building blocks of power equipment.

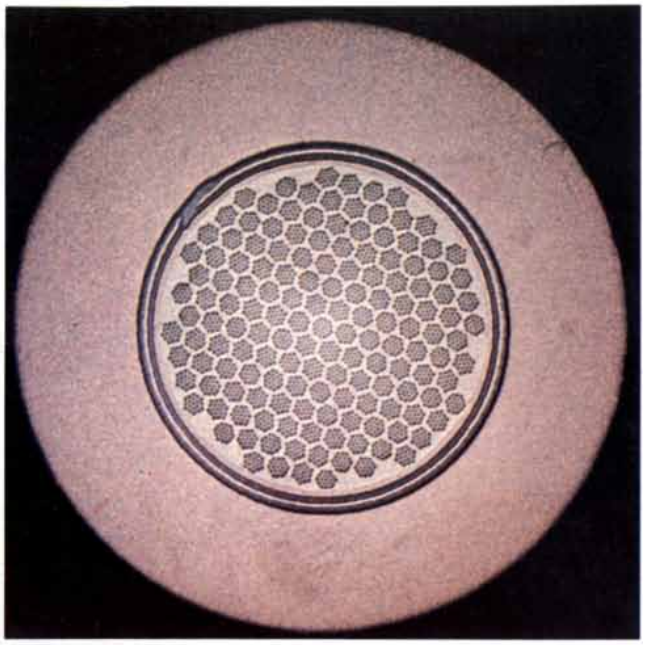
The next major advance was also made by Faraday; it was his discovery in 1831 that an electric current is induced in a conductor when the conductor is moved through a magnetic field. Faraday later constructed model generators of both the homopolar, or rotating-disk, type, which yield direct current, and the rotating-coil type, which yield alternating current. Industrial exploitation of these principles was delayed until about 1870, when the invention of the electric light created an economic incentive for the construction of community electric-power networks. The modern power industry emerged rapidly after 1870, through the efforts of inventor-entrepreneurs such as Thomas Edison and George Westinghouse.

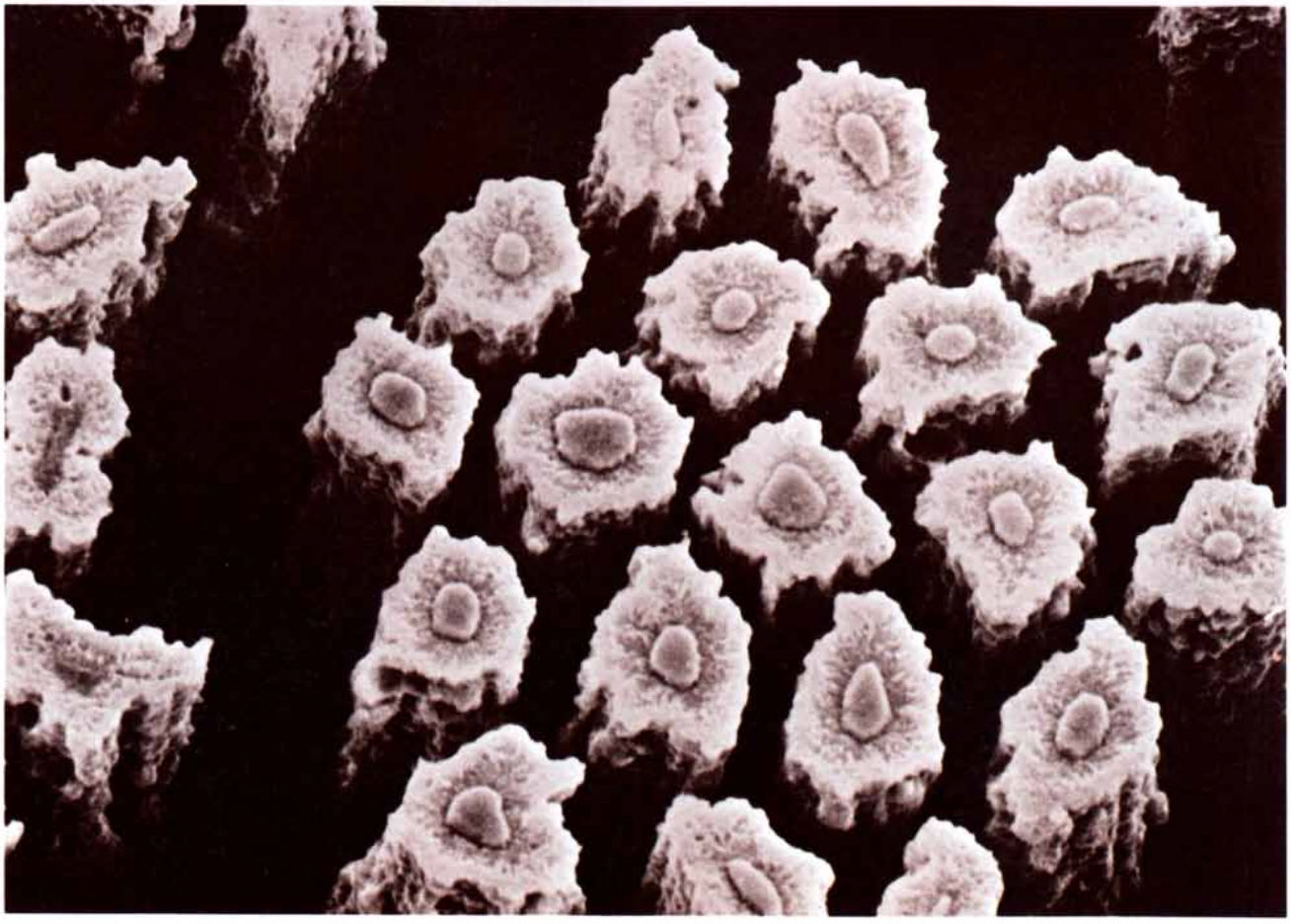
The advantages of transmitting power at high voltages but of generating and utilizing it at much lower voltages soon led the industry to adopt alternating current, for which voltage transformation is comparatively simple. As central-station alternators grew in size, Faraday's model generator was turned inside out. The electromagnet was rotated in the center of the machine and power was generated in stationary coils surrounding the magnet. Intensive development of this concept in the past century has enabled power outputs of more than 1,000 megawatts to be obtained from a single alternator. In principle about 400 such machines could supply the present electric-power needs of the U.S.

All electrical machines today are excited by electromagnets that employ copper windings. In these devices most of the magnetic flux results from the high ferromagnetic permeability of iron or iron-based alloys; the function of the copper coils is simply to apply a small exciting field to the iron core. Each atom of the iron or other ferromagnetic metal has a magnetic moment, which can be induced to align itself with an externally imposed field. The proportion of the atomic moments that are aligned depends on the strength of the applied field and hence on the excitation current. Even with a comparatively small current most of the atomic moments are lined up, with the result that the magnitude of the total field greatly exceeds that attributed to the coils alone. The effect of the iron core is thus to enhance the magnetic field generated by the excitation current.

This process has an obvious limit: once all the atomic moments are parallel, further increases in the excitation current can have no effect on the magnetization. The core is then said to be saturated. In the case of iron, saturation is reached at a field strength of about two teslas, or 20,000 gauss. (For comparison, the magnetic field at the surface of the earth has an average value of about one gauss.) Magnets, electrical







**FILAMENTARY SUPERCONDUCTOR will carry a current of 16,000 amperes in the windings of a magnet with a maximum field of eight teslas. The magnet is one of six that are being built to test magnet designs for a thermonuclear-fusion reactor. In the photograph at the upper left the entire cable is shown in cross section; it consists of 486 strands in a stainless-steel conduit, through which helium will be pumped under pressure to maintain the low temperatures needed for superconductivity. The photograph at the upper right is a magnified cross section of a single strand. Some 3,000 superconducting filaments, arranged in hexagonal groups of 19, are embedded in a matrix of bronze. The bundle of filaments is encased in a thick jacket of copper, which will take over the current if the superconductor is quenched, or returned to the resistive state. The irregular ring surrounding the filaments is a barrier of tantalum that prevents tin in the bronze from diffusing into the copper jacket. An outer sheath of semiconductor inhibits the formation of eddy currents. The lower photograph is a scanning electron micrograph of a single group of filaments, which consist of the niobium-tin compound $Nb_3Sn$. The compound is formed in place by allowing tin from the bronze to react with filaments of metallic niobium. A core of unreacted niobium can be distinguished in each filament. The cable was manufactured by Airco Superconductors for the Westinghouse Electric Corporation.**

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machines and all other components of the power system are today limited in performance by the saturation barrier.

The two-tesla flux barrier of electric-power technology is not rigid; it can be penetrated in a number of ways in the laboratory. For example, the saturation flux level of certain rare-earth metals, such as dysprosium, approaches four teslas at low temperature. Steady magnetic fields exceeding 20 teslas can also be obtained with high-power, water-cooled copper solenoids of the kind first developed by Francis Bitter in about 1935. Short-duration fields of still higher peak values can be attained by pulsed-coil techniques pioneered by Peter Kapitza in the 1920's or by the explosive compression of magnetic flux in a metallic enclosure.

Enormous power is needed to drive copper-solenoid magnets of this kind, and large volumes of water must be pumped through the windings to keep them from melting. Such brute-force methods are suitable for research but not for everyday use in the electric-power system. Even if such a magnet could be operated reliably in a generator, the energy consumed in its windings would exceed any gain in efficiency resulting from the stronger field.

The large quantities of energy dissipated in the windings of a copper magnet are not needed to sustain the magnetic field. On the contrary, no energy at all is needed to maintain a steady magnetic field once it has been established. The energy is lost solely in overcoming the resistance of the copper to the flow of the excitation current. It follows that a superconducting magnet, which has a resistance of zero, can maintain a steady field without input of energy. The maximum strength of the magnetic field is limited not by power requirements or heat dissipation but only by the intrinsic properties of the superconducting material.

Superconductivity was discovered 70 years ago by the Dutch investigator Heike Kamerlingh Onnes, who noted with some surprise that a thread of frozen mercury abruptly lost all electrical resistance at a temperature of just below 4.2 degrees Kelvin, the boiling point of helium. The same abrupt transition to a resistanceless state was later found in lead at 7.2 degrees and in tin at 3.7 degrees. The possibility of constructing a high-field electromagnet occurred to Onnes at once, and in 1913 he wound a coil of lead in order to test the idea. The results were disappointing. Although the coil was superconducting as long as the excitation current was small, the lead reverted to the resistive state whenever the magnetic field exceeded a moderate strength. Further experiments showed that for all pure-metal superconductors there is a distinct and sharply defined critical field strength, usually less than .1 tesla, at which the superconductivity is suddenly quenched.

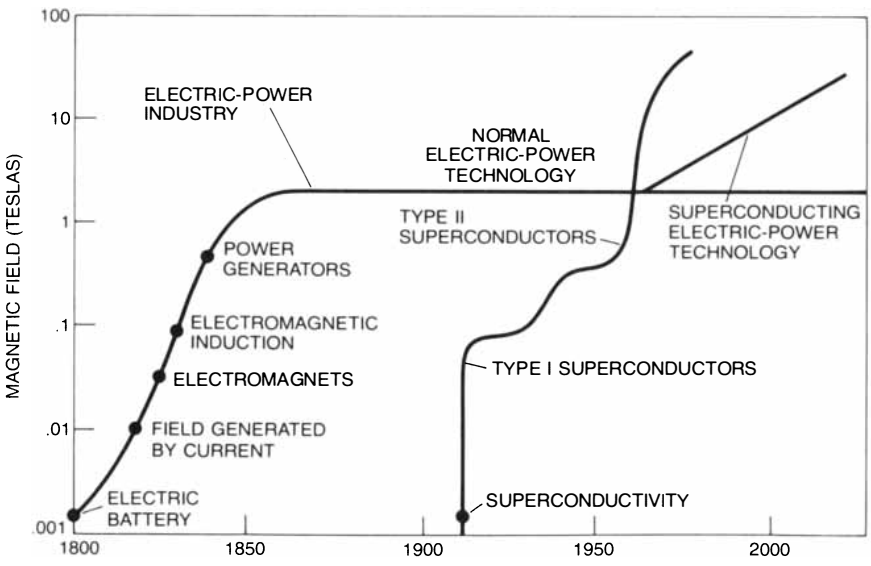
The magnetic properties of a superconductor are unusual even at fields below the critical level. If a small field is applied to a superconductor, it induces a permanent supercurrent at the surface of the metal, which excludes the magnetic flux from the interior. The magnetic field penetrates only a thin layer at the surface. The distance the field extends into the material, which is called the penetration depth, is usually $10^{-5}$ centimeter or less.

By the end of the 1930's superconductivity was understood to arise from a phase transition among the conduction electrons of a metal. At room temperature the electrons form a gas, but below a critical transition temperature some of them enter a condensed phase, which has a lower energy than the gas. Still lacking was a quantum-mechanical theory of the condensation built on the basic interactions of electrons.

Such a theory was formulated in 1957 by John Bardeen, Leon N. Cooper and J. Robert Schrieffer, who were then at the University of Illinois. Their analysis was based on the idea that the carriers of electric current in a superconductor are not individual electrons but bound pairs of them. All electrons, of course, have the same negative electric charge, so that they ordinarily tend to repel one another rather than bind together. In the crystal lattice of a metal, however, an attractive interaction between electrons can be mediated by the background of positive metal ions. The positive ions are heavier than the electrons and move much slower; hence their response to the passage of an electron is delayed. The persistence of the response after one electron has passed creates a concentration of positive charge that attracts the second electron in a pair. The indirect attractive force between electrons is exceedingly weak, and at room temperature it is readily overcome by their thermal agitation. Near absolute zero, however, in a metal with a suitable chemical and crystal structure, the electrons can reduce their total energy by condensing into pairs. Since all the electron pairs necessarily have the same momentum, the momentum of a pair cannot be changed by scattering and so there is no resistance.

The theory introduced by Bardeen, Cooper and Schrieffer gave a remarkably successful account of most of the basic features of the superconducting state, including the reduced energy of the electron pairs and the existence of a critical magnetic field. A number of other aspects of superconductivity were not dealt with, however, such as the properties of superconducting alloys.

Superconducting alloys had come un-




**ELECTRIC-POWER TECHNOLOGY could be developed only as methods became available for creating the strong magnetic fields required by motors, generators and other electrical devices. In the normal or nonsuperconducting technology the fields are derived from electromagnets of copper and iron, which have a practical maximum field strength of about two teslas. Superconductivity was discovered in 1911, but it could not initially be adopted for power devices because the early superconductors, which are now classified as Type I, could not operate in strong magnetic fields. The discovery that a few Type II superconductors (most of which are alloys or metallic compounds) can tolerate extreme fields has overcome the two-tesla barrier. The development of Type II superconductors that not only withstand strong fields but also carry a high density of electric current has aroused interest in superconducting power devices.**

der study in the 1930's, and several of them had been found to have a greater tolerance for magnetic fields than the pure-metal superconductors. In alloys of lead and bismuth, for example, the transition from the superconducting state to the fully normal state took place not at a single, well-defined critical field but over a wide range of field strengths. Traces of superconductivity remained up to about two teslas.

In 1934 Cornelius J. Gorter of the University of Leiden and Heinz London of the University of Oxford independently suggested that the extended transition region in alloys might be explained by the formation of superconducting and normal domains alternating throughout the material. They noted that the domains would be stable if the energy associated with the phase boundary between domains became negative.

In 1953 Brian Pippard of the University of Cambridge introduced the concept of a coherence length in superconductors, which is a measure of the scale of the quantum-mechanical wave functions that define the superconducting electron pairs. The coherence length can also be characterized as the minimum thickness of the interface between a superconducting region and a normal one. Pippard found that the coherence length decreases in alloys with increasing solute concentration. He noted that if the coherence length were to become smaller than the penetration depth, the negative-interface-energy condition of Gorter and London would be satisfied. A broadened transition in a magnetic field would then result.

These ideas were put into a new form in 1957 by the Russian physicist A. A. Abrikosov. He distinguished two categories of superconductors, designated Type I and Type II. In a very weak magnetic field the two kinds of material act in much the same way: they both expel the field entirely. Differences appear when the applied field is made stronger. In Type I materials, which are most often pure metals, the surface shielding current collapses and the magnetic flux enters the material suddenly at a well-defined critical field strength. Type II materials give up their superconductivity through a more gradual process. The magnetic flux begins to penetrate at a low field intensity (the lower critical field), but the last trace of superconductivity is not eliminated until a much stronger field is applied (the upper critical field).

The penetration of the magnetic flux into a Type II superconductor depends crucially on a quantum-mechanical constraint: the existence of a minimum quantum of magnetic flux. The field inside a Type II superconductor therefore cannot build up continuously but must grow stepwise, one flux quantum at a time. Abrikosov suggested that each flux quantum passes through the material in a microscopic channel of normal resistive metal. Each channel is surrounded by a small supercurrent vortex, which acts to shield the neighboring superconducting material from the internal field of the flux quantum. The current in the vortex is analogous in function to the surface shielding current at lower field intensities.

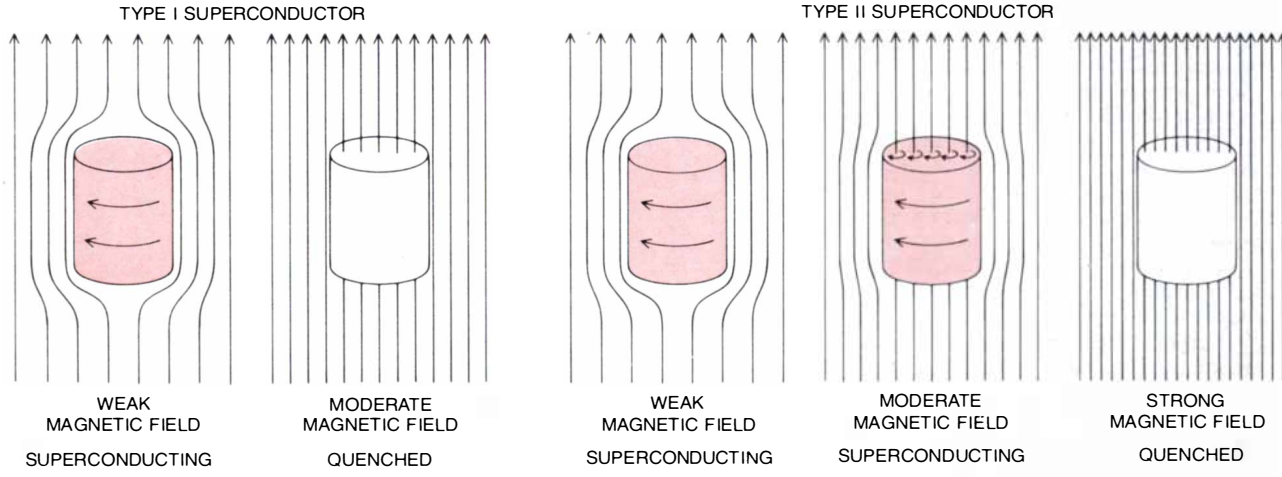
A cross section of such a vortex would reveal a narrow core region where the magnetic field is at a maximum and the density of superconducting electron pairs is at a minimum. Moving outward from the core, the density of paired electrons increases, and it approaches the equilibrium density characteristic of the bulk material at a distance of one coherence length. Conversely, the magnetic field decreases with distance from the core, and it is effectively zero at a distance of one penetration depth.

Whether a given superconductor is of Type I or Type II is determined by the relative values of the coherence length and the penetration depth. In pure metals and other Type I materials the coherence length is larger than the penetration depth and vortexes do not form. The energy cost of creating a vortex is greater than that of eliminating the superconducting state entirely. In Type II materials the coherence length is smaller than the penetration depth. The formation of vortexes is therefore energetically favored.

As the magnetic field applied to a Type II superconductor is raised, the flux quanta threaded through the material increase in number. Typically they form a crystal-like lattice with a triangular unit cell. Regions of superconducting metal remain between the vortex channels, and so superconductivity persists in the bulk material. Indeed, as long as a single continuous thread of superconductor remains, the measured resistance of the specimen must be equal to zero. The Type II superconductor is quenched only when the vortexes are packed so close that such a continuous path cannot exist; that is what happens when the upper critical field is reached.

Although Abrikosov's model provided a theoretical basis on which high-field superconductors could be understood, it did not immediately stimulate interest in superconducting technology. For one thing, the possibility of extremely high critical fields (greater than two teslas) was not obvious. Moreover, the question of current density was not considered at all.

The discovery of technologically use-




**TYPE I AND TYPE II SUPERCONDUCTORS are distinguished by their responses to a magnetic field. A weak field is expelled by both kinds of material as a result of shielding supercurrents formed in a surface layer. In a Type I superconductor these currents collapse when the field is raised to a moderate intensity, usually less than .1 tesla; the field then penetrates the metal and the superconductivity is abolished. In a Type II material quanta of magnetic flux begin to enter at a moderate field but are isolated from the surrounding superconductive regions by vortical supercurrents. The last trace of superconductivity is not eliminated until the field reaches a higher level.**

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ful superconductors resulted from a search for new high-critical-temperature materials. The work was done at the University of Chicago and at Bell Laboratories by us and by Bernd T. Matthias. A great many candidate materials were tested, and particular attention was given to alloys and compounds of metals in the transition series (the eight groups of elements that fall roughly in the middle of the periodic table).

One group of transition-metal compounds was found to include a number of materials with notably high critical temperatures for the onset of superconductivity. These materials are characterized by a crystalline structure designated *A*15. The prototypical member of the class is the niobium-tin compound $Nb_3Sn$, which becomes a superconductor at 18 degrees K. In 1961 the magnetic properties of $Nb_3Sn$ were investigated by J. Eugene Kunzler, Ernest Buehler, Frank S. L. Hsu and Jack H. Wernick at Bell Laboratories. The compound was found to greatly exceed the capabilities of all materials known up to then: superconducting $Nb_3Sn$ sustained a current density of more than 100,000 amperes per square centimeter while immersed in a magnetic field of almost nine teslas. The critical field of $Nb_3Sn$ was later found to exceed 20 teslas.

Further investigations showed that the high tolerance of $Nb_3Sn$ for magnetic fields could be accounted for by Abrikosov's model. The material is an extreme Type II superconductor, that is, the coherence length is much shorter than the penetration depth. More work was needed to explain the high critical current density of $Nb_3Sn$.

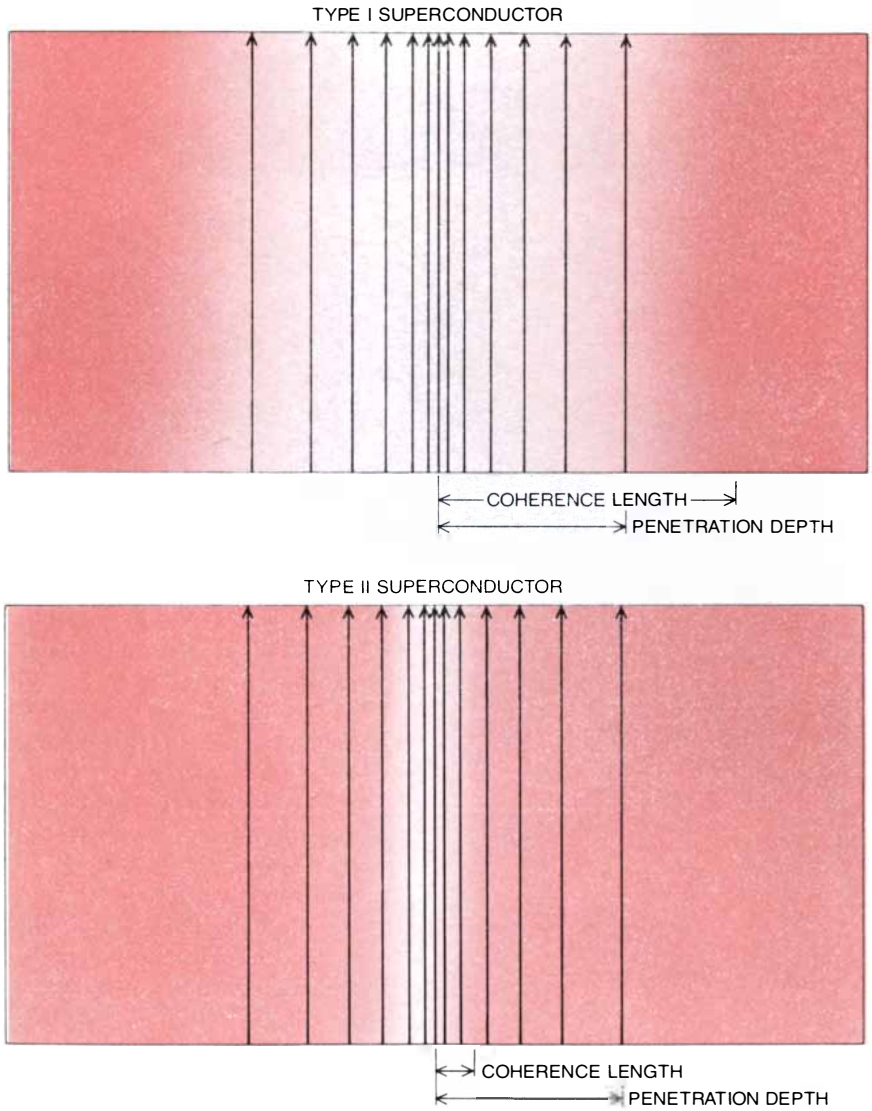
Key ideas in the solution of this problem were put forward simultaneously by Gorter and by Philip W. Anderson of Bell Laboratories. They noted that the current in the superconductor would exert a force on the magnetic flux lines, tending to push them at right angles both to their own axis and to the direction of current flow. The force is the same one that is ultimately responsible for movement in an electric motor or in a loudspeaker. The movement of the flux lines under the influence of this force can cause local heating and thereby quench the superconductivity.

Gorter and Anderson suggested that vortexes could become pinned at defects in the crystal structure and thus be able to resist the force arising from the supercurrent; only when a threshold was exceeded at the critical current density would the vortexes break loose. Many kinds of defects can serve to pin the vortexes; they include dislocations, grain boundaries, voids and clusters of impurity atoms.

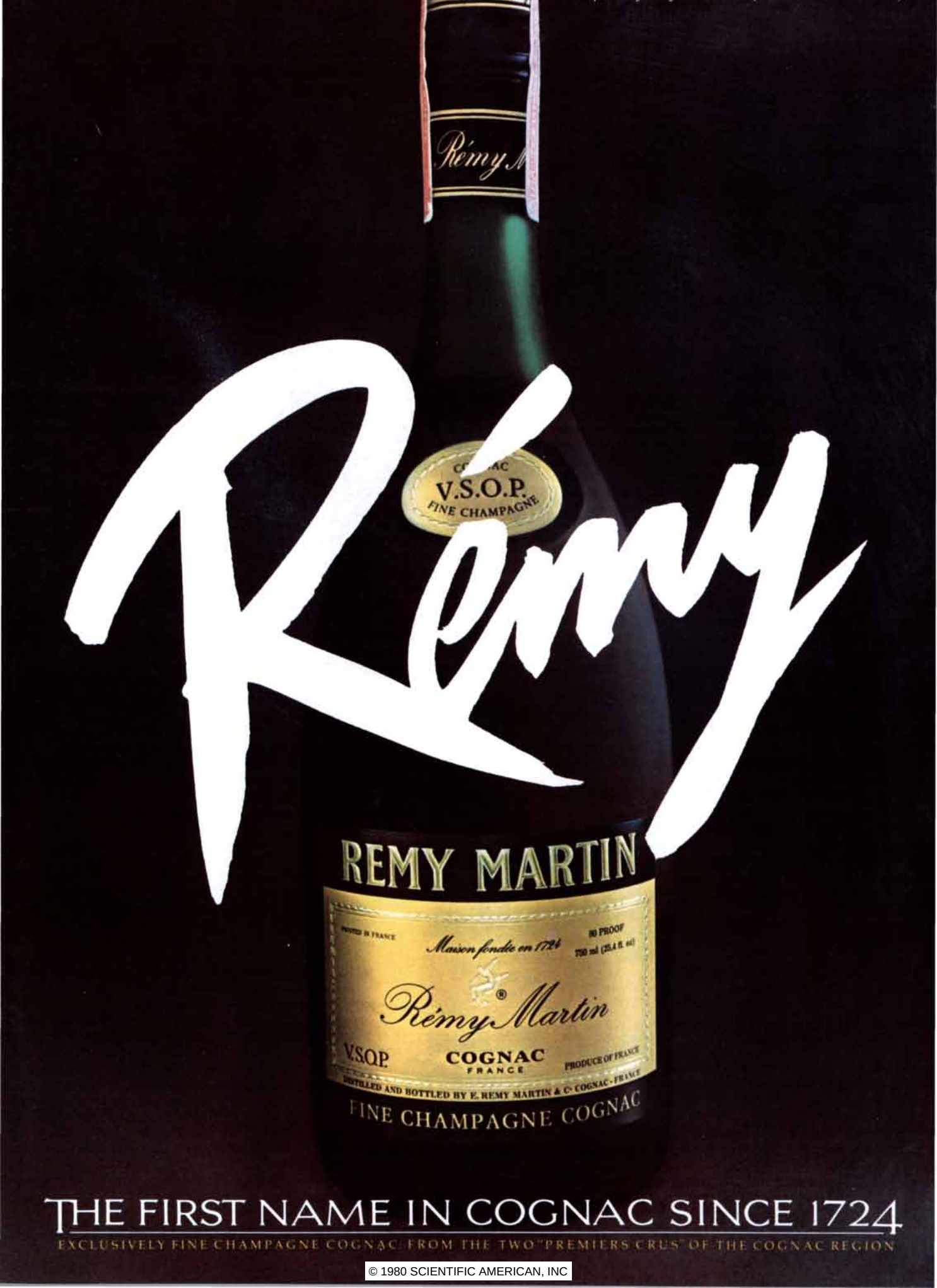
The list of specifications for a high-field and high-current superconductor therefore describes materials that seem to be distinguished mainly by their imperfections. They are generally quite poor conductors in the normal resistive state. The materials also have a high density of structural defects for pinning vortexes. In practice the superconductors of technological interest have a critical temperature greater than nine degrees K., an upper critical field greater than about eight teslas and a critical current density greater than 10,000 amperes per square centimeter.

Since the 1960's a number of materials have been discovered that satisfy the criteria for high-field, high-current operation. Just two of them, however, have emerged as the workhorses of superconducting-magnet technology: $Nb_3Sn$ and the niobium-titanium alloy $Nb_{40}Ti_{60}$. Both materials have extreme Type II properties, with a coherence length much smaller than the penetration depth. In the niobium-titanium alloys vortexes are pinned by tangles of dislocations, which pile up during the drawing of a wire. In $Nb_3Sn$ pinning seems to take place mainly at grain boundaries, and so a high critical current density requires a small grain size. Most of the techniques for preparing $Nb_3Sn$ yield small grains.

Even with the availability of suitable



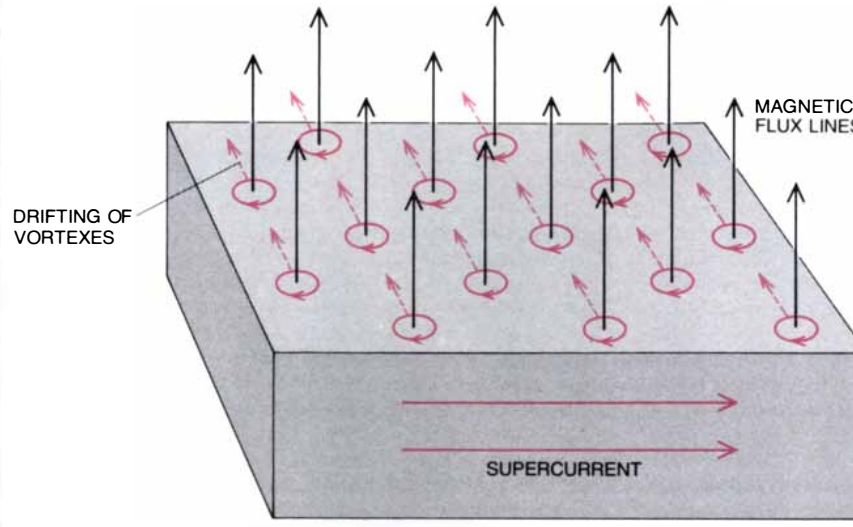

**QUANTUM OF MAGNETIC FLUX in a superconductor is confined by vortical supercurrents to a narrow channel of normal resistive metal. The core of the channel is swept free of superconducting electron pairs, but the density of such pairs (*indicated by color*) increases gradually away from the core and reaches its equilibrium value at a distance called the coherence length. Conversely, the magnetic field has its maximum intensity in the core and decays to zero in a distance called the penetration depth. The relative values of the coherence length and the penetration depth determine the magnetic properties of the material. If the coherence length is greater than the penetration depth, vortexes are energetically costly and do not form; the material is of Type I and cannot tolerate a strong magnetic field. (The hypothetical Type I vortex shown here is therefore an unstable structure and would never be observed.) A coherence length smaller than the penetration depth favors formation of vortexes in Type II superconductors.**



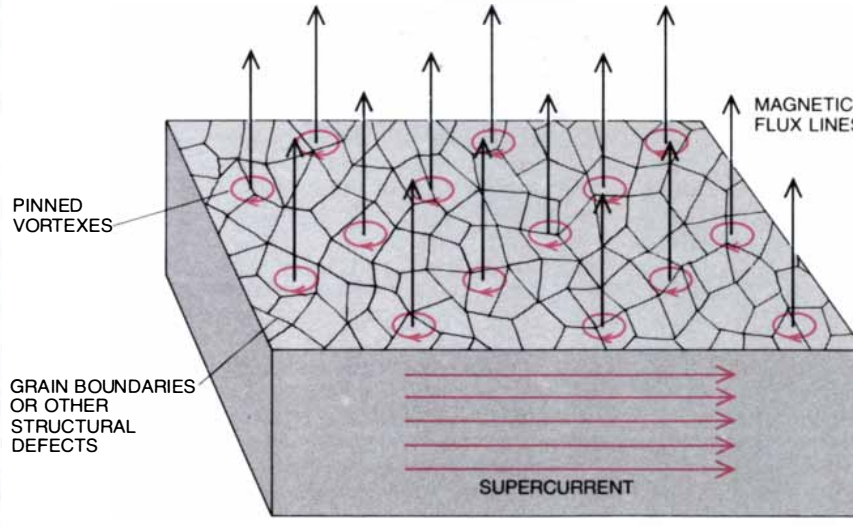
materials, building a superconducting magnet is not a simple or straightforward undertaking. If some small region of the winding exceeds the critical current density and is thereby quenched, a practical superconducting magnet must be able to enter the normal state safely. In a coil of pure superconductor such a region would be an isolated link of high resistance and would immediately be subject to strong resistive heating. The heat given off would of course quench surrounding regions of the superconductor, so that the normal region would grow. If this process is not controlled, the consequences can be dire. High voltages are induced by the collapse of the field; they can break down insulation and permanently damage the structure.

A first step in the effort to avoid such a catastrophic failure was to clad the superconductor with a low-resistance normal conductor, such as copper. If a region of the winding then loses its superconductivity, the excitation current is diverted into the copper.

Copper cladding allows a small superconducting magnet to be driven into the resistive state with safety. For a larger magnet, however, the energy of the field is too great for it to be dissipated as heat

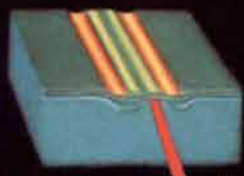



LOW-CRITICAL-CURRENT TYPE II SUPERCONDUCTOR




HIGH-CRITICAL-CURRENT TYPE II SUPERCONDUCTOR

**MOVEMENT OF FLUX LINES is responsible for the quenching of superconductivity when a Type II material is forced to carry a current density exceeding a critical value. The flux lines are acted on by a force directed perpendicular both to their own axis and to that of the supercurrent. Their movement can liberate enough heat to quench the superconductor. A high critical current density is achieved when there is an ample supply of grain boundaries or other defects in the crystal structure, which pin the flux lines. Superconductors of technological interest are those few that have both a high critical magnetic field and a high critical current density.**



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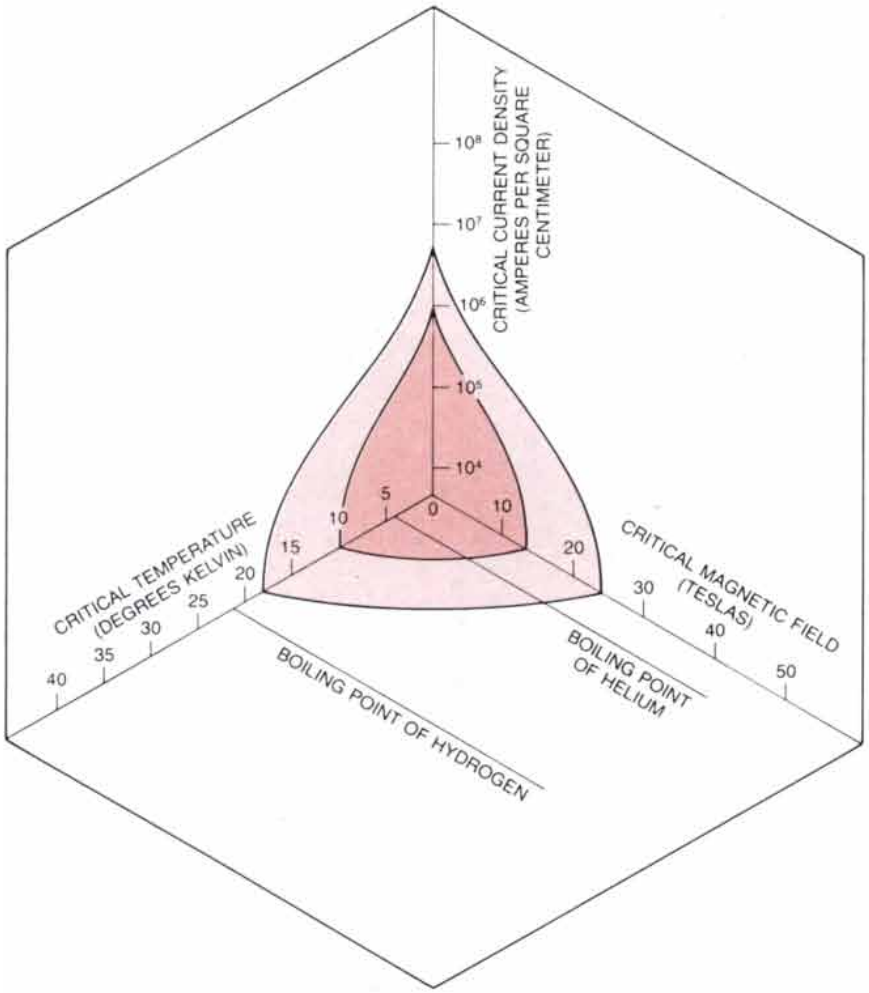
in the windings. A solution to this problem developed in the mid-1960's was called cryostatic stabilization. The ratio of copper to superconductor in the windings was greatly increased, usually to a value of at least 20 to one. In addition the helium coolant was circulated directly over the surface of the windings so that heat could be extracted rapidly. By these means all the heat evolved by a small resistive region can be drawn off without a rise in temperature, and so the growth of the normal zone is stopped. After a short time the superconducting path is reestablished.

The main disadvantage of cryostatic stabilization is that the overall current density in the winding is much reduced. For a high-performance magnet the superconducting windings cannot be so heavily diluted with copper. In order to reach higher fields a new strategy has evolved, aimed at eliminating the causes of premature quenching. It had been observed in the 1960's that experimental superconducting magnets tended to quench at current densities well below the critical value measured in small samples of the winding material. Repeated excitation of the magnet often led to a gradual improvement, an effect called training. The premature quenching is caused by the release of energy in the windings during excitation. Two sources of such energy release have been identified. One source is called a flux jump; the other is motion of the conductors in response to mechanical stress.

As the field in a superconducting magnet changes, the large excitation current in the winding gives rise to induced shielding currents, which circulate in each superconducting strand. Under some conditions the shielding currents become unstable and can collapse spontaneously. The resulting flux jump, or sudden movement of the flux lines, introduces a "spike" of heat,




**PHASE DIAGRAM for two Type II materials specifies the conditions of temperature, current density and magnetic field under which superconductivity can be maintained. At the boiling point of helium, which is the most convenient temperature of operation, alloys of niobium and titanium must be limited to a field of roughly 10 teslas and a current density of less than 100,000 amperes per square centimeter. $Nb_3Sn$ can operate under more extreme conditions. The maximum field of $Nb_3Sn$ at the boiling point of helium is more than 20 teslas and in a less intense field the current density can approach a million amperes per square centimeter.**

which can raise the temperature enough to quench the superconductor.

The thermal energy per unit volume released by a flux jump is proportional to the diameter of the superconducting wire. Hence it is possible to reduce the effect of flux-jump instabilities by replacing a single conductor with a composite of small superconducting strands embedded in a matrix of a good normal conductor such as copper. For niobium-titanium alloys the filament diameter has been reduced from roughly a millimeter (for single-strand superconductors) to about 10 micrometers (for a composite).

The fabrication of such multifilamentary composites is a complex technology. The commonest procedure is to extrude a billet of copper in which several alloy rods are embedded. The composite rods are then drawn into wires, assembled into bundles and redrawn to finished size. It is also usual to twist the conductor around a central axis.

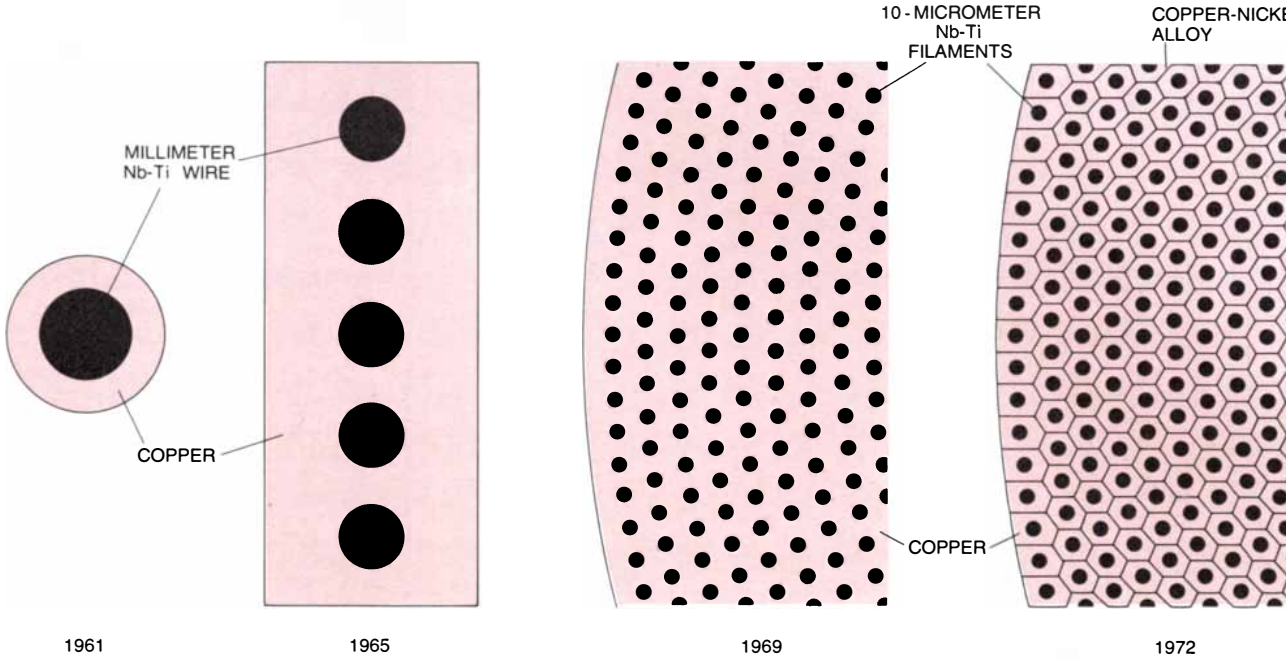
The development of multifilamentary composites has not completely eliminated training in superconducting magnets. As larger magnets have been designed the problem has resurfaced and has proved to be quite serious in magnets operated at current densities near the capacity of the conductor material. The main cause of this residual training effect is probably frictional heating resulting from mechanical motion of the conductors. It seems that when a magnet is first excited, the conductors must "shake down" into new positions, releasing heat spikes in the process. Although it might seem desirable to prevent such movement by strong mechanical constraints, that is not easily accomplished while at the same time providing access to the conductor surface for the liquid-helium coolant.

In addition to heat spikes caused by flux jumps and conductor motion, heat is also introduced into a magnet winding by screening currents that are induced whenever the internal field changes. The screening currents become more important as the field changes more quickly, and so the heating they cause is called a dynamic loss. Many large research magnets, including those in particle accelerators and in nuclear-fusion reactors, must be pulsed on and off, so that the field changes rapidly. Hence steps must be taken to reduce the dynamic losses as much as possible. Making the filaments still smaller reduces the screening-current loss in the superconductor itself; twisting and transposing the filaments in a composite reduces losses caused by eddy currents in the copper matrix. The eddy currents can be further reduced by incorporating a resistive barrier in the copper. The barrier can be formed of a high-resistance copper-nickel alloy applied to each copper-clad rod before the filaments are bundled for the final stages of drawing. The finished material then has a complicated structure. It is an assembly of twisted and transposed superconducting filaments, each one embedded in copper and isolated from its neighbors by a thin copper-nickel wall.

A fine filamentary structure is equally important in superconductors based on $Nb_3Sn$ and related *A*15 compounds. Because these materials are extremely brittle, however, fabrication is still more difficult. The first $Nb_3Sn$ conductors were made by compacting a mixture of niobium and tin powders inside a niobium tube and drawing the tube into a length of wire. The $Nb_3Sn$ compound was formed by heat treatment only after the wire had been wound on the magnet armature, so that there would be no need for further bending.

In a more recent technique a filamentary composite of pure niobium metal is formed in a matrix of bronze (an alloy of copper and tin). After the wire is drawn to its final size it is heated, causing some of the tin to migrate from the bronze into the niobium, where it reacts to form $Nb_3Sn$. The superconductor $V_3Ga$ (an *A*15 compound of vanadium and gallium) can be made in much the same way. Several other methods of fabricating *A*15 superconductors as finely divided composites are also under investigation.

Perhaps the simplest application of superconducting technology is the construction of stationary magnets intended to generate a constant field or a field that changes only slowly. Eventually such magnets will have a place in the electric-power industry, but most of




**FILAMENTARY COMPOSITE MATERIALS circumvent several causes of premature quenching in high-power superconductors. Four stages in the evolution of conductors made with niobium-titanium alloys are shown. In the earliest designs a niobium-titanium wire about a millimeter in diameter was clad with a thin layer of copper to absorb the current if the superconductor was quenched. Later the ratio of copper to superconductor was increased in an attempt to keep local hot spots from spreading. A major cause of hot spots was the collapse of shielding currents in the superconducting strands. Both the incidence of such flux jumps and the energy dissipated by them could be reduced by making the strands smaller, and so filaments about 10 micrometers in diameter were embedded in copper. A further step in reducing dynamic losses was to isolate each filament in a copper cell bounded by walls of a copper-nickel alloy, which acts as an insulator.**

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those built so far have been employed in research.

One realm of inquiry where superconducting magnets have proved particularly useful is in the physics of elementary particles. For example, the largest of all superconducting magnets is one that surrounds a bubble chamber at the European Organization for Nuclear Research in Geneva. It has a working volume of some 80 cubic meters and a maximum central field of 3.5 teslas; the energy stored in the field is 800 megajoules.

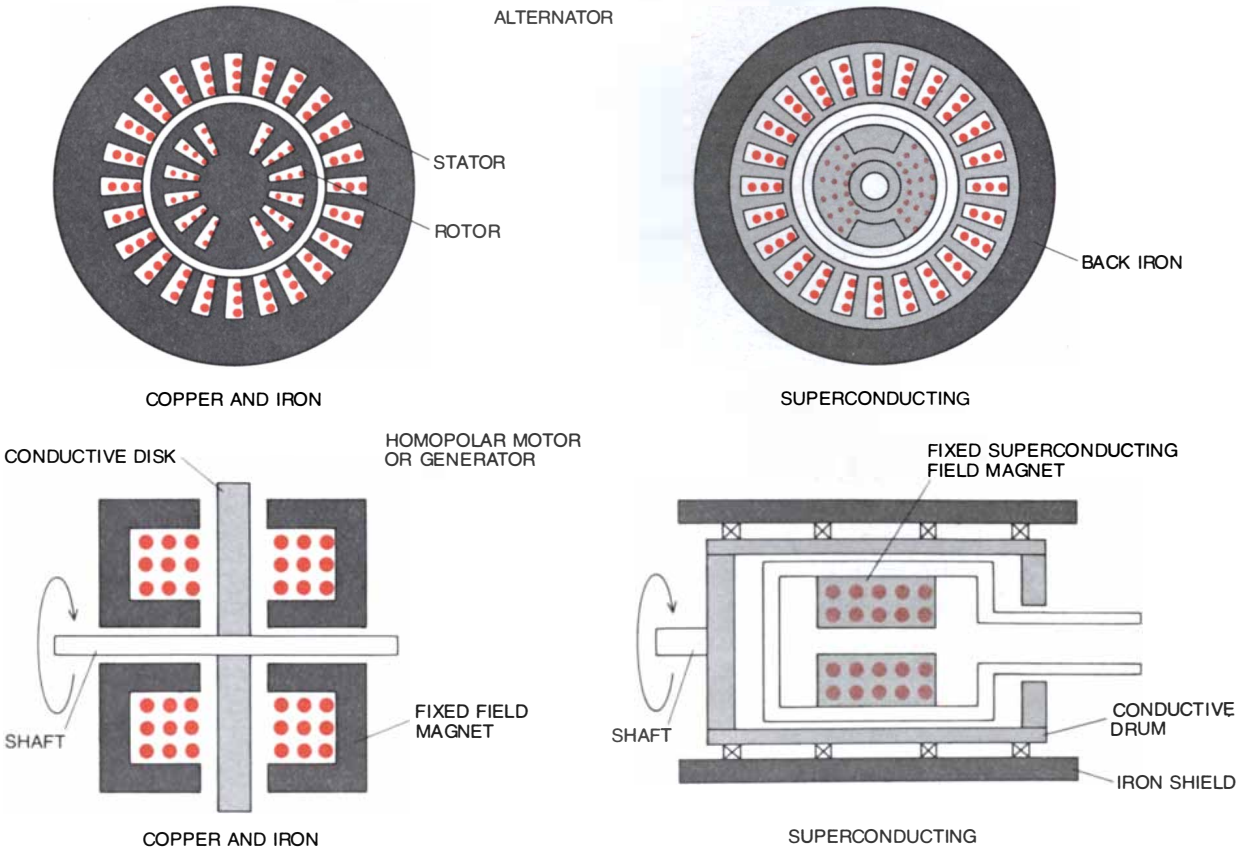
At the Fermi National Accelerator Laboratory (Fermilab) near Chicago almost 1,000 superconducting magnets are being constructed for eventual installation in an underground ring six kilometers in circumference. The magnets are components of a synchrotron, in which protons are accelerated to high energy as they repeatedly circle a ring-shaped vacuum chamber; the purpose of the magnets is to steer and focus the protons so that they stay in the ring. The superconducting accelerator is expected to reach twice the maximum energy of an existing synchrotron in the same tunnel, which is equipped with copper-and-iron magnets; at the same time energy consumption will be reduced. The magnets, which are being wound with multifilamentary niobium-titanium wire, will have a peak field of 4.5 teslas. The field must be uniform to an accuracy of a few parts in 10,000. Cooling the magnets will demand 5,000 liters of liquid helium per hour.

A still larger ring of superconducting magnets is under construction at the Brookhaven National Laboratory for ISABELLE, a device in which high-energy protons will be stored in counterrotating beams. The ISABELLE magnets differ in design from those employed at Fermilab, but they have similar basic specifications, with a maximum field of five teslas. The need for field uniformity is even more stringent: a few parts in 100,000.

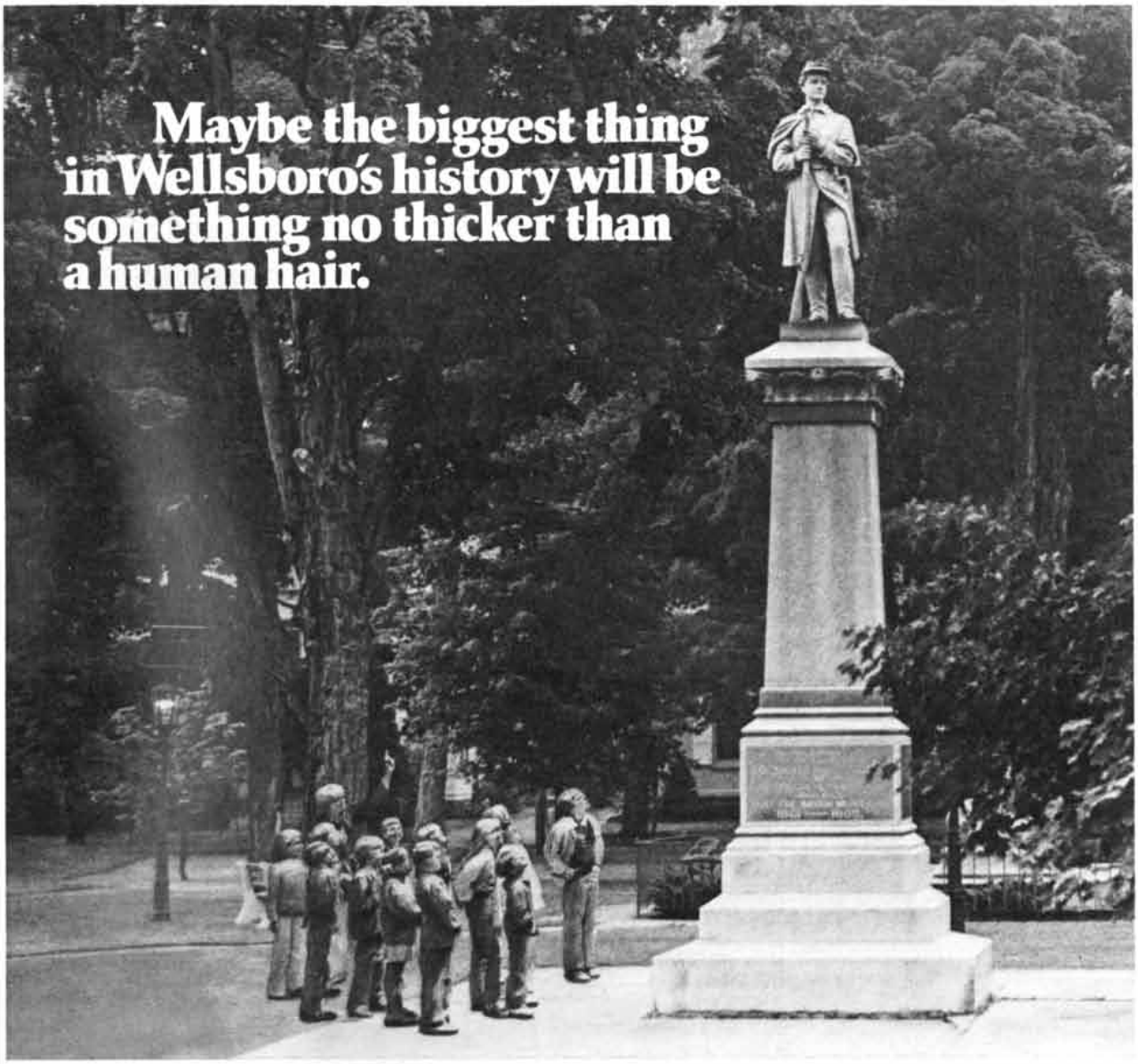
The highest field strength yet attained in a superconducting magnet was produced by a much smaller device, built in the U.S. but operated in Japan for materials research. It has attained a maximum central field of 17.5 teslas in a working volume of 70 cubic centimeters. This magnet is also one of the few now in service made with *A*15 compounds rather than the more easily fabricated alloys. The windings consist of a mixture of $Nb_3Sn$ and $V_3Ga$.

Large superconducting magnets powered by direct current have a number of potential applications in the electric-power industry. One application that has been under investigation for some years is generation by the magnetohydrodynamic, or MHD, tecnnique. An MHD system would replace the boiler, turbine and alternator of a coal-fired or oil-fired power plant; electric power would be derived directly from the combustion of the fuel. At the heart of an MHD generator is a "channel," where a high-temperature plasma, or ionized gas, is forced through a magnetic field at high velocity. Positive and negative ions in the plasma are deflected in opposite directions by the field, which gives rise to a voltage difference in a plane perpendicular both to the magnetic field and to the direction of plasma flow. Electrodes in contact with the plasma collect the separated charges in order to drive a current in the external circuit. The MHD generator has no moving parts other than the plasma itself.

The efficiency of an MHD channel




**MOTORS AND GENERATORS rely for their operation on the interaction of an electric current with a magnetic field. Because the power output is a function of field intensity, significant improvements can be expected from the replacement of copper-and-iron magnets with superconducting ones. In an alternator, or alternating-current generator, an electromagnet excited by direct current is rotated inside a cage of stator coils, in which the alternating current is induced. With present materials dynamic losses prohibit a superconducting stator, but a superconducting rotor is possible. A direct-current generator or motor of the homopolar type consists of a conductive disk or drum that rotates in a magnetic field. Again power output can be raised if the exciting magnet is a superconducting one.**




You could easily mistake Wellsboro, Pennsylvania for other small American towns.

But last year, Wellsboro (population 4,003) made history.

It became the first town in America to put a commercial optical fiber telephone system into everyday use.

We should explain that optical fibers are threads of ultra-pure glass as thin as a human hair.

And over them, telephone signals can be transmitted by laser light.

What's so great about optical fibers? Well, if you wind them into a cable, you have a miracle telephone line.

Which can carry far more telephone traffic than conventional copper lines.

And these lines, which cost less than copper, aren't subject to noise interference from nearby power lines, as copper lines are.

It was an ITT scientist who first made optical fibers practical.

And ITT people, working with the Rural Electrification Administration and Commonwealth Telephone, brought fiber optics to Wellsboro.

Mind you, Wellsboro may still not loom as large in history as that other Pennsylvania town, Gettysburg.

But for Wellsboro (and America) it's quite a first.

**The best ideas are the ideas that help people.** ITT

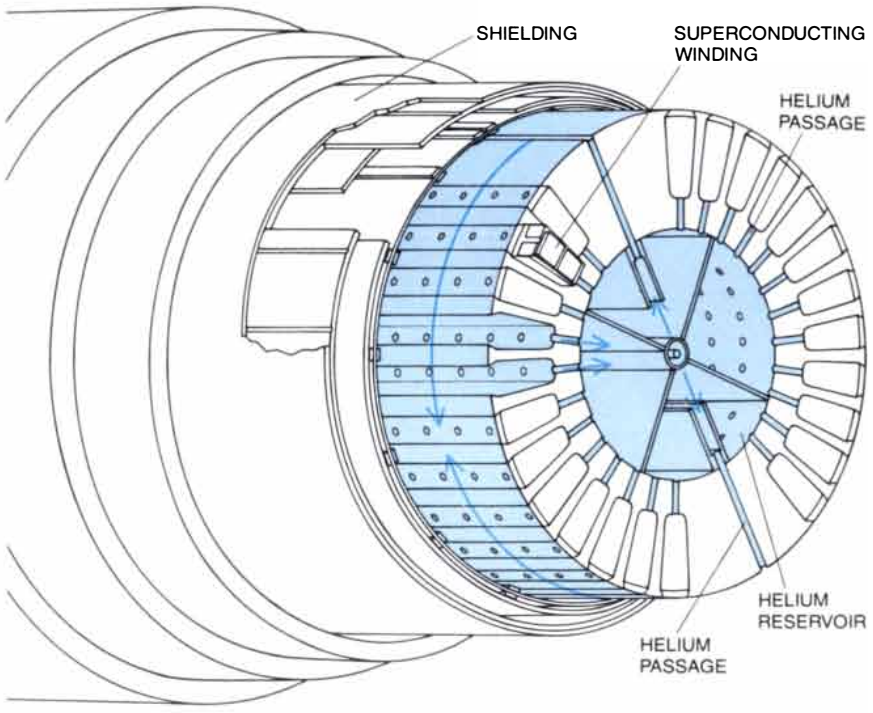
improves as the plasma is made hotter and as the magnetic field is made stronger. The maximum temperature must be limited to prevent damage to the walls of the channel; as a result field strength is paramount. At attainable temperatures, acceptable efficiency demands a field of between five and 10 teslas, and so a superconducting coil is mandatory.

A prototype MHD generator with a power capacity of 25 megawatts is being tested in Moscow in a joint U.S.-U.S.S.R. project (which is now in abeyance). The magnet for the generator was built at the Argonne National Laboratory outside Chicago. It has a maximum field strength of five teslas and a working volume of about a cubic meter; the stored field energy is 20 megajoules.

A still larger MHD magnet, weighing about 400 tons, is being designed for the MHD Component Development and Integration facility in Butte, Mont. This program represents the first step toward a full-scale MHD power plant, with a capacity of 600 megawatts. Design studies suggest that such a plant would require a superconducting magnet capable of reaching six teslas and weighing about 2,000 tons.

There is hope that the generation of power by thermonuclear fusion may be possible and eventually lead to worldwide energy abundance in the 21st century. For a fusion reaction to be sustained a plasma must be confined at sufficient density while being heated to a temperature of more than a million degrees K. Any contact with the walls of a material container would quickly cool the plasma and also contaminate it. For now the major research effort is based on confining the plasma in a magnetic field, which can be arranged so that charged particles are always deflected before they reach the walls of the chamber. The field strength needed is in the range of from eight to 12 teslas, and so there is no practical alternative to superconducting-magnet coils.

In recent years the kind of fusion reactor given the most attention has been the Tokamak, in which the confining field and the reaction chamber have a toroidal form. A large project intended to evaluate magnet technologies for Tokamaks has recently been undertaken. Six different magnets will be built by groups in the U.S., Europe and Japan, then assembled in a large vacuum vessel at the Oak Ridge National Laboratory in Tennessee. The magnets differ in design, but they will all supply a field of eight teslas




**SUPERCONDUCTING ALTERNATOR is to be constructed by Westinghouse in a joint program with the Electric Power Research Institute (EPRI). The rotor of the alternator is shown in cross section here. Only the rotor has a superconducting winding; because of dynamic losses the stator must be made of copper and iron. The rotor is encased in an insulating vacuum flask, which rotates with it. Liquid helium enters through a rotary coupling and is held in a reservoir in the central cavity. It circulates by convection: helium that has absorbed heat from the windings tends to flow toward the center, where it is drawn off in the gas phase. The windings, which are made of a niobium-titanium alloy, have the form of elongated ovals. The alternator will have a power capability of 270 megawatts. It is to be tested in a commercial power plant.**

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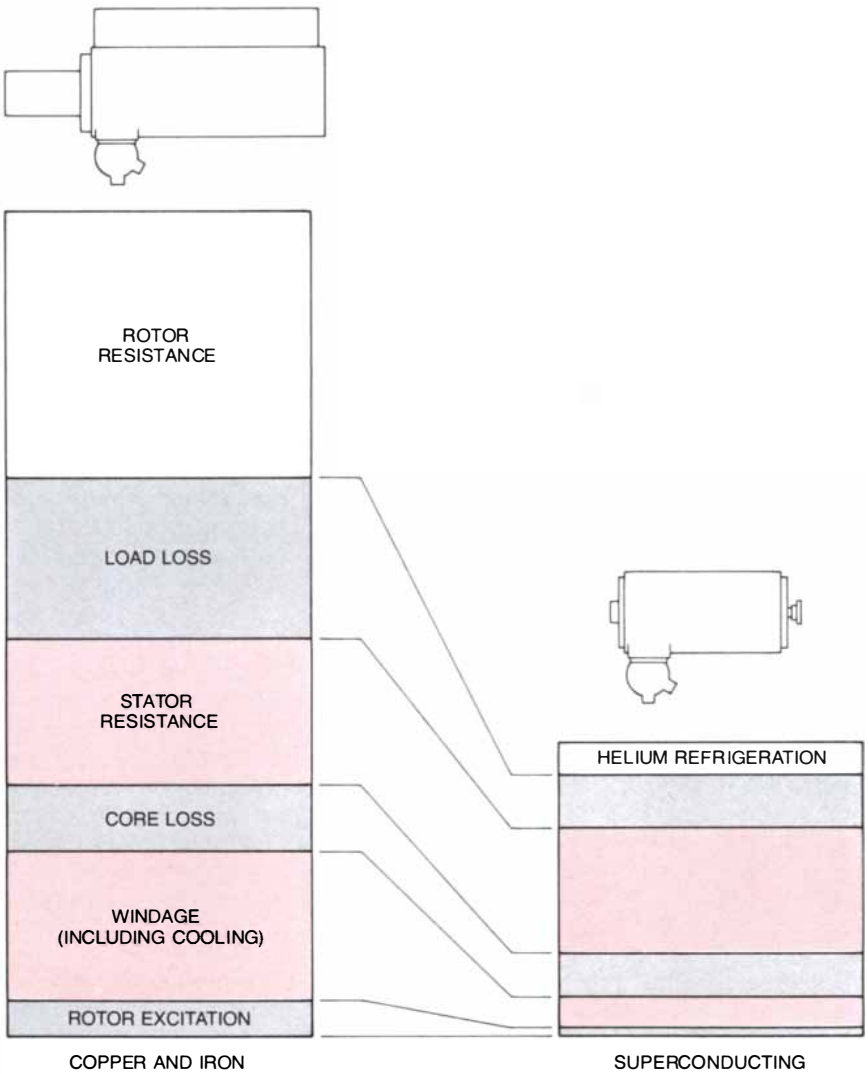
**We reach the people who make the future happen.**

within a *D*-shaped bore of 2.5 by 3.5 meters. A practical fusion reactor would require still larger coils.

Five of the six magnets will be wound with niobium-titanium alloy, but a design by the Westinghouse Electric Corporation calls for superconductors of $Nb_3Sn$. The fabrication of complex structures out of such difficult materials has now reached an advanced state, as is indicated by the cable now being manufactured for Westinghouse by Airco Superconductors. The cable consists of 486 strands, separated by channels for the helium coolant, which will circulate under pressure as a supercritical fluid with a temperature of 5.2 degrees K. (In the supercritical phase gas and liquid cannot be distinguished.) Each strand has a thin outer coating of a semiconductor, which serves as a barrier to eddy currents that might arise between the strands. Inside the semiconductor coating is a jacket of pure copper, which is intended to take over most of the current if the superconductor is quenched; the copper is separated from the core of the strand, which is bronze, by a layer of tantalum that blocks the diffusion of tin from the bronze. Embedded in the bronze core are some 3,000 microfilaments of $Nb_3Sn$ arranged in hexagonal groups of 19. The $Nb_3Sn$ compound is formed in situ by diffusion of tin from the bronze into filaments of pure niobium metal.

An alternative to the Tokamak design is the magnetic-mirror fusion reactor, in which a plasma is confined to an approximately cylindrical volume by magnets at each end. A large mirror-fusion test facility is under construction at the Lawrence Livermore Laboratory in California. A pair of superconducting coils will yield a maximum field of 7.7 teslas. The




**ENERGY LOSS might be reduced by between 50 and 65 percent in an alternator with a superconducting rotor winding. Resistive losses in the rotor are eliminated entirely, and there are savings of other kinds as well. The superconducting winding requires a helium refrigerator, but its power demands are much smaller than those of the blowers that cool a copper-and-iron rotor. The superconducting alternator is also smaller and lighter than the copper-wound one.**

# COMPARISONS

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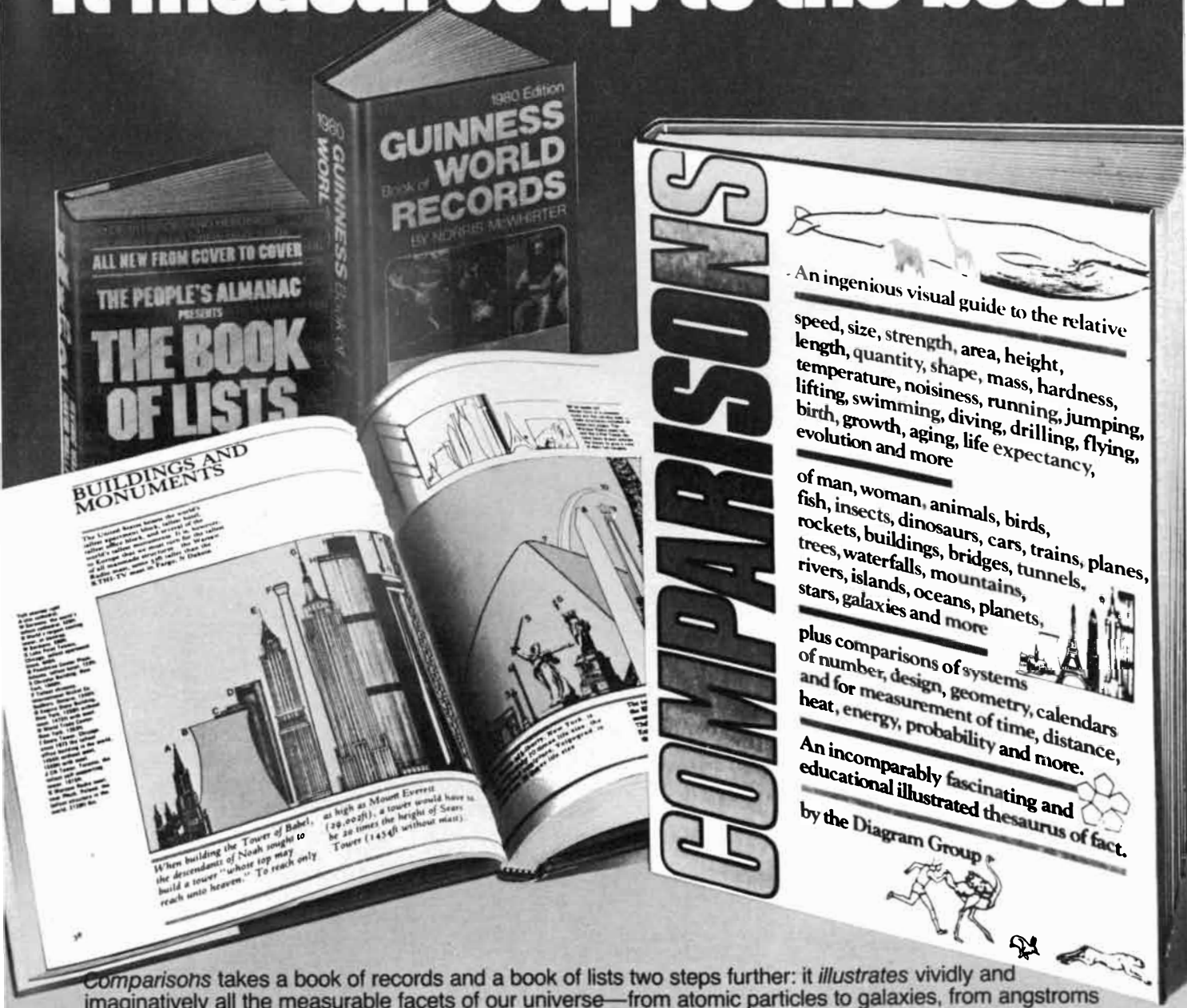


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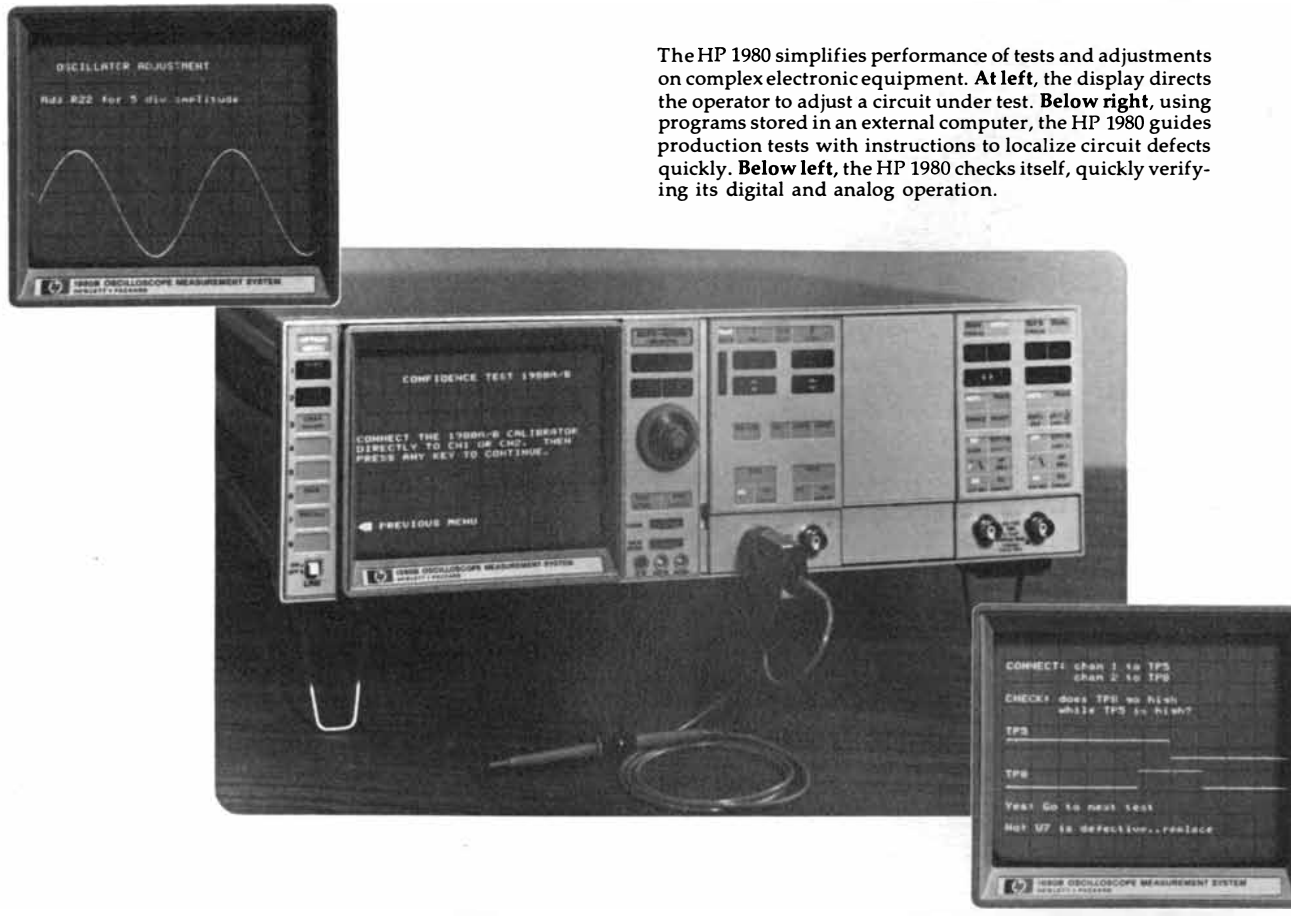
## For example: HP's new Oscilloscope Measurement System: The real surprise is not just that it's better, but that it is fully programmable and extremely easy to use.




The HP 1980 simplifies performance of tests and adjustments on complex electronic equipment. **At left**, the display directs the operator to adjust a circuit under test. **Below right**, using programs stored in an external computer, the HP 1980 guides production tests with instructions to localize circuit defects quickly. **Below left**, the HP 1980 checks itself, quickly verifying its digital and analog operation.

The most obvious difference between the HP 1980 and conventional scopes is the front panel. The Hewlett-Packard system does away with the bewildering maze of knobs and switches scope users have had to master, and replaces them with a clean, logical array of color-coded keys and a single rotary control.

Internally, too, the HP 1980 is designed unlike any other oscilloscope. Controlled by a microprocessor, the HP 1980 reduces knob twiddling to the point that only minimal training is needed to operate it. (For instance, to obtain an initial display, only one key, AUTO-SCOPE, need be pressed.)

One immediate result is that complex measurements no longer require the skills of highly trained technicians, freeing them for more creative, productive, and cost-effective work.

The HP 1980's automated operation—though both built-in and remote computer programming capabilities—brings new possibilities and time savings to product development and production test:

- HP-IB (IEEE-488) compatibility makes it possible for the HP 1980 to receive programming instructions from a computer, or to send measurement information to a computer for processing, evaluation, and hard copy printout.

- The simplified panel cuts setup time by as much as a factor of five. Front panel setups can be saved in the system's nonvolatile memory (they can't be lost even if the system is turned off), then recalled and implemented with only two keystrokes.

- Calibration menus called up on the CRT display permit complete calibration via the front panel, with no operator's manual and minimal test equipment. What's more, the HP 1980 can be calibrated in its operating environment in less than 45 minutes—compared with the 6 to 10 hours it now takes trained technicians to calibrate conventional scopes in a calibration lab.

If you are developing or manufacturing products that use electronics technology, you owe it to yourself to find out more about the HP Oscilloscope Measurement System. Price of the HP 1980 is $8500*.

# enhance your skills?

## For example: a new approach to making continuous, reliable measurements of a patient's respired $CO_2$, noninvasively.

Ordinarily, the amount of $CO_2$ in the blood is regulated automatically by the brain's respiratory center, which controls the rate and depth of respiration. But when a patient is anesthetized, or when disease prevents normal breathing, $CO_2$ can get seriously out of balance. And it is at just such critical times that the physician most needs to know the patient's $CO_2$ status, in order to control ventilation effectively.

$CO_2$ is often measured directly from arterial blood samples, in spite of the fact that significant time may pass between drawing the sample and analyzing it in the laboratory. In such a case, the physician must rely on information that may no longer reflect the state of the patient.

Nevertheless, the analysis of samples from an arterial tap is the favored method, simply because monitoring by other means has been cumbersome and unreliable.

Now, with the introduction of the HP 47210 $CO_2$ monitor (or capnometer), the physician can get stable, repeatable, continuous $CO_2$ measurements noninvasively. Microprocessor augmented, and using technology which departs radically from that of other $CO_2$ monitors, the HP capnometer makes direct measurements of inspired and expired $CO_2$ by on-line monitoring on a breath-by-breath basis.

The measurement is made optically by a small sensor secured to an airway adapter at the patient's mouth.

A beam of infrared light from the sensor is transmitted through the adapter, and the absorption of this light by the breathing gases gives an accurate, continuous measure of the patient's $CO_2$.

The advantages of the HP capnometer are impressive:

- Simplicity of operation makes it possible to concentrate on the patient rather than the monitor.
- Built-in gas cells make it easy to check and recalibrate the instrument.
- The capnometer monitors itself continuously, and calls attention to itself if a malfunction occurs.
- It also monitors the ventilator or anesthesia machine, and alerts the staff in case of apnea or breathing system disconnections.

An innovative option makes possible the noninvasive *cutaneous* monitoring of $CO_2$ diffusing through a small area of the patient's skin. Its availability is subject to FDA approval, which is pending.

Price of the HP 47210 is $5800*.

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.

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system is comparable in scale to the Tokamak magnets. The stored energy of the field will be 400 megajoules, and the total mass of the superconducting coils will be about 50 tons.

In the turbine-driven alternators that now supply virtually all electric power, the adoption of superconducting materials has one obvious complication: some parts of the machine rotate at high speed, which makes the delivery of helium coolant awkward. It might seem, therefore, that the easiest course would be to install superconductors first in the stationary field coils of an alternator. The stator windings, however, carry alternating current, and so the magnetic field must decay to zero and be reestablished in the opposite direction 100 or 120 times per second. Under these conditions the dynamic losses in present-day superconducting composites reach an intolerable level.

The problem of losses in alternating-current magnets might ultimately be solved by further refinements in the fabrication of superconducting materials. In the meantime superconductors seem attractive for the rotor magnet of an alternator, which is excited by direct current. Here the main difficulties are not physical or electrical but mechanical. The magnet and its surrounding vacuum vessel must rotate inside the stator, typically at 3,600 revolutions per minute, and liquid helium must be supplied through a rotary coupling.

In the early 1970's small experimental alternators with superconducting rotors were built by the Massachusetts Institute of Technology and by Westinghouse. With a rotor field of about 5.5 teslas these machines were designed to generate up to about five million volt-amperes. They were operated under both open-circuit and closed-circuit conditions, but they were not brought up to full power. A 270-megawatt superconducting alternator is now being designed by Westinghouse in a joint program with the Electric Power Research Institute. The niobium-titanium windings of the rotor will yield a maximum

| DEVICE | BUILDER | SUPER-CONDUCTOR | MAXIMUM FIELD (TESLAS) | WORKING VOLUME (CUBIC METERS) | STORED ENERGY (MEGA-JOULES) | SYSTEM POWER (MEGAVOLT-AMPERES) |
|---|---|---|---|---|---|---|
| BUBBLE-CHAMBER MAGNET | EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH | Nb-Ti | 3.5 | 80 | 800 | |
| PARTICLE ACCELERATOR (STEERING AND FOCUSING MAGNETS) | FERMI NATIONAL ACCELERATOR LABORATORY | Nb-Ti | 4.5 | .06 | .5 | |
| PARTICLE STORAGE RING (STEERING AND FOCUSING MAGNETS) | BROOKHAVEN NATIONAL LABORATORY | Nb-Ti | 5.0 | .08 | .85 | |
| HIGH-FIELD MAGNET FOR MATERIALS RESEARCH | INTERMAGNETICS GENERAL | $Nb_3Sn$ AND $V_3Ga$ | 17.5 | $7 \times 10^{5}$ | 1.7 | |
| ROTOR MAGNET FOR ELECTRIC-POWER ALTERNATOR | WESTINGHOUSE ELECTRIC CORPORATION | Nb-Ti | 5.5 | $4 \times 10^{2}$ | 1 | 5 |
| 60-HERTZ ALTERNATOR | WESTINGHOUSE ELECTRIC CORPORATION | Nb-Ti | 5.2 | .86 | 9.2 | 300 |
| HOMOPOLAR MOTOR AND GENERATOR FOR SHIP PROPULSION | GARRETT CORPORATION | Nb-Ti | 5.0 | .06 | .46 | 2.2 |
| HOMOPOLAR MOTOR | GENERAL ELECTRIC COMPANY | Nb-Ti | 6.0 | .06 | .9 | 2.2 |
| 400-HERTZ ALTERNATOR FOR AIRCRAFT | GENERAL ELECTRIC COMPANY | Nb-Ti | 5.7 | .06 | .8 | 20 |
| ROTOR COILS FOR AIRCRAFT ALTERNATOR | WESTINGHOUSE ELECTRIC CORPORATION | $Nb_2Sn$ | 5.7 | .06 | .8 | |
| MAGNET FOR MAGNETO-HYDRODYNAMIC GENERATOR | ARGONNE NATIONAL LABORATORY | Nb-Ti | 5.0 | 1 | 20 | 25 |
| MAGNET FOR MAGNETO-HYDRODYNAMIC GENERATOR | GENERAL ELECTRIC COMPANY | Nb-Ti | 6.0 | 5 | 72 | 183 |
| MAGNETS TO BE EVALUATED FOR THERMONUCLEAR-FUSION CONFINEMENT | SIX INDEPENDENT BUILDERS | 5 Nb-Ti<br>1 $Nb_3Sn$ | 8.0 | | | |
| POWER TRANSMISSION LINE | BROOKHAVEN NATIONAL LABORATORY | $Nb_3Sn$ | .1 | | | 1,000 |

**LARGE SUPERCONDUCTING DEVICES either completed or now under construction include several that could lead directly to applications in the electric-power network. An alternator based on a superconducting rotor will probably be the first of these. Magnetohydrodynamic power generation and thermonuclear fusion are more distant prospects, but in both of them there is no alternative to superconducting technology. Various magnets for research have provided experience in the building of large-scale superconducting systems.**

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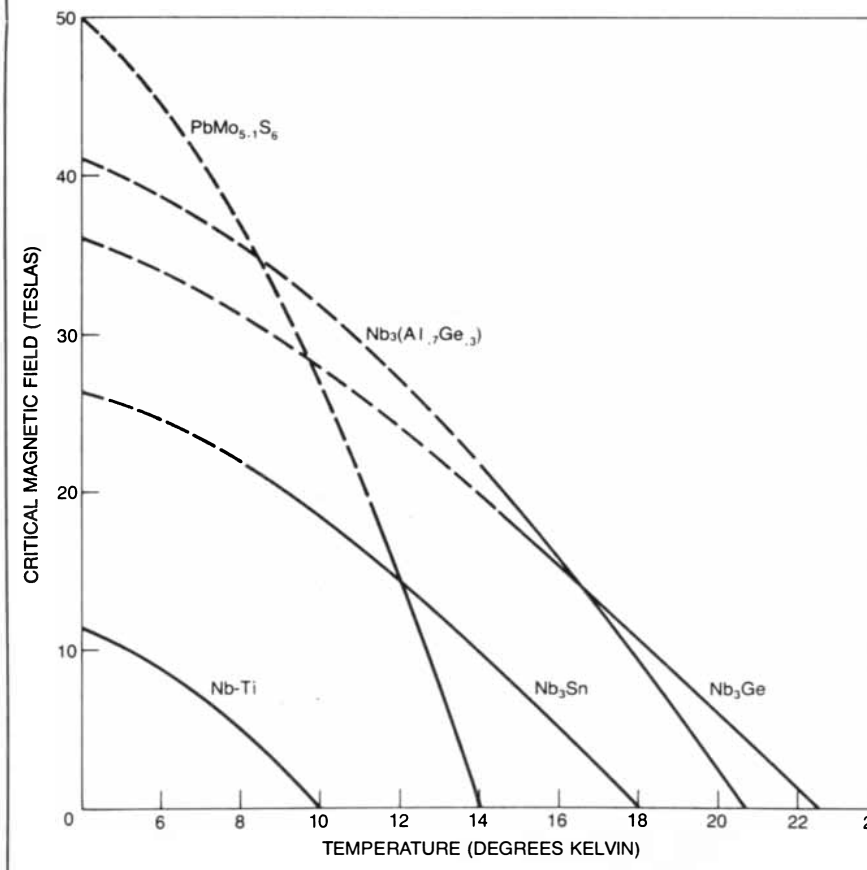
field of 5.2 teslas. The alternator will be completed in 1984, and plans are being made to test it in an electric-utility power plant. If the project succeeds, it will constitute the first major industrial application of superconductivity.

Several advantages can be expected from the adoption of superconductors in large alternators. Total electrical losses should be reduced by 50 percent or more, which would amount to a significant savings of energy during the lifetime of the machine. Even if the initial cost of the superconducting alternator were somewhat higher, the improved electrical efficiency would give it an economic advantage. Only part of the savings can be attributed directly to the elimination of resistive losses in the rotor windings. Another important contribution comes from elimination of the normal rotor cooling load. Although a helium refrigerator must be provided for the superconducting rotor, its energy consumption is much less than that of the blowers that are needed to cool a copper-wound rotor. A superconducting alternator would also be smaller than a copper-and-iron machine of the same power capability, which should reduce transportation costs and ultimately construction costs.

Even if the stator coil of an alternator is wound with copper, its design is influenced by the presence of a superconducting rotor. The stronger field of the rotor allows the iron "teeth" to be eliminated from the inner surface of the stator; the teeth ordinarily improve the coupling of the magnetic flux from the rotor to the stator, but at fields above two teslas they would be saturated and would serve no purpose. The detailed consequences of this change are not yet clear, but it seems to allow stator coils to be better insulated and possibly to generate higher output voltages. Power might even be generated at transmission-line voltage, thereby eliminating a transformer and its associated losses.

The reductions in size and weight made possible by the higher magnetic fields of superconducting systems are quite attractive for airborne and shipboard power equipment. These advantages have led the Air Force to develop 400-hertz superconducting alternators based on principles similar to those of power-station designs.

For direct-current generators and motors the problem of dynamic losses is




**STRONGER MAGNETIC FIELDS than any now contemplated in practical superconducting devices are within the capability of certain Type II materials. These materials cannot be exploited, however, until their critical current density can be raised and until they can be fabricated as finely divided conductors. Magnetic fields of more than about 20 teslas can be generated only in pulses, and so portions of the curves shown as broken lines were measured in that way.**

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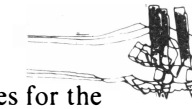

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not critical. The Navy has successfully tested a 400-horsepower superconducting direct-current motor and has issued contracts to the General Electric Company and the Garrett Corporation for the development of two 3,000-horsepower motors and a 3,000-horsepower generator for electric propulsion of ships. The machines are of the homopolar type, but instead of a conductive disk rotating between the poles of a magnet they have a drum that surrounds the field magnet. The drum is a normal conductor, but the magnet windings are superconducting.

Certain other applications of superconducting magnets and coils in the electric-power system can be envisioned. An intriguing possibility is the temporary storage of electrical energy in the magnetic field of a superconducting coil. During periods when surplus capacity is available the coil could draw power from the network in order to build up the field. If the coil were then short-circuited, the current would continue to circulate and the field would be maintained indefinitely. Reconnecting the coil to a load would allow the energy to be withdrawn as the field gradually collapsed. Such storage coils may be useful as short-term stabilizing devices in large power networks and as longer-term power reservoirs for load leveling. The Los Alamos Scientific Laboratory is now building a prototype stabilizing device for the Bonneville Power Administration. It will have a capacity of 40 megajoules. Even larger coils for storage on a daily cycle are being investigated by workers at the University of Wisconsin for several utilities.

The transmission of electric power through a superconducting medium would seem to be easier in at least one respect than the construction of generators, motors and the like. Because the conductor is not coiled, the only magnetic field is the internal one generated by the passage of the current itself. That field is typically .1 tesla or less, and so it is well within the capabilities of most Type II superconductors. Nevertheless, the development of superconducting transmission lines is in a stage of exploratory research rather than approaching commercial practice, as in the case of magnets and machines. The main reason is that superconducting transmission becomes economic only at very high power levels, somewhere between $10^9$ and $10^{10}$ watts, which is well beyond the present requirements of the electric utilities. Also, competing technologies, such as water-cooled cables and conduits filled with sulfur hexafluoride, are advancing rapidly as candidates for very-high-power transmission.

There is certainly the potential for major economic benefits in improving the efficiency of electric-power trans-

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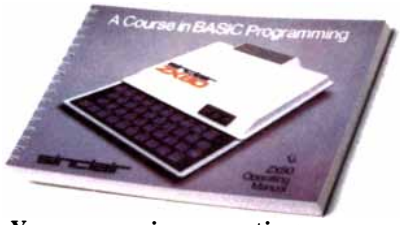


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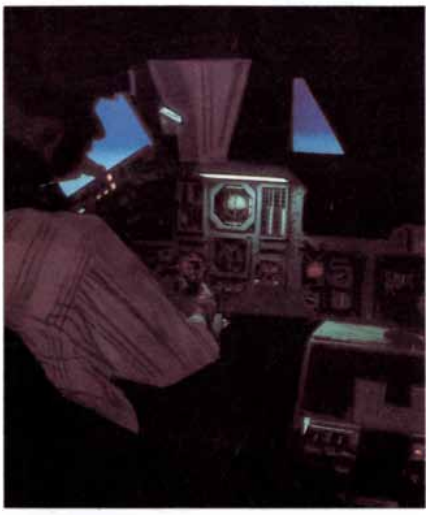
When the NASA Space Shuttle goes into orbit for the first time, the pilot and crew will feel that they've been through it all many times before.

In a sense, they have—at the Johnson Space Center, where they are training in one of the most advanced flight simulators ever built. At the heart of the simulator are 23 Perkin-Elmer 32-bit minicomputers which deliver the real-time response needed to create a true sensation of flight. They also control and coordinate the simulation from takeoff to landing.



*Minicomputers give crew the "feel" of real flight.*

The simulator windows are actually high-resolution video screens. When the pilot moves the stick, feedback control coordinates video imagery with the motion of the simulator Crew members see, hear and feel the changes their actions cause—the jerks and bumps, for example, as thrusters are fired or air brakes let out.

The minicomputers also create appropriate instrument readings and simulate ground communication links. They can even tie the "flight" into NASA's worldwide communications network

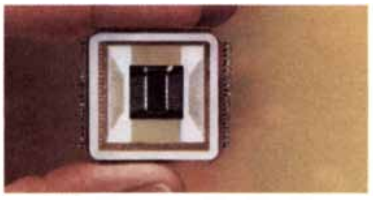
The high-speed data acquisition capability of Perkin-Elmer's 32-bit computers makes them ideal for the heavy input/output load of real-time, event-driven simulations. The unique Perkin-Elmer shared memory permits up to 14 computers to share a common memory; if one or more units become overloaded, others can pick up the workload.

*Simulator allows the crew to practice such tasks as launching the Space Telescope*

More than 25 commercial and military training simulators are now equipped with Perkin-Elmer 32-bit computers. Several computers have been ordered by the European Space Agency to simulate experiments to be carried into space by NASA's Shuttle.

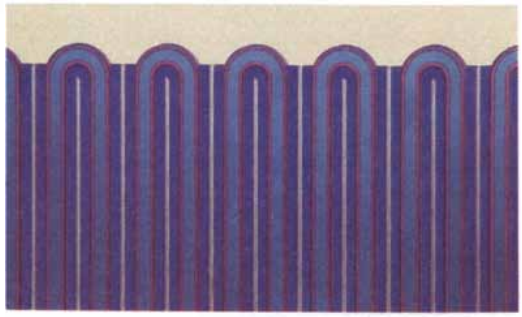
# Sharp new eyes warn against laser-guided weapons

Highly accurate laser-guided weapons pose a new kind of threat to military aircraft, tanks and ships. Effective countermeasures depend on fast detection and identification of the laser beams such weapons use to "zero in" on their targets



*Etalon, the "eye" that identifies the laser beam, is the small rectangle in the center of the detector array.*

A compact laser warning receiver developed by Perkin-Elmer provides this kind of information swiftly and accurately. The receiver measures a laser beam's direction, wavelength, intensity and modulation characteristics. Its basic optical component is



*Magnified section of detector array in laser warning receiver.*

a small interferometer called an etalon. The etalon refracts and reflects incoming laser light to form an interference pattern that is actually a unique identifying signature for each laser beam. It rejects false signatures such as light from the sun, lightning, searchlights, flares or explosives.

The laser warning receiver is not only efficient but, because of its modular construction, economical to manufacture. It is built with low-cost optical elements and reprogrammable microprocessor logic.

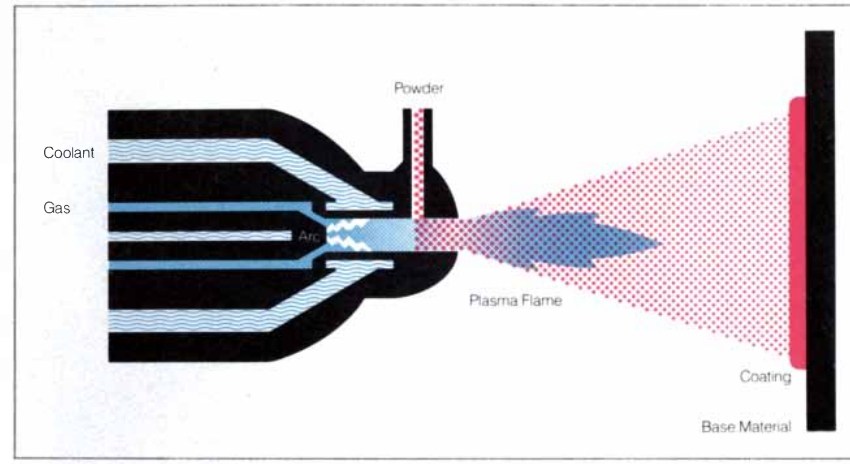
# Plasma spray is a life saver for thousands of jet engine parts

When jet engines run, their finely machined parts encounter a variety of wear conditions. A process called plasma spraying—pioneered by METCO, a Perkin-Elmer subsidiary—prolongs the life of original parts and quickly restores worn parts to original dimensions.

In plasma spraying, a gas ionized by an electric arc creates a high-velocity plasma stream whose temperature can exceed 30,000°F. A powdered material is melted in the hot plasma and propelled onto a surface where it bonds and rapidly builds up to the required thickness.

The dense coating has superior resistance to wear and, in some cases, to corrosion and high temperature. For example, parts made of titanium, which has an excellent strength-to-weight ratio but virtually no wear resistance, can be protected with a material such as tungsten carbide. In higher temperature areas, chrome carbides are used.

Major jet engine manufacturers use this process to coat a number of components. And airline maintenance shops around the world rebuild more than 2,000 worn parts with plasma spraying to reduce downtime.




*Plasma spray coatings are produced by injecting a powder into a plasma gas stream. The powder particles are melted and projected onto the surface being coated.*

METCO's latest development is a vacuum-chamber plasma spray system, which opens up the potential for applying protective coatings in areas of high-temperature corrosion, such as turbine seals, blade tips and turbine airfoils.

Other industries with similar problems can follow the airlines' example.

Plasma coatings are finding increasing use in the automotive, chemical, mining, paper, power generating and textile industries.

With plasma spraying, these users can stretch service life and reduce maintenance for parts subjected to heat, wear and corrosion.

***For More Information***

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mission. Efficiency at very high power levels will become even more important if nuclear and fossil-fuel power plants must be built at greater distances from urban centers. It also seems likely that more underground transmission lines will be built, particularly for bringing power into large cities. The outcome of the present competition among the various transmission-line technologies is still uncertain.

In principle a superconducting transmission line carrying an unvarying direct current would operate with perfect efficiency; there would be no losses except the energy needed to refrigerate the line. Any change in the current, however, introduces eddy currents and flux motion that dissipate energy as heat. For reliable operation losses from all sources in a superconducting transmission line must be kept below about 10 microwatts per square centimeter. This is a challenging requirement for an alternating-current line, where the current varies continuously. Even when operating with direct current from an a.c.-to-d.c. converter a residual "ripple" voltage causes variations of from 2 to 3 percent in the current.

Certain other demands must also be met by a transmission line. In alternating-current operation, momentary overloads of between three and 10 times the rated current can arise from sudden interruption of the supply or from other disturbances in the network; the overload currents must be carried without damage to the transmission line. In direct-current systems the highest surge currents are considerably smaller, perhaps twice the normal current. Either kind of power-transmission line must also be capable of withstanding the 300-degree changes in temperature during cool-down and the accompanying thermal expansion and contraction.

A superconducting transmission line 100 meters long is being assembled as a demonstration project at Brookhaven. The line will carry $10^9$ volt-amperes of 60-hertz alternating current. The superconductor is $Nb_3Sn$ fabricated in the shape of a flat tape: it is made from a niobium substrate on which layers of $Nb_3Sn$ are formed and then clad with copper or stainless steel. The tape will be wound into two coaxial helixes, which will carry the load; additional helixes isolated from the electric fields of the coaxial pair will handle overloads.

As large-scale applications of superconducting technology draw near, attention tends to focus on the problems that remain outstanding. There is concern, for example, over the efficiency and the reliability of refrigeration systems. Most helium liquefiers have been intended for laboratory use, and there is little experience with systems required to operate continuously. The supply of

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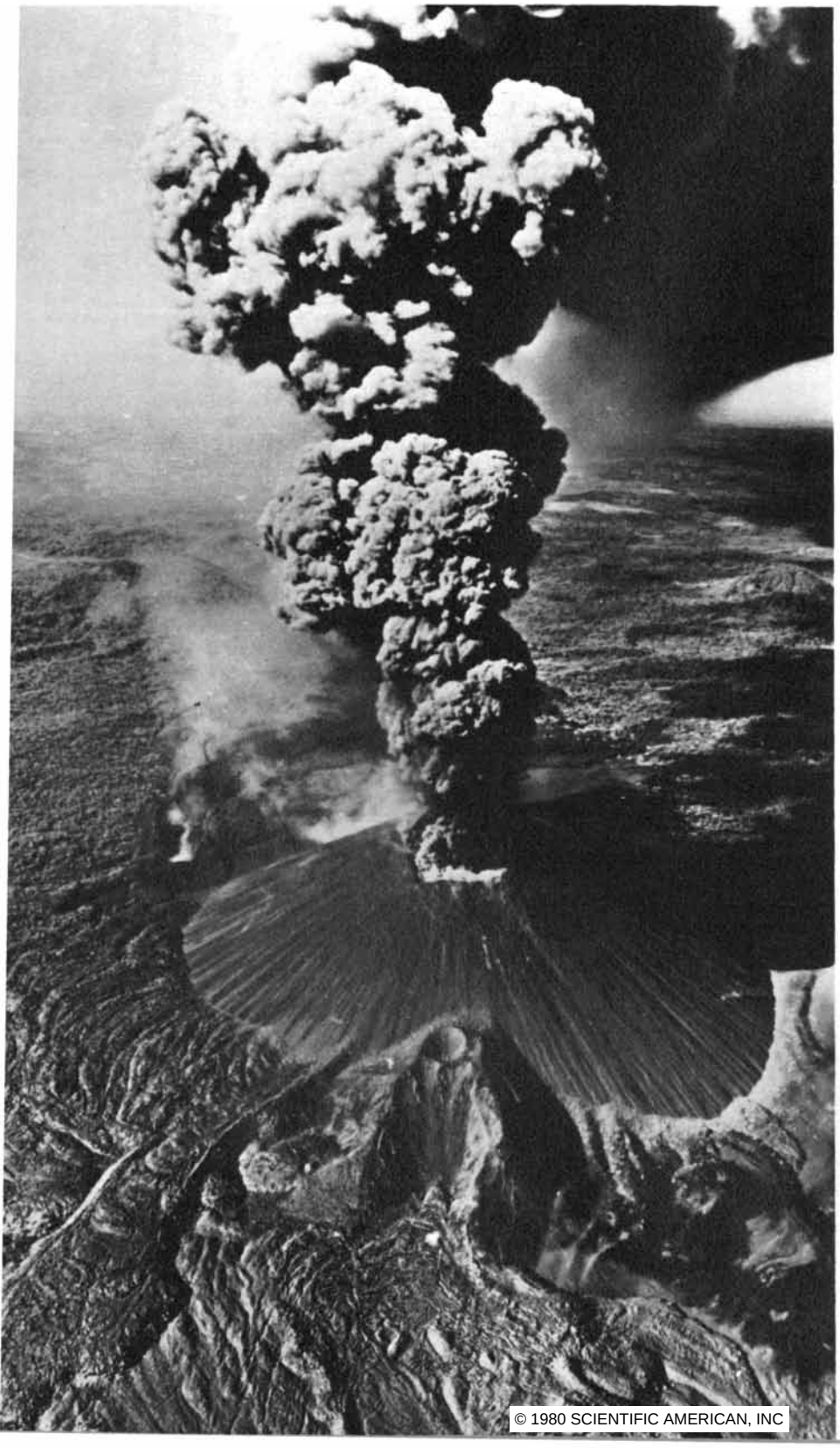



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helium itself is uncertain. The most concentrated source of the element is underground in a few major fields in the south-central U.S., where it has existed since prehistoric times as a dilute component of natural gas. It is now being allowed to escape into the atmosphere as the gas is burned. This loss of future resources seems regrettable. It appears that by 1990 the most concentrated sources will be exhausted. In previous years helium was separated from the natural gas before burning and returned to underground storage. The quantity of helium currently in storage is probably adequate for research magnets and superconducting machines, if conservation practices are employed. If magnetic-confinement nuclear fusion and superconducting power transmission are adopted, however, the supply of low-cost helium would be inadequate. Extraction from the atmosphere would then be necessary at a very high energy cost.

Use of liquid hydrogen as a refrigerant would offer important advantages over helium, including availability, cost and thermodynamic efficiency. What is missing is a superconductor with adequate critical current and field to operate in liquid hydrogen. New superconductors are being discovered each year; a few $A15$ compounds are close to possessing the needed properties. A continuing search for high-temperature superconductors is clearly justified.

In the U.S. the great majority of magnets and of other superconducting devices have been made with the niobium-titanium alloys. Much experience has been gained with these materials, and their properties are well established. One consequence, in our view, is that not enough attention has been given to the engineering of magnets with windings of $Nb_3Sn$ and the other $A15$ materials. Although the mechanical properties of these compounds are far from optimal, the $A15$ superconductors have a greater potential for improved electrical performance. At any given temperature they have the higher critical field and critical current density, as well as a greater thermal margin: the temperature rise that can be tolerated before the superconductor is quenched.

Finally, all the practical applications of superconductivity attempted so far have been confined to magnetic fields of less than 12 teslas. Type II materials are known, however, that retain their superconductivity up to almost 50 teslas. There is ample reason for striving to reach these higher fields: whenever the range of a fundamental property is extended, new science is likely to emerge. It is not yet known whether the very-high-field superconductors can be made to carry enough current for magnet construction, but it certainly seems worth an investment of some effort to find out.

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# The Peopling of the Pacific

*It began 40,000 years ago with the first-known ocean voyages. How Melanesia, Micronesia and Polynesia were colonized later is suggested by linguistic, genetic and archaeological evidence*

by P. S. Bellwood

The peopling of the Pacific was the greatest feat of maritime colonization in human history. If one begins at the beginning and chooses to trace all the movements of its major actors, the record spans perhaps two million years in time and extends beyond the Pacific proper as far west as Madagascar and as far north as mainland China above the Tropic of Cancer. Its main arena, however, consists of the islands of Southeast Asia, the subcontinent of Australia and its island neighbors, and the great ocean reaches of what today are called Melanesia, Micronesia and Polynesia. Its first maritime phase was well under way 40,000 years ago. By then certain hunter-gatherers had managed to cross a minimum of 70 kilometers of open water to settle Australia and New Guinea.

Long before the region was known to Europeans it was settled by diverse populations that have maintained their diversity down to the present day. It is impossible to explain this diversity purely on the basis of today's physical, cultural and linguistic patterns; hence the confusion of hypotheses that have proliferated until recently. Advances in archaeology, physical anthropology and comparative linguistics, mainly over the past three decades, now make possible a fresh assessment of the problem. Here I shall present this modern view. It is to some extent my own and one that not all scholars will support. It is, however, at least simple and logical and can be subjected to constant review as new data come to the fore.

To begin, consider the geography of the main arena. With the exception of New Zealand and the southern half of Australia it is a tropical area. On the west the large islands of Borneo, Sumatra and Java lie together on the shallow Sunda Shelf. At times of low sea level during the great continental glaciations of the Pleistocene these islands not only were joined together but also were connected to the mainland of Asia, thereby forming an even larger land mass that has been named Sundaland. The eastern frontier of Sundaland is delimited by the biogeographical divide called Huxley's Line, a variation on a better-known divide, Wallace's Line.

The flora and fauna on opposite sides of this frontier differ markedly from each other. To the east, in the Philippine and eastern Indonesian biogeographical zones, plant and animal life is less diverse and cosmopolitan than it is in Sundaland. Indeed, Sulawesi and the Lesser Sunda Islands in eastern Indonesia have definitely not been linked with Sundaland since at least Lower Pleistocene times, more than a million years ago. The same may be true for the Philippines.

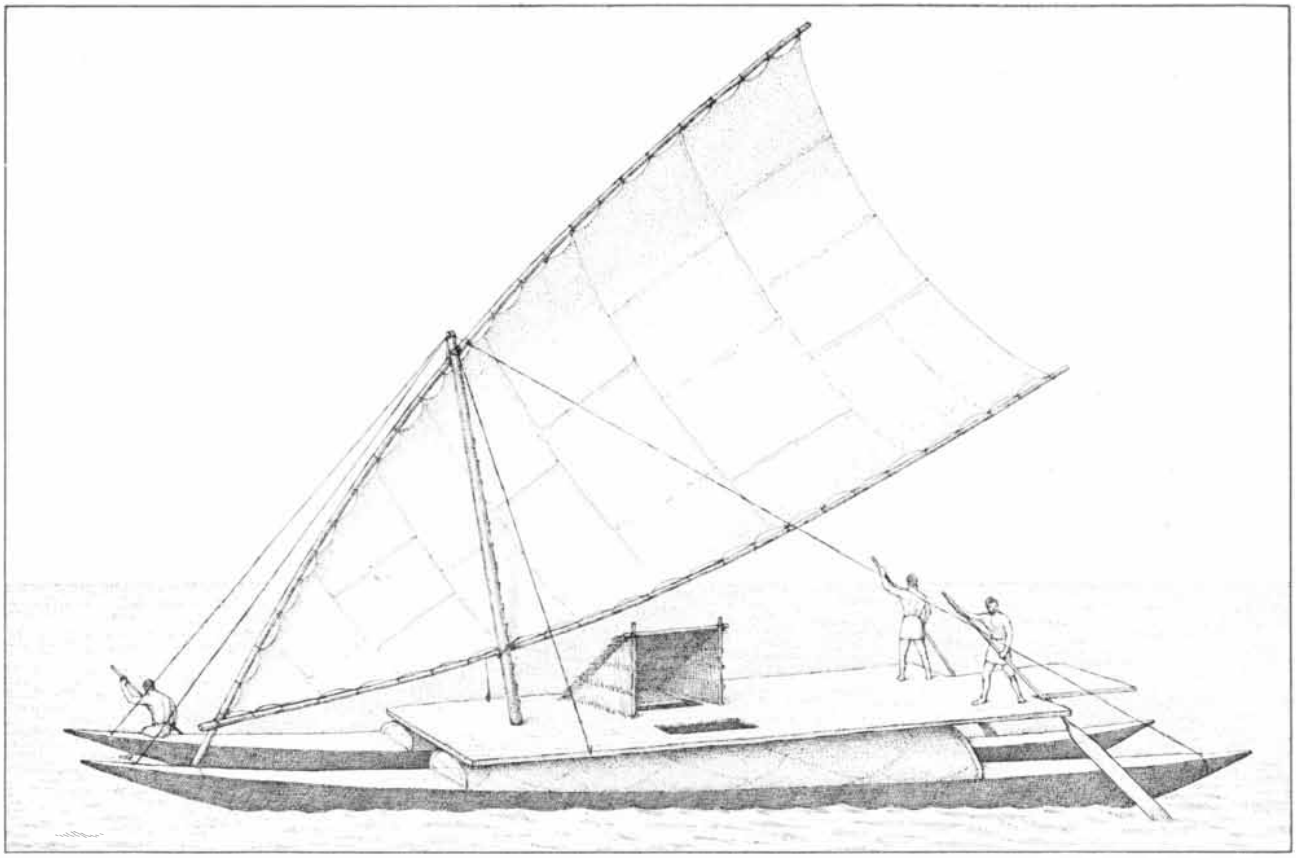
East of this area lie Australia and New Guinea, connected by the shallow Sahul Shelf, which was also dry land at times of Pleistocene low sea level. Here the mammalian fauna includes two primitive forms—monotremes and marsupials—that have been evolving in isolation within Sahulland since continental drift separated the area from Antarctica more than 50 million years ago in Eocene times. It is true that certain marsupials managed to reach eastern Indonesia, perhaps before man first arrived there. It is also true that such advanced mammals as rats and bats reached Australia and New Guinea from Asia. Nevertheless, the basic biogeographical differences between Sahulland and its neighbors imply a high degree of isolation for Sahulland. The deep seas of eastern Indonesia have probably never been bridged.

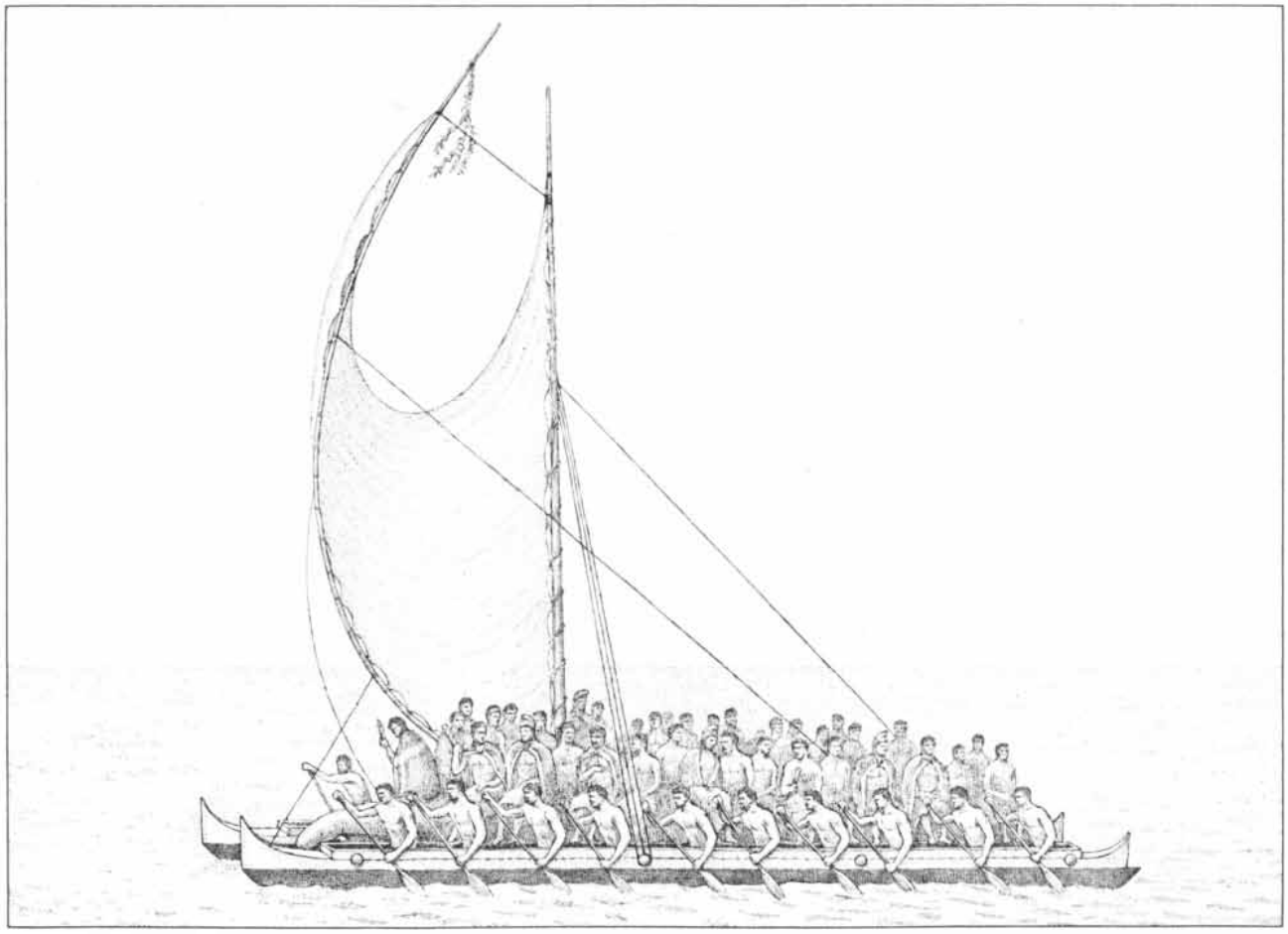
East of New Guinea lies Oceania, first the large and close-set "black" islands of Melanesia and then the increasingly fragmented island worlds of Micronesia (meaning "small islands") and Polynesia ("many islands") that lie across the Andesite Line. (Andesite, a volcanic rock, is characteristic of the great offshore arc of active volcanism around the rim of the Pacific basin.) The islands west of the line are large and geologically complex and exhibit such features as sedimentary rocks and mature river valleys. Beyond Fiji (and New Zealand, far to the south) these features are not known; the islands of Micronesia and Polynesia are small, jagged volcanic formations or coral atolls built on mountains long submerged. Many of these islands are ranged in chains. Nevertheless, they tend to be small, isolated and impoverished in their flora and fauna. To cite one example, in order to develop the elaborate societies that greeted Captain James Cook in the 18th century the immigrants who settled Polynesia had to bring all their domestic animals and major food plants with them on their migration eastward.

At some time between one and two million years ago man first entered the western margin of this vast and empty area. The migrants were populations of *Homo erectus;* their remains have been found in central and eastern Java in geological formations of the Lower and Middle Pleistocene. Recently a few simple stone tools have been discovered in associated formations. So far there is no proof of the frequent assertion that these same early representatives of man reached either the Philippines or eastern Indonesia. Faunal evidence suggests the strong possibility that Sulawesi was connected to Borneo by a land bridge in Lower Pleistocene times, but as yet there is no definite evidence that *Homo erectus* was able to take advantage of it to migrate farther eastward.

The most recent fossil traces of *Homo erectus* in Sundaland may date back about 300,000 years. Thereafter information is virtually absent until about

**DOUBLE CANOES with considerable room for passengers and cargo and often with deckhouses for shelter were still being built in Polynesia at the time of the first contacts with Europeans. The upper of the two vessels seen on the opposite page is reconstructed from a sketch by William Hodges made when Captain James Cook called at Tonga on his second voyage (1773–74). The lower, shown carrying the paramount chief of the island of Hawaii on Cook's visit to the Sandwich Islands, is smaller. It nonetheless supported some 50 passengers and crewmen.**





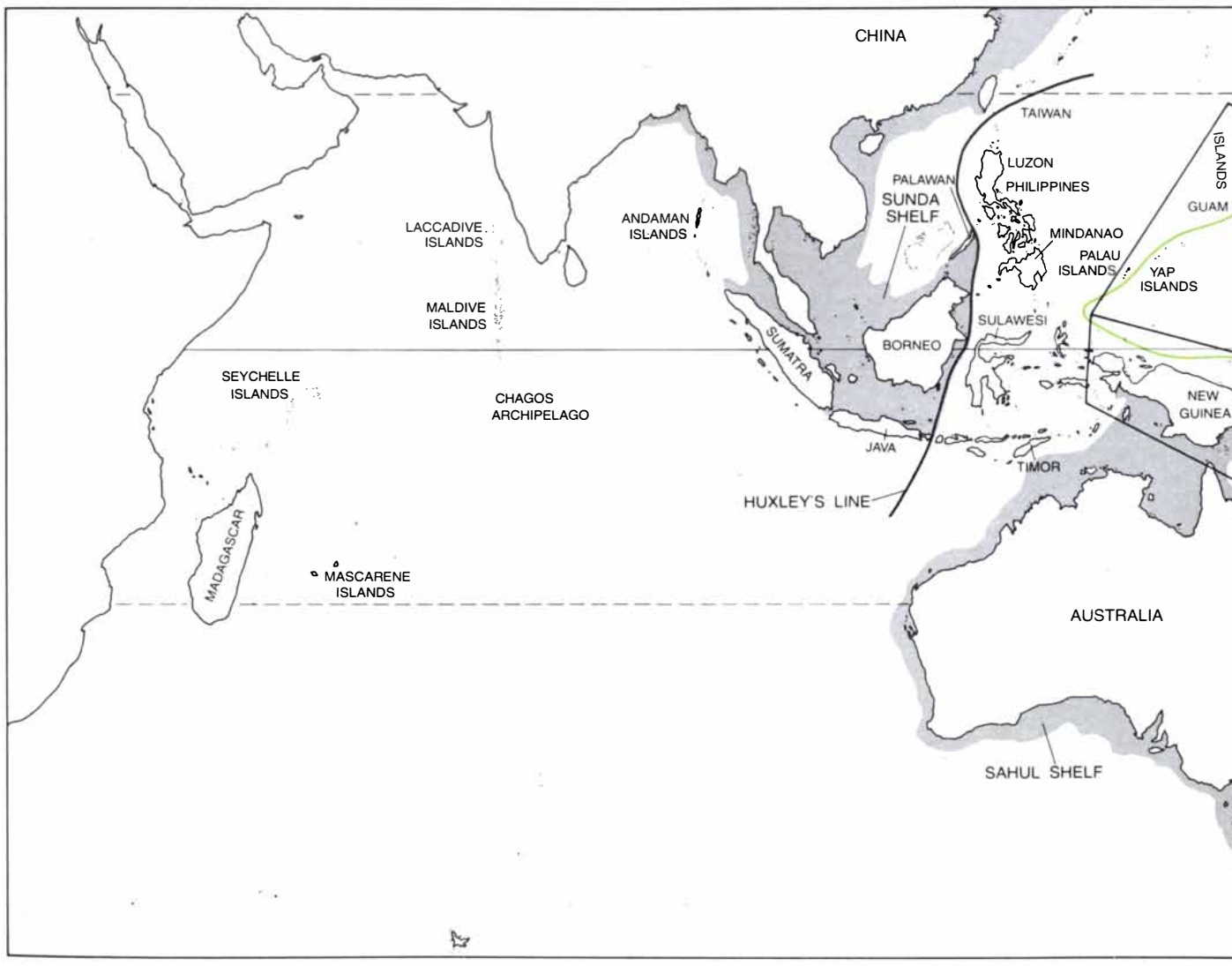
40,000 years ago. Then populations of hunter-gatherers, who must have flourished in Indonesia at the time, somehow succeeded in crossing deep water to settle empty Australia and New Guinea. Perhaps their entry coincided with one of the periods of the lowest Pleistocene sea levels, which are now known to have been some 55,000 and 35,000 years ago. Even so, the immigrants still had a minimum of 70 kilometers of open water to cross; their claim to the title of the first ocean voyagers seems unchallengeable.

Physically these people were the direct ancestors of the modern Australoids. Their own ancestry, in turn, can be presumed to have included a combination of genetic inputs from mainland Southeast Asia and from the earlier *Homo erectus* population of Sundaland. The clearest archaeological evidence of their arrival comes from sites such as Lake Mungo in western New South Wales in Australia and Kosipe in the Papuan highlands of New Guinea; the sites date to between 35,000 and 25,000 years ago.

The significance of this first maritime colonization in human prehistory should be assessed in the light of similar activities elsewhere in the world. For example, major islands in the Mediterranean such as Crete and Cyprus appear not to have been settled before Neolithic times, some 8,000 years ago, even though Cyprus lies within 80 kilometers of the Mediterranean shore. Some island-hopping in the interest of procuring obsidian was going on in the eastern Mediterranean earlier than that, in Mesolithic times, but no colonization resulted.

Where are Australoid populations to be found today? The Aborigines of Australia and the Highlanders of New Guinea are the basic representatives of the group. The so-called Negritos of Malaya and the Philippines are almost certainly Australoid relatives, and the isolated pocket of similar peoples in the Andaman Islands north of Sumatra may also be. The people of Melanesia too are basically Australoid, but they show a genetic complexity stemming from both ancestral and recent Polynesian and Micronesian penetrations. The last two populations are of Mongoloid affinity.

In this connection some physical anthropologists are unhappy when the term Mongoloid is applied to the people of Polynesia, and it is true that the Polynesians do not present a classic East Asian Mongoloid appearance. Indeed, many Polynesians and many peoples of southern and eastern Indonesia show a high degree of Australoid genetic inheritance. This, of course, is to be expected, given the earlier Australoid dominance in island Southeast Asia. To my mind the Indonesians, Filipinos, Microne-




**OCEANIC ARENA of prehistoric maritime expansion is bounded on the west by the mainland of East and Southeast Asia and the islands that were connected to the mainland at times of low sea level during the Pleistocene glacial maximums, when the Sunda Shelf was dry land. Huxley's Line, a variation of the more familiar Wallace's Line, is the boundary between the rich biogeographical zone of Sundaland and the relatively impoverished island regions to the east. Human occupation of Sundaland began perhaps two million years ago;**

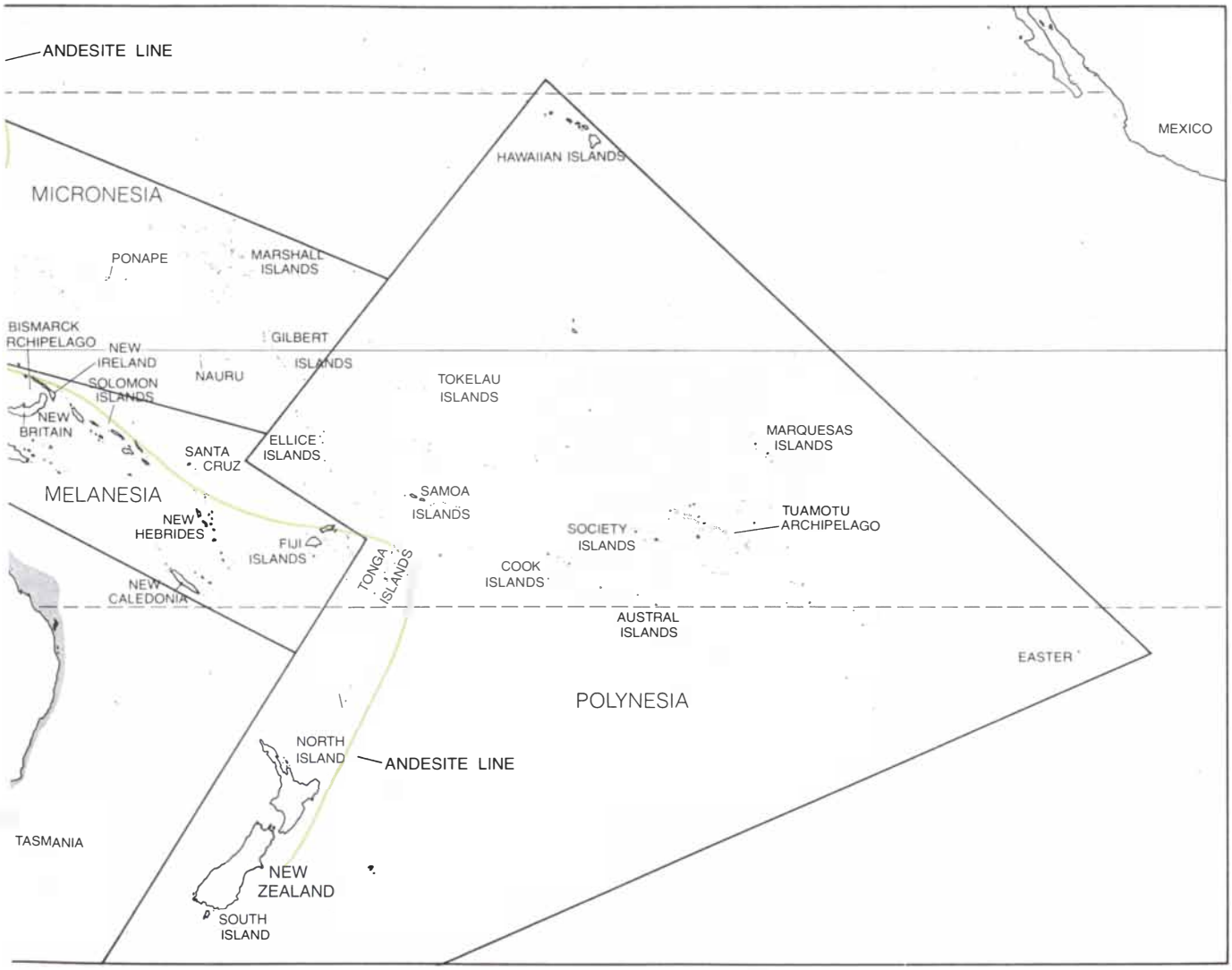
sians and Polynesians owe their ancestry to complex patterns of migration and gene flow that originated ultimately on the mainland of East Asia, possibly north of the Tropics. Within the past 6,000 years these populations of Mongoloid ancestry have come to dominate island Southeast Asia and have gone on to settle the empty areas of Micronesia and Polynesia. Why the Mongoloid populations had so little genetic impact on much of Melanesia is a subject to which I shall return.

Having come to within six millenniums of the present, we enter the phase of Pacific settlement that has been the focus of my own research for a decade. In this phase all areas of the Pacific (apart from Australia, most of New Guinea and perhaps some adjacent Melanesian islands) were settled by people who subsisted largely by gardening and who spoke related languages within a large single family: Austronesian (previously known as the Malayo-Polynesian family). Putting aside for the moment these peoples' advanced material culture, the linguistic situation in the region is approximately as follows.

Australia for some reason remained totally isolated from the Austronesian-speakers' expansion into the Pacific, with the result that only languages unrelated to this family are found in the aboriginal population of the subcontinent. That is also true of the greater part of New Guinea, where the many languages belong to the ancient and highly diversified Papuan grouping. Other Papuan languages are found in parts of the Molucca Islands adjacent to New Guinea and in similarly adjacent Melanesian islands. Archaeological and linguistic evidence suggests that Papuan-speaking populations settled the Melanesian islands of New Britain and New Ireland (and perhaps the Solomon Islands) no later than 6,000 years ago and perhaps much earlier. The settlement of the Pacific islands beyond the Solomons, however, was solely the achievement of the Austronesian-speakers and evidently began some 5,000 years ago.

Most linguists today trace the earliest-known ancestor of the Austronesian family of languages, called Proto-Austronesian, to the island of Formosa (Taiwan), where a single such language (or a group of related languages) was probably spoken some 6,000 years ago. The ancestry of the Austronesian family before that stage is difficult to trace. No Austronesian languages are spoken today on the coast of southern China adjacent to Formosa, but it is possible that there is a relationship between Austronesian and the Thai family of languages on the mainland.

When linguists reconstruct the Proto-Austronesian vocabulary, they can make certain deductions about the




**it is indicated by fossil remains of *Homo erectus* discovered in central and eastern Java. The Andesite Line (*color*), named for a characteristic volcanic rock, divides the geologically complex Pacific islands of the west and south from the smaller volcanic and coral islands of Oceania. From presumed but still uncertain points of origin in southern China, Austronesian seafarers first occupied Taiwan and then sailed on to the Philippines, Sundaland and eastern Indonesia. They eventually voyaged west to Madagascar and east to Easter Island.**


**FIRST OCEAN VOYAGES of perhaps 40,000 years ago carried the ancestors of today's Australoids from Sundaland to Australia and New Guinea, then perhaps a single expanse named Sahulland. The Negritos of the Philippines, Malaya and the Andaman Islands (*light color*) are Australoid relatives. So are the Melanesians (*dark color*), who colonized the islands eastward to Fiji at least 3,500 years ago.**

material culture of its speakers. Thus it appears that they cultivated rice and millet, and perhaps also yam, taro and sugarcane. Their domestic animals included pigs, dogs and perhaps chickens. Very early in the expansion of Austronesian-speakers into the islands to the south a number of purely tropical crops were added to this inventory: breadfruit, banana, sago and presumably coconut.

The earliest Austronesian-speakers made pottery, built seagoing canoes of outrigger design and practiced various techniques of fishing. They are unlikely, however, to have known the use of metal. Hence the enormous geographical expansion of the Austronesian-speakers over the following millenniums—westward to Madagascar and eastward to Easter Island, places more than half the earth's circumference apart—was accomplished by an essentially Neolithic group of cultures. The practice of rice cultivation was not carried east of the Mariana Islands. At some time later than 3,000 years ago the peoples of island Southeast Asia acquired metal and possibly domestic cattle as well, but the use of metal did not extend beyond western New Guinea before the time of the first contact with Europeans. One may therefore conclude that the original impetus for one of the greatest colonizations achieved by man arose among peoples supported by a Neolithic economy and technology.

Recent excavations in coastal areas of China south of the Yangtze indicate a possible cradle area for what later emerged as the Austronesian expansion. Sites assigned to the Ch'ing-lien-kang culture have yielded evidence of rice cultivation, stone reaping knives, the bones of cattle and pigs, and pottery, both plain and red-slipped, that date to sometime between 6,000 and 5,000 years ago. Sites similar to these, some of them perhaps equally old, have been found on Formosa. They are assigned to cultures known respectively as Ta-p'en-k'eng, Lungshanoid (after the site of Lung-shan-chen in Shandong Province) and Yüan-shan. The Ta-p'en-k'eng culture, the earliest of the three, may reasonably be equated with the earliest recognizable stages of the Austronesian family of languages.

Here, then, is a crucial point in the prehistory of the Pacific. Populations identified as cultivators of cereals and Austronesian-speakers reached Formosa about 6,000 years ago. If their method of growing rice was the slash-and-burn one, which is particularly prodigal of land, they would have had a good reason to seek more land in the island archipelagos to the south that lay within reach of their technically advanced outrigger canoes. The archaeological evidence suggests that at this time those southern islands were inhabited exclusively by thinly-spread bands of hunter-gatherers, who in the long run were overwhelmed by the expansion from the north.

Little evidence is available at present from Java and Sumatra, but in the Philippines, in northern Borneo, in Sulawesi and as far east as Timor rock-shelters and caves have yielded clear archaeological sequences. Some of these show the sudden appearance of plain or red-slipped pottery between 5,500 and 4,500 years ago. Adzes made of stone shaped by grinding that are quite different from the simpler indigenous flaked stone tools also appear, although in less secure archaeological contexts. There is little alternative at present but to regard these new assemblages of artifacts as a record of a marked cultural change associated with an expanding Neolithic population, exactly as the linguistic evidence suggests.

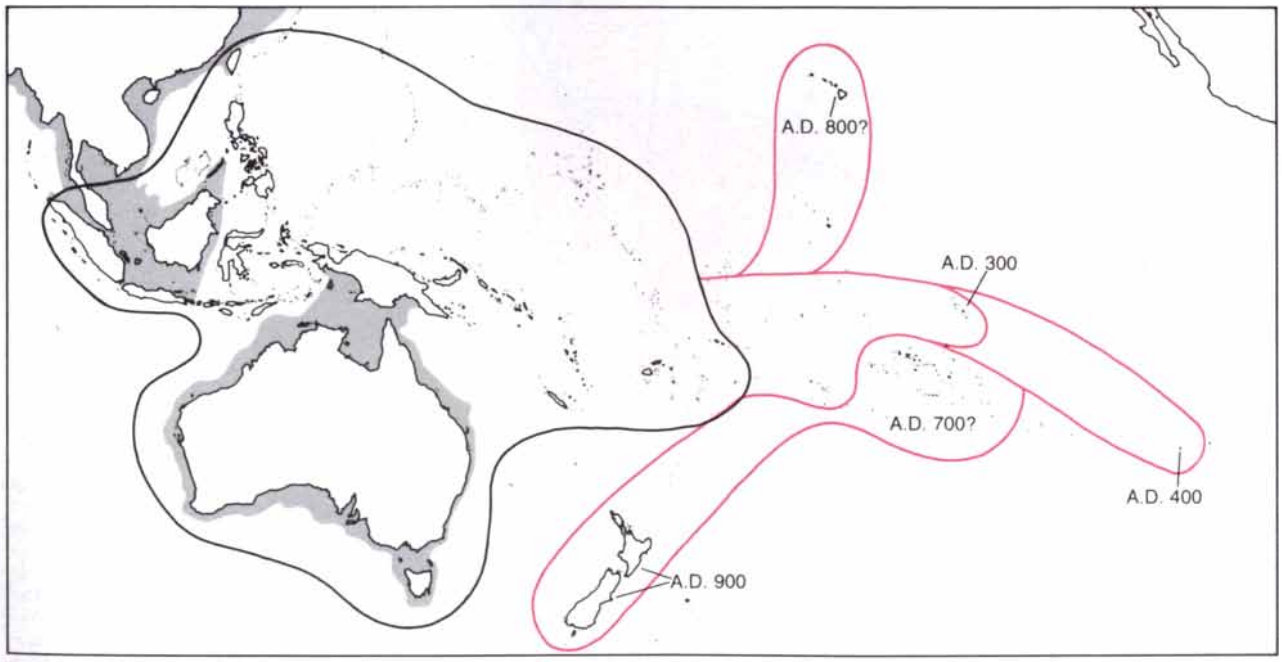
By combining archaeological, linguistic and ecological information one can fill in the picture a little more. First, as the expanding population moved south through the Philippines, Borneo and Sulawesi its members entered a region of constantly humid equatorial climate where the early cultivated rices did not thrive and where land clearance without metal and a reliable dry season became more difficult. (The peoples of island Southeast Asia do grow rice today, but the practice seems to have spread into many areas only in recent millenniums.) Hence the newcomers' cereal crops gradually diminished in importance and were replaced as major sources of food by the tree fruits indigenous to the south (such as breadfruit, banana and coconut) and by sago-palm starch. Although the indigenous peoples were hunter-gatherers, not horticulturists, they probably exploited the same wild foodstuffs, along with wild taro and some varieties of wild yam.

Pigs, dogs and chickens appear to have adapted successfully to the southern environment. Indeed, native wild


**EARLY PACIFIC VOYAGES by Austronesian-speaking migrants from Melanesia up to 3,000 years ago resulted in the colonizations mapped here. The western islands of Micronesia had already been reached, perhaps from the Philippines. So had Fiji and the early western Polynesian outposts: Samoa and Tonga. So perhaps had the rest of Micronesia, although no definite evidence of it has yet been found.**

pigs are found today in both the Philippines and Sulawesi. Cattle, if the colonists attempted to transport them, did not thrive; archaeological sites of this period in island Southeast Asia hold no cattle bones. As a result when the Austronesian colonists went on to settle the Pacific, their economy was based almost entirely on tubers and fruits and included neither major cereal plants nor herbivorous animals.

By some 4,500 years ago Austronesian peoples had been expanding into the equatorial islands of eastern Indonesia for about a millennium. This expansion, which ultimately encompassed the whole of island Southeast Asia, can be compared to the expansion of Neolithic societies into Mesolithic Europe. The economy of the expanding population had undergone basic changes with respect to food plants, and the colonists themselves had doubtless come in wide contact with the indigenous Australoid hunter-gatherers of the region. One may suspect that as a result of interbreeding many of these Austronesian-speaking




**FINAL POLYNESIAN PUSH, starting early in the first millennium A.D., advanced eastward against prevailing winds and currents from the Tonga-Samoa area 3,500 kilometers to the Marquesas Islands, which were settled in about A.D. 300. Remote Easter Island was colonized perhaps a century later, and within another 500 years so were central Polynesia, the Hawaiian Islands and New Zealand.**

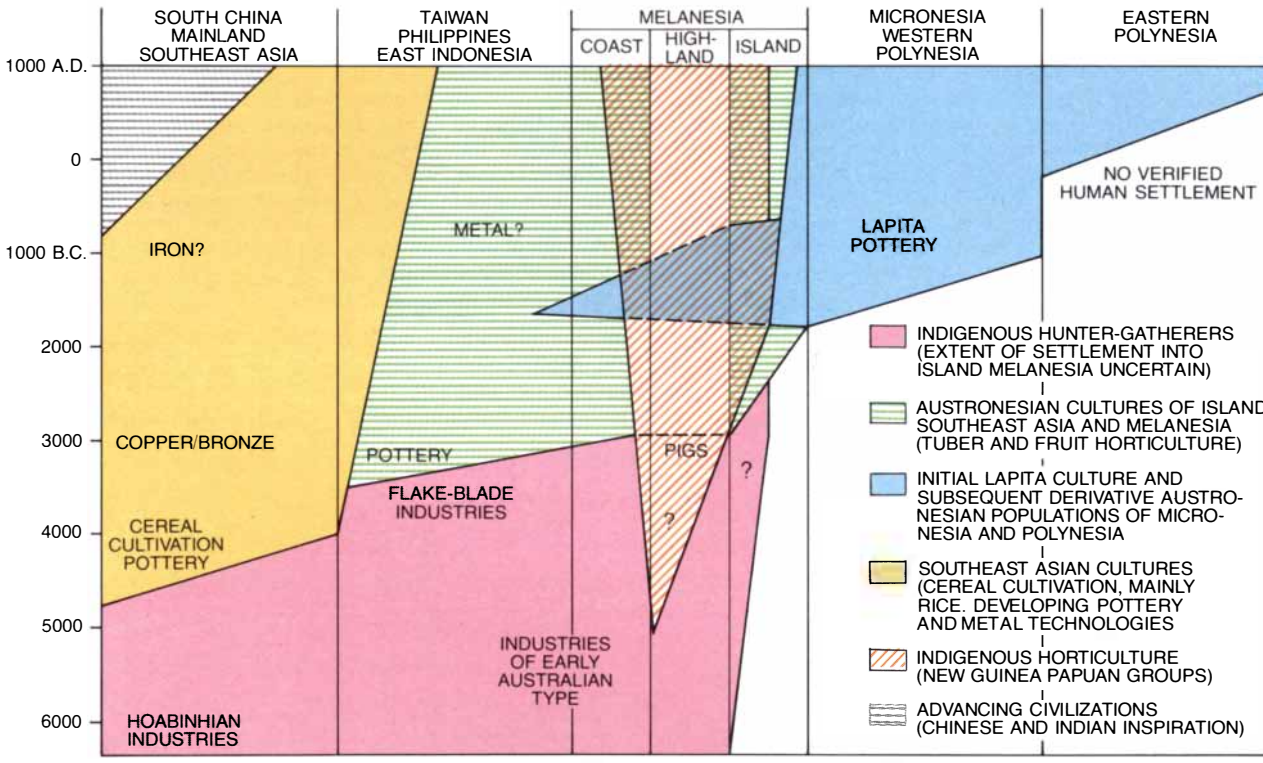
colonists had become genetically intermediate between the classical Mongoloid and Australoid norms. Even when allowance is made for a constant Mongoloid gene flow from the north up to the present day, one can still see, moving south from the Philippines to Java or the Moluccas, a gradual increase in the Australoid genetic inheritance. One may perhaps also infer that many of the Austronesian-speaking colonists in eastern Indonesia some 5,000 years ago would have resembled the more recent Polynesians. It must be admitted, however, that human skeletal remains in support of this view have not yet been uncovered.

By this time—that is, some 5,000 years ago—Austronesian-speaking colonists were probably on the move eastward, establishing footholds on the northern coast of New Guinea and in the neighboring Admiralty, Bismarck and Solomon islands. Here their reception was quite different from the one they had met in moving south, which brings us back to the subject of why the Mongoloid populations had so little genetic impact on Melanesia.

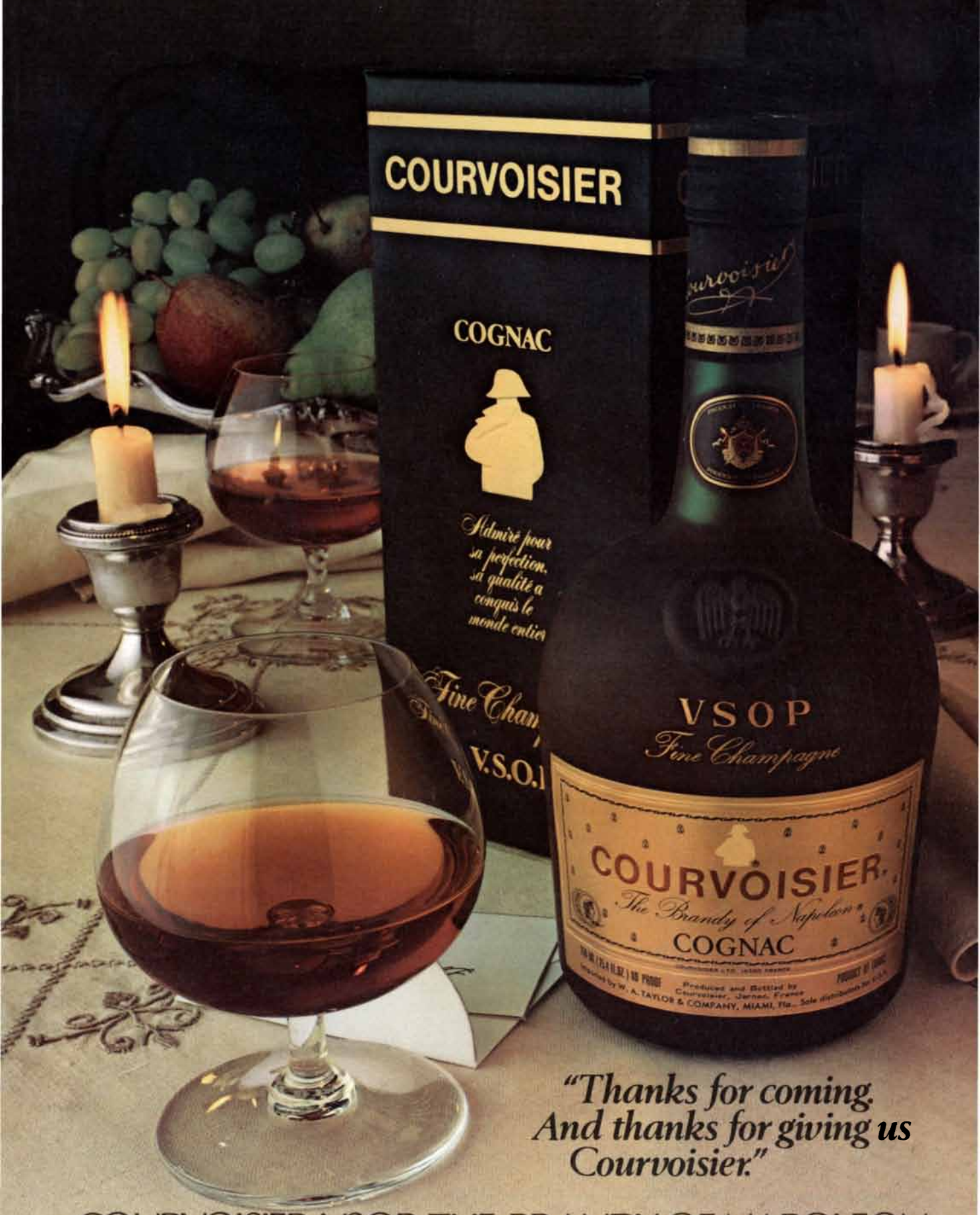
For some time scholars have wondered why Melanesia did not become simply a racial and cultural extension of Indonesia. The progress of the Austronesian colonists might have been slowed by their encounter with malaria, particularly if this parasitic disease was as devastating in Melanesia then as it was until quite recently. A more likely explanation, however, is that the long-established residents, in particular those of New Guinea, may have been able to hold out against the newcomers. Key information in support of this view has recently been supplied by archaeological work in the malaria-free New Guinea highlands near Mount Hagen.

Archaeologists from the Australian National University have found that beginning at least 6,000 years ago and perhaps as early as 9,000 years ago large areas of highland swamp in New Guinea were being drained by quite elaborate systems of ditches. The implication is that the drainage was undertaken to promote horticulture (perhaps the cultivation of taro, although the plant is not known to have been indigenous to New Guinea). This new discovery in the highlands raises numerous questions that are under active exploration. At present it is only possible to point out that horticulture of some kind was practiced in highland New Guinea before, on the basis of any reasonable estimate, there was contact between the Melanesians and the horticulturist Austronesians. Indeed, the Austronesians never did reach the New Guinea highlands.

The implications of early horticulture in Melanesia are great. It is possible to hypothesize that the Melanesians of New Guinea (and probably those of New Ireland, New Britain and the Solomons) had become large, fairly sedentary populations sustained by horticulture more than 5,000 years ago. If future archaeological work supports this hypothesis, then the failure of the Austronesian-speakers to overrun Melanesia may be attributable to their not having the numerical and economic superiority they had once had over the scattered hunter-gatherers of island Southeast




**AUSTRONESIAN MOVEMENT into the Pacific is plotted in relation to advances in material culture in five regions: mainland Southeast Asia and southern China; Taiwan, the Philippines and eastern Indonesia; Melanesia; Micronesia and western Polynesia, and finally eastern Polynesia. Until some 7,000 years ago from the Asian mainland to Melanesia most tools were of flaked stone rather than ground stone, and their users were indigenous hunter-gatherers. On the mainland soon thereafter farming and pottery appeared; metallurgy was known by 5,000 to 4,000 years ago and iron by about 3,000 years ago, long before Indian and Chinese civilization began to affect the area. The Neolithic arts of pottery and horticulture also appeared in Taiwan, the Philippines and eastern Indonesia between 6,000 and 4,500 years ago and spread to Melanesia. There, beginning in highland New Guinea, an indigenous form of horticulture had arisen perhaps even earlier. The Austronesians, facing cultural equals, could not displace or absorb the Melanesians as they had the hunter-gatherers of the Philippines and eastern Indonesia. Instead, beginning less than 4,000 years ago, they spread into unpopulated western Micronesia and from island Melanesia into eastern Micronesia and western Polynesia. The colonization was marked by the appearance of a distinctive pottery: Lapita ware. Finally, early in the Christian Era, when the Austronesian colonists had evolved most attributes of Polynesian culture, they began their greatest maritime venture, settling the Marquesas, Easter Island, central Polynesia, the Hawaiian Islands and New Zealand.**

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Asia. There would have been a standoff between two Neolithic cultures.

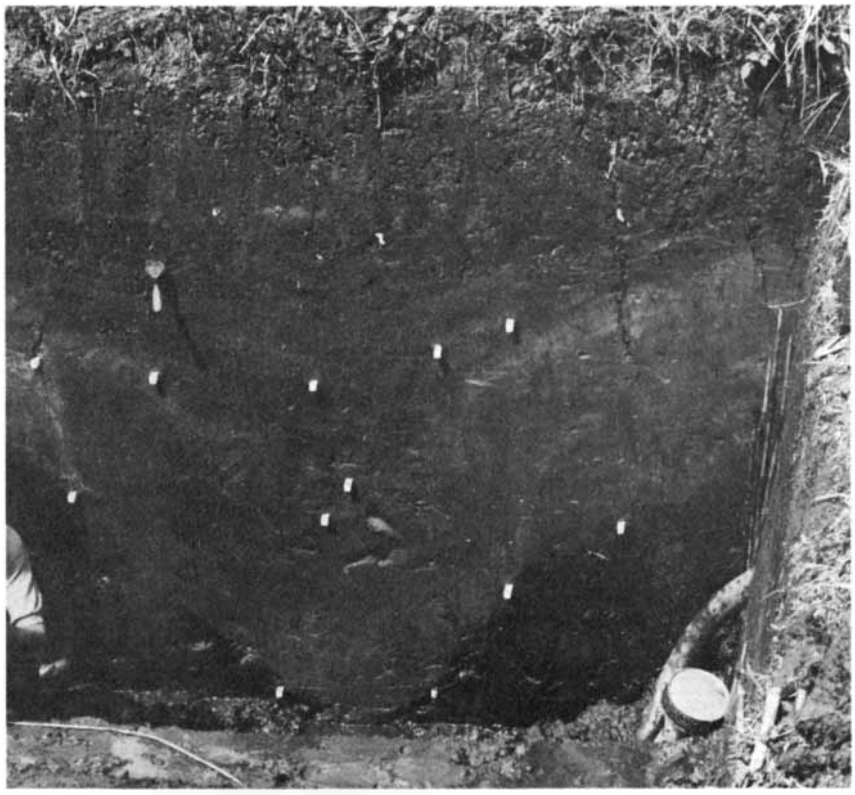
The past 5,000 years of prehistory in western Melanesia brought about a degree of cultural, genetic and linguistic complexity that is unparalleled in the Pacific and perhaps in the world. Hundreds of discrete Papuan and Austronesian languages interdigitate as far east as Santa Cruz. Most of them are spoken only in a small area, perhaps in a single valley. Genetic diversity is also enormous, and it is not correlated in any obvious way with the linguistic diversity.

Why should Melanesia be so different? One may perhaps get some answers by reconstructing the prehistory of those crucial past 5,000 years. The earliest evidence for Austronesian-speaking settlers in Melanesia comes from linguistic analysis. There is no coherent archaeological evidence of their presence before the appearance all across Melanesia of the pottery-making Lapita culture (named after the type site in New Caledonia) between 3,500 and 3,000 years ago. But by at least a millennium earlier, according to linguistic reconstructions, Austronesian-speakers had already moved into coastal locations in western Melanesia, where during an ensuing period of isolation from their Indonesian base they developed a number of linguistic peculiarities that today characterize the languages of the eastern Austronesian group. For example, the languages of eastern Micronesia and Polynesia are believed to stem from this earlier matrix in western Melanesia, rather than being transferred directly to those islands from Indonesia or the Philippines.

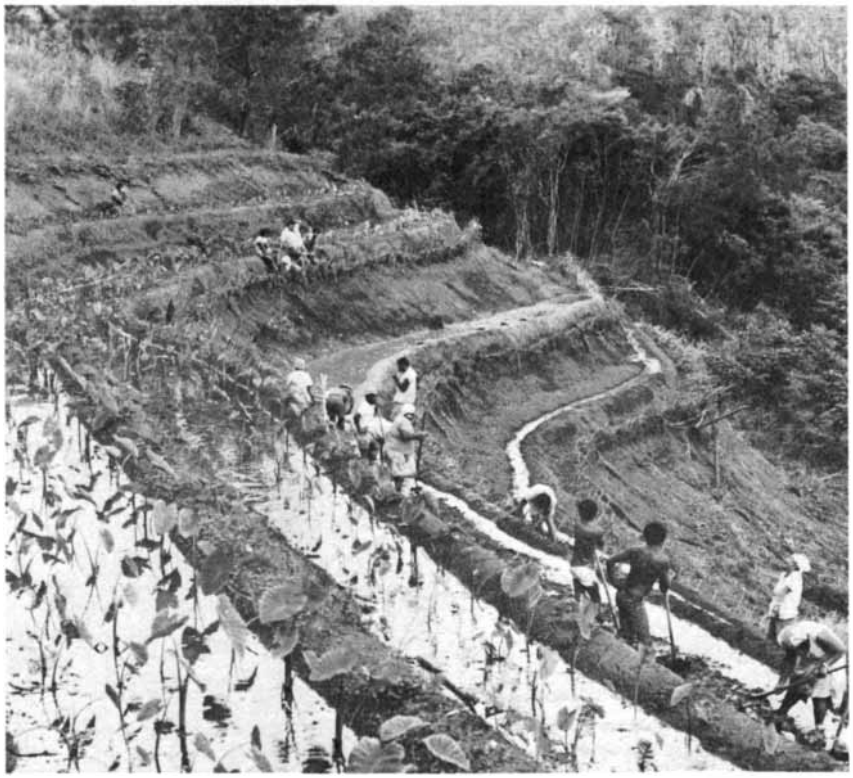
As for prehistoric social and economic developments in Melanesia, if an initial assumption can be made, the records both of archaeology and of recent ethnography provide some guidance. The necessary assumption is that Melanesian societies in prehistory were no more complex, particularly with respect to political integration, than they are today. If this was the case, then I suggest that the initial hunter-gatherer populations of New Guinea were organized into fairly mobile bands, each consisting of a few families, for at least the first 20,000 years of their residence. Up until the recent past such social systems were characteristic of the aboriginal peoples of Australia and the Philippines.

The next prehistoric phase would have been the initiation of horticulture in New Guinea and perhaps in adjacent islands. Along with horticulture would have come settlement into more or less permanent villages adjacent to the garden areas. As mobility became limited, the Melanesian ethnographic pattern, in which ethnic groups occupy small areas and tend to marry within them, came into existence.

Among these ethnic groups leader-



**DRAINAGE-DITCH PROFILE is revealed by the contrast between soil colors in this cross-section excavation into an ancient swamp deposit at the Kuk Tea Research Station near Mount Hagen in the New Guinea highlands. Some of the drainage ditches at the site, presumably dug to facilitate the growth of garden root crops such as taro, are thought to be 9,000 years old.**



**MODERN TARO GARDENING in the South Pacific often utilizes terraced irrigation ditches; this ditch system occupies a hillside in New Caledonia. Taro and other starchy plants of the arum family are still a major food resource for many Pacific horticulturists to this day.**

ship is rarely hereditary. It is usually acquired in adult life by individuals, so-called big men, who are able to build up advantages over their fellow tribesmen in wealth and prestige. Until the recent past active hostilities between geographically restricted groups were frequent. If such has been the social pattern in Melanesia for 5,000 years, it is not difficult to see how genetic, linguistic and societal diversity arose. In recent times peaceful contacts between groups depended on shifting alliances, cemented by occasions of ceremonial feasting and by elaborate and often extensive trading activities. In areas of high population density the trade networks often developed into systems of great ritual complexity. At the time of the first contact with Europeans the Melanesians were the businessmen and traders of the Pacific. In this sense they were quite different from the Polynesians and many of the Micronesians, who formed ethnic groups geographically far more widespread, whose societies were characterized by systems of inherited leadership and for whom trading by individuals was usually subordinated to patterns of communal tribute or of redistribution that were focused on chiefly leaders.

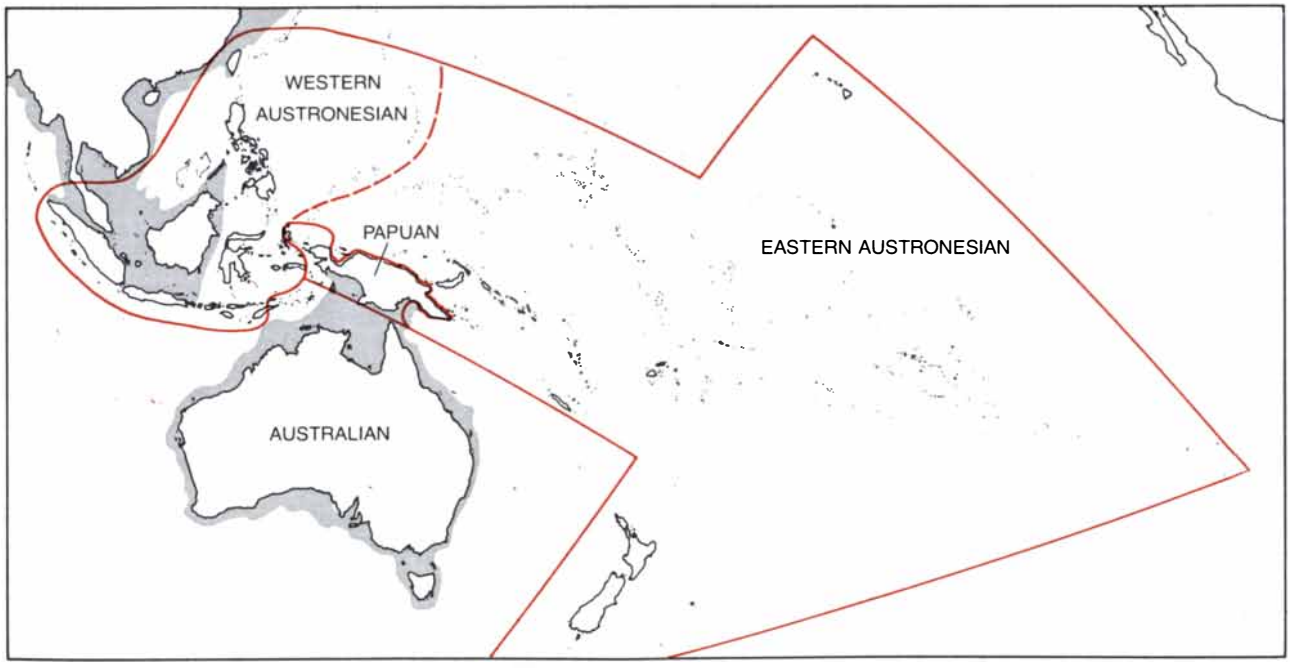
Such, it seems likely, was the prevailing social and ethnic pattern in Melanesia when the first Austronesian colonists arrived. The newcomers were unable to impose their own order on Melanesia; their settlements simply increased the diversity in the region. By about 4,000 years ago cultures of the indigenous Melanesian kind had been planted as far away as New Caledonia and the New Hebrides. It is even possible that these last two areas had been colonized by Melanesians well before the first Austronesian-speakers appeared, although clear archaeological evidence for it is lacking. Meanwhile, elsewhere in the western Pacific, western Micronesia may have been settled by Austronesian-speakers moving directly from the Philippines. The extended archipelagos of eastern Micronesia, of Fiji and of all Polynesia, however, still awaited their first human settlers.

The prehistory of Oceania now reaches its most remarkable and most expansive phase. About 3,500 years ago in western Melanesia representatives of the Lapita culture had established themselves, perhaps in the vicinity of the Bismarck Archipelago, where their distinctive stamped and incised pottery has been found. This population may have entered the area not long before, coming perhaps from eastern Indonesia or from the Philippines. So far there is no archaeological evidence on the precise point of origin of the Lapita culture, and it may even be that the characteristics that distinguish Lapita pottery actually evolved within Melanesia.

Whatever its origin, the new population did not make extensive genetic or cultural contact with the neighboring Melanesians. Instead, as the presence of Lapita pottery at coastal and offshore-island sites makes clear, the Lapita people over the next 500 years went on to colonize Tonga and Samoa, some 5,000 kilometers away in the central Pacific. The Polynesians had at last arrived in Polynesia.

So, perhaps, had the eastern Micronesians arrived in their area, although the absence of true Lapita pottery in those clayless atolls makes that part of the story hard to read. Where archaeological facts are absent, however, the linguistic evidence is suggestive. The languages of Fiji, of Polynesia as a whole and of the archipelagos of eastern Micronesia—the Caroline, the Marshall and the Gilbert islands (now Kiribati, an independent member of the British Commonwealth)—all have a common immediate origin within the Austronesian family of languages. Hence there seems little doubt that the colonizers of eastern Micronesia were also bearers of the Lapita culture.

What, besides a distinctive pottery, were the main elements of this culture? First, like the coastal Austronesian-speakers of the Philippines and Indonesia, the Lapita people practiced horticulture and caught fish. Second, also like their forebears, they were voyagers. They were more than simple sailors; they were skilled mariners who were able to maintain some degree of contact between their widely scattered settlements for several hundred years. On this point the archaeological record affords evidence of their early seafaring feats within Melanesia. Obsidian from volcanic New Britain has been unearthed at




**LINGUISTIC DIVISIONS of the Pacific and island Southeast Asia are twofold. Languages of the Austronesian family are found from Taiwan, a presumed proto-Austronesian locale some 6,000 years ago, southward through island Southeast Asia and the Malay Peninsula and western Micronesia; these languages comprise the western Austronesian half of the family. Elsewhere in Micronesia, throughout Polynesia and in parts of Melanesia are found languages of the eastern Austronesian half of the family. The second family of languages is Papuan, a highly diversified grouping found principally in New Guinea but with outliers in the Molucca Islands and in adjacent Melanesia, where Papuan and Austronesian languages are mingled. The aboriginal Australian languages seem to be unrelated to Papuan.**

Lapita sites in Melanesia up to 2,600 kilometers away. Last of all, the Lapita people were highly successful colonizers of virgin islands.

After its initial phase of successful expansion the Lapita culture was subject to inexorable change. It vanishes from the archaeological record in Melanesia some 2,500 years ago, in the latter half of the first millennium B.C. In Tonga and Samoa, its first Polynesian outposts, the Lapita culture was longer-lived. There during the entire first millennium B.C. the new settlers developed many of the cultural characteristics that were to spread to the farthest corners of Polynesia over the next 1,000 years. Nevertheless, here too change was apparent. For example, these western Polynesians lost the craft of pottery making, possibly as a result of reduced contact with the already waning Lapita societies of Melanesia. In this connection the people of Fiji did maintain contacts with the west and as a result had a more complex archaeological record of cultural development. Today the Fijians are a population that is intermediate between the Melanesians to the west and the Polynesians to the east.

Early in the first millennium A.D. the western Polynesians, whose colonies were now more than 1,000 years old, were ready to undertake their greatest voyages. Large double canoes, able to carry the food plants and the domestic animals required for colonization, sailed off against the prevailing winds and currents to settle the Marquesas Islands in about A.D. 300 and Easter Island, one of the most isolated places on the face of the earth, perhaps a century later. By the end of another five centuries the western Polynesians had also colonized the islands of central Polynesia, the northern outlying Hawaiian chain and finally, by perhaps A.D. 900, the two great southern outliers of New Zealand.

One element that was undoubtedly essential to the success of these long and grueling voyages of discovery was strong leadership. Here the Polynesian social system of hereditary and religiously sanctioned rule must have been a great asset. By the time of Captain Cook this aspect of Polynesian social organization had given rise to the despotic and powerful chiefdoms of Tonga, the Hawaiian Islands and the Society Islands, to mention only the most developed and populous parts of Polynesia.

The Maori, the Polynesians who ended up in temperate and, by island standards, vast New Zealand, were forced into some drastic economic adaptations. They replaced their unsuccessful tropical foodstuffs with the sweet potato (introduced before A.D. 1000 from Ecuador or Peru by means unknown) and the rootlike rhizomes of native ferns. Pigs were not taken to New Zealand but dogs were, and other major sources of meat included marine mammals and moas, species of flightless birds, some of great size, that rapidly became extinct.

**POLYNESIAN TEMPLE PLATFORM built in 1767 was seen by the naturalist Joseph Banks during Captain Cook's visit to Tahiti two years later. Banks described it as "a most enormous pile" and declared that its "size and workmanship almost exceeds belief." When this sketch was made in 1799 the platform was 10 steps high; today all that remains is a part of the foundation.**

Early in the first millennium A.D., at a time when ocean trade between China and India had begun, the Polynesians' Austronesian cousins in the East Indies made an epic voyage of their own and settled in Madagascar, off the coast of Africa. It was not, however, until the second millennium A.D., at some time after A.D. 1100, that the Easter Islanders, some 21,000 kilometers away on the other side of the world, began to quarry and erect their famous stone statues in rows on temple platforms. Although these works have attained more notoriety than any other Polynesian architectural feat, the temple platforms, statues and funerary monuments in other parts of Polynesia are equally impressive.

So ends this reconstruction. Some of my colleagues will disagree with me when I derive the Polynesians from a homeland in Indonesia or the Philippines. There is even a published view that the Polynesians may have arisen directly from a Melanesian genetic and linguistic matrix. There is scope here for complex disagreement, but I can see little evidence in support of that hypothesis, particularly from a genetic viewpoint. At least one thing is now quite certain: the Polynesians are not of American Indian ancestry, in spite of some evidence for minor contacts with the Pacific coast of South America.

Perhaps I may finish with an observation that could have some general anthropological significance. The Polynesians, whose feats of colonization were undoubtedly the most stressful in all Oceania, also developed the largest and most centralized forms of government by hereditary chiefs in the Pacific. The ancestral Polynesians of the period of the Lapita expansion had quite clearly achieved a number of cultural adaptations—social, economic and navigational—without which the settlement of Polynesia would have been unthinkable. The systems of chieftainship, the domesticated food plants and the great canoes did not spring into being fully formed and purely by chance. They evolved partly in the early millenniums of Austronesian expansion and evolved still further as the Polynesians pushed themselves toward ever longer voyages of settlement.

For me Pacific prehistory as a whole provides a record of cultural equilibrium over long periods coupled with advancement toward greater cultural complexity. I see no signs of long-term cultural simplification or degradation, although it is true that some islands, atolls in particular, are so deficient in natural resources that the cultural development of their settlers was necessarily limited. It is also true that some islands, Easter Island in particular, had periods of cultural and demographic decline as a result of either warfare or a reduction in available resources or both. Numerous examples of environmental damage, including the degradation of vegetation and the extinction of animals in prehistoric times, can also be found throughout the Pacific. None of these exceptions, however, implies any irreversible decline in human cultural complexity. Given the many thresholds the migrants of Oceania had to cross in their long period of settlement, it is likely that any groups who slipped backward would have left few descendants to tell the tale.

# Chemical Reactions without Solvation

*Chemical reactions are strongly influenced by the solvent medium in which they proceed. New techniques make it possible to examine the behavior of "bare" chemical reactants in the absence of solvent*

by Robert T. McIver, Jr.

Chemistry is the science of molecules. It is concerned with how and why atoms bond together to form molecules and how rapidly molecules can be transformed into new configurations. Most chemical reactions take place in a solvent medium such as water whether they do so in the test tube or in the living cell. Chemists have long been curious about what happens when solvents are changed or, better yet, when they are removed entirely. In the absence of a solvent would chemical reactions still proceed? Would the same products be formed?

Few textbooks consider such questions because a comprehensive theory of the role of solvents has not yet been developed. Nevertheless, the questions are important for a variety of reasons. First, the fundamental factors that influence reaction rates cannot be studied in solution because the solvent molecules themselves interact strongly with the reacting species. If the solvent could be totally removed, the intrinsic reactivity of the "bare" reactants could be measured and distinguished from the effects attributable to solvation. A second reason for having an interest in the role of solvation is evidence that in living organisms the active sites on enzyme molecules exclude water, so that they can engineer reactions that either would not proceed in bulk water solution or would proceed only very slowly.

Here I shall describe experiments in which ions, the electrically charged fragments of molecules, undergo chemical reactions totally without interference from solvents. Such experiments are conducted by trapping freshly created ions in a magnetic field and then identifying the reaction products by a form of mass spectrometry that measures the response of the trapped particles to an alternating electric field. The apparatus for conducting the experiments is called a pulsed-ion cyclotron-resonance mass spectrometer. Although it has long been assumed that solvents retard the rates of reaction, the degree of retardation has been hard to measure. Our experiments show, in one typical case, that ionic species in the gas phase react three billion times faster than the same species do when they are dissolved in acetone and a million billion ($10^{15}$) times faster than they do in water.

Other experiments show how solvation affects the acidity and basicity of ions. We have been able to measure for the first time with high precision the amount of energy released when an acid (a donor of protons, or hydrogen ions) reacts with a base (an acceptor of protons) in the gas phase. These investigations have yielded a proton-affinity table that shows the relative basicity of some 300 compounds. For example, one of the strongest bases, a negative hydrogen ion ($H^-$), releases about 10 times as much energy in combining with a proton to form a hydrogen molecule ($H_2$) as does one of the weakest bases, helium (He), when it combines with a proton to form a helium hydride ion ($HeH^+$).

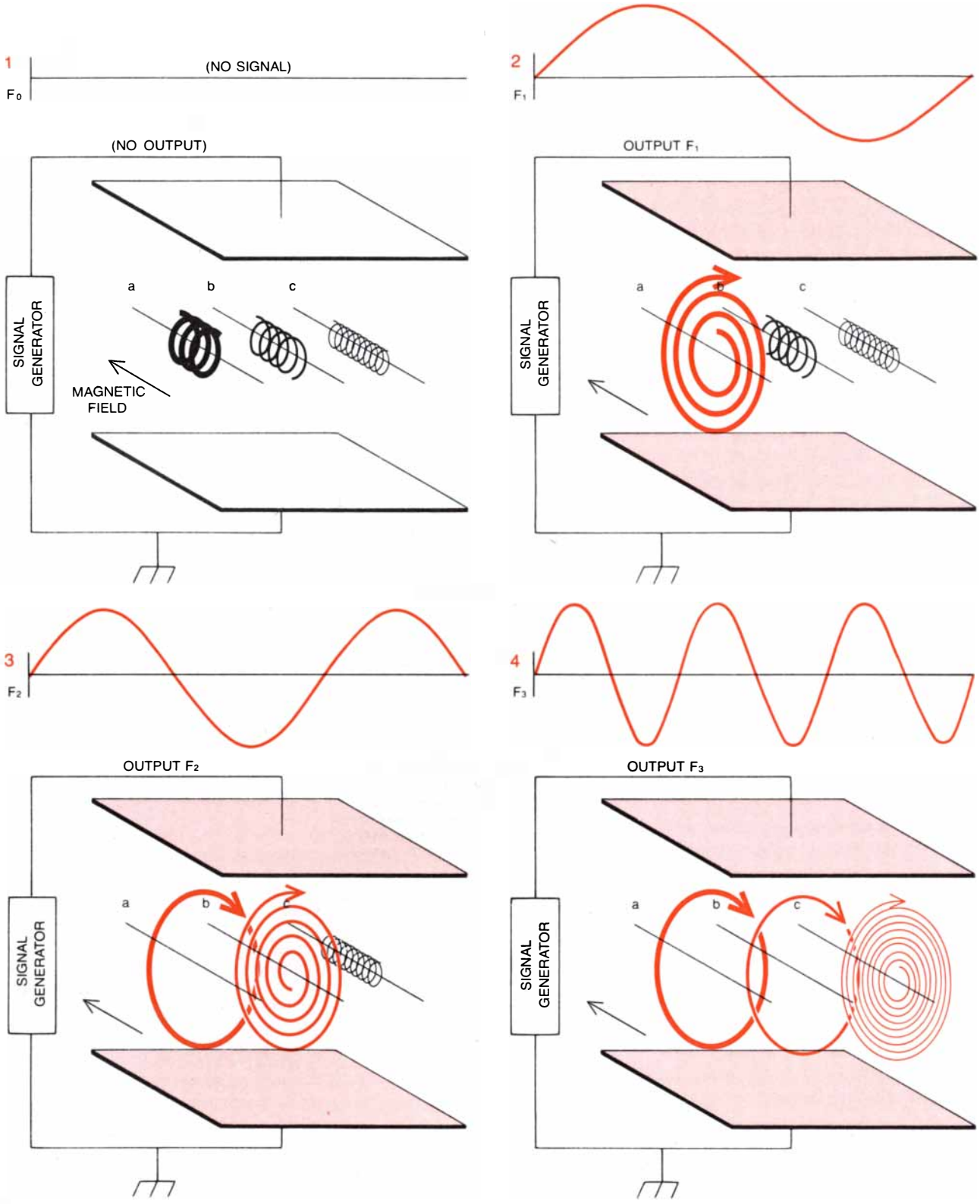
Studying the reactions of isolated ions and molecules in the absence of solvation is a difficult experimental problem. The reactant species must be created in a low-pressure gas, the motions of the reactants must be made to avoid collisions with a solid surface and a sensitive method must be devised to detect the products of the reaction. Let us see how each of these problems can be overcome.

Ions are atoms or molecules with an excess or deficiency of electrons. For example, a hydrogen atom has one electron. The removal of that electron leaves a bare proton ($H^+$); the addition of an electron yields an ion with one proton and two electrons ($H^-$). A fluorine atom (F) has nine protons and nine electrons; a fluoride ion ($F^-$) has nine protons and 10 electrons. Many important types of reactions in solution involve ions either directly or indirectly as intermediates in the reaction. Generally such reactions are sensitive to the nature of the solvent medium because the electric charge of the ion causes it to interact strongly with solvent molecules.

In solution reactant ions can be created simply by adding certain substances to the solvent. For example, when sodium chloride (NaCl), common table salt, is poured into water, it dissolves to form sodium ions ($Na^+$) and chloride ions ($Cl^-$). And when hydrogen chloride gas (HCl) is bubbled through water, it is readily absorbed to form a solution of hydrochloric acid. In water most of the hydrogen chloride molecules are broken apart to form ions: $HCl + H_2O \rightarrow H_3O^+ + Cl^-$. The species $H_3O^+$, the hydronium ion, is a simplification of the actual structure that exists in solution. In reality the proton is extensively solvated, or linked to a cluster of water molecules, by a network of hydrogen bonds, in which hydrogen atoms form bridges between oxygen atoms.

In the absence of solvation unusual means must be exploited to create ions. Ions are produced in hot gases, such as flames, but at room temperature ionization does not occur to a significant degree. In order to dissociate gaseous hydrogen chloride molecules into the ions $H^+$ and $Cl^-$ energy in the amount of 333 kilocalories per mole must be provided. (A mole of a substance is equal to its molecular weight in grams; a mole of hydrogen chloride is 36.5 grams.) The energy of ionization considerably exceeds the 103 kilocalories per mole needed to break hydrogen chloride into atoms. One can see that the electrical attraction between positive and negative charges must exert a strong force between $H^+$ and $Cl^-$ in the gas phase. The attraction is greatly attenuated in solution because the solvent molecules intervene between the ions and shield them from one another.

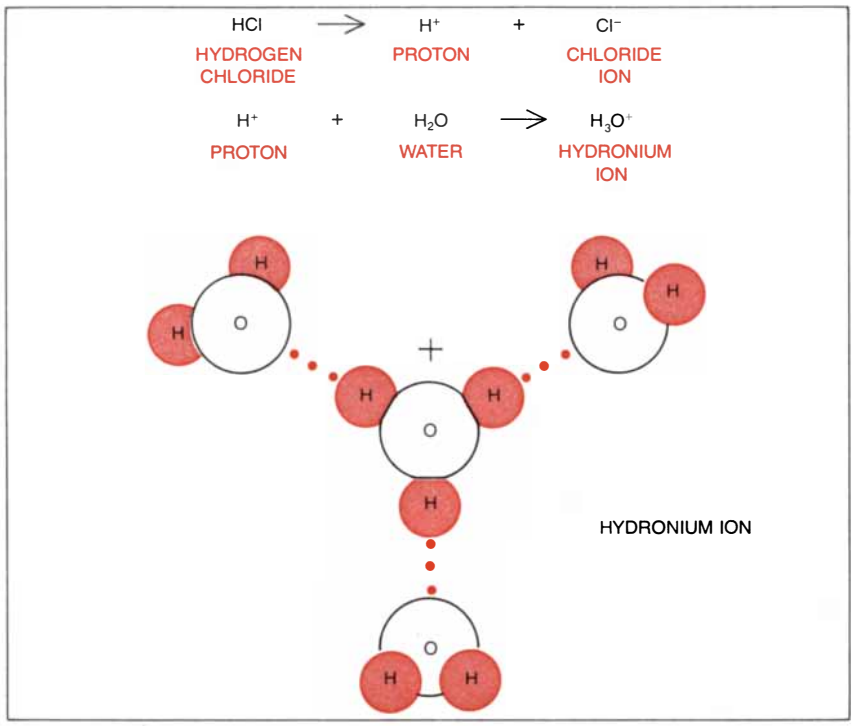
For isolated ions to be created in the gas phase, energy must be supplied by some means other than solvation. The most widely used method is ionization



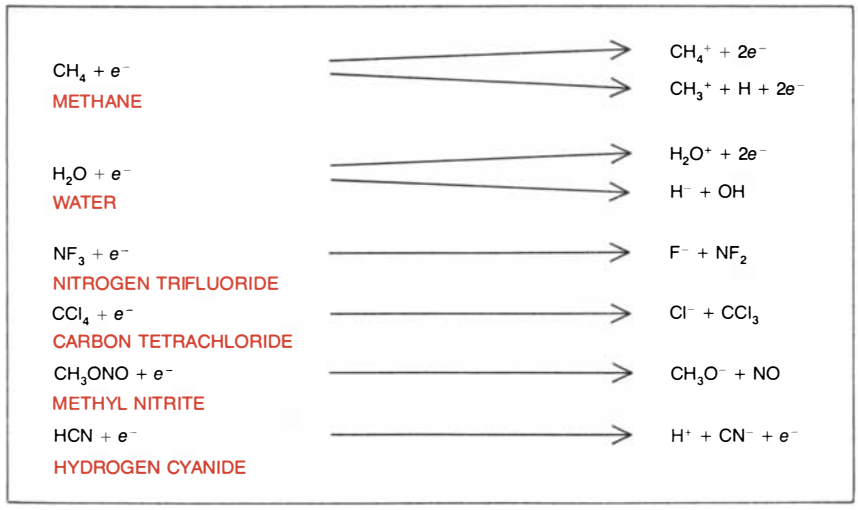

**ION-CYCLOTRON-RESONANCE SPECTROMETER** provides the means for identifying the products of reactions between ions brought together in the gas phase in the absence of solvents. The reactions give rise to new ions whose mass-to-charge ratio can be established as follows: A charged particle in a magnetic field travels in an orbit with a frequency of revolution fixed by the field strength and the particle's mass and charge. If the particle is subjected to an oscillating electric field whose frequency matches the particle's frequency of revolution, the particle will absorb energy through the process called cyclotron resonance and will move to a larger orbit while maintaining the same frequency of revolution. This four-part diagram shows how the orbits of three particles with different mass-to-charge ratios can be selectively expanded by cyclotron resonance. The three particles *a*, *b* and *c* are assumed to have ratios of mass to charge that are in the ratio of three to two to one. Therefore the cyclotron frequency of *a* is a third that of *c*, and the frequency of *b* is one-half that of *c* (*1*). If a sine-wave signal with a frequency equal to the cyclotron frequency of particle *a* is turned on, particle *a*'s orbit will expand steadily, and *b* and *c* will remain essentially unaffected (*2*). If the frequency of the signal is raised to match the cyclotron frequency of particle *b*, *b*'s orbit will expand without affecting *a* or *c* (*3*). Finally *c*'s orbit can be expanded by selecting a signal of still higher frequency (*4*).

by electron impact. Electrons emitted from a heated filament are accelerated by an electric field and made to collide with gas molecules. Ionization results if the impact energy of the electrons is greater than a threshold value called the ionization potential. As the impact energy is raised above the threshold the yield of ions generally increases. With this method a wide variety of positive and negative ions can be made.

Ions in solution are stabilized and kept from wandering off by the molecules of surrounding solvent. In the gas phase the situation is quite different. Since the ions are produced by the impact of electrons, they move rapidly in all directions through the gas at speeds as high as 500 meters per second. Gaseous ions are destroyed when they strike a solid surface. Their charge is lost to the solid, and they usually react with molecules adsorbed on the surface. It is apparent, therefore, that a special container must be used to restrict the motion of the ions and to hold them long enough in the gas phase so that their chemical behavior can be observed.




**HYDRONIUM IONS form in water solution when acids such as hydrogen chloride (HCl) dissolve and ionize. The ionization of hydrogen chloride yields a proton, or hydrogen ion ($H^+$), and a chloride ion ($Cl^-$). The released protons combine strongly with the water molecules to form hydronium ions, written as $H_3O^+$. In reality the hydronium ion is a complex structure consisting of many water molecules around a proton. The structure is held together by hydrogen bonds (*colored dots*), in which a hydrogen atom is a bridge between two oxygen atoms.**




**IONIZATION BY THE IMPACT OF ELECTRONS is an efficient way to create ions in the gas phase. Ions with either a positive or a negative charge can be made by adjusting the energy of the impacting electrons. For example, if a water molecule is struck by an electron carrying 6.5 volts of energy, the electron remains attached to the hydrogen atom when the molecule dissociates to form $H^-$ and OH. When the energy is higher than 13 volts, the water molecule is stripped of an electron, forming the ion $H_2O^+$. Ions so formed are free particles in gas phase.**

Several methods have been devised for storing gaseous ions. The one my colleagues and I have found most useful is the static magnetic ion trap. This device combines a strong, uniform magnetic field and a weak electric field to restrict the motions of ions in three directions. The magnetic field causes the ions to move in small circular orbits and thereby restrains their motion perpendicular to the magnetic field. Motion parallel to the magnetic field is restrained by a weak electric field that is generated by voltages applied to plates at opposite ends of the trap. A positive voltage on opposite plates repels and thereby traps positive ions. A negative voltage traps negative ions. The trap is so efficient that ions can be stored for several minutes. The pressure within the trap is kept lower than a billionth of an atmosphere to eliminate contaminants that might interact with the ions. When the ions are first produced by the electron impact, they acquire some excess vibrational and translational energy, but within a few tenths of a second they cool to room temperature through repeated collisions with the few remaining unionized gas molecules. Even at room temperature, however, the ions and molecules travel at the speed of sound, about 320 meters per second.

Since our objective was to study the chemical reactions of ions in the absence of solvents, we had to devise methods for identifying both the reacting species and the products that are formed. The method had to be extremely sensitive: only about a million reactant ions enter into each experiment. A useful instrument for detecting ions in such small quantities is the mass spectrometer. In this instrument the ions are projected into a magnetic field and follow arcs of different radii according to their ratio of mass to charge. By adjusting the strength of the magnetic field one can focus ions of different mass-to-charge ratios on a detector and selectively "weigh" them.

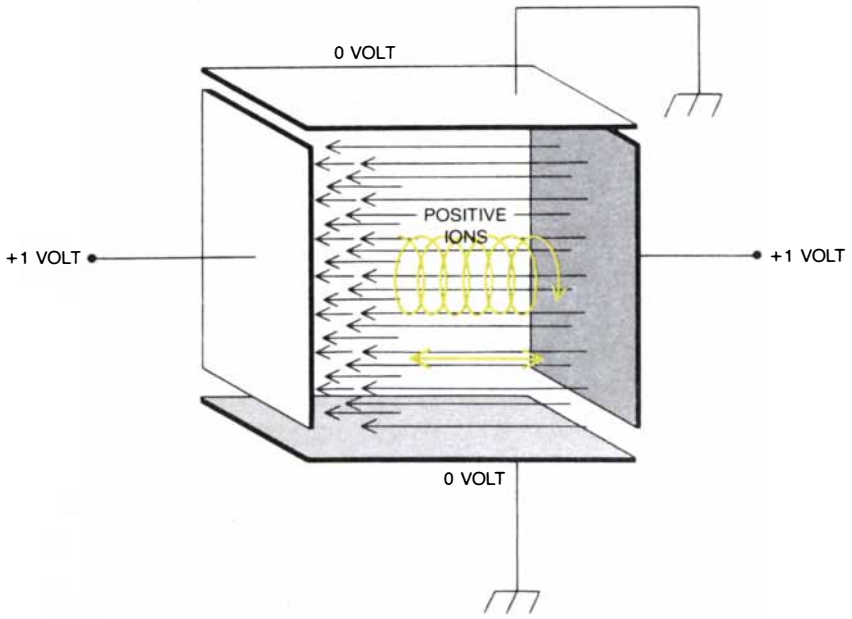
In our laboratory at the University of California at Irvine we have adopted a form of mass spectrometry in which the orbital radii of ions trapped in a magnetic field are selectively amplified by a radio-frequency electric field. The method

is called ion cyclotron resonance (ICR). It is a rather recent addition to the instrumental techniques used by chemists, but as with most new techniques the basic idea goes back many years. The concept of cyclotron resonance was exploited by Ernest O. Lawrence in the early 1930's in building his first machines for accelerating protons and other particles. Lawrence recognized that the equations of motion for a charged particle in a uniform magnetic field predict a constant period of revolution. He saw, furthermore, that particles can be accelerated to speeds approaching the velocity of light by subjecting them to an electric field that oscillates in resonance with the particle's orbital period.

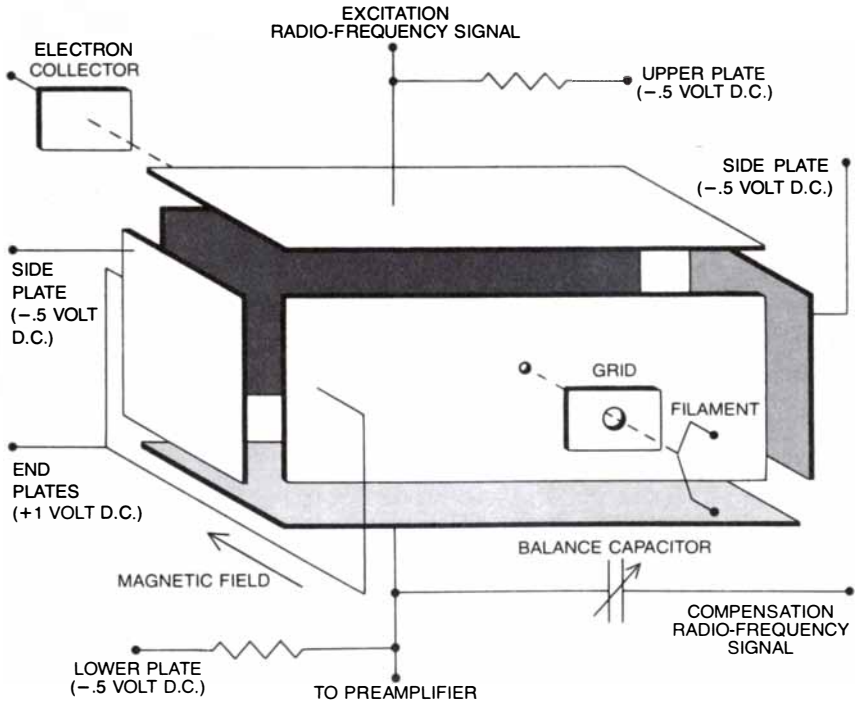
In ICR mass spectrometry the emphasis is on selectivity rather than on particle acceleration for its own sake. At the outset ions of various masses and charges are held in circular orbits by a uniform magnetic field of suitable strength. The orbital frequency of each species is a product of the ion's electric charge and the magnetic field's strength divided by the ion's mass. As an example, at a magnetic field strength of one tesla ($10^4$ gauss), which is readily obtainable with a laboratory electromagnet, an ion with a mass-to-charge ratio of 10 makes 1,530,000 revolutions per second. An ion with a mass-to-charge ratio of 100 makes 10 times fewer revolutions per second: 153,000.

Ions with differing mass-to-charge ratios are identified by changing the frequency of the alternating electric field to which they are exposed. When the frequency of the signal generator is not equal to the cyclotron frequency of an ion, there is very little interaction between the two, and the ion's energy and orbit remain essentially unchanged. When the signal frequency and the ion's cyclotron frequency are identical, however, resonance occurs, and the ion is steadily accelerated to an orbit of larger and larger radius. In this way ions of a given mass-to-charge ratio can be accelerated selectively and thereby separated from all others.

In 1970, while working as a graduate student with J. D. Baldeschwieler at Stanford University, I demonstrated that the cyclotron-resonance principle could be applied to identify ions stored in a static magnetic ion trap. The technique is now called pulsed ICR mass spectrometry. Ions are formed by passing a short pulse of an electron beam through a low-pressure gas and are stored in a trapped-ion analyzer cell. After a short time delay, measured in seconds, ionic reaction products are detected by accelerating them at their cyclotron frequency with an alternating electric field. Finally all the ions are swept out of the analyzer cell by a quench pulse. The pulse sequence is re-




**CONFINEMENT OF IONS in the gas phase can be accomplished with a static magnetic ion trap, which is able to preserve ions for several minutes. A strong uniform magnetic field forces the ions to travel in small circular or helical orbits and thereby restrains their motion in a direction perpendicular to the magnetic field. Motion parallel to the magnetic field is restrained by a weak electric field that is generated by voltages applied to the end plates of the trap. The sign of the voltage is chosen to be the same as the sign of the charge on the ions one seeks to confine. Electrical repulsion then forces the ions to oscillate back and forth without touching the end plates. The pressure in the magnetic ion trap is held at less than a billionth of an atmosphere.**




**TRAPPED-ION ANALYZER CELL provides the three functions necessary for measuring the reactivity of bare ions in the gas phase. The initial supply of gaseous ions is produced by bombarding selected atoms or molecules with electrons, which are emitted from a heated filament. The ions are promptly trapped by a combination of electric and magnetic fields (the magnetic ion trap). After the reaction between ions has progressed for a predetermined brief period (usually less than a second) an oscillating radio-frequency signal accelerates the trapped ions selectively by cyclotron resonance. Initially a compensation radio-frequency signal balances the radio-frequency signal applied to the upper plate and creates a null at the input of the preamplifier. When energy is being absorbed by ions undergoing cyclotron resonance at a particular frequency, the coherent motion of the ions unbalances the signal entering the preamplifier.**

peated with various time delays to discover how rapidly product ions of different species are formed. The pulsed ICR technique has been adopted by many laboratories around the world. Let us now turn to some of the findings.

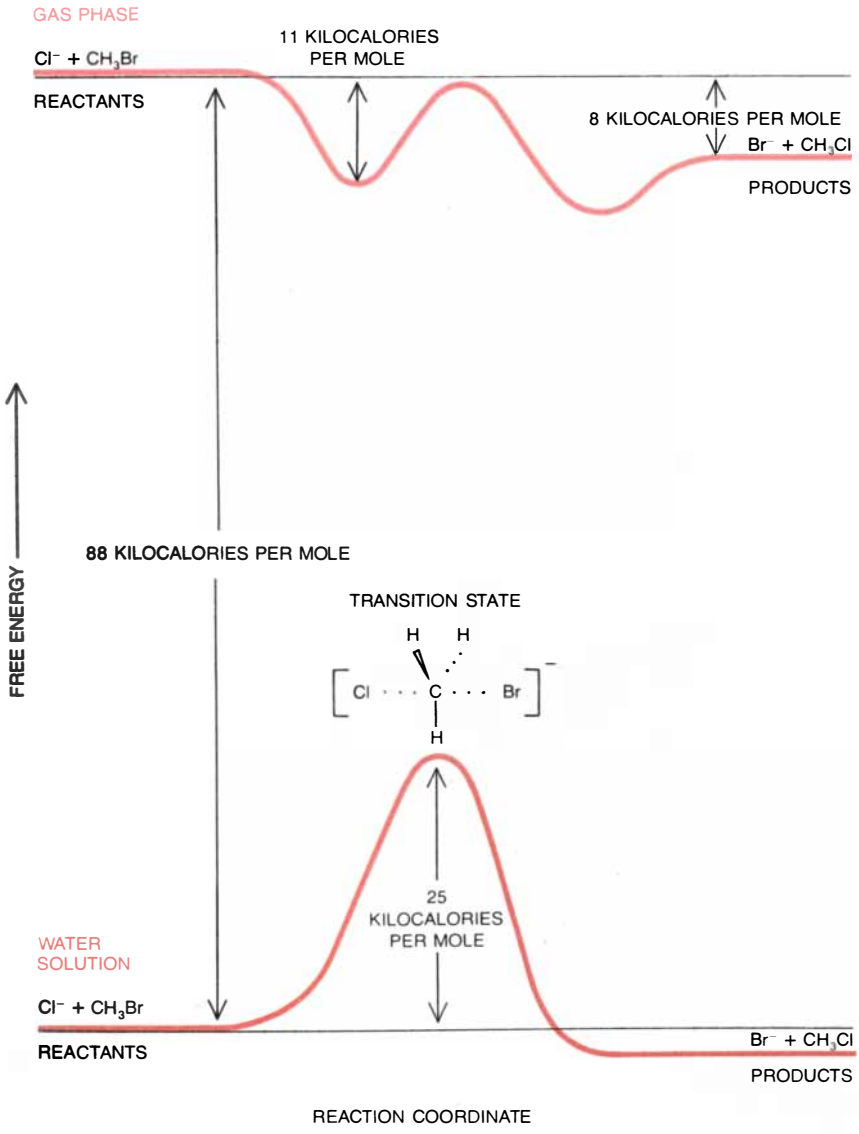
One of the classic reactions of chemistry is the displacement of one atom or small group of atoms in a molecule by another. A simple example is the reaction $Cl^- + CH_3Br \rightarrow Br^- + CH_3Cl$, in which a chloride ion ($Cl^-$) replaces bromine (Br) in methyl bromide ($CH_3Br$), yielding methyl chloride ($CH_3Cl$) and a bromide ion ($Br^-$). Detailed mechanisms for substitution reactions such as this one have been elucidated; they are among the best-understood of all classes of reactions in organic chemistry.

It has long been recognized that such reactions are highly sensitive to the nature of the solvent medium. With water as the solvent the reaction between the chloride ion and methyl bromide is so slow that several days are needed for it to proceed to completion. By simply changing the solvent to acetone the reaction rate is increased by a factor of a million; the reaction now occurs in just a few tenths of a second.

The nature of the solvent can also change relative orders of reactivity. For example, in water a large ion such as the iodide ion ($I^-$) undergoes substitution reactions much faster than does a small ion such as the fluoride ion ($F^-$). Generally the halogen family of ions increases in reactivity in the following order: fluoride, chloride, bromide and iodide. When acetone is the solvent, however, the order of reactivity is exactly reversed.

At first one is at a loss to explain such dramatic responses to solvents. The equations for substitution reactions, as they are ordinarily written, offer no clue to the origin of the solvent effects. Indeed, the equations are downright misleading: they fail to acknowledge that the solvent plays any role at all in the reaction. One is led to question just what would happen if the solvent were totally removed. Would the substitution reaction take place at all?

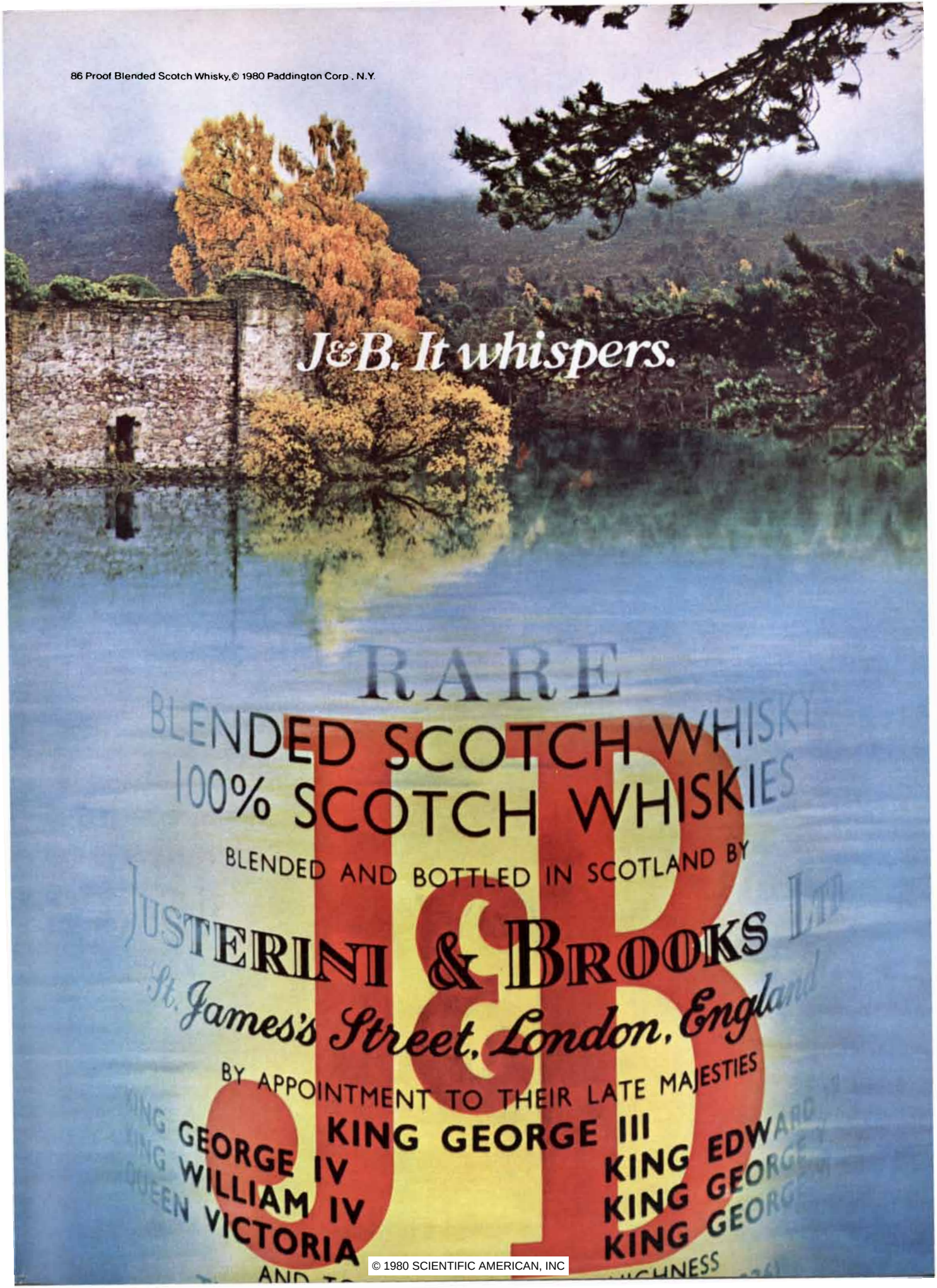
The question can be answered by the technique of pulsed ICR mass spectrometry. Chloride ions in the gas phase, completely isolated from solvent molecules, can be created by directing a beam of low-energy electrons at carbon tetrachloride ($CCl_4$) in the vapor phase. The bombardment yields chloride ions and carbon trichloride radicals ($CCl_3$). While the chloride ions are stored in a trapped-ion analyzer cell enough gaseous methyl bromide is added to the cell to raise the pressure to about a ten-millionth of an atmosphere. The result is truly remarkable: even such a minute amount of methyl bromide is sufficient to take the substitution reaction to completion in less than a tenth of a second. In the gas phase the reaction of chloride ion with methyl bromide turns out to be three billion ($3 \times 10^9$) times faster than it is in acetone and a million billion ($10^{15}$) times faster than it is in water.




**POTENTIAL-ENERGY DIAGRAM traces how the energy in a chemical reaction changes as the reactants are converted into products. The two curves describe the substitution reaction in which a chloride ion ($Cl^-$) changes places with a bromide ion ($Br^-$) in methyl bromide. The top curve shows the change in potential energy when the reaction proceeds in the gas phase in the absence of a solvent. The bottom curve describes the same reaction in water solution. When the reaction is transferred from the gas phase to a water solution, the potential energy in the reactants drops markedly. Most of the energy released (81 out of the 88 kilocalories per mole) reflects the formation of a "cage," or shell, of water molecules around the chloride ion. For the reaction to proceed the shells must be at least partially broken so that chloride ion and methyl bromide can come into contact. Disruption of the cages takes about 25 kilocalories per mole.**

Additional experiments in the gas phase and in solution have supplied an explanation for these enormous differences in reaction rates. The explanation is best understood with the help of a potential-energy diagram [*see illustration at left*]. A wavy line at the top of such a diagram shows how the potential energy of the reactants changes in the gas phase as an isolated chloride ion approaches a molecule of methyl bromide. Initially the potential energy decreases as the two particles approach each other. The decrease is due to the long-range electrical forces of attraction between the ion and the neutral molecule. In response to the attractive force the particles move faster and faster toward each other until they collide.

At the moment of collision the complex consisting of the chloride ion and the methyl bromide molecule has an internal energy of about 11 kilocalories per mole and is stabler than the separated particles. In order for the substitution of chloride for bromide to take place the



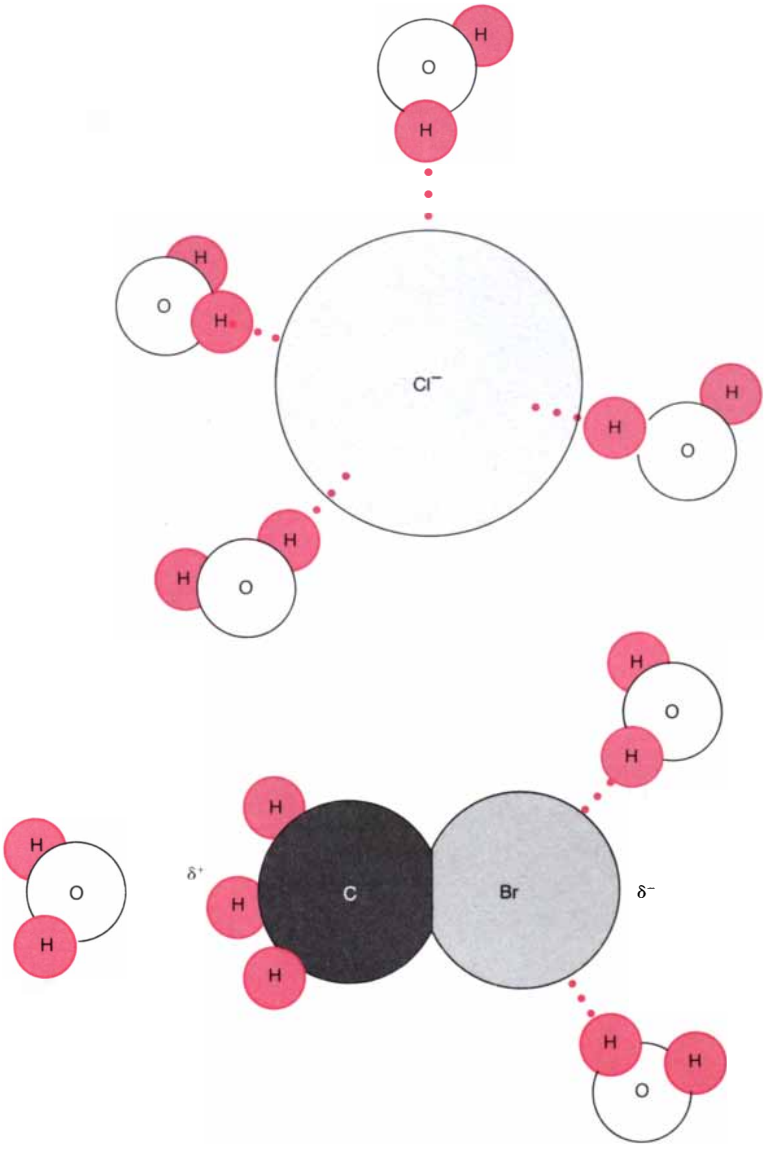
reactants must pass over a potential-energy barrier that is nearly as high as the binding energy of the complex. About 1 percent of the complexes surmount the barrier to yield the reaction products $Br^-$ and $CH_3Cl$; 99 percent of the complexes break apart, regenerating the reactants. As a result the observed rate for the substitution reaction in the gas phase is about 1 percent of the rate of random collisions between the chloride ion and the methyl bromide molecule.

When the substitution reaction takes place in water solution, the potential-energy curve looks quite different. In the first place the curve lies at a much lower level, because when chloride ion and methyl bromide are transferred from the gas phase to water solution, about 88 kilocalories per mole of energy are released. Most of the total, 81 kilocalories per mole, goes into stabilizing the chloride ion with solvent molecules. Water is a particularly good solvent medium for ions. It has a large dielectric constant (meaning that it is a good insulator), a large dipole moment (meaning that the positive and negative electric charges in the molecule are widely separated) and the ability to form hydrogen bonds.

Once dissolved in water both the ion and the neutral reactant molecule are tightly surrounded by a "cage," or shell, of water molecules that greatly attenuate the electric forces of attraction that induce collisions in the gas phase. Before the chloride ion and the methyl bromide can come into contact the solvation shells around the two reactants must be at least partially disrupted. The reaction rate, therefore, is determined primarily by the amount of energy needed to rupture the solvation shells. The resistance to breakage corresponds to a potential-energy barrier of about 25 kilocalories per mole. This is sufficient to make the reaction rate in water solution 15 orders of magnitude lower than the rate in the gas phase.

Another way of understanding the low reaction rate in water is to compare the solvation energies of the reactants and of the transition state: the complex consisting of chloride ion and methyl bromide: $(Cl \cdot\cdot CH_3 \cdot\cdot Br)^-$. The transition state is the highest point on the potential-energy curve that separates reactants and products. The transition state has some 25 kilocalories per mole more internal energy than the reactants have and thus constitutes a high potential-energy barrier between the reactants and the products. The barrier arises because the reactants are more strongly stabilized by solvation than the transition state is. Generally speaking ions such as the chloride ion, which are small and have a localized charge, are more strongly stabilized by water than are larger structures such as $(Cl \cdot\cdot CH_3 \cdot\cdot Br)^-$, in which the charge is spread over several atoms.

Reaction rates in solvents other than water can be similarly explained by differences in solvation between reactants and the transition state. The reaction of chloride ion with methyl bromide proceeds much faster in acetone than it does in water because the reactants are not as strongly solvated in acetone. Acetone is termed a dipolar aprotic solvent because it is incapable of forming hydrogen bonds yet has a dipole moment large enough to stabilize ions in solution. Strongly bound solvation shells cannot form around ions dissolved in acetone, and so reactions in acetone tend to resemble reactions in the gas phase.




**SOLVATION SHELLS develop around ions and neutral molecules in water. The solvent molecules tend to insulate the reactants and make it difficult for them to come in contact. These schematic drawings show the shells around a chloride ion (*top*) and a molecule of methyl bromide (*bottom*). The chloride ion, which is small and has a localized negative charge, is more strongly stabilized by solvation than methyl bromide, which exhibits only a partial positive charge ($\delta^+$) near the methyl group and only a partial negative charge ($\delta^-$) near the bromine atom. Shells are dynamic structures where water molecules are continuously coming and going.**

The concept of acids and bases is one of the oldest and most useful in chemistry. The present definition of acids and bases dates from 1923, when Johannes N. Brönsted and Thomas M. Lowry described an acid as any substance that gives up a proton and a base as any substance that accepts a proton. Proton-transfer reactions are particularly important in water because water can function either as an acid or a base. In reactions with a strong acid such as hydrogen chloride, water can accept a proton and yield a hydronium ion, $H_3O^+$, while releasing a chloride ion, $Cl^-$. On the other hand, in reactions with a base such as ammonia ($NH_3$) water can do-

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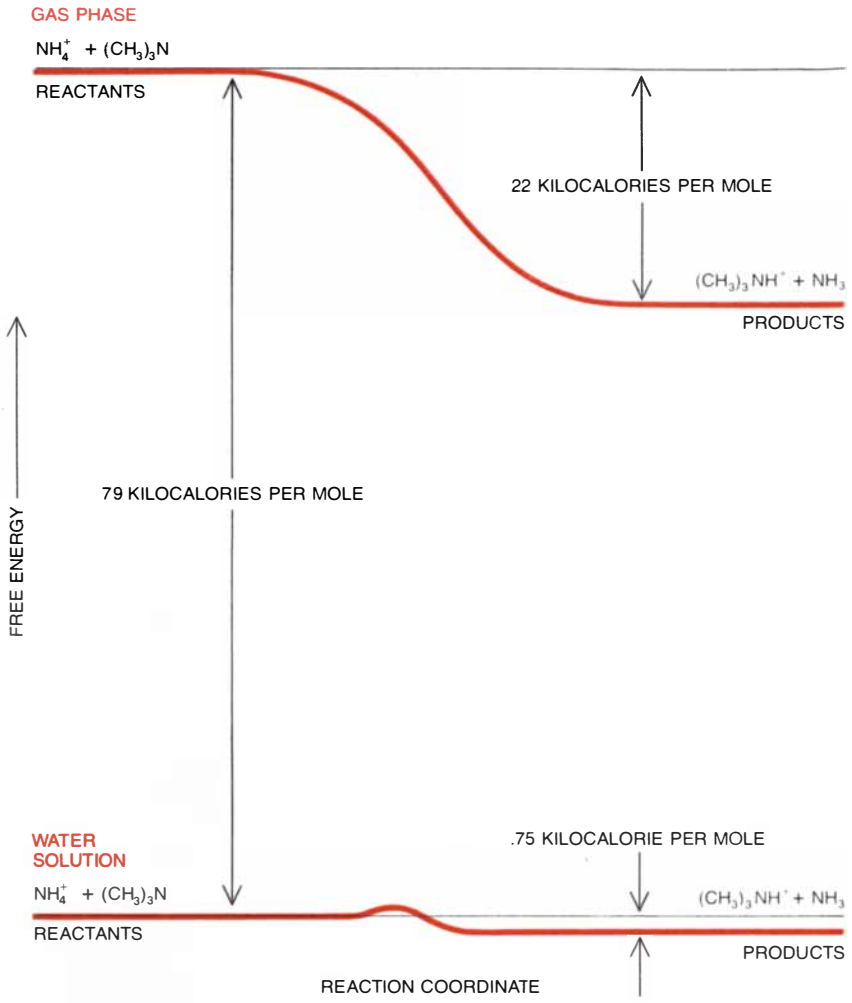
nate a proton to form the ammonium ion, $NH_4^+$, leaving behind a hydroxide ion, $OH^-$. Extensive tables showing the relative acidity and basicity of hundreds of compounds have been developed. With such tables one can predict the products of a proton-transfer reaction and calculate how much energy should be released.

Most acid-base reactions involve ions. Since ions interact strongly with a solvent medium, one would like to know how acid-base reactions are affected by solvation. In particular, are the acid-base properties of unsolvated molecules any different from the properties exhibited by molecules in solution?

Rapid progress has recently been made in understanding how solvation affects acidity and basicity. The progress is due primarily to pulsed ICR mass spectrometry and other techniques that are able to measure equilibrium constants for proton-transfer reactions in the gas phase. Consider a reaction in which the ammonium ion, $NH_4^+$, an acid, transfers a proton to trimethylamine, $(CH_3)_3N$, a base. In water the reaction rapidly yields the trimethylammonium ion, $(CH_3)_3NH^+$, and ammonia, but the reverse reaction also proceeds at a significant rate because the energy barrier inhibiting reversal is quite low. Equilibrium is established when the rate of the reverse reaction equals the rate of the forward reaction. Measurement of the equilibrium constant, which is the ratio of products to reactants at equilibrium, shows that trimethylamine is a slightly stronger base than ammonia in water solution. A plausible conclusion is that the substitution of three methyl groups ($-CH_3$) for three hydrogens in ammonia causes only a small increase in basicity.




**RELATIVE ACIDITY AND BASICITY of atoms and molecules are strongly affected by the presence or the absence of solvents. Acids are broadly defined as substances that give up protons in the course of a reaction; bases are proton acceptors. The two curves show the reaction in which the ammonium ion, $NH_4^+$, an acid, transfers a proton to trimethylamine, $(CH_3)_3N$, a base. In the gas phase (*top*) the products $(CH_3)_3NH^+$ and $NH_3$ are stabler than the reactants by 22 kilocalories per mole. When the reaction proceeds in water solution (*bottom*), the energy difference between reactants and products falls to less than one kilocalorie per mole because of preferential solvation of the $NH_4^+$ ion by hydrogen bonding. At equilibrium in the gas phase the concentration of $NH_4^+$ is $10^{15}$ times lower than it is at equilibrium in a water solution.**

A few years ago the relative basicity of ammonia and trimethylamine was measured in the gas phase, in the absence of solvation, with the pulsed ICR technique. The results are strikingly different from those in water solution. In water the products of the reaction are less than one kilocalorie per mole stabler than the reactants; in the gas phase the products are stabler by 22 kilocalories [*see illustration on this page*]. This means that at equilibrium in the gas phase the concentration of ammonium ion, $NH_4^+$, is lower by a factor of $10^{15}$ than it is under comparable conditions in water solution.

To explain such enormous solvation effects let me first discuss the gas-phase results and then point out how they are modified when the reaction is transferred to water solution. The first question, therefore, is why trimethylamine is such a strong base in the gas phase. Several investigators have shown that substitution of methyl groups for hydrogen has little effect on the stability of the neutral amine molecules but greatly increases the stability of their ionic derivatives. Methyl groups stabilize the trimethylammonium ion, $(CH_3)_3NH^+$, in two ways. First, there is an "inductive" effect, which tends to release electrons and shift the electron density in the chemical bonds toward the positively charged nitrogen atom. Second, the methyl groups, being much larger than the hydrogen atoms they replace, are polarized by the positive charge. The electric field of the positive charge permeates the space around the molecule and distorts the electron clouds of the methyl groups. Both the inductive effect and the polarizability effect make $(CH_3)_3NH^+$ a far stabler ion than the ion $NH_4^+$, in which the two effects are absent. As a result trimethylamine has a much higher affinity for a proton than ammonia does.

Now consider what happens to the same reaction in the presence of water. Evidently something intervenes to greatly weaken the intrinsic stabilizing action of the still-present methyl groups. Thermodynamic analysis shows that the un-ionized molecules, ammonia and trimethylamine, are solvated about equally well in water. The major changes in the reaction are therefore due to the solvation of the ions: $NH_4^+$ is solvated much more strongly than is $(CH_3)_3NH^+$. There are evidently several reasons for it.

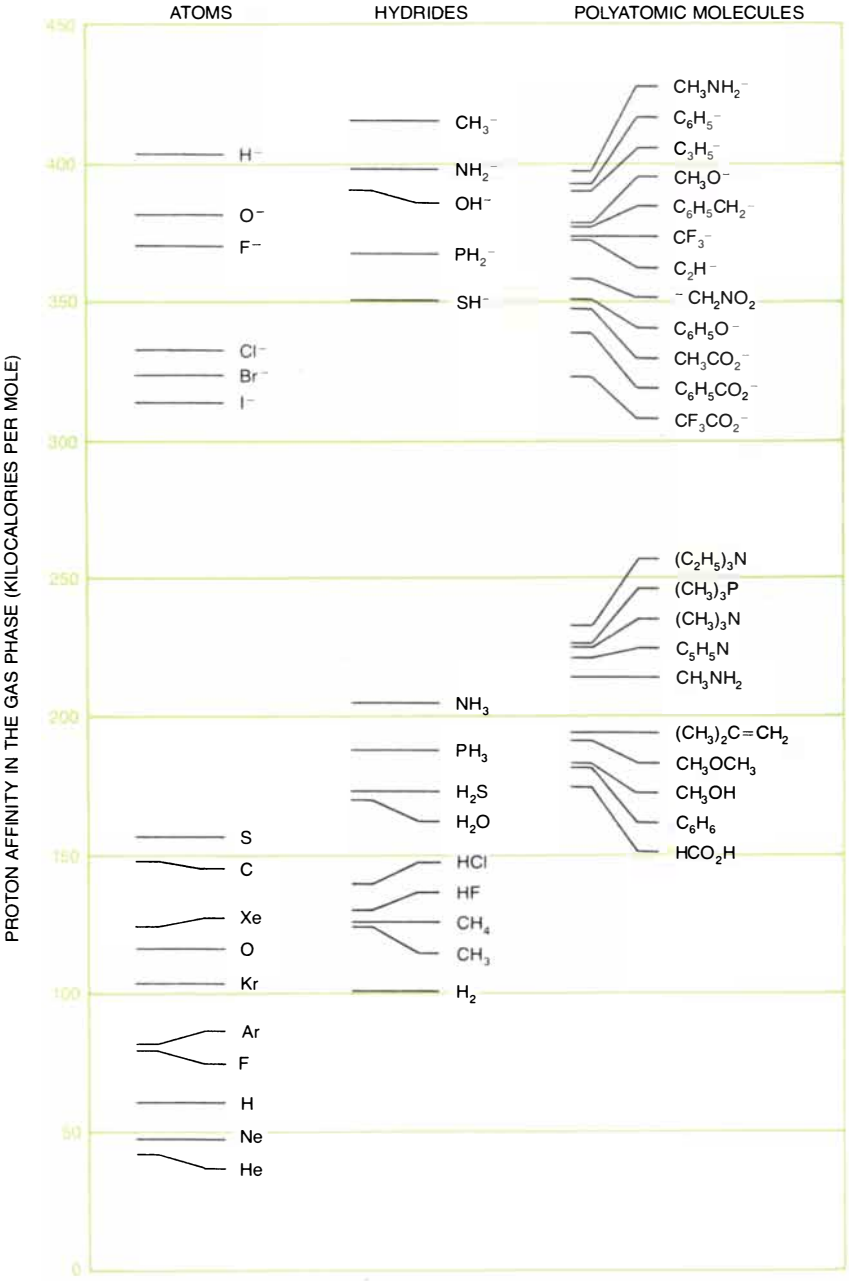
Probably the most important reason is that $NH_4^+$ can be stabilized by the formation of four primary hydrogen bonds to surrounding water molecules, whereas $(CH_3)_3NH^+$ has only one acidic hy-

drogen and can form only one hydrogen bond. Hydrogen bonds are very important for stabilizing ions in a solvent such as water, and hydrogen bonds of this type can contribute from five to 10 kilocalories of stabilization per mole. When solvent molecules are clustered around an ion, the polarizability effect of the methyl group is much attenuated because the electric charge is spread over several solvent molecules. Part of the difference in the solvation energies of ions can also be attributed to differences in ion size. For example, the large size of the methyl groups in $(CH_3)_3NH^+$ excludes solvent molecules, making it more difficult for them to get close enough to solvate the ion.

Over the past six years the acidity and basicity of more than 300 compounds have been measured in the gas phase. The results can be presented in a "proton affinity" table that shows the energy released when a proton ($H^+$) combines with a base (B) to yield a positively charged ion ($BH^+$). If B happens to be a neutral base such as ammonia, the reaction yields the ammonium ion, $NH_4^+$, and releases 205 kilocalories per mole of energy. If B happens to be a negative ion such as the chloride ion, $Cl^-$, the reaction yields neutral hydrogen chloride, HCl, and 333 kilocalories of energy per mole.

The gas-phase experiments provide many examples in which the proton affinities depart significantly from those measured in solution. For example, in the gas phase the hydroxide ion, $OH^-$, is a stronger base than the benzyl ion, $C_6H_5CH_2^-$. This means that in a reaction where the two species compete for a proton, the proton will be grabbed by the hydroxide ion, converting it into water. As a result in the gas phase the reaction $OH^-$ plus toluene ($C_6H_5CH_3$) proceeds rapidly, with the release of energy, to yield $C_6H_5CH_2^-$ and $H_2O$. In a water solution the reaction goes in the opposite direction: a proton is transferred from water to the benzyl ion, converting it into toluene.

The role of solvents in chemistry, long a hazy area, is being clarified with gas-phase experiments of the type I have been describing. One can now measure quantitatively the differences in reactivity between molecules that are solvated and the intrinsic reactivity of unsolvated molecules. Experimental techniques such as pulsed ICR are being steadily improved to encompass a broader range of reactions. One noteworthy development is the ability to generate in the gas phase partially solvated ions such as $Cl^-\cdot(H_2O)_2$, a chloride ion bonded to two water molecules. By clustering a few solvent molecules around an ion the gas-phase experiments may simulate the solvent-cage effects that are so important in solution. Another useful development is the extension of the pulsed ICR technique to deal with the reactions of biological molecules of low volatility. In our laboratory we have recently measured the gas-phase acidity and basicity of the simplest amino acid, glycine ($NH_2$–$CH_2$–COOH). In water solution glycine forms what is called a zwitterion, or hybrid ion, in that it carries a positive charge at one end and a negative charge at the other: $NH_3^+$–$CH_2$–$COO^-$. In contrast, we find that in the gas phase glycine exists as a nonionic molecule. Enormous solvation effects have been found in the acid-base properties of other amino acids. The clarification of such properties should contribute much to understanding the behavior of amino acids in living organisms. For example, it will be possible to speak in quantitative terms about how the properties of an amino acid change as it is transported from a water environment in one part of the cell to a water-repelling environment in an enzyme molecule or a cell membrane.




**PROTON-AFFINITY SCALE shows the amount of energy released when a proton combines in the gas phase with the particular atomic or molecular species listed. For example, when $H^-$, at the upper end of the scale, combines with a proton to yield $H_2$, about 400 kilocalories per mole of energy are released. When helium, He, combines with a proton to yield $HeH^+$, only about 43 kilocalories per mole are released. The scale also indicates the relative basicity of polyatomic molecules in the gas phase. The strongest bases are at the top of the scale because they have the highest affinity for a proton. The weakest bases are at the bottom of the scale.**

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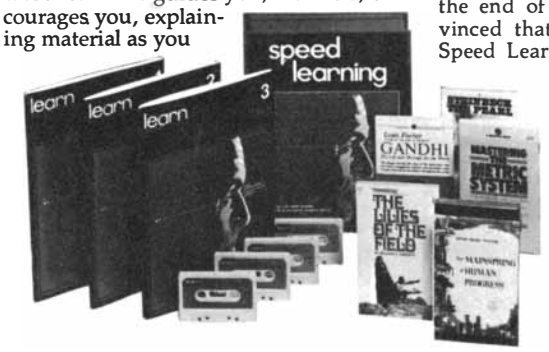


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# THE AMATEUR SCIENTIST

## *More about random-dot displays, plus computer programs to generate them*

by Jearl Walker

My discussion of random-dot displays in April elicited many comments from people who had devised variations on the experiments. Here I shall describe several of the new experiments. And for the amateur who owns or has access to a home computer I shall present a program for generating random-dot displays.

In my April article I described random-dot displays in which circles, spirals and other nonrandom forms could be perceived. The first step in generating a display was to sprinkle paint on a sheet of paper. A transparent copy of the resulting pattern was made and laid over the original. If the two displays had the same scale and were aligned carefully, the experimenter saw nothing unusual. If one of the displays was rotated around a point, however, concentric circles appeared (formed by pairs of correlated dots). In some trials the transparency had a scale different from that of the original; rotating it over the original then gave rise to spirals. A variety of nonrandom forms could be created by choosing different scales and angles of rotation.

I had characterized the circles and spirals as illusions. Several readers corrected me by pointing out that the forms are not illusory but real (as a result of juxtapositions of the two displays). A better term for what is seen is therefore perception.

Some of the most extensive investigations of such perceptions have been conducted by Leon Glass of McGill University. He prefers to call the effects random-dot moiré patterns. In one variation of the basic setup he lays a random-dot pattern over its own negative. The original consists of black dots on a white or transparent background, the negative of white dots on a background of halftone gray. When Glass rotates the top sheet, petal-like patterns (rather than circles) appear. Apparently circles are generated only when the contrast between the dots and the background is similar; arrays with dissimilar contrast yield the petals.

In another experiment Glass generates a random-dot display by splattering black paint on white paper and making a negative image of the result; he then has the original printed in yellow and the negative in blue by a photographic silk-screen process. When these prints are superposed and rotated, circles appear. Glass then repeats the experiment but reverses the colors. This time superposition and rotation yield petals.

Several people have written to me about applications of the moiré patterns. One of the most interesting letters came from Edward B. Seldin of the Harvard School of Dental Medicine and the Massachusetts General Hospital. In oral and maxillofacial surgery Seldin must correct certain types of deformity by moving parts of the facial skeleton. He traces the anatomy of a patient from X-ray photographs and then studies the possibilities for change. In many cases he seeks the one axis around which part of the facial skeleton can be rotated to accomplish the change.

To determine that axis Seldin has devised a new technique based on random-dot moiré patterns. He traces the fixed skeletal parts on a background array of random dots. On a transparent sheet having the same array of dots he traces just the movable skeletal parts. When the transparent sheet is carefully lined up with the other drawing, the random dots are aligned. Seldin then rearranges the movable parts by sliding the transparent sheet over the other drawing. The unique axis of rotation for the particular rearrangement he has just achieved with the drawings is neatly indicated by the circles that appear in the overlapping random-dot arrays. The rearrangement could be made by rotating the movable part around the point that was the center of the circles.

The illustrations on page 203 demonstrate Seldin's technique. He began by tracing the contours of a patient's hard and soft tissues and certain landmarks based on an X-ray plate. The patient had an open bite and a protruding lower jaw. Seldin made a tracing of just the upper part of the facial anatomy and superposed on it a random-dot display. The tracing was done on acetate, and the dot array was the one made by A. G. Klein that I showed in April. Seldin also made a tracing of just the lower facial anatomy superposed on the same random-dot display.

The top illustration on page 203 shows the upper and lower facial parts aligned as they were in the patient. Notice that the overlapping random-dot displays do not reveal any particular ordering of the dots. In the next illustration Seldin has moved the transparency of the lower anatomy so that the teeth meet properly and the lip contour is improved. The axis of rotation for this correction lies at the center of the circles that can be perceived in the dot arrays.

This new technique can aid Seldin in planning for the actual surgery. For example, he could cut the ramus (ascending part) of the lower jawbone to give it the radius of curvature that would enable the bones to slide over each other until the correction is made. Alternatively he could make the correction by cutting and removing an appropriate amount of bone in the lower jaw.

Seldin says the exact location, size and shape of the osteotomy (the removal of bone) can be determined by drawing a line extending from the rotational axis and then rotating it through the same angle as in the rotation of the dots. I find this practical application of random-dot arrays exciting.

Philip Garrison of Montreal wrote to me about how he worked with a Xerox copying machine to produce circles and spirals in a random-dot array. He made a Xerox copy of a blotter from a technician's desk and ran the copy through the machine after turning the blotter slightly from its original orientation. When the paper emerged, it bore two copies of the blotter, one rotated from the other. The copied arrays of random dots gave rise to circles.

On some copying machines a copy is reduced in scale from the original. With such a machine you can get spirals or "sunbursts" in the random arrays. Make a copy of something like the blotter Garrison had. Replace the blotter with the copy and make a second copy. Replace the first copy with the second copy and produce a third. The third copy is reduced in scale from the first. To get the two patterns on the same sheet insert the third copy in the machine while again reproducing the first copy.

Guy Ottewell of Furman University suggested that one of the best moiré effects can be created by putting a large halftone picture under its negative. If the two are carefully aligned, the entire area is black because each transparent area on the negative is matched by a black area on the print. Any slight misalignment gives rise to a relatively white area. If you slide the negative over the print, the white area skims the surface.

A clever version of this technique was

sent to me by Joe Huck of Irving, Tex. He had originally sought to create a pattern of elements that were randomly spaced but did not vary much in density. He had been working with arrays of dots that, when one was laid over the other, generated moiré patterns of aligned rows of the dots.

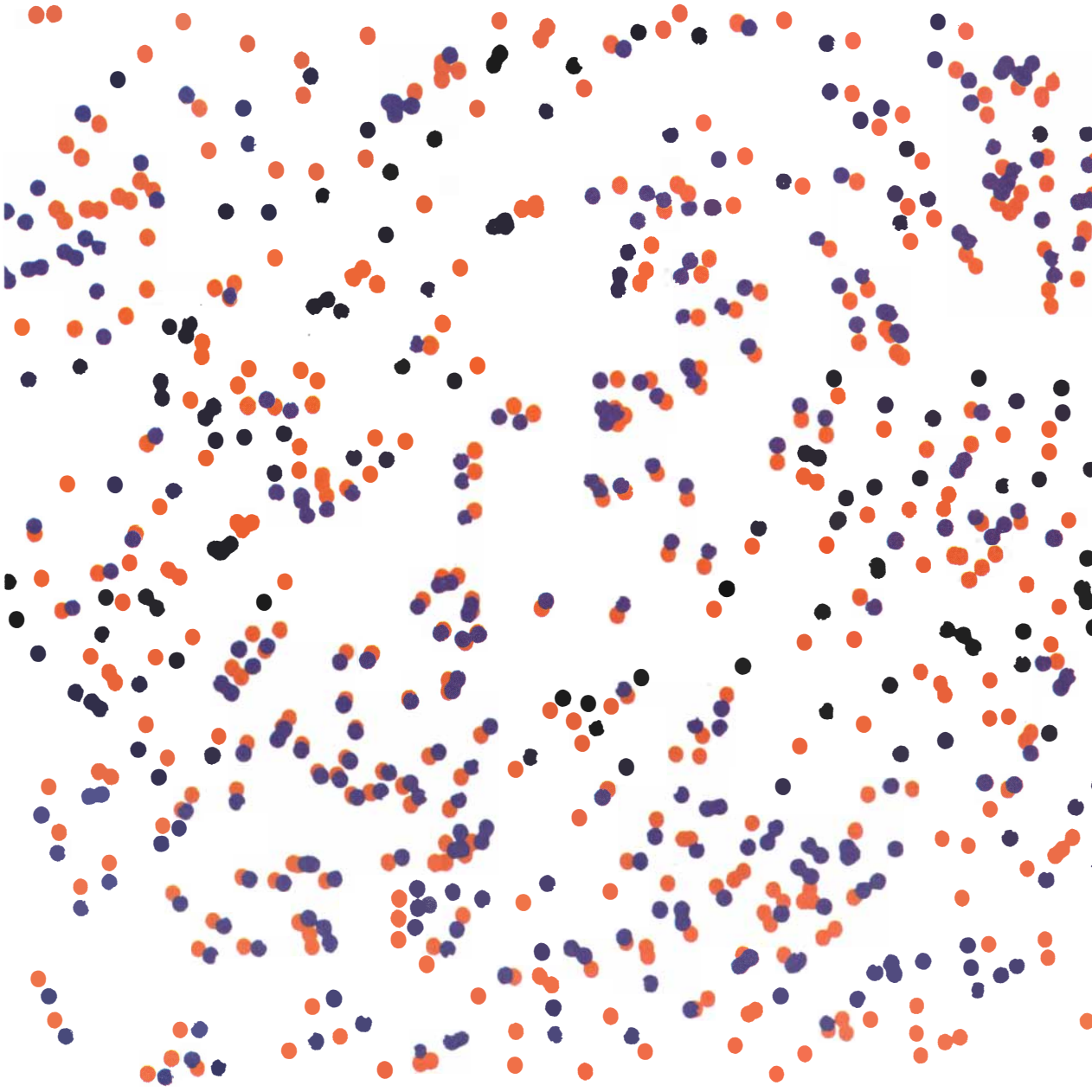
To create a pattern of only one image he modified his procedure. He made a photographic print of a series of dots. With a quarter-inch circular punch he removed circles from the print in such a way that each circle held one dot. He glued the circles on paper with their edges touching; the result was a triangular array of the circles.

When the triangle was several inches long on each side, Huck photographed it with high-contrast film. Only the dots appeared in the negative. From the negative Huck made many prints, which he pasted together in a triangular array that he photographed with a reduction of 50 percent. The product, which was some 8 by 10 inches in size, had a pattern of dots with an average spacing of an eighth of an inch.

Huck made three more transparencies with a pinhole camera in which this pattern of dots formed the pinholes. A light was shone into the camera through a panel consisting of a clear glass plate and a plastic sheet to diffuse the light. On this panel he put a ruby-colored transparent film from which he had cut a large star so that the resulting photograph would consist of stars.

Near the other end of the box Huck placed a glass photographic plate bearing a copy of the dot array. The dots functioned as pinholes, each casting an image of the star onto a piece of photographic film at the far end of the box. The developed film (a negative) was the second of the transparencies he sent to me, the original array of dots being the first.

In his third transparency, which was a contact print of the second, the black and white were reversed. A fourth transparency was like the second but had overlapping stars. The size of the stars on the second, third and fourth transparencies was governed by the position of the glass photographic plate. Although the patterns varied somewhat in size, the



*A pattern developed by Leon Glass's superposed-color method*

# Helping to keep the eyes

# Lockheed knows how.

## Posting strong new guards.

When the submarine USS Francis Scott Key put to sea in October, 1979, the new, long-range Trident missile system went on active duty—a major step upward in our nuclear deterrent capability.

The development signaled a triumph of teamwork by the U.S. Navy, Lockheed, and other contractors. In praising the performance of Lockheed and the entire program team, the Navy confirmed that all goals of Trident's range, accuracy, and reliability were met or exceeded, on schedule, and that missile production unit-cost was less than original design-to-cost figures.

A well-managed bargain, considering the leap in strength of the Free World's defense posture.

## Hitting trouble before trouble hits.

Another seagoing system, Lockheed's Mk 86 weapon-control system, is now on board or designated for seven classes of Navy ships. For those vessels, it's an upper hand in combat.

With great accuracy, the Mk 86 can simultaneously control a mix of weapons including guns up to 8" and surface-to-surface and surface-to-air missiles.

In action, the advanced system can track numbers of incoming attack threats. Then it automatically computes trajectories and triggers the right firepower to intercept and destroy the hostile targets before they can home in.

## Watchdogs over the waters.

For 40 years, Lockheed planes have bedeviled enemy submarines. Lockheed Hudsons, Venturas, and Harpoons helped win the World War II battles of the oceans. And later came the Neptunes, many still in operation.

*The S-3A Viking (top) and P-3C Orion.*

The versatile P-3C Orion evolved from those forebears to become the most advanced land-based antisubmarine aircraft in the world.

Able to dash at high speeds or loiter on-station, the far-ranging Orion carries acoustic, infrared, and electronic detection systems that are technological masterpieces. If that weren't enough, the Orion fleet is a cost-effective standout in America's defense allotments—its procurement takes less than 1% of the U.S. Navy's budget.

Not to be outdone by Orion, Lockheed's S-3A Vikings do a similar job operating from carriers, and since 1974 they've proved to be the world's most advanced sea-based sub-hunters.

# sharp and the talons strong.

## Seeing beyond the hills and trees.

The U.S. Army will have sharp new eyes when the Lockheed-developed Aquila goes on duty. A breakthrough in target acquisition systems, the remotely piloted Aquila carries television and laser systems to pinpoint and designate otherwise unseeable enemy forces and weapons.

Small—6′ long with 13′ wingspan—light, and quick in its maneuvers, Aquila can flit over enemy terrain, transmit real-time TV pictures to a control station, and successfully dodge a heavy mix of enemy ground fire that manned aircraft could not survive. (That's been proved in extensive test flights.) Then, on command, Aquila streaks for its base, lands in a retrieval net, and is ready to fly again.

*The Aquila test program RPV on its truck-mounted launching ramp.*

## The birds of burden.

Around the world today, "Hercules" usually means the rugged Lockheed C-130 Hercules, flown by the U.S. Air Force, Navy, Marines, and Coast Guard. Able to carry even large, fully-assembled trucks and bulldozers, Hercules can use short, remote airstrips of almost any surface—dirt, gravel, sand, or even snow. It's the world's most versatile airlifter.

*The airlift experts: the C-130 (front), C-141, and giant C-5.*

Then there's the fanjet Lockheed C-141 StarLifter. Now being given in-flight refueling capability for global range, each of the 270 USAF C-141s is also having its cargo hold "stretched" by one-third to add the equivalent capacity of 90 more StarLifters.

And finally, there's the C-5 Galaxy, world's biggest airlifter. Depending on load, it also can use short, unprepared airstrips. But it's further able to carry immense tonnages of outsize cargo, like two main battle tanks at once. No other airlifter approaches that capability.

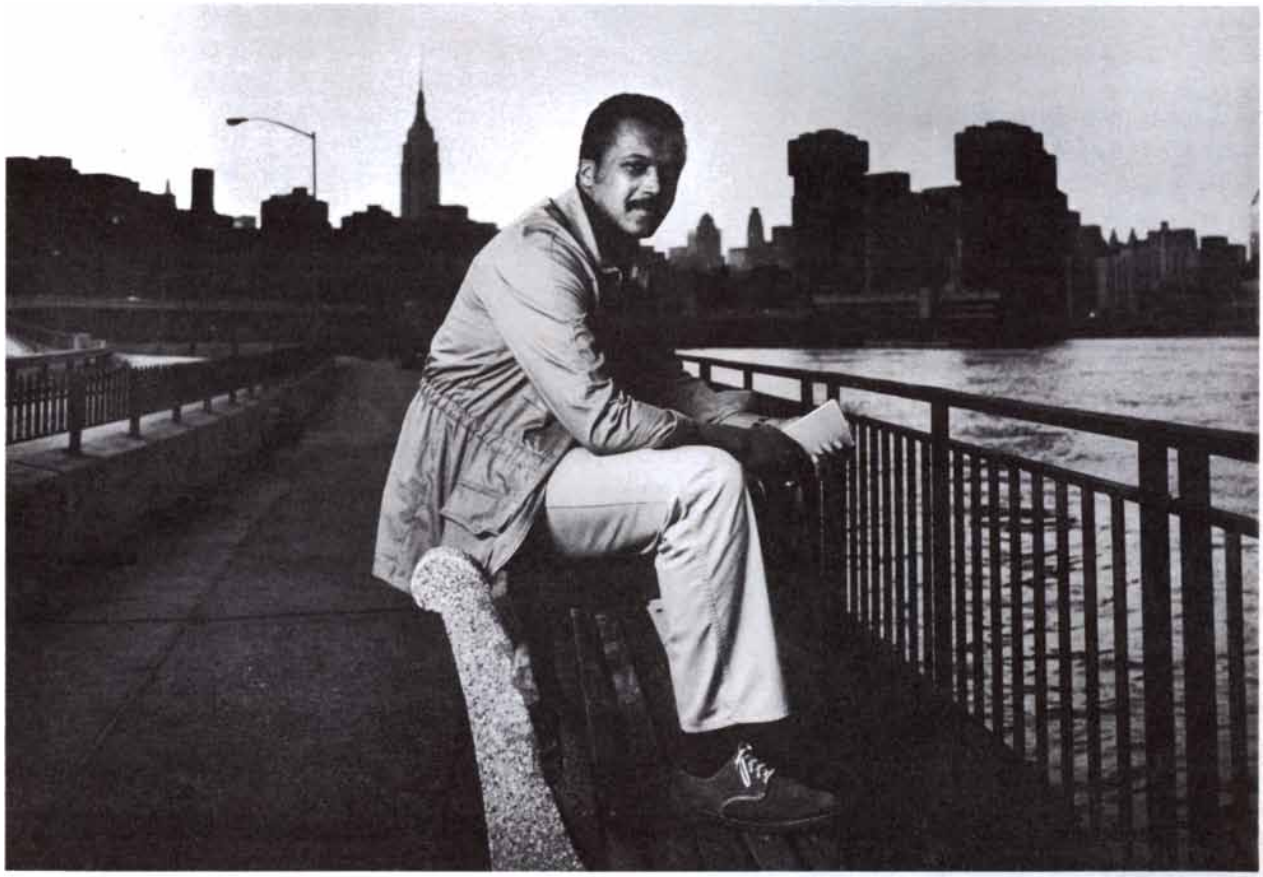
Those are just some of the many ways Lockheed helps keep America strong and its liberty secure—liberty being granted only to those who stand ready to guard and defend it.

When it comes to contributing effectively to military support, Lockheed knows how.

# Lockheed


# DEWAR'S® PROFILE

A thirst for living...a taste for fine Scotch.



## DAVID HARDY

**BORN:** Plainfield, New Jersey, 1942
**HOME:** West New York, New Jersey
**PROFESSION:** Investigative/political reporter, *New York Daily News*.
**RESPONSIBILITY:** "To share reality with others, even though I'm mindful that reality is not always an inspiring spectacle."
**STORY:** "Be it a homicide, a zoning fight, a political scandal, or simply a tale of a compassionate Jersey City hot dog vendor, my job is sometimes thrilling, often onerous, occasionally perilous, but always interesting."
**QUOTE:** "Every human being should possess a sense of morality about society and accept personal responsibility for his or her role."
**SCOTCH:** Dewar's "White Label."® "On the rocks with a splash, when relaxing with my chess computer."

David W Hardy

BLENDED SCOTCH WHISKY • 86.8 PROOF • © 1980 SCHENLEY IMPORTS CO., N.Y., N.Y.

spatial dimensions of the arrays were all proportional because they were all generated by the same array of dots on the glass plate.

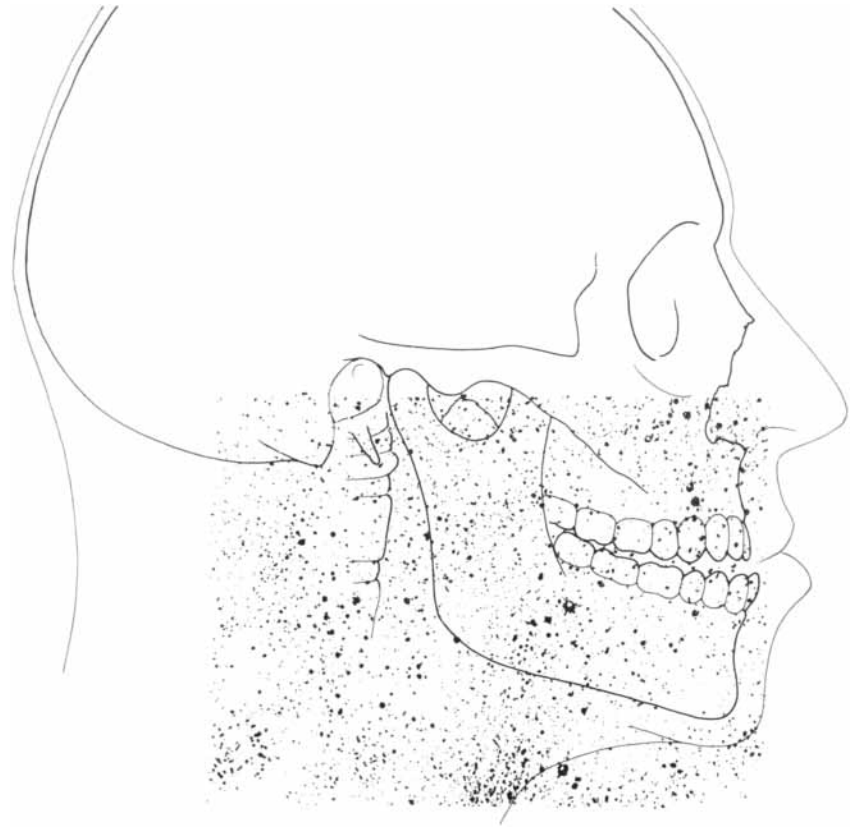
When I lay Huck's first transparency over any of the others (either on a light table or against a large window) and adjust the alignment, an image of a large star appears. Huck recommends combining the first and fourth transparencies. Although the individual star elements in the fourth one are obscured by overlapping, a large dark star image is nonetheless quite apparent in the combination. Overlaying the first and third transparencies generates a large white star. The result of overlaying the second and third transparencies is an image that resembles a large spiderweb.

Henry M. Gerstenberg of the National Bureau of Standards sent me two photographs of buttons. The first one shows a collection of buttons that he photographed with high-contrast film. With the negative he produced the second photograph, in which the rotation of the buttons creates a circular pattern like the ones resulting from the rotations I have described in the random-dot displays.

R. N. O'Brien of the University of Victoria described to me how he applied the rotation technique to investigating an array of humps on the surface of a salmon egg. When the egg is fertilized, the sperm approaches one of the humps. The humps are in a hexagonal array and appear to be similar. Nevertheless, the sperm favors a particular hump in a collection that is about three hexagons in diameter. How that particular hump differs from the others is the subject of O'Brien's investigations.

To study the regularity in the hump patterns O'Brien made large transparencies of electron micrographs of the egg surface. The magnification was some 2,300 diameters. He overlapped two identical transparencies and rotated one of them. With a rotation of about 15 degrees he observed a structure in the transparencies that was about three diameters larger than the unit hexagonal array. This size (about 15 micrometers) was approximately equal to the length of a straight line that could be extended through the humps on the surface of the egg. O'Brien suggests that small-scale ordering in seemingly random arrangements might be studied in a similar way. As examples he puts forward the possibility of examining "such diverse things as patterns in feeding flamingos, grazing antelope, shoppers in a bazaar and people in a mob."

Some of the moiré patterns studied by Glass can be generated on a home computer. The upper illustration on page 206 sets forth a program that I employ to create circles or spirals similar to the ones that appear when I overlay identical patterns of random dots and then rotate one of them. The program is writ-



*Uncorrected facial structure with a random-dot pattern superposed by Edward B. Seldin*

*The correction suggested by moving superposed patterns*

ten in Level II Basic for a TRS-80 microcomputer system, which should be easy to modify for any variation of the Basic computer language. (In the illustration there are blanks between the commands for ease of reading, which should be eliminated so that the lines are compressed when the program is entered into the computer.)

I shall briefly explain first how the program works and then what it causes to be displayed on the monitor screen of the computer. Line 10 clears the screen, sets a value for PI and the conversion (DR) of degrees to radians. (The trigonometric functions in Basic require radians.) The next two lines ask (1) how many spots should be displayed, (2) how much of a rotation should be between the two identical displays that will be generated and (3) whether the second display should be shrunk in relation to the first. Without shrinkage circles appear; with shrinkage spirals appear.

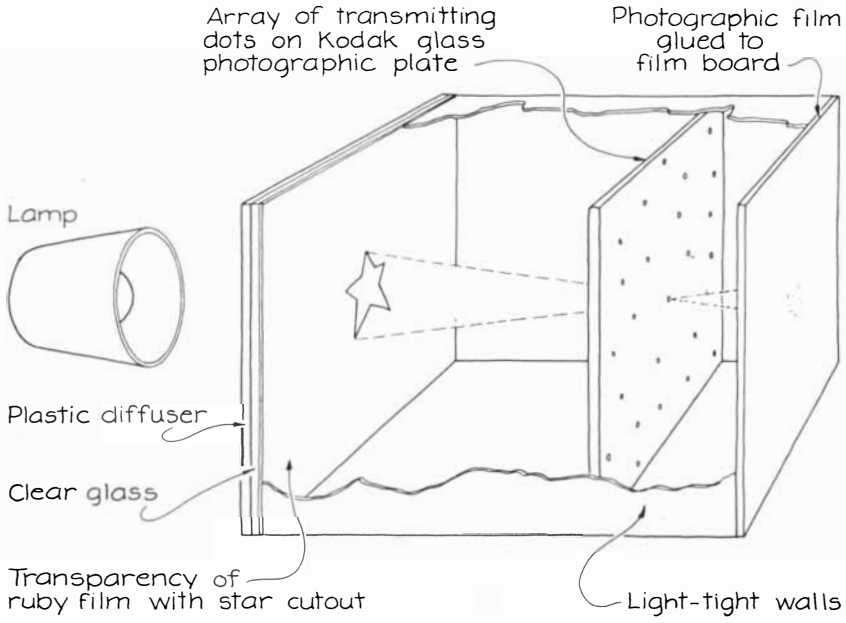
The $X$ and $Y$ coordinates for a random spot (labeled $K$) are chosen on the screen through the pseudorandom generator RND on line 40. (The computer considers the upper left-hand corner to be the origin of an $X$-$Y$ coordinate system. The $X$ axis extends to the right, the $Y$ axis downward.) Then the program calculates the horizontal distance $XX$ and the vertical distance $YY$ between the randomly chosen spot and the center of the screen. Lines 60 through 90 assign an angle $T(K)$ to the spot on the screen. The distance from the spot to the center of the screen is computed and called $R(K)$. The last part of line 100 allows for a shrinkage factor to make the spirals. The program repeats the procedure of locating a randomly chosen spot and assigning it an angle $T(K)$ and a distance $R(K)$ until it has assembled the number of spots you wanted.

In line 120 the screen is cleared of the questions, the desired rotation is put into radians and the machine prints an asterisk at the center of the screen and (in the upper left-hand corner) the rotation (in degrees). The random-spot array is turned on by the SET command in line 130. The program finds a partner for each random spot in such a way that the partner is rotated about the center of the screen by the angle you chose. The $X$ and $Y$ values for the second spot of each pair are computed in line 140; the values are rounded off in line 141. If the location of the second spot is off the screen, the program is told to go to the next spot in the initial random array. If the second spot is on the screen and a spot is not already displayed there, the program turns on the second spot of the correlated pair.

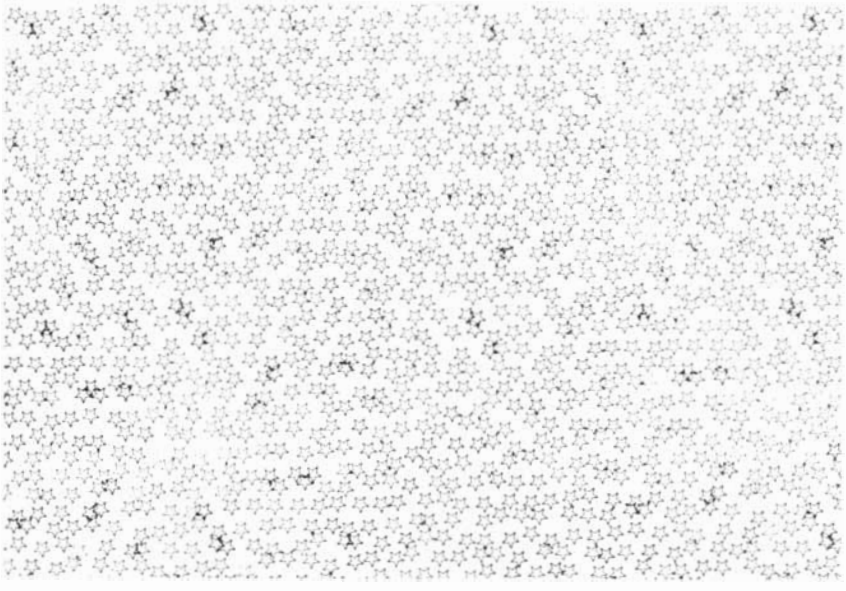
The procedure is repeated until each of the spots in the initial random array of spots has a partner (provided it is on the screen) that is rotated around the center by the chosen amount. Once all the pairs are turned on line 180 provides time for you to examine the screen. If you want more time before the screen is erased, change the 400 in that line to a larger number.

After one rotation the program erases the screen and turns on the initial array plus the same display rotated through twice the angle you originally chose. Again you have a chance to examine the screen before the program shows further rotations. The number of rotations is controlled by the 15 in line 120. If you want more rotations or fewer, change the 15. When the machine has completed the last rotation, it cycles in line 200 until you push the BREAK key. Up to that point the last rotation is held on the screen. The spots on the screen are really small rectangles half as wide as they are high. Therefore I must include scaling factors in the calculations: the division by 2 in the first part of line 50 and the multiplication by 2 in the first part of line 140.

To check the program I run it with one spot, an initial rotation of two degrees and no shrinkage. The circling around the center is usually easy to perceive. Once I am sure of the program I run 100 or 200 spots with the same initial rotation of two degrees and no shrinkage. The circles appear first on the outer edges of the screen and then, as the rotation is increased during the running




*The apparatus devised by Joe Huck to make star patterns*



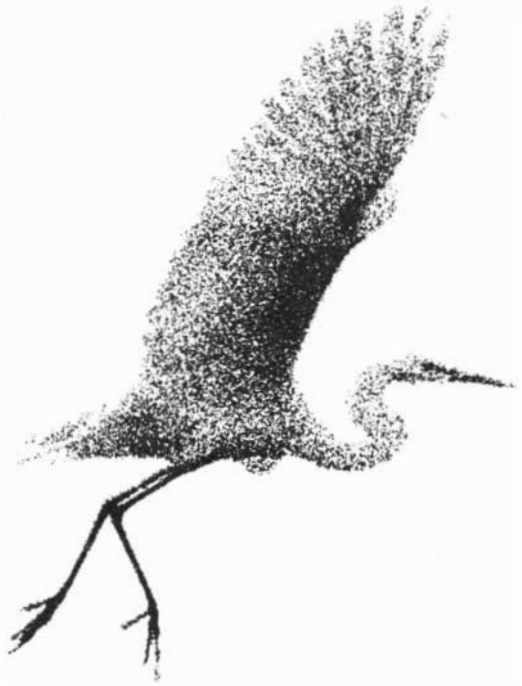
*One of Huck's patterns*

# The Coastal Almanac

## For 1980—The Year of the Coast


## Paul L. Ringold and John Clark

THE CONSERVATION FOUNDATION

MARK HOOPER

*The Great Egret, formerly the Common Egret, is found in the Western, Southern, and Eastern regions of the United States. It now faces loss of its habitat due to the draining of wetlands.*

President Carter has declared 1980 to be "The Year of the Coast." *The Coastal Almanac* has been produced by The Conservation Foundation to celebrate this proclamation.

Includes:

- The most up-to-date data, collected by known and uniform standards.
- Information available by individual states.
- A list of coastal counties designated as truly coastal in character.
- A section on the coastal regions of the Great Lakes.
- Tabular presentations accompanied by charts, maps, and line and bar graphs.
- Recreational as well as resource information.

*The Coastal Almanac* is an indispensable reference for all concerned with the conservation and use of our coastal resources.

November 1980, 172 pages, 20 illustrations, 54 tables

of the program, they move toward the center, leaving a random muddle of spots on the outer edge. After a rotation of 10 degrees or so the perception of circles in the array is lost. I am not certain at what point I last perceive circles, since they seem to disappear slowly.

I have designed the program so that a spot and its partner are printed successively. In the early stages of the construction of a newly rotated pattern a correlated pair probably will appear in a rather isolated area of the screen. Their rotation from each other is easy to perceive. Soon, however, more and more spots are created around them and perhaps even between them, and the perception becomes progressively more difficult.

To introduce shrinkage into the patterns enter a value for the percent shrinkage ($S$) when the program asks you about it in the beginning stages of running. A value of zero produces no shrinkage. A value of 5 produces a shrinkage of 5 percent between the initial random-spot pattern and the rotated one. At the smaller angles of rotation and small shrinkages spirals appear in patterns on the screen. With either large shrinkages or large rotations the spirals usually disappear.

A peculiar image materializes if the shrinkage is about 10 percent and the rotation is zero. (Enter 0 when the program asks you for the rotation angle.) The screen appears to place you at the end of an infinite "cylinder" of stars, something like the patterns employed in films to give the audience the sensation of traveling through the stars at great speed.

The program presented in the lower illustration on this page causes a linear translation of a random-spot array on the TRS-80 screen. The program asks how many spots are desired. Then you decide whether the motion is to be strictly horizontal or vertical or if it is to include both directions. Line 70 causes the randomly selected spots on the screen to turn on and computes the shifted partner for each of the originally selected spots. The partner is then turned on in line 90.

When all the partners are found and displayed, the program gives you a delay in line 110 so that you can examine the screen. Then the screen is erased and the original random spots and the new partners, now further shifted, are turned on. This procedure is continued for 15 shifts of the size that you enter in answering the question on line 20. If you want more or fewer shifts, change the 15 in line 60 correspondingly.

In the early stages of the shifts the array on the screen develops a noticeable pattern that betrays the direction of the shift. The fewer spots there are on the screen, the more apparent the shift direction is. By appropriately selecting the initial shift you can cause the array to shift straight to your left, straight upward or at an angle toward the upper left. After several shift cycles the pattern in the random array begins to disappear. Too many of the correlated pairs of spots then have other spots between them or next to them, so that the visual process can no longer pick out the correlated pairs. Shifts thereafter do not noticeably alter the array on the screen. Each shift goes from one random array to another.

As with the other program, a pattern is more easily perceived in the array when the density of spots is relatively low. Nevertheless, I usually run this program with from 100 to 200 spots in the original pattern. In each shift cycle the screen is cleared and then the correlated pairs (one original spot and its shifted partner) are displayed. In this early stage of the cycle the direction of shift is easy to pick out. Later, however, it becomes much harder or even impossible to perceive because of the larger density of spots.

Several changes can be made in an investigation of the random-spot patterns on a home computer. My TRS-80 monitor has a black-and-white display. If your home computer has a color monitor, you might modify my programs so that the spots and the background on the screen appear in color. Then you can do some of the experiments Glass did with colored arrays.

Can you arrange the colors so that with one choice a rotated array on its original gives rise to circles but with an interchange of colors the circles do not appear? Several of the other brands of home computers have a better resolution on the screen than mine, which may make the perception of linear shifts or rotations much easier.

You may want to try one of Glass's random-dot patterns. The pattern is not rotated but is expanded in one direction (say horizontally) and contracted in the other (vertically). Readers experienced with home computers can doubtless modify my programs so that they run faster and perform various new tricks. I would welcome letters about any modifications.

A peculiar visual effect can be seen if you quickly swing your view across a television screen in an otherwise dark

```
 10 CLS: PI=3.1416: DR=.01745
 20 INPUT "NUMBER OF DOTS"; D: INPUT "SHIFT ANGLE (DEG)"; DD
 30 INPUT "SHRINKAGE (%)"; S: DIM X(D), Y(D), R(D), T(D)
 40 FOR K=1 TO D: X(K)=RND (127) : Y(K)=RND (47)
 50 XX=(X(K)-64)/2: YY=Y(K) - 24
 60 IF XX=0 GO TO 110 ELSE T(K)=ABS( ATN(YY/XX) )
 70 IF XX<0 AND YY=>0 THEN T(K)=PI - T(K)
 80 IF XX<0 AND YY<0 THEN T(K)=PI + T(K)
 90 IF XX>0 AND YY<=0 THEN T(K)=2*PI - T(K)
100 R(K)=SQR ( XX↑2+YY↑2): R(K)=R(K)*(1 - S/100)
110 NEXT K
120 FOR J=1 TO 15: CLS: DT=DD*J*DR: PRINT @ 544, "*";:
    PRINT @ 0, DT/DR;
130 FOR K=1 TO D: SET (X(K), Y(K)) : NT=T(K)+DT
140 NX=64+2*R(K)*COS(NT) : NY=24+R(K)*SIN(NT)
141 NX=INT( NX+.5) : NY=INT( NY+.5)
150 IF NX<0 OR NX>127 OR NY<0 OR NY>47 GO TO 170
160 IF POINT (NX, NY) THEN GO TO 170 ELSE SET (NX, NY)
170 NEXT K
180 FOR L=1 TO 400: NEXT L
190 NEXT J
200 GO TO 200
```

*A program for rotating a random-spot display on a home computer*

```
 10 CLS: INPUT "NUMBER OF DOTS"; D: DIM X(D), Y(D)
 20 INPUT "SHIFT SIZE=? ANSW IN X, Y"; SX, SY:CLS
 30 IF SX=0 THEN N=0 ELSE N=1
 40 IF SY=0 THEN M=0 ELSE M=1
 50 FOR K=1 TO D: X(K)=RND(127): Y(K)=RND(47) : NEXT K
 60 FOR J=1 TO 15: CLS:PRINT @ 0,J;
 70 FOR K=1 TO D: X=X(K) - (SX+J)*N: Y=Y(K) - (SY+J)*M:
    SET (X(K), Y(K) )
 80 IF X<0 OR Y<0 GO TO 100
 90 IF POINT (X,Y) THEN GO TO 100 ELSE SET (X,Y)
100 NEXT K
110 FOR L=1 TO 400 : NEXT L
120 NEXT J
400 GO TO 400
```

*A program for shifting a random-spot display horizontally and vertically*

# Is Northwestern Mutual Crazy?

## Yeah, like a fox.

When the Northwestern Mutual Life Insurance Company announced its "GET MORE OUT OF LIFE" program this year, other life insurance companies were a bit worried. Imagine America's 9th largest life insurance company offering permanent policyowners a 14% average increase in coverage without increasing the policy premium*. While future dividends will be slightly lower than they would have been, future cash values on these policies will be higher. This offer is made possible because of a massive and dedicated effort in research and development. It provides a tax savings which can be channeled back to the true owners of the company, the policyowners. The "GET MORE OUT OF LIFE" program is just another example of over a century of continued dedication to providing the best possible life insurance value. As for those other life insurance companies...guess you can say they've been out-foxed again.

*Policies issued after December 31, 1977 already contain these improved features.

**NORTHWESTERN MUTUAL LIFE**
The Quiet Company
usually

room. For example, if you stand about six feet from the screen, starting your view about a foot to the left of the screen and rapidly shifting it equally far to the right side of the screen, you will probably see an image of the picture on the screen "floating" in midair off to the right of the screen. The extra image will be slanted, with its top displaced to the right from its base. The image may have the same amount of detail as the picture on the screen. If you move your view through a larger angle (and perhaps adjust your distance from the screen), you may see several of the ghost images off to the right, although the ones at each end of the series may be incomplete. If you move your eyes in the opposite direction, the ghost images appear to the left of the screen. They are similar to the ones at the right except that they lean in the opposite direction.

I believe this effect was first reported by T. G. Crookes in 1957. He explained it in terms of the way the picture is created on the television screen and the position at which the image is formed on the retina as the eyes sweep across the screen. A television picture is built up by an electron beam that moves across the screen, exciting phosphors that emit light when they drop to lower energy levels. The beam is swept horizontally across the screen line by line until it reaches the bottom. The sweep is so rapid that the viewer is unaware of it.

Suppose that as you begin to move your view across the screen from left to right the beam has begun filling in another picture, starting at the top of the screen. The line that is generated just then falls on your retina at a position labeled *AB* in the illustration below. The creation of the picture continues as you shift your line of view. Soon the bottom line of the picture is generated, but it does not fall on the same place on the retina because the view has been moving. Instead it occurs at *CD*. This position is actually to the right of *AB* on the retina, but your brain interprets it as being to the left. (The brain reverses left and right as well as up and down when it interprets what you are seeing.) The image, which lies to the right of the screen because of your rotated view, is a parallelogram, with its top shifted to the right from its bottom.

If you shift your view quickly enough and are at an appropriate distance from the screen, you may see another ghost image. The first one is off to the right and the second one is between it and the screen. The second image is created by the next projection of a picture on the screen. The first line of this new picture falls on the retina to the right of the first image (at a place labeled *EF* in the illustration). The last line falls at *GH*. Your brain interprets this new image as a parallelogram, slanted in the same way as the first image.

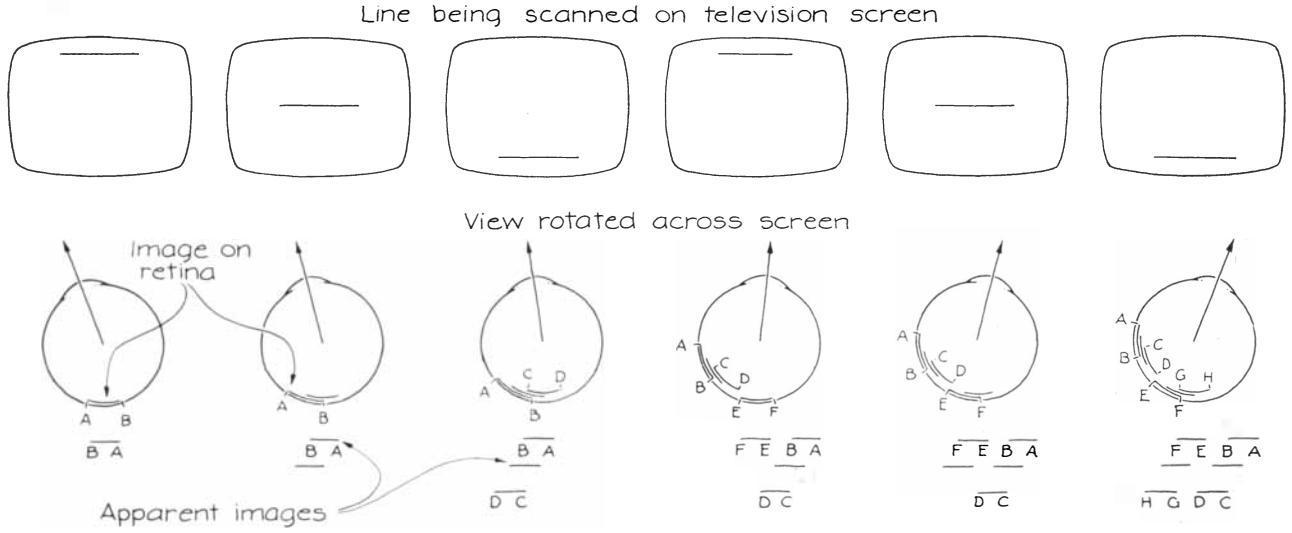
If you repeat the observations at a greater distance from the screen but keep the rate at which you rotate your view the same, you will find two changes. The ghost images are smaller because the television screen occupies a smaller angle in your field of view. They are also tilted more. This second effect is a result of the first. Because the images are smaller the top and bottom lines of each image are also smaller. Since you are shifting your view at the same rate as before, the shorter image of the bottom line means that it will be more displaced from the image of the top line than it was in the observations made closer to the screen. Hence the image you see is more tilted.

At sufficiently close distances the ghost images will overlap because of inadequate separation of the images on the retina. At larger distances the images may be well separated but too small for you to see the details of the picture that had been built up on the screen. When multiple ghost images are observed, the one closest to the screen will be less clear than the others because it arises from an image that falls well off the visual center of the retina.

To maintain the rate at which you sweep your eyes across the screen you can follow Crookes's suggestion of mounting small luminous objects in the plane of the television screen but off to the sides. Sweep your view from one to the other. If you move away from the screen but want to maintain the same sweep rate, move the luminous objects farther to the sides so that the angle between them in your field of view remains the same.

When you move your eyes rapidly up or down, the screen produces less dramatic ghost images. If the motion is downward, a bright, squashed image of the picture appears below the screen. Upward motion yields a fainter image (above the screen) that is elongated vertically. The images are produced in the same manner as the more dramatic ones. The difference in their height is a function of the way the picture is built up on the screen. The line sweep begins at the top and moves to the bottom. If you move your view downward, the images of the top and bottom line in the picture are relatively close on your retina, giving you a squashed image of the screen. If you move your view upward, the images of the two lines are relatively far apart, producing a vertically elongated image.

Most other luminous pictures will not yield this effect because they lack the rapid creation and disappearance of the picture. For example, if you sweep your view across a motion-picture screen, you will see only blurred streaks to the side. The entire picture in a frame of a motion-picture film is projected simultaneously. The visual effect appears only when, as in television, the individual elements of illumination in the picture turn on and off rapidly.




*How extraneous images from a television display are built up on the retina*

# SCIENCE/SCOPE

Transmitting the entire Encyclopaedia Britannica in just two seconds would be possible with technologies being perfected at Hughes for increasing data rates of communications satellites. Experimental hardware -- including signal processors, switches, and logic circuits -- has demonstrated rates up to 4 billion bits per second while using but a fraction of the power of conventional equipment. Satellites carrying these components and using time-sharing techniques would need only one transponder to carry thousands of telephone conversations, computer data links, and TV channels among scores of cities simultaneously.

A potentially lethal leak of hydrochloric acid from a million-gallon tank on the Chicago docks was neutralized recently with the aid of a hand-held infrared viewer. The device, a Hughes Probeye® viewer, senses heat to create bright red pictures for display through an eyepiece. It let firemen see through a huge gas cloud and determine the level of acid in the tank, so they would know how much slaked lime to use to neutralize the acid. At a manufacturing complex in Long Beach, California, a maintenance man used the viewer to discover two loose connections in a high-voltage transformer feeding the plant's computers. Repairs kept the transformer from burning up. Inquiries about the energy and safety uses of the Probeye viewer should be directed to (714) 438-9191, Ext. 223.

A revolutionary mosaic infrared seeker, which creates TV-like pictures of a scene's radiated heat to allow missiles to lock on and guide themselves to tactical military targets, promises to provide increased performance at reduced size, cost, and complexity. The seeker incorporates more than 1000 infrared detectors mated to a corresponding number of charge-coupled devices used for signal processing. All these elements are located at the focal plane of the seeker. Unlike conventional sensors, which mechanically scan a scene, the focal plane array "stares" at an entire scene to provide extremely high sensitivity. The seeker, only four inches in diameter, is being developed for the U.S. Army and the Defense Advanced Research Projects Agency (DARPA).

The Manufacturing Division of Hughes Missile Systems Group in Tucson has many immediate openings for engineers. These career opportunities require expertise in designing test equipment for advanced major electronic and missile system programs. Openings range from digital logic, analog, and IF/RF circuit design to electro-optical and IR system design. Also needed are industrial engineers and manufacturing production engineers. For immediate consideration, send resume to Engineering Recruitment, Hughes Aircraft Company, P.O. Box 11337, Dept. SE, Tucson, AZ 85734. Or call (602) 746-8484. Equal opportunity employer.

Increased productivity is one major benefit enjoyed by the electronics business since the advent of employee Quality Circles. Quality Circles are groups of volunteers from a single area doing the same or similar work who meet regularly to explore work-related problems and possible solutions. Besides solving problems, the circles help improve morale because employees have a voice in how their work can best be done. Since Quality Circles began four years ago at Hughes, about 160 groups have been formed, involving some 1400 persons.

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*Readers interested in further explanation of the subjects covered by the articles in this issue may find the following lists of publications helpful.*

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