SCIENTIFIC AMERICAN

THE HEARING OF THE BARN OWL

$2.00

December 1981

© 1981 SCIENTIFIC AMERICAN, INC

© 1981 SCIENTIFIC AMERICAN, INC

© 1981 SCIENTIFIC AMERICAN, INC

The new Dodge 400

A newly created driving machine introduces performance and high mileage to the world of personal luxury.

© 1981 SCIENTIFIC AMERICAN, INC

Dodge 400 is a driving machine that has been shaped to slice the wind . . . it is aerodynamically designed.

Dodge 400 is a driving machine that will pull you through tight turns with marvelous precision and control . . . it has front-wheel-drive and rack-and-pinion steering.

Dodge 400 is a driving machine that is capable of delivering 40 estimated highway miles on a single gallon of gas* . . . it has an Electronic Fuel Control System.

Dodge 400 is a superbly built machine that has recaptured "the thrill of the drive" . . . in the form of a new personal luxury car.

Advanced technology, remarkable performance separate it from ordinary personal luxury cars.

Today most competitive personal luxury cars are still content with yesterday's technology . . . still content to be "pushed around" by rear-wheel-drive . . .

Well, not Dodge 400.

Dodge 400 is engineered with advanced front-wheel-drive . . . teamed with rack-and-pinion steering and MacPherson struts.

The result: Precise handling. Quick response. Tight cornering. And remarkable stability.

Slip into the luxury of a Dodge 400 cockpit and you'll discover driving rewards not possible in ordinary personal luxury cars. Strong crosswinds won't bully you into the wrong lane. And vicious hairpin turns need not be hair raising experiences . . . but swift, cool responses.

The simple truth is . . . we designed and engineered Dodge 400 to satisfy one very human passion . . . Driving!

And we've done our job well.

That's why we say, Dodge 400 is no ordinary personal luxury car, but a personal driving machine.

40 EST HWY | **26** EPA EST MPG*

Extraordinary mileage for a personal luxury car.

At the heart of the Dodge 400 engine—a Trans-4 overhead cam—is an Electronic Fuel Control System that monitors engine functions and continuously adjusts the timing of spark plug firings and the mixture of air and fuel for optimum mileage efficiency.

Dodge 400. A quality machine.

Dodge 400 is more than a driving machine, it's also a superb quality machine.

Dodge 400's are built and assembled in one of the most technologically advanced plants in the world. Robots perform 98% of all the welds on every new 400 body to insure maximum body strength and to help eliminate squeaks, rattles and wind noise.

Electronic consoles monitor 37 different engine functions with 66 individual computer tests. If the engine flunks one test, it is automatically rejected.

And with the creation of the new Dodge Quality Assurance Center, Dodge 400 quality is checked and double-checked after final assembly.

1 out of every 3 Dodge 400's—selected at random—gets doors, hoods and deck lids rechecked for proper fit. Moldings and stripes are carefully inspected for alignment. Paint and metal finishes are scrutinized for flaws.

When you buy a new Dodge 400, you get a driving machine . . . that's a quality machine.

Dodge 400, not outrageously priced for a personal driving machine. $8043.

Dodge 400's base sticker price includes an impressive list of standard features . . . many far above standard.

A spacious cockpit, which provides room and comfort for 5.

A 2-spoke wheel. An electronic digital clock. Power steering. Power front disc brakes. Ignition switch light with time delay.

The list continues: Padded Landau vinyl roof. Counterbalanced hood. Clutch with automatic free play adjuster.

If your thirst for luxury is

unquenchable, you have options†: Leather and vinyl reclining bucket seats. Leather wrapped steering wheel. Cornering lamps. Sun roof. Tilt steering column. Power windows.

Buy or lease this magnificent machine at your Dodge dealer. Experience high mileage and extraordinary performance in the world of personal luxury. Dodge 400.

America's Personal Driving Machine

*Use 26 EPA est. mpg for comparison. Your mileage may vary depending on speed, weather and trip length. Actual highway mileage will probably be lower. Calif. est. lower.
**Sticker price excludes taxes and destination charges. †Some options may require the purchase of additional optional equipment.

© 1981 SCIENTIFIC AMERICAN, INC

Be careful! That's Chivas Regal!

© 1981 SCIENTIFIC AMERICAN, INC

Established 1845 **SCIENTIFIC AMERICAN** December 1981 Volume 245 Number 6

ARTICLES

DEPARTMENTS

BOARD OF EDITORS Gerard Piel (Publisher), Dennis Flanagan (Editor), Brian P. Hayes (Associate Editor), Philip Morrison (Book Editor), Francis Bello, John M. Benditt, Peter G. Brown, Michael Feirtag, Paul W. Hoffman, Jonathan B. Piel, John Purcell, James T. Rogers, Armand Schwab, Jr., Joseph Wisnovsky

ART DEPARTMENT Samuel L. Howard (Art Director), Steven R. Black (Assistant Art Director), Ilil Arbel, Edward Bell

PRODUCTION DEPARTMENT Richard Sasso (Production Manager), Carol Hansen and Leo J. Petruzzi (Assistants to the Production Manager), Carol Eisler (Senior Production Associate), Karen O'Connor (Assistant Production Manager), Carol Albert, Lori Mogol, Martin O. K. Paul, Julio E. Xavier

COPY DEPARTMENT Sally Porter Jenks (Copy Chief), Regina De Nigris, Mary Knight, Dorothy R. Patterson

GENERAL MANAGER George S. Conn

ADVERTISING DIRECTOR C. John Kirby

CIRCULATION MANAGER William H. Yokel

SECRETARY Arlene Wright

SCIENTIFIC AMERICAN (ISSN 0036-8733), PUBLISHED MONTHLY BY SCIENTIFIC AMERICAN, INC., 415 MADISON AVENUE, NEW YORK, N.Y. 10017. COPYRIGHT © 1981 BY SCIENTIFIC AMERICAN, INC. ALL RIGHTS RESERVED. PRINTED IN THE U.S.A. NO PART OF THIS ISSUE MAY BE REPRODUCED BY ANY MECHANICAL, PHOTOGRAPHIC OR ELECTRONIC PROCESS, OR IN THE FORM OF A PHONOGRAPHIC RECORDING, NOR MAY IT BE STORED IN A RETRIEVAL SYSTEM, TRANSMITTED OR OTHERWISE COPIED FOR PUBLIC OR PRIVATE USE WITHOUT WRITTEN PERMISSION OF THE PUBLISHER. SECOND-CLASS POSTAGE PAID AT NEW YORK, N.Y., AND AT ADDITIONAL MAILING OFFICES. AUTHORIZED AS SECOND-CLASS MAIL BY THE POST OFFICE DEPARTMENT, OTTAWA, CANADA, AND FOR PAYMENT OF POSTAGE IN CASH. SUBSCRIPTION RATE: $21 PER YEAR, U.S., ITS POSSESSIONS AND CANADA; $27 PER YEAR, ALL OTHER COUNTRIES. POSTMASTER: SEND ADDRESS CHANGES TO SCIENTIFIC AMERICAN, 415 MADISON AVENUE, NEW YORK, N.Y. 10017

© 1981 SCIENTIFIC AMERICAN, INC

© 1981 SCIENTIFIC AMERICAN, INC

THIS YEAR, GIVE A GREAT AMERICAN TRADITION.

Back in 1903, the L.C. Smith Company introduced its first typewriter. They didn't know it then, but they started a great tradition.

Over the years, the name Smith-Corona® has become a household word. (And you don't get that sort of recognition unless you're the best.) Over the years, people have found out that Smith-Corona stands for the very finest quality and workmanship. That Smith-Coronas are built to last and last and last.

In fact, think about this: of all the great portable typewriters that have been sold over the years, Smith-Corona is the only one that's still doing business at the same old stand! Doesn't that tell you something about the kind of tradition Smith-Corona started way back then?

Now, in 1981, one thing about the Smith-Corona hasn't changed: it's still built to last. It's still built to match exacting quality control standards.

But the Smith-Corona of 1981 is a far cry from the first typing machines. For one thing, it's electric. For another, it has a unique cartridge system that gives every Smith-Corona a versatility no other portable typewriter in the world has. So you can type on fabric or film, in black or in colors. And you can correct mistakes two different ways, including our brand-new Lift-Rite,™ that actually *lifts* mistakes clean off the page!

When you're out holiday shopping, put a great American tradition through its paces—a Smith-Corona Coronet® XL or Super 12. Type on it. Listen to it. Correct a mistake on it. Examine it closely.

You'll see why Smith-Corona has been given for years and years to generations and generations. After all, not every typewriter gets to be a tradition.

Smith-Corona

© 1981 SCIENTIFIC AMERICAN, INC

The New Rand McNally Astronomy Atlases

Latest and Most Authoritative Books on the Subject

THESE extraordinary books, the most complete and up-to-date available, are backed by the authority of the Royal Astronomical Society. The text, by Patrick Moore and Garry Hunt, summarizes latest scientific findings and describes current ideas about the Moon, Jupiter, and that planet's four largest satellites, the "Galileans."

Hundreds of spectacular illustrations, many in color, include recent NASA space probe photos and exclusive maps of both sides of the Moon.

JUPITER
by Garry Hunt
and Patrick Moore

THE MOON
by Patrick Moore

A superlative gift for the amateur and professional observer.

8¼" x 11" $14.95 each

wherever books are sold
Rand McNally
P.O. Box 7600, Chicago, Ill. 60680

THE COVER

The photograph on the cover shows the face of the common barn owl, *Tyto alba*. The ring fixed to the owl's head is an electromagnetic coil forming part of the experimental apparatus employed to determine the precision with which the owl localizes sound and the cues it selects from among those present in natural sounds (see "The Hearing of the Barn Owl," by Eric I. Knudsen, page 112). With the bird perched so that the head coil intersects horizontal and vertical magnetic fields, changes in the current in the coil indicate movements of the head as the owl locates a movable speaker. Such experiments have shown that the barn owl's ability to locate the source of a sound is better than that of any other species that has been tested. This great acuity is needed in the aerial hunting of field mice at night. The owl's face makes up a critical part of its auditory equipment. Its external ears are two troughs that run through the facial feathers. Because the ears are vertically asymmetric they can provide clues to the vertical angle of a sound source as well as to its horizontal angle.

THE ILLUSTRATIONS

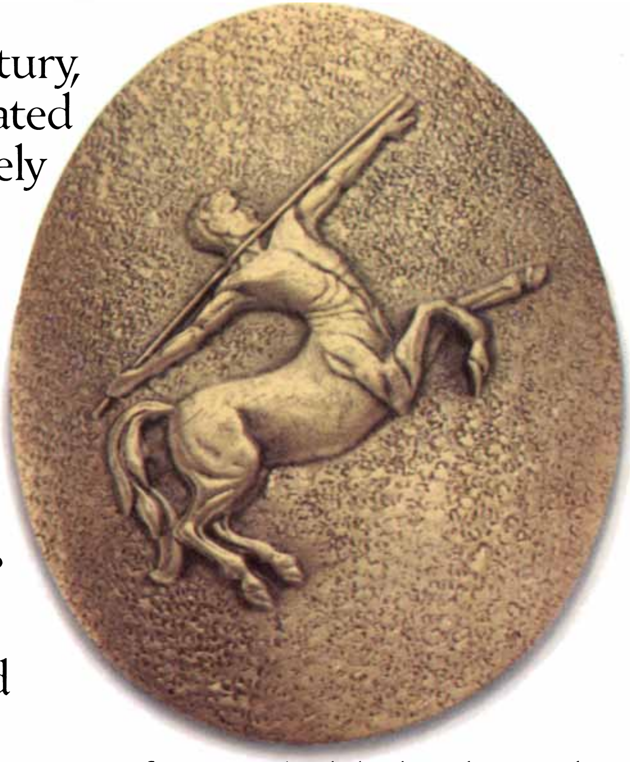
Cover photograph by Jon Brenneis

Page	Source
18–31C	Ilil Arbel
51–57	Ian Worpole
59	Richard P. Blakemore and Nancy Blakemore
60	Alan D. Iselin
61	Richard P. Blakemore
62	Denise Maratea and Nancy Blakemore (*top*), Richard P. Blakemore (*bottom left*), Richard P. Blakemore and Wendy O'Brien (*bottom right*)
63	David L. Balkwill and Denise Maratea (*top*); Richard P. Blakemore and M. Ingerfeld, University of Canterbury (*bottom*)
64–65	Alan D. Iselin
67	The Royal Commission on the Ancient and Historical Monuments of Scotland
68	Andrew Christie
69	The Royal Commission on the Ancient and Historical Monuments of Scotland (*top*), Mick Sharp (*bottom*)
70–72	Andrew Christie
91	Jet Propulsion Laboratory, California Institute of Technology

Page	Source
92–93	Walken Graphics
96	Jet Propulsion Laboratory, California Institute of Technology, and Walken Graphics
98–100	Jet Propulsion Laboratory, California Institute of Technology
103	Andrew P. Ingersoll
104	Gareth P. Williams
108	Walken Graphics
112	Eric I. Knudsen, Stanford University School of Medicine
115–125	Tom Prentiss
127	Emil O. Bernstein and Eila Kairinen, Gillette Research Institute
128	Robley C. Williams, University of California at Berkeley
129–135	George V. Kelvin
137	Gabor Kiss
138	Carol Hansen
139–146	Gabor Kiss
151	R. F. Bonifield
155–160	Ian Worpole
162	Laszlo Kubinyi
164	Ian Worpole
172–173	R. F. Bonifield
174–178	Michael Goodman

© 1981 SCIENTIFIC AMERICAN, INC

ONCE AGAIN, REMY MARTIN CREATES A COGNAC
MADE FOR ROYALTY.
INTRODUCING CENTAURE ROYAL.



In the Mid-Eighteenth Century, The House of Remy Martin created a cognac expressly and exclusively for the rulers of the Austro-Hungarian Empire, The Royal House of Hapsburg.

Today, Remy Martin has once again created an exquisite cognac expressly for the discerning connoisseur.

Centaure Royal, the "Royal" Remy Martin. A singular blend of perfectly aged *fine champagne* cognac.

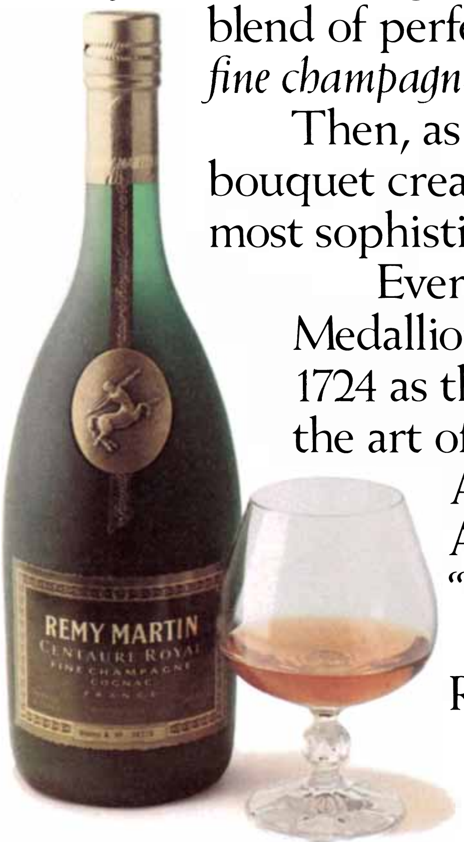
Then, as now, a cognac of remarkable body and bouquet created to grace a Royal Table or please the most sophisticated palates and "noses" in the world.

Every bottle bearing the brass Centaure Medallion, the mark of Remy Martin, known since 1724 as the house in Cognac that has raised the art of making cognac to its highest level.

A limited bottling will be available in America. Each bottle bearing its own "Reserve" number.

We believe you'll accord Centaure Royal the welcome it has always deserved.

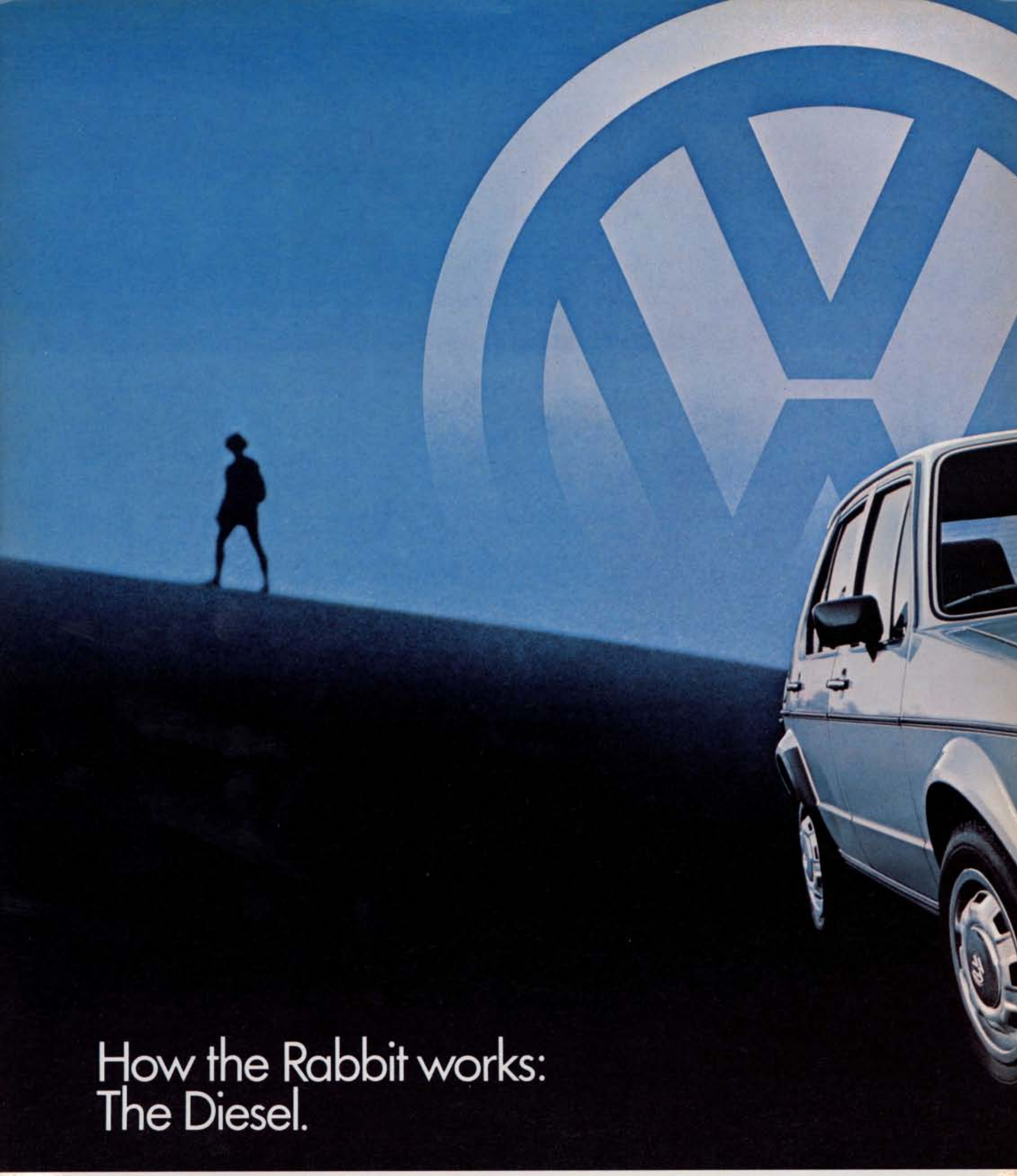
The Royal Welcome.



CENTAURE ROYAL. THE ROYAL REMY MARTIN.
EXCLUSIVELY FINE CHAMPAGNE COGNAC FROM THE TWO BEST DISTRICTS OF THE COGNAC REGION

Sole U.S.A. Distributor Foreign Vintages, Inc. New York, N.Y. 80 Proof. © 1981

© 1981 SCIENTIFIC AMERICAN, INC



How the Rabbit works: The Diesel.

Oil is a natural liquid-energy storage system created by the slow decomposition of organic matter buried under hundreds of tons of pressure for 200 million years. Prudence dictates that we use it sparingly.

The 1982 Volkswagen Rabbit with its diesel engine not only accomplishes that goal admirably, it does it better than any other car on the road.*

Its engine operates on Rudolf Diesel's principle of compression ignition. That is, fuel, injected into a cylinder filled with hot compressed air, ignites instantly. And it doesn't need spark plugs, coils or a distributor.

© 1981 SCIENTIFIC AMERICAN, INC

But the Rabbit has features that would impress even Dr. Diesel. It has a faster 7 sec. glow plug warm-up time, a unique upshift light that tells you exactly when to shift for optimum mileage, and an incredibly light engine that gives the car excellent pickup and passing power.

Add that to front-wheel drive, rack-and-pinion steering, and all the other details found on a Rabbit and you wind up with a diesel that behaves like a Volkswagen.

And nothing short of one.

*EPA estimated [45] mpg, 58 highway estimate. (Use "estimated mpg" for comparisons. Your mileage may vary with weather, speed and trip length. Actual highway mileage will probably be less.)

© 1981 SCIENTIFIC AMERICAN, INC

LETTERS

Sirs:

I read with interest the September issue of *Scientific American,* devoted to industrial microbiology. Although the articles were, as usual, well written and authoritative, there is no apparent reference to the huge commercial production in the U.S.S.R. of *Candida* yeast protein from hydrolyzed peat. The plan, which was targeted to produce about two million tons of feed yeast annually, calls for 95 plants, including 62 in European Russia, 12 in Latvia, three in Byelorussia and one each in Lithuania and Estonia. According to 1977 reports, 13 of these plants had been authorized for immediate construction, following a four-year pilot-plant study (1971–75) at Bobruisk in Byelorussia (V. S. Shimanski et al. in *The Production of Food Yeast from Peat,* edited by V. E. Rakovskii, Nauka i Tekhnika, Minsk). I have summarized some of the relevant data in my book *Peat: Industrial Chemistry and Technology,* Academic Press, 1980. Yeast protein is being produced from hydrocarbon sources too.

G. B. Carter ("Is Biotechnology Feeding the Russians?" in *New Scientist,* April 23) points out that Russian single-cell-protein production "has been largely overlooked in the Western press." He reports that 1.1 million tons of yeast protein per year are being produced in the U.S.S.R., and that a gigantic plant (300,000 tons per year) is now under construction at Mozyr in Byelorussia. It is evident that the rapid growth of this industry is significantly reducing Russian dependence on imported grain. The program thus has political and economic as well as scientific importance.

CHARLES H. FUCHSMAN

Director
Center for Environmental Studies
Bemidji State University
Bemidji, Minn.

Sirs:

I am responding to the admirably written article on Sadi Carnot ["Sadi Carnot," by S. S. Wilson; SCIENTIFIC AMERICAN, August], which emphasizes the practical intent of Carnot's famous essay. Considerable work has been done by Carnot scholars to try to document a connection between him and the actual construction of steam engines. But the practical nature of Carnot's work, beyond what is suggested in his essay, remains obscure, as does much of his personal history. A number of points, which the author does not mention, have been brought to light by scholars in France. Perhaps the most striking is the discovery of evidence that Carnot died in a hospital for the mentally disturbed at Ivry-sur-Seine, just outside of Paris. Professor Arthur Birembaut in his article in *Sadi Carnot et l'essor de la thermodynamique* (*Sadi Carnot and the Rise of Thermodynamics*), published by the Centre National de la Recherche Scientifique (C.N.R.S.) in 1976, offers the hypothesis that Hippolyte Carnot, younger brother of Sadi Carnot, may have deliberately concealed the unusual circumstances of his brother's death in order to protect the family's honor. The cholera epidemic of the summer of 1832 provided a convenient solution to a delicate problem.

A second intriguing find that is keeping scholars busy is Carnot's correspondence with military headquarters in Paris in 1827 indicating that he was involved in a legal proceeding in which all he possessed was at stake.

A review of the French research, emphasizing the biographical aspects, by Birembaut, René Taton and others is provided in my article "Sadi Carnot: French Avant-Garde Energy Engineer," *Social Science Energy Review,* Fall, 1979, which is available from the Yale University Institution for Social and Policy Studies, Box 16A, Yale Station, New Haven, Conn. 06520. The article also mentions evidence of the existence of an early paper of Carnot's on a problem in geometry, which I believe has not been discussed elsewhere. In addition it mentions the possibility of a connection between Carnot and the Saint-Simonians via his brother, who was an active member of that religious/technocratic sect.

S. GORDON

Yale University
New Haven, Conn.

Sirs:

Bernstein and Phillips' timely article on fiber bundles and quantum theory ["Fiber Bundles and Quantum Theory," by Herbert J. Bernstein and Anthony V. Phillips; SCIENTIFIC AMERICAN, July] resolved a disquieting mystery for me that may be of interest to some readers. One of C. L. Stong's last "Amateur Scientist" columns [SCIENTIFIC AMERICAN, December, 1975] described an "antitwister mechanism" I frankly could not believe. It was a device that supposedly made it possible to connect an electric cable, a hydraulic hose or an optical link from a rotating body to a fixed base without slip rings or any other sliding members. After a few moments' reflection I concluded that Stong was playing a joke on us—including the editors. The thing could plainly not be done.

As soon as I saw the photographs of the Philippine dancer continuously rotating a wineglass resting firmly on one hand (in the fiber-bundle article) the light dawned like a flashbulb. My engineer's intuition still has not assimilated this preposterous idea—but it is true! I am just glad no one was there to see me twisting my hand around to prove it for myself.

Other readers may want to refer to the antitwister column for suggestions of possibly useful applications of this remarkable effect described by fiber-bundle theory.

E. W. MCWHORTER

Longview, Tex.

Sirs:

Another comment on the Philippine wineglass dance and the letter from Rosemarie Swanson ["Letters," SCIENTIFIC AMERICAN, October].

One practical application of this theory is a method of handling a garden hose in order to store it for the winter. If loops are gathered in one hand, there will be a back twist generated in the uncollected hose that must be shaken out to prevent kinking.

If the gathered coil is oscillated 180 degrees between each collection of a loop, it is the equivalent of the dancer's elbow being above and below the plane of the wine. This will make it possible to coil the hose with no back twist.

NEWELL MCDONALD

Cheshire, Conn.

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

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

Offprint correspondence and orders should be addressed to W. H. Freeman and Company, 660 Market Street, San Francisco, Calif. 94104. For each offprint ordered please enclose 60 cents.

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

Name ______

New Address ______

______

______

Old Address ______

______

______

© 1981 SCIENTIFIC AMERICAN, INC

If music is one of your pleasures, it is our pleasure to introduce you to a unique audio system that will put unlimited access to music at your fingertips, from anywhere in your listening room.

This system, the Beocenter 7000, is equipped with a micro-computer which allows you to select your program source from the turntable, cassette tape player, and pre-programmed FM stations, by remote control. You can switch between program sources, adjust volume levels, and enjoy full command of your tape cassette for recording or playback, all without ever touching the Beocenter itself. And the micro-computer will keep you constantly informed on the status of the Beocenter, via an LED display.

It almost goes without saying that in addition to these unique features, the Beocenter 7000 includes superb components that have become the hallmark of Bang & Olufsen.

The single-touch turntable allows you to play records of any size or speed at the touch of one button.

The advanced cassette deck has bias adjustment for all forms of tape, and automatically

demagnetizes its tape head after every recording.

If music is indeed one of your pleasures, we invite you to experience the unique pleasure of music brought to you automatically, remotely, intelligently, by the Beocenter 7000. In the world of advanced music systems, there is indeed nothing remotely like it.

Bang&Olufsen

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

THE BEOCENTER 7000. IN THE WORLD OF ADVANCED MUSIC SYSTEMS, THERE'S NOTHING REMOTELY LIKE IT.

© 1981 SCIENTIFIC AMERICAN, INC

50 AND 100 YEARS AGO

SCIENTIFIC AMERICAN

DECEMBER, 1931: "We have lost a sincere and valued friend, one who for more than half a century of eventful activity has ever been willing to respond where he could give aid and encouragement. Thomas Alva Edison died on October 18. From the historic day in 1877 when he gave the first public demonstration of his phonograph in the offices of this magazine, to his recent favor of allowing us to reproduce his favorite portrait on our cover, his association with us has been constant and his courtesies innumerable. Born in Milan, Ohio, on February 11, 1847, the son of parents of comfortable means, he early embarked on his own account in a variety of businesses. It was while a telegrapher in Boston that he took out his first patent, No. 90,640, granted June 1, 1869, for an electric vote recorder. From a monetary standpoint this was a failure. His next invention was a stock ticker, and this he sold for $40,000, thus starting a line of inventions represented by more than 1,000 patents, which placed him among the immortals of industry and science."

"With the greatest existing telescopes it is possible to photograph a nebula of the 21st magnitude—two million times farther than anything that can be seen with the naked eye. There must be more nebulae beyond even this limit, so remote that no existing telescope can reveal them. The evidence for this is remarkably simple, depending on mere counts of the numbers of nebulae down to successively decreasing limits of faintness. Suppose we count all the nebulae in the sky down to a given apparent brightness. Then let us take a lower limit one quarter as bright as before and count again. We shall evidently now include objects to twice our former limit of distance, hence we shall get all that lie within a sphere of eight times the volume we had at first. Hence if the nebulae are scattered uniformly through space, we shall get eight times as many as before. If they thin out at great distances, the number we find will increase less than eightfold. Edwin P. Hubble's counts, when analyzed in this way, show that on the average the eightfold rate of increase actually occurs right down to the faintest object that can be accurately measured for brightness. The nebulae are still there, scattered no more sparsely than the nearer ones, to the farthest limit of telescopic vision. The material universe extends beyond the utmost limits of our observation. We have sounded its depths with the longest line that human skill has yet devised, and our final report is 'No bottom.'"

"Eighteen persons stepped aboard a large transport plane of Eastern Air Transport. The chief pilot of the company, Harold A. Elliott, took off from Newark Airport, set his compass course for Washington, threw out a clutch and abandoned his post at the controls. The plane flew on steadily under perfect control for 10 minutes and then Elliott threw in the clutch, turned the plane on a course back toward Newark, again threw out the clutch and let the plane fly with no hand at the controls. In 11 minutes so unerring was the aim and so perfect the control that the plane passed over the center of Newark Airport. This flight was the first public demonstration of the Sperry gyro-pilot, which does everything but take off and land a plane. New possibilities can therefore be seen for a wider and more confident use of airplanes."

SCIENTIFIC AMERICAN

DECEMBER, 1881: "The Edison system of electrical conductors now being placed under the street pavements of New York will rely on gigantic dynamo-electric machines. With engines of the most perfect build, and with the armature weighing 8,500 lb. as a fly wheel, the Edison machine attains great uniformity of speed and consequently ensures perfect steadiness in the light. The central station now in process of construction will be provided with 12 steam engines of 150 horse power each, actuating the dynamo-electric machines, each of which will be capable of supplying 2,400 lamps of eight candle power. The current furnished to these lamps comes through the large-sized conductors laid in the streets, from which smaller conductors lead into the houses. These conductors virtually bring the poles of the generator into each house, where the lamp wires can be brought in connection with them, thus rendering each house independent of any other for a supply of both light and motive power."

"If the world were not already accustomed to the unprecedented fertility of Mr. Darwin's genius, it might well be disposed to marvel at the appearance of yet another work, now added to the magnificent array of those that bear his name. This work is *The Formation of Vegetable Mould through the Action of Worms, with Observations on Their Habits.* Mr. Darwin writes: 'It was shown that small fragments of burnt marl, cinders, etc., which had been thickly strewed over the surface of several meadows, were found after a few years lying at a depth of some inches under the turf, but still forming a layer. This apparent sinking of superficial bodies is due to the large quantity of fine earth continually brought up to the surface by worms in the form of castings. These castings are sooner or later spread out, and cover up any object left on the surface. I was thus led to conclude that all the vegetable mould over the whole country has passed many times through the intestinal canal of worms. Hence the term animal mould would be more appropriate than that commonly used of vegetable mould.'"

"A glance at the map of Central Europe will show the importance of the line of railway upon which the great St. Gothard tunnel is situated. A territory lying in the heart of the continent, and containing the most delightful scenery in the civilized world, is for a distance of 100 miles north and south (between Lucerne and Milan) and 300 miles east and west (Geneva to Innsbruck) without a line of railway. Nothing but the until recently believed impossibility of working such long subterranean passages has delayed till the present time the construction of railways so urgently needed for the conveyance of the thousands of visitors who annually flock to the summer resorts of grand and beautiful Switzerland. The total length of the St. Gothard tunnel is 15 kilometers ($9\frac{1}{3}$ miles). The engineers assert that the tunnel will be ready for traffic by the 1st of January next, although the whole line from Lucerne to Biasca will not be opened until next July."

"In 1832 Biela's comet crossed the earth's orbit. In 1846 the comet had divided into two, which in 1852 reappeared. In 1859 the comet was not observed, but it would have been so placed in reference to the earth as to account for that. In 1866 and 1872, however, it should have been seen. Now, in 1872 it was known that in September the comet should cut the earth's level at a point corresponding to the place of the earth on November 27. And it was suggested that on that day, the earth being then where a comet had been before in September, a meteoric shower might be observed; and further, that this shower would move in the precise path of the comet, and therefore, from the known direction of the comet path and the velocity due to that particular point of its path, that the apparent radiant would be in Andromeda. These predictions were precisely realized, and being realized they established the fact that the meteors of November 27, 1872, move in the same orbit as Biela's comet. These remarkable facts suggest an association of some sort between meteors and comets, but what the connection is has not been established."

© 1981 SCIENTIFIC AMERICAN, INC

Now that they're ready for a change of pace it's time to give them John Jameson.

Introduce them to John Jameson. They'll like the light, delicate taste. Luxurious and smooth as they would expect a premium whiskey to be. But with a distinctive character all its own. Step ahead of the crowd—give John Jameson, the world's largest selling Irish Whiskey.

© 1981 SCIENTIFIC AMERICAN, INC

TO FIND A FASTER SHOE, WE WASTED A LOT OF ENERGY.

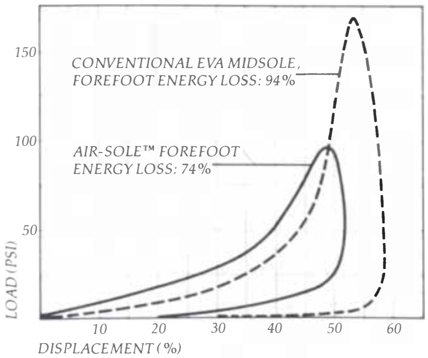
It would have been simpler had we never heard those famous words: 3.79 ml O_2/kg/km.

Up until then, we knew what everyone else did. The surest way to make a shoe faster was make it lighter. Carve 100 grams from a pair of racing flats and you give the athlete a one percent energy rebate.

That's what the Nike Eagle is all about. At about 150 grams, it remains the lightest flat on the market. And the minute we introduced it, the shoe posted a 2:10 marathon.

Obviously, we didn't cut weight haphazardly. And since different runners need different amounts of comfort to race effectively, what we didn't put in the Eagle, is there in the Magnum, the Boston and the Elite.

Everything made sense. Until we started fooling around with air.



The Air-Sole™ returns 20% more energy on pushoff than conventional EVA midsole.

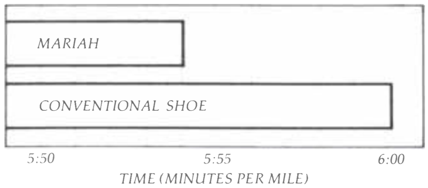
Suddenly, conventional wisdom flew right out the laboratory window.

The Tailwind, developed for cushion, refused to act like a typical 290 gram shoe. And more like 170 gram model. The Air-Sole™ proved to be about two percent more energy efficient than it had any right to be.

In plain language, a 3.79 ml O_2/kg/km discrepancy. And nothing to take lightly.

So we began work on an even faster model. We carefully reduced the weight. Tuned the air for high speeds. Put world-class athletes through grueling workouts on treadmills. Ran impact tests to check shock attenuation.

In the end, we called the shoe Mariah.



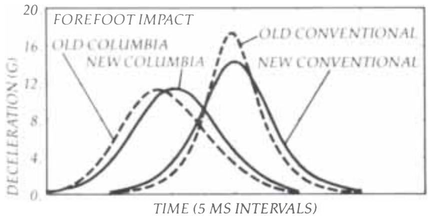
Average pace for nine subjects (5',10"; 149 lbs.) expending same effort in Mariah vs. conventional shoe of same profile and weight. Based on 108 trials of each shoe.

A runner capable of a 2:10 marathon in a shoe of similar weight, now has the potential of running 2:07:32. Put another way, the same amount of energy that would take athletes 50 miles, will now take them about 51 miles.

There were other surprises. Our lab tests showed that, contrary to all logic, the Air-Sole actually increased the Mariah's stability.

It appeared we not only had a great racing flat, but the makings of a revolutionary training shoe. So we made it. The Columbia.

We were immediately handed another little shock. While most midsoles exhibit substantial cushioning loss after 300 miles, the Columbia, after more than 800, had practically the same resiliency as the day it came off the production line.



In impact tests, after more than 600 miles, the Columbia showed no loss in cushioning while conventional training shoe with EVA midsole displayed a loss of 21.4%.

There are, however, some things we are not going to tell you about air shoes. We are not going to tell you they reduce injury. Or speed recovery between races or heavy training runs. Many athletes, even researchers, think so. But we don't have enough hard data. Not quite yet.

We will tell you this.

You really don't need one of the most sophisticated research labs in the world to come up with a fast shoe. It's a lot less exhausting if you make sure—one way or the other—your shoe gets on a fast runner.

That's fine. But around here, we have to know that once it's there, it does the job better than any other shoe possibly could.

And that's what all the sweat's about.

NIKE

Beaverton, Oregon

© 1981 SCIENTIFIC AMERICAN, INC

THE AUTHORS

KOSTA TSIPIS ("Laser Weapons") is a physicist at the Massachusetts Institute of Technology, where he serves as associate director of the physics department's Program in Science and Technology for International Security. A native of Greece, he came to the U.S. in 1954 to study electrical engineering and physics. His degrees are from Rutgers University (B.Sc., 1958; M.Sc., 1960) and Columbia University (Ph.D., 1966). He has been a member of the physics department at M.I.T. since 1966. This is the sixth article Tsipis has contributed to SCIENTIFIC AMERICAN, either as author or coauthor, on various aspects of the role of science and technology in the formulation of national-defense policy.

RICHARD P. BLAKEMORE and RICHARD B. FRANKEL ("Magnetic Navigation in Bacteria") describe their work together respectively as "a healthy and fruitful obligate mutualism between a physicist and a biologist" and as "a true interdisciplinary collaboration, in which each has had to learn the other's language in order to carry on." Blakemore, the biologist, discovered the phenomenon of magnetotaxis in bacteria six years ago, while he was still a graduate student at the University of Massachusetts at Amherst. He went on to obtain his Ph.D. in microbiology and then joined the faculty of the University of New Hampshire, where he is now assistant professor of microbiology. Frankel, the physicist, says that since joining forces with Blakemore he has become "a real biology addict." A graduate of the University of Missouri, he has a Ph.D. from the University of California at Berkeley. He has been a member of the research staff of the Francis Bitter National Magnet Laboratory at the Massachusetts Institute of Technology since 1965.

AUBREY BURL ("The Recumbent Stone Circles of Scotland") has directed several archaeological excavations of megalithic sites in England and Scotland. Born in London, he was educated at Wyggeston Boys' School in Leicester and subsequently served as a sublieutenant in the Royal Navy from 1943 to 1947. He later read history and archaeology at the University of London and at the University of Leicester, where he prepared his thesis on the stone circles. He served as lecturer in archaeology at Leicester and at the Hull College of Higher Education from 1970 to 1980. "Now in semiretirement," he writes, "I spend my time researching and writing in a pleasant Georgian house in the even pleasanter Edgbaston region of Birmingham, West Midlands." Burl's most recent book, *Rites of the Gods,* which is about prehistoric religion in Britain, was just published. He is currently working on another book, this time about megalithic tombs.

ANDREW P. INGERSOLL ("Jupiter and Saturn") is professor of planetary science at the California Institute of Technology. He is a graduate of Amherst College (B.A., 1960) and Harvard University (A.M., 1961; Ph.D., 1965), and he has been at Cal Tech since 1966. A specialist in planetary atmospheres, he has taken part in the analysis of data from a number of U.S. space missions. Recently he was awarded the National Aeronautics and Space Administration's Exceptional Scientific Achievement Medal for his work on the Voyager project. He writes: "I live with my wife, five children, several Cal Tech graduate students and a postdoc in a fine old Pasadena house that has sometimes been called 'the commune for hard-working scientists.' I enjoy challenges and am overcompetitive; I credit my family and friends for maintaining my civility."

ERIC I. KNUDSEN ("The Hearing of the Barn Owl") is assistant professor of neurobiology at the Stanford University School of Medicine. He earned his degrees in the University of California system: an A.B. in 1971 and an M.A. in 1973 (both at Santa Barbara) and a Ph.D. in 1976 (from San Diego). He began his research career, he reports, "as an undergraduate working on the bioluminescence of the sea pansy, a primitive animal in one of the lowest phyla (Coelenterata). Since then my interests have moved progressively up the phylogenetic ladder, from the horseshoe crab (master's thesis) to the catfish (doctoral thesis) to the owl (postdoctoral work). I fully expect to be studying mammals, including human beings, before long."

RUSSELL F. DOOLITTLE ("Fibrinogen and Fibrin") is professor of biochemistry at the University of California at San Diego. He studied biology as an undergraduate at Wesleyan University and biochemistry as a graduate student at Harvard University, receiving his Ph.D. from the latter in 1962. After two years as a postdoctoral fellow at the Karolinska Institute and the University of Lund he moved to San Diego to continue his work on the structure and evolution of fibrinogen. During the academic year 1971–72 he was a visiting fellow at Wolfson College of the University of Oxford.

RICHARD PAVELLE, MICHAEL ROTHSTEIN and JOHN FITCH ("Computer Algebra") collaborate at long range on the application of computer methods to mathematical problems in various areas of science. Pavelle is on the staff of the Massachusetts Institute of Technology's Laboratory for Computer Science. He has a B.S. in nuclear engineering from Columbia University, an M.S. in theoretical physics from Case Western Reserve University and a Ph.D. in mathematics from the University of Sussex. He became a "devotee" of computer algebra, he says, in 1974, when a calculation dealing with alternative theories of gravitation that had taken him three months to do "by hand" the year before "was redone (and confirmed) on the MACSYMA system at M.I.T. in two minutes." Rothstein is assistant professor of computer science at Kent State University. His interest in computer science was nurtured at the National University of Colombia at Bogotá, where he was graduated with a degree in mathematics in 1970. A Fulbright fellowship then took him to the University of Wisconsin at Madison, where he got his M.S. in 1973 and his Ph.D. in 1976. Before joining the faculty at Kent State in 1980, Rothstein taught computer science at Simón Bolívar University in Caracas. Fitch is professor of software engineering in the school of mathematics at the University of Bath, where he also serves as director of the university's computer unit and head of the numerical analysis and computer science group. He was educated at the University of Cambridge, obtaining his B.A. in mathematics and his Ph.D. in algebraic manipulation. (In 1972 he was joint winner of the John Couch Adams Mathematical Prize at Cambridge.) Fitch taught at Cambridge, the University of Utah and the University of Leeds before taking up his present positions at Bath.

GEORGE GALE ("The Anthropic Principle") is associate professor of philosophy and physical science at the University of Missouri at Kansas City. His degrees, all in philosophy, are from the University of Santa Clara (B.A., 1965), San Francisco State University (M.A., 1967) and the University of California at Davis (Ph.D., 1971). "Much of my doctoral dissertation," he reports, "was written while I was a visiting student at the University of Oxford. The dissertation, the topic of which was 'Leibniz: the Physicist as Philosopher,' examined the impact of Leibniz' physical ideas on his philosophical system and traced his influence on the origins of field dynamics. The history of early field theory remains one of my avid interests. My other research interest is modern physics, in particular particles and relativity.... When I'm not burying my nose in a book, I'm burying my hands in the dirt of a 10-acre vineyard or busy in its attached 10,000-gallon-per-year winery, of which I'm the wine maker."

© 1981 SCIENTIFIC AMERICAN, INC

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.

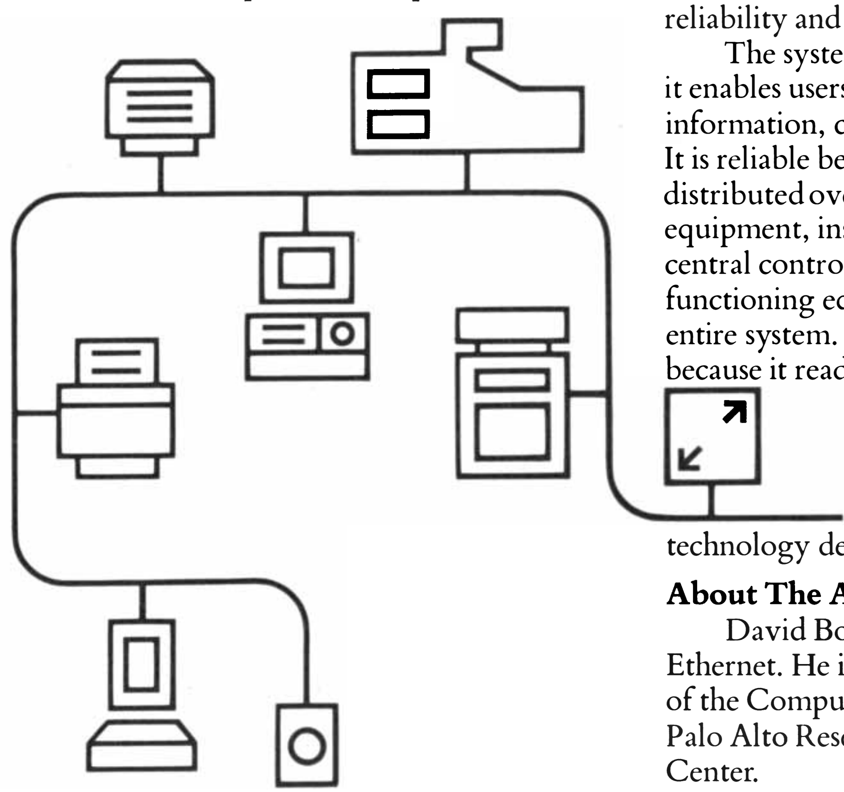
While someone is speaking, everyone else waits. When the current speaker stops, those who want to say something pause, and then launch into their speeches. If they *collide* with each other (hear someone else talking, too), they all stop and wait to start up again. Eventually one pauses the shortest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

© 1981 SCIENTIFIC AMERICAN, INC

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.

XEROX

XEROX® and Ethernet are trademarks of XEROX CORPORATION

© 1981 SCIENTIFIC AMERICAN, INC

MATHEMATICAL GAMES

The Laffer curve and other laughs in current economics

by Martin Gardner

TheKettle-Griffith-MoynihanScheme for a New Electricity Supply, Travelling in the Olden Times,[4] American Lake Poetry, the Strangest Dream that was ever Halfdreamt.[5]

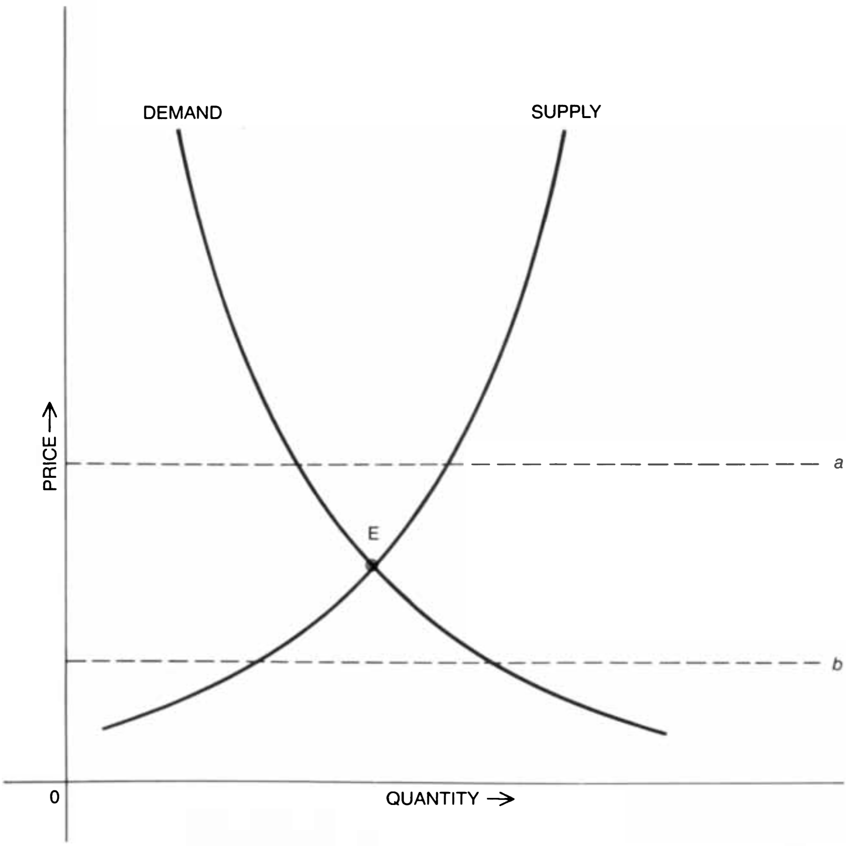
[4]I've lost the place, where was I?

[5]Something happened that time I was asleep, torn letters or was there snow?

—JAMES JOYCE, *Finnegans Wake*

Economists love to draw curves. In the early decades of modern capitalism classical economists were fond of explaining prices by constructing supply and demand graphs such as the one shown below. If the price of a commodity is on the level indicated by the line *a*, it is easy to see from where this line crosses the curves that people will buy less of the product. Since the seller will have an oversupply, he will lower its price to get rid of it. If the prices are on the lower level of the line *b*, increased demand will bid up the product's price and the seller will produce more.

These up and down forces stabilize the price at *E*, the equilibrium point where the amounts demanded and supplied are equal. At this point the seller maximizes profit. If there is a general increase in demand, with supply constant, the demand curve shifts to the right and *E* rises. If there is a general increase in supply, with demand constant, the supply curve shifts to the right and *E* falls. If both curves move to the left or the right the same distance, *E* stays at the same level.



Classical supply and demand curves

These curves still hold because supply and demand play basic roles in any economy, even one without free markets, but these days economists refer to them less because in a mixed economy such as ours hundreds of variables play havoc with the curves. The government, by innumerable stratagems, keeps many prices far above or below what they would be in a free market. Organized labor pushes up wages and companies pass the increases along to prices, in what Arthur M. Okun of the Brookings Institution calls "the invisible handshake." Oligopolists find subtle ways of getting together to avoid market fluctuations, something they must do to remain efficient.

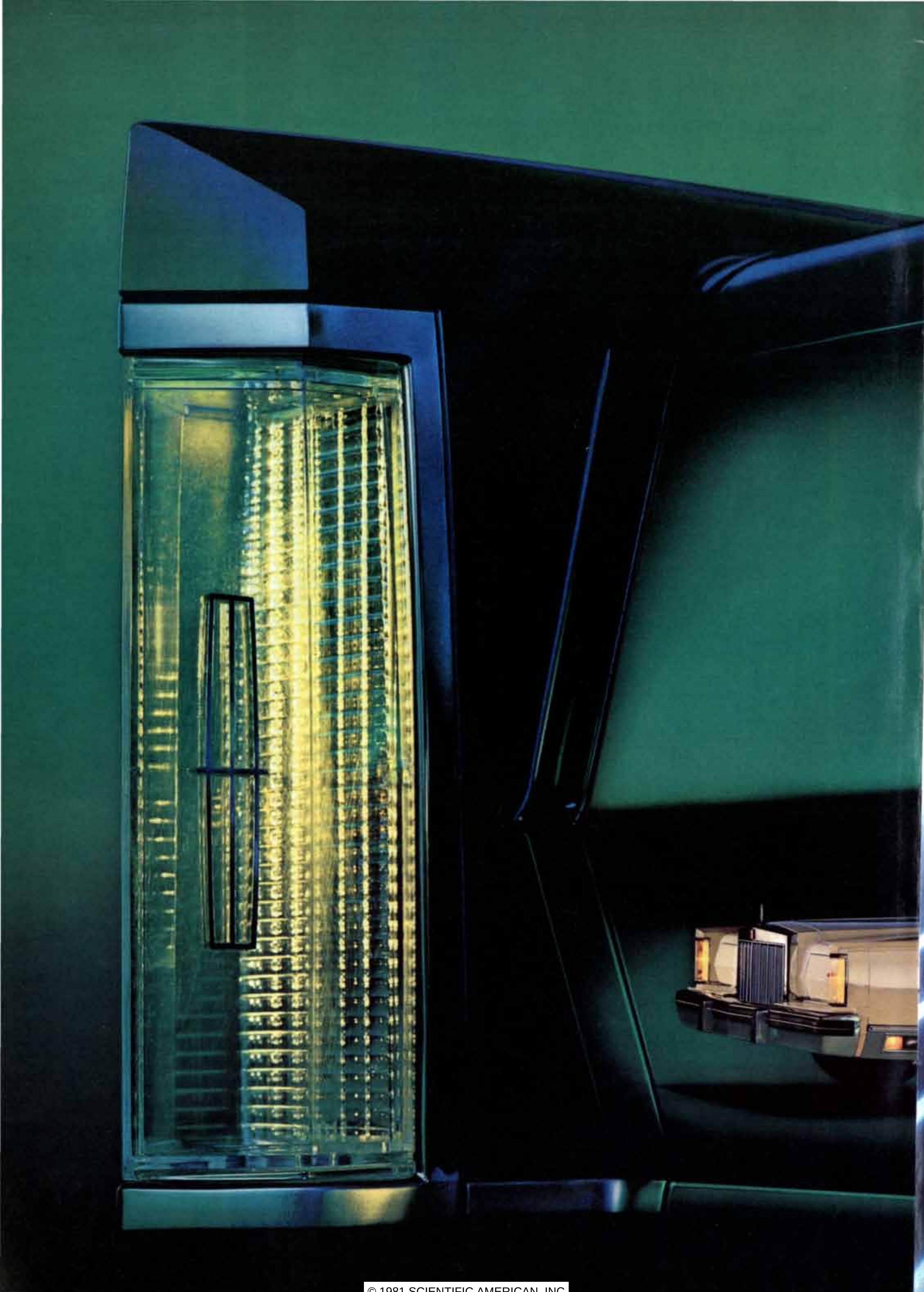
In the 1960's, when Keynesian economics was still carrying all before it ("We are all Keynesians now," said Richard Nixon), many economists were impressed by the Phillips curve. This curve was first proposed in 1958 by the London economist Alban William Housego Phillips, and it was applied to the U.S. economy in 1960 by the neo-Keynesians Paul A. Samuelson and Robert M. Solow. As you can see from the illustration on page 24, a typical Phillips curve plots the inverse relation between unemployment and inflation. By taking into account the ability of labor and business to administer prices, the Phillips curve indicates that the double goals of full employment and price stability are not compatible in a mixed economy. Full employment (*F*) is attainable only at the cost of steady inflation. Stable prices (zero inflation) are impossible without high unemployment (*U*).

What to do? The best we can hope for, implies the curve, is to find a reasonable trade-off that does the minimum amount of harm. If prices rise too high, let a recession pull them down. If too many people are out of work, let inflation restore their jobs. With luck a government may find a point on the curve where "normal" unemployment will combine with an acceptable mild inflation of, say, 4 or 5 percent per year.

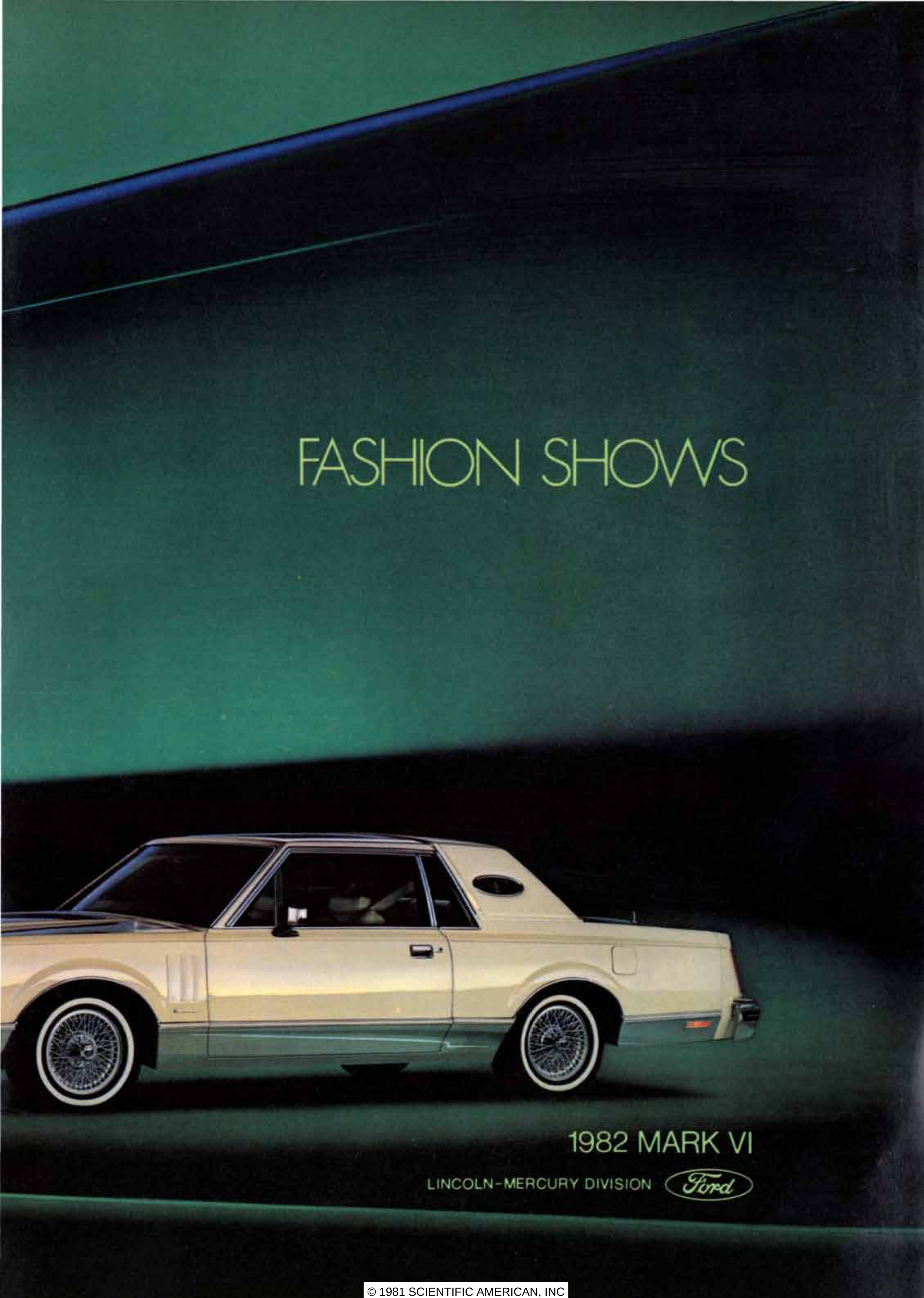
Then something funny happened. The economy, in the U.S. and elsewhere, got itself into the mysterious state of "stagflation," where contrary to the Phillips curve unemployment and inflation kept rising simultaneously. The process shifted the curve ominously up and out as indicated by the broken line in the illustration. The trade-off dream turned

© 1981 SCIENTIFIC AMERICAN, INC

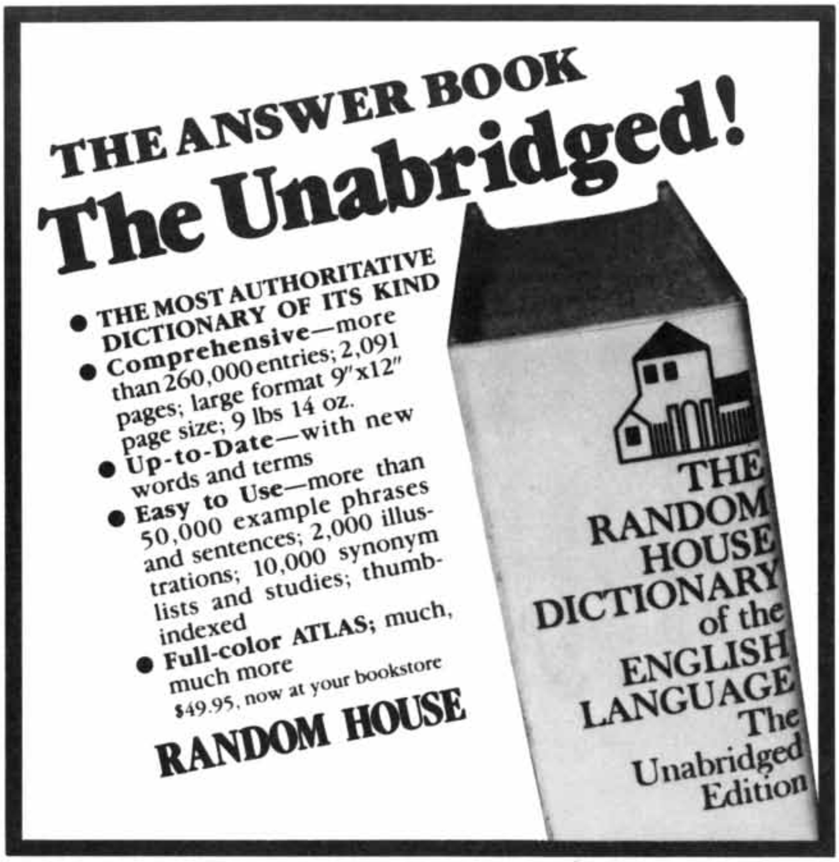
© 1981 SCIENTIFIC AMERICAN, INC



© 1981 SCIENTIFIC AMERICAN, INC



© 1981 SCIENTIFIC AMERICAN, INC



into a nightmare economists called the "cruel dilemma." A government had no "menu of choice" that would not lead to either a deep recession or a galloping inflation.

Keynesians struggled to rescue the curve. It was soon obvious that there is no such thing as a Phillips curve that is stable in the short run. The curve can be drawn dozens of ways, depending on what variables (including psychological expectations) are taken into account, and it varies widely from time to time and place to place. Is there a Phillips curve that is stable in the long run? Some say yes, some say no. Even if there is, economists disagree on how to apply it. Should the government try somehow to slide up and down the curve, with inflation and unemployment fluctuating like a seesaw? Should it try "looping" around the curve in various risky ways?

According to Keynesians, a force called demand-pull tries to twist the curve into a vertical straight line, while another force called cost-push tries to twist it into a horizontal line. The long-run curve compromises with a steep downward slope. What is needed, of course, is some way of shifting the entire curve back down and to the left to allow trade-offs that will not lead to social chaos. Some economists, for example John Kenneth Galbraith, believe this can be done now only by combining fiscal and monetary policies with wage and price controls. Nothing could be worse, says Milton Friedman. In Friedman's monetarist view the long-run Phillips curve is a vertical line at the "natural rate" of unemployment, and any trade-off effort to reduce unemployment below that line will set off an explosive inflation.

The Phillips curve, Daniel Bell wrote last year (summarizing earlier remarks by Solow), "provided more employment for economists... than any public-works program since the construction of the Erie Canal." Today the curve is rapidly becoming little more than an out-of-focus symbol of the fact that inflation and unemployment are not independent evils but are functionally linked in complex ways that nobody is yet able to understand.

Now, as a result of the upsurge of interest in "supply side" economics, the curve of the hour is a brand-new one called, with strangely resonant overtones, the Laffer curve. Arthur B. Laffer is a 41-year-old professor of business at the University of Southern California. The curve was named and first publicized by Jude Wanniski, a former writer for *The Wall Street Journal,* in his bible of supply-side theory, which is confidently titled *The Way the World Works: How Economies Fail—and Succeed* (Basic Books, 1978). The upper illustration on page 27 shows how Wanniski ori-

© 1981 SCIENTIFIC AMERICAN, INC

Shown smaller than actual size. Overall height: 7 inches

The National Wildlife Federation presents

THUNDER ON THE PLAINS

by Chapel

Inaugurating
the Federation's first collection
of original wildlife sculptures.
A dramatic new work
in the great tradition of
bronze animal sculpture.

Available
in a single, limited edition.
Ordering deadline:
December 31, 1981.

For the first time in its history, the National Wildlife Federation has commissioned the creation of a collection of original sculptures portraying North America's great wildlife.

Inaugurating this historic collection will be a superb sculpture of the American buffalo, entitled *Thunder on the Plains.* Finely detailed, crafted in cold-cast bronze and meticulously hand-finished, it is a brilliant study of the bison and an impressive work of art.

This new and original work has been created for the National Wildlife Federation by one of America's most gifted wildlife sculptors — Chapel. It portrays the bison in full charge — wheeling in mid-stride past a clump of prairie sage. The ominous crescent horns, the flaring nostrils, the surprising agility of its powerful body — all are captured with an artistry that is completely true to nature. A quality valued throughout the long tradition of bronze animal sculpture.

To faithfully capture all the rich detail and subtle nuances of the sculptor's art, the work will be crafted in cold-cast bronze — a medium capable of holding even finer detail than traditional hot-cast bronze. Each sculpture will be individually cast from a carefully prepared sculptor's blend of powdered bronze and resins. Once hardened, it will be meticulously finished with a fine patina — hand-rubbed to a soft luster.

Thunder on the Plains is available in a limited edition — reserved *exclusively* for those who order from the Federation's first collection of original wildlife sculptures during 1981. The appointed issuing agent, The Franklin Gallery, will fulfill all valid orders, and then the edition will be permanently closed. A Certificate of Authenticity from the National Wildlife Federation will accompany each sculpture.

As an original sculpture that will enrich your home, *Thunder on the Plains* will be a truly rewarding acquisiton. A work of art in the honored tradition of fine animal sculpture. One that will remain a source of enjoyment and a treasured family possession.

To reserve this important new work, simply return your application by December 31, 1981. No payment need accompany your order, but the attached application must be postmarked by December 31st.

© 1981 FG

RESERVATION APPLICATION

THUNDER ON THE PLAINS

Must be postmarked by December 31, 1981.
Limit: One per person.

The National Wildlife Federation 44
c/o The Franklin Gallery
Franklin Center, Pennsylvania 19091

Please accept my reservation for *Thunder on the Plains,* to be crafted for me in cold-cast bronze at $195.* plus $2.50 for shipping and handling.

I need send no money now. When my sculpture is ready to be sent to me, I will be billed for my deposit of $39.50* and, after shipment, for the balance in four monthly installments of $39.50* each.

*Plus my applicable state sales tax

Signature ____________
ALL APPLICATIONS ARE SUBJECT TO ACCEPTANCE.

Mr.
Mrs.
Miss ____________
PLEASE PRINT CLEARLY

Address ____________

City ____________

State, Zip ____________

© 1981 SCIENTIFIC AMERICAN, INC

ents the Laffer curve at the beginning of his Chapter 6.

Is it not a thing of beauty bare? As any child can see from inspecting the curve's lower end, if the government drops its tax rate to nothing, it gets nothing. And if it raises its tax rate to 100 percent, it also gets nothing. Why? Because in that case nobody will work for wages. If all income went to the state, people would revert to a barter economy in which a painter paints a dentist's house only if the dentist caps one of the painter's teeth.

The Laffer curve gets more interesting when we slide along its arm toward the center. At point *A*, where taxes are not quite 100 percent, people will find it to their benefit to take some of their income in taxable wages. At point *B* the economy hums along with unfettered high production, but because tax rates are low the government gets the same small amount it would get if taxes were at *A*.

Now look at point *E* at the extreme right of the curve. That is where the tax rate maximizes government revenue. If taxes fall below *E*, that may stimulate production, but it obviously weakens the government. Since by definition *E* is the point of maximum revenue, the government also must get less if taxes rise above *E*. The supply-siders stress many reasons for this being so. Some rich people find it unprofitable to work as productively as before. Some escape from excessive tax burdens by finding unproductive "shelters." Some even move to another country where taxes are low. If the government is relying on high taxes for welfare programs, millions of people are encouraged not to work at all. Why work if you can get almost the same income from welfare? Big corporations spend less on research and development. Entrepreneurs, the backbone of dynamic growth, are less willing to take risks. As a result of these factors and others the economy becomes sluggish and tax revenues decline.

It is important to understand, Wanniski tells us, that *E* is not necessarily at the 50 percent level, although it could be. The shape of the Laffer curve obviously changes with circumstances. Thus in time of war, when people and business are persuaded that a sacrificial effort is essential, they are willing to accept a high tax rate while they keep production booming. In peacetime they are less altruistic.

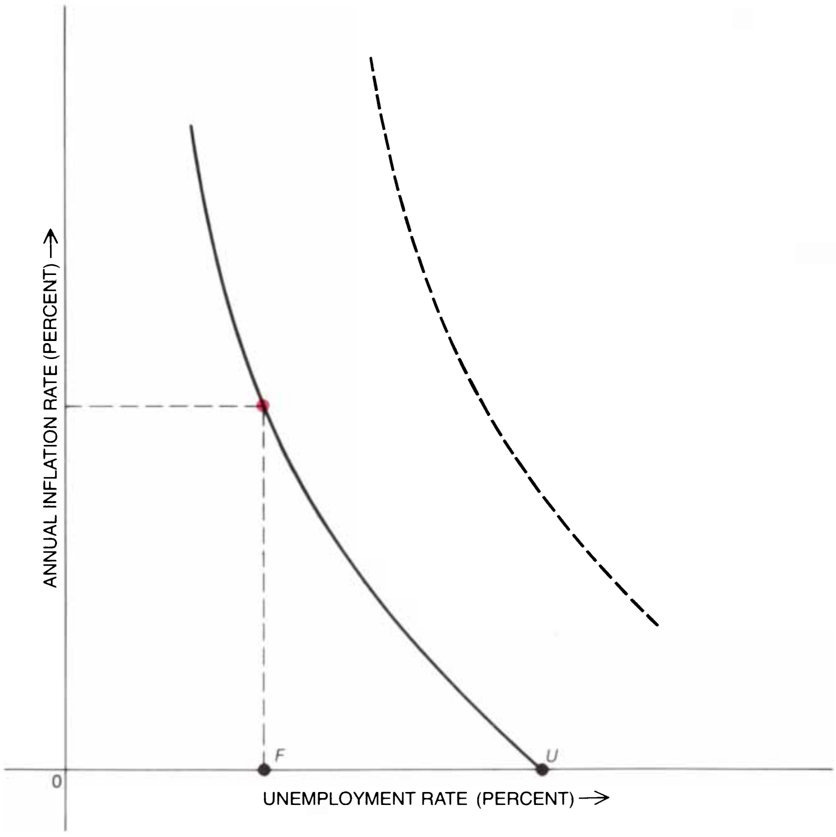
Now, the heart of the supply-side argument is the conviction that our current economy is somewhere near *C*, far too high on the Laffer curve. Lowering taxes (which some supply-siders believe calls for huge cuts in welfare spending) will give the supply side of the economy such a shot in the arm that the U.S. will slide down the Laffer curve to point *E*, perhaps not right away but soon. Tax revenues eventually will rise enough to take care of increased funding of the military, stagflation will end, dynamic growth will begin, the budget will be balanced by 1984 and the American dream will regain its luster.

Of course, supply and demand are always intertwined, but the supply-siders call themselves supply-siders in order to emphasize how they differ from neo-Keynesians. John Maynard Keynes stressed the importance of maintaining demand by minimum-wage laws and welfare payments. The Lafferites turn this around and stress the importance of stimulating supply. With the government off the back of business, production will soar, new inventions will be made, more people will be employed and real wages will rise. Everyone benefits, particularly the poor, as prosperity trickles down from the heights.

The second book to proclaim the virtues of Lafferism is George Gilder's *Wealth and Poverty* (Basic Books, 1981). The title intentionally plays on the title of Henry George's best seller *Progress and Poverty*, which created a stir late in the 19th century by recommending the abolition of all taxes except a single tax on land. Gilder's book is more impassioned than Wanniski's. "Regressive taxes help the poor!" Gilder writes in *Wealth and Poverty*. William Safire once described capitalism as the "good that can come from greed." Gilder is furious when people talk like that; he finds capitalism motivated by the good that comes from "giving." By this he means that the best way to give the poor what they want, particularly the unemployed young men of minority groups, is to leave the free market alone so that the economy will start growing again.

The trouble with the Laffer curve is that, like the Phillips curve, it is too simple to be of any service except as the symbol of a concept. In the case of the Laffer curve the concept is both ancient and trivially true, namely that when taxes are too high they are counterproductive. The problem is how to define "too high." No economist has the foggiest notion of what a Laffer curve really looks like except in the neighborhood of its end points. Even if economists did know, they would not know where to put the economy on it. Irving Kristol, defending supply-side economics in *Commentary* (April, 1981), writes that he cannot say where we are on the Laffer curve but that he is sure we are "too far up." President Reagan's across-the-board tax cuts are, he says, just what we need in order to slide the economy toward point *E*.

To bring Laffer's curve more into line



The Phillips curve

© 1981 SCIENTIFIC AMERICAN, INC

© 1981 SCIENTIFIC AMERICAN, INC

NEW NISSAN STANZA

ONLY AT YOUR DATSUN DEALER.

32 MPG,* 5 PASSENGERS BIG.

Outstanding gas mileage, spine-tingling acceleration, room to pamper five adults. All in harmony, all in Nissan Stanza, the car everyone's trying to build.

SHAPED BY THE WIND TO RUN WITH IT.

From sloping nose to sharply angled windshield to contoured roofline, Nissan Stanza is aerodynamics at its slippery best.

A spirited new NAPS-X engine powers that wind-cheating wedge to a combination of acceleration and fuel economy that is virtually unprecedented in 5-passenger cars.

ADVANCED FRONT-WHEEL DRIVE.

Nissan Stanza's weight is distributed almost equally between front and rear wheels.

This balanced stance lightens steering effort and, combined with a precise rack-and-pinion system, lets you groove around curves as though on rails.

46	32
EPA EST. HWY	EPA EST. MPG

*EPA estimates for comparison, with standard 5-speed. Actual mpg may differ depending on speed, trip length and weather. Highway mpg will probably be less. California mpg lower.

YOU CAN CROSS YOUR LEGS IN THE BACK OF A NISSAN STANZA.

Both 2- and 4-door Nissan Stanza hatchbacks treat you and your luggage to room you'd never expect in an economy car: over 100 cubic feet, riding smoothly on a wide track, long wheelbase and

refined 4-wheel independent suspension.

Nissan has been building fuel-efficient cars since gasoline was 18¢ a gallon. But we're most proud of our quality. For we are driven to bring you more miles per gallon and more years per car.

DATSUN
WE ARE DRIVEN

Product of NISSAN

© 1981 SCIENTIFIC AMERICAN, INC

with the complexities of a mixed economy dominated by what Galbraith likes to call the "technostructure," and also with other variables that distort the curve, I have devised what I call the neo-Laffer (NL) curve. (See my "Changing Perspectives on the Laffer Curve," in *The British Journal of Econometricousness,* Vol. 34, No. 8, pages 7316–7349; August, 1980.) The NL curve is shown in the lower illustration on this page. Observe that near its end points this lovely curve closely resembles the old Laffer curve, proving that it was not a totally worthless first approximation. As the curve moves into the complexities of the real world, however, it enters what I call the "technosnarl." In this region I have based the curve on a sophisticated statistical analysis (provided by Persi Diaconis, a statistician at Stanford University) of the best available data for the U.S. economy over the past 50 years. Since the data are represented on the graph by a swarm of densely packed points, the actual shape of the curve is somewhat arbitrary. Nevertheless, it dramatizes a number of significant insights.

Consider any value *r* on the revenue axis within the segment directly below the technosnarl. A vertical line through *r* intersects the snarl at multiple points. These points represent values on the tax-rate axis that are most likely to produce revenue *r*. Note that this also applies to the maximum value of *r,* producing multiple points *E* on the technosnarl. In brief, more than one tax rate can maximize government revenue.

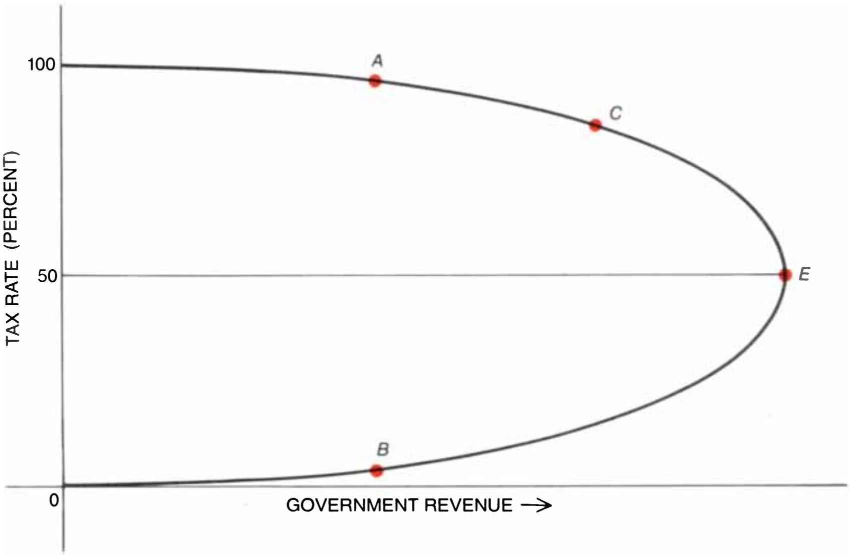
Consider any value *t* on the tax-rate axis within the segment directly to the left of the technosnarl. A horizontal line through *t* also intersects the snarl at multiple points. These points represent values on the revenue axis that are most likely to result from tax rate *t.*

Note that at some intersection points lowering taxes from a given tax rate will lower revenue, and that at other points for the same tax rate it will raise revenue. Even if we could determine at which point to put the economy, it is not clear from the snarl just what fiscal and monetary policies would move the economy fastest along the curve to the nearest point *E.*

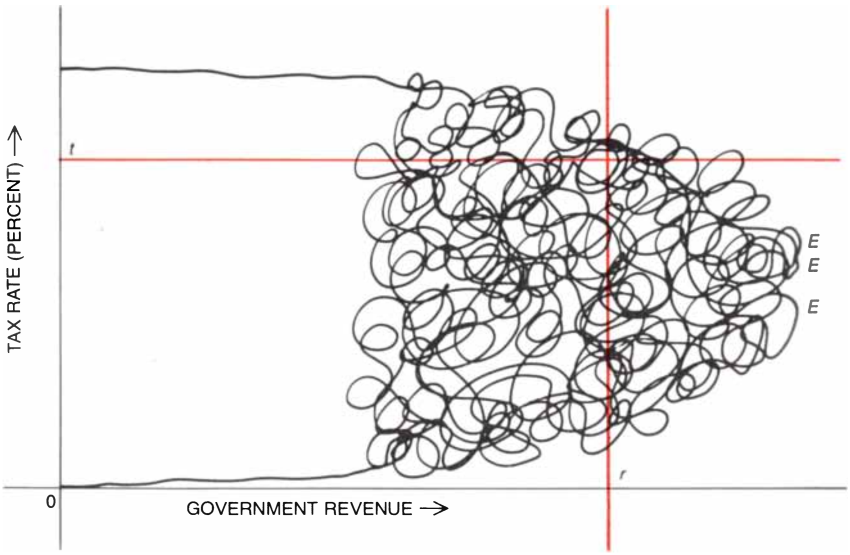
Like the old Laffer curve, the new one is also metaphorical, although it is clearly a better model of the real world. Since it is a statistical reflection of human behavior, its shape constantly changes, like the Phillips curve, in unpredictable ways. Hence the curve is best represented by a motion picture that captures its protean character. Because it takes so long to gather data and even longer to analyze all the shift parameters, by the time an NL curve is drawn it is out of date and not very useful. I have been told in confidence, however, by one of Jack Anderson's more reliable informants that the Smith Richardson Foundation has secretly funded a multimillion-dollar project at Stanford Research International to study ways of improving the construction of NL curves. It is possible that with better software, using the fast Cray computer at the Lawrence Livermore Laboratory, one will be able to assign current probability values to the multiple intersection points. If one can do so, the NL curve could become a valuable forecasting tool for rational Federal decisions.

The Lafferites combine supreme self-confidence with a supremely low opinion of their detractors. Of the 18 economists who have won Nobel prizes, only two, Milton Friedman and Gunnar Myrdal, appear in the index of *The Way the World Works.* Not even Alan Greenspan, now of the abandoned "old right," gets a mention. You might suppose that, since Friedman and Wanniski are both mentors to conservatives, Wanniski would have a high opinion of Friedman. Not so. Wanniski goes to great lengths in his book to explain why three famous economic models—Marxian, Keynesian and Friedmanian—are all wrong. They cannot even explain why the economy crashed in 1929.

There is now an enormous literature on the many causes of the crash, much of it written by eminent economists. We can throw it all away. Wanniski has figured out the real reason. There would have been nothing wrong with the stock



The Laffer curve

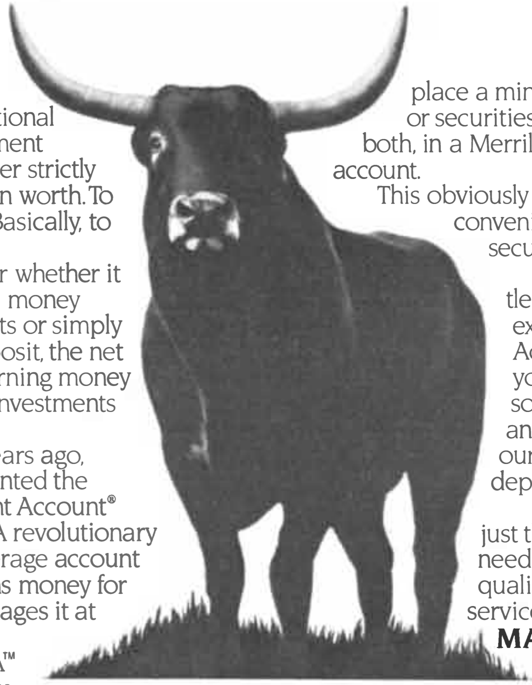


The neo-Laffer (NL) curve

© 1981 SCIENTIFIC AMERICAN, INC

IF YOUR INVESTMENTS ARE
THEY AREN'T DOING

PRESE
THE MERRILL LYNCH CASH



Until quite recently, the traditional role for an investment portfolio was rather strictly defined: To grow in worth. To provide income. Basically, to earn money.

But, no matter whether it was stocks, bonds, money market instruments or simply certificates of deposit, the net result was that earning money was all that your investments could do for you.

Then a few years ago, Merrill Lynch invented the Cash Management Account® financial service. A revolutionary new kind of brokerage account that not only earns money for you, but also manages it at the same time.

In effect, CMA™ allows your money to work continually at its maximum potential, without relinquishing the least amount of liquidity, flexibility and convenience that you demand.

Today, there is no question about CMA's proven abilities and potential for the sophisticated investor. In fact, more than 450,000 investors with over 25 billion dollars invested now rely on its many features.

The only question remaining should be how the Cash Management Account program can begin working for you, immediately.

QUALIFICATION. To open a CMA account requires that you place a minimum of $20,000 in cash or securities, or a combination of both, in a Merrill Lynch brokerage account.

This obviously affords you a safe and convenient place to hold your securities.

And, importantly, it entitles you to the services of an experienced Merrill Lynch Account Executive whom you can rely upon for sound advice, counsel and an immediate conduit to our number-one research department.

But, much more, this is just the beginning your assets need to give them the special qualities that make the CMA service so unique.

MAXIMIZATION. There is virtually no such thing as idle cash in a CMA account. On opening your account, any cash you originally place there is automatically invested in your choice of three professionally managed money market funds. The choice of which fund is best for your particular investment strategy is, of course, your decision. But the CMA Money Fund, Tax-Exempt Fund or the new Government Securities Fund can provide definite advantages for any portfolio.

Daily, the dividend on your money market fund is reinvested for you. And any cash that is generated on your securities (i.e. dividends, interest, proceeds from sales) is also automatically invested in your money fund. Without you, your

CMA™ is not available in all states. The Cash Management Account program is proprietary to Merrill Lynch, U.S. Patents Pending.

© 1981 SCIENTIFIC AMERICAN, INC

ONLY EARNING YOU MONEY, NEARLY ENOUGH.

NTING MANAGEMENT ACCOUNT.®

broker or the postman ever getting involved. So, your money continually works earning more money, without your having to work at doing anything.

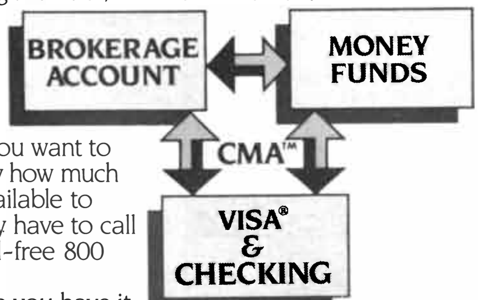
LIQUIDITY. Now, let's assume that while your money is busy working for you, it's necessary to take an important business trip. Or, on vacation in Mexico City, you spot a rare antique.

With the CMA service, you have instant access to your assets, anywhere in the world, at any time. You can make purchases. And although Merrill Lynch is not a bank, you can get cash advances when you need to.

CMA's special checking and VISA® card (provided by Bank One of Columbus, Ohio,

N.A.) are all the credentials you'll need to use your money when you want to. If there is not enough cash to cover your purchases from the balance in your money market fund, you are entitled to borrow up to the full margin value of your securities, instantly. This constitutes an automatic loan on *our* part. With no time limit of repayment on *your* part.

CONVENIENCE. At the end of each month, you'll receive CMA's comprehensive computerized statement. It lists all your transactions, and a daily reconciliation of your account. You'll have a record of everything from the market value of your security positions, including annual percent yield and estimated income, as well as all your VISA and checking activities, on one convenient form.



And, if on any business day during the month, you want to know exactly how much money is available to you, you only have to call a special toll-free 800 number.

So, there you have it: The Merrill Lynch Cash Management Account. A unique service that keeps your money working productively, while giving you immediate access to your assets.

For more complete information, including a prospectus containing all sales charges and expenses, call 800-526-3030 (in New Jersey, call 800-742-2900). Read the prospectus carefully before you invest or forward funds. We're convinced that once you realize all that your investments can do for you, you won't want to be without it.

THE MORE YOU DEMAND OF YOUR MONEY, THE MORE YOU NEED CMA.™

Merrill Lynch

Merrill Lynch, Pierce, Fenner & Smith Inc

A breed apart.

©1981 Merrill Lynch Pierce Fenner & Smith Inc Member SIPC

© 1981 SCIENTIFIC AMERICAN, INC

SAVE BIG at ELEK-TEK

NEW! SLIMLINE Shirtpocket Styled Power Packed Programmable LCD PROBLEM SOLVERS

by HEWLETT PACKARD CALCULATORS

HP-11C Scientific.......... 100
HP-12C Financial.......... 115

HP-41C......... $189
HP-41C V........ 249
Optical Wand............ 95
Card Reader........... 165
Printer.................. 285
Quad R.A.M. (for HP41C).... 75
Mem. Module (for HP41C)... 23

HP-41 APPLICATION PACS
All titles of 4K Pacs 25.50
All titles of 8K Pacs 38.00
(Not including Petroleum Fluids Pac)

HP-97.......................... $575
HP-67.......................... 295
HP-38C.......................... 115
HP-37E.......................... 59
HP-34C.......................... 115
HP-33C.......................... 69
HP-33E.......................... 49
HP-32E.......................... 43

HP-85 COMPUTING SYSTEM

The HP-85 Personal Computing System for Professionals helps solve difficult engineering problems and simplifies financial analysis. The HP-85 is a powerful BASIC language computer with keyboard, CRT display, printer and tape drive complete in one compact unit. (HP-83 is the same as above but without the built-in printer and tape drive.)

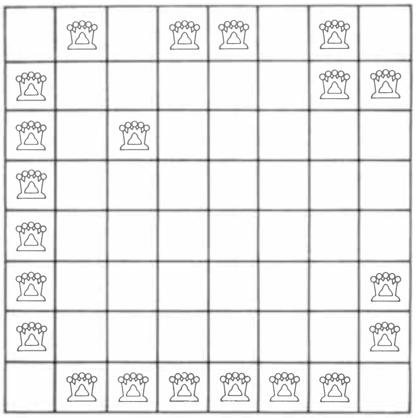
	Mfr. Sugg. Ret.	Elek-Tek Price
HP-85 COMPUTER	$3200	$2500
HP-83 COMPUTER (as HP-85 but no Printer or Tape Drive)	2250	1800
2631B PRINTER	3650	3200
82905A PRINTER	945	775
7225B PLOTTER (incl. Personality Module)	2800	2550
GRAPHICS TABLET	2050	1650
VisiCalc™ PLUS	200	162
APPLICATION PACS	95	77

and all related accessories and software at SIZEABLE DISCOUNTS
VisiCalc™ is a trademark of Personal Software, Inc.

CALL TOLL FREE 800-621-1269
EXCEPT Illinois, Alaska, Hawaii

Accessories discounted too. Corporate Accounts Invited. Mastercharge or Visa by mail or phone. Mail Cashier's Check, Money Order, Personal Check (2 wks to clear). Add $4.00 1st item, $1.00 ea. add'l shpg & handl. Shipments to IL address add 7% tax. Prices subject to change. WRITE for free catalog. ALL ELEK-TEK MERCHANDISE IS BRAND NEW, FIRST QUALITY AND COMPLETE.

ELEK-TEK, inc.
5344 W. Devon Ave., Chicago IL 60646
(800) 621-1269 (312) 631-7800



The 21-queen solution to Scott Kim's problem

market if Herbert Hoover had just left it alone. Instead he and Congress made a stupid political blunder. Writes Wanniski: "The stock market Crash of 1929 and the Great Depression ensued because of the passage of the Smoot-Hawley Tariff Act of 1930."

How did it happen that the crash occurred in October of the previous year? It is simple. The stock market, says Wanniski, anticipated the dire consequences of the coming restraints on free trade. Not all supply-siders agree. Jack Kemp, the New York congressman who coauthored the Kemp-Roth tax bill (which paved the way for Reagan's fiscal program), is one who does. In Kemp's rousing book *An American Renaissance: A Strategy for the 1980s* (Harper & Row, Inc., 1979) he assures us that Wanniski has "demonstrated beyond any reasonable doubt" the truth of his remarkable discovery.

What do professional economists make of supply-side theory? Most of them, including the most conservative, regard it in much the same way as astronomers regard the theories of Immanuel Velikovsky. To Galbraith it is "a relatively sophisticated form of fraud." Walter W. Heller has likened it to laetrile, and Solow terms it "snake oil." Vice-president Bush has called it "voodoo economics." Nevertheless, the books by Wanniski, Gilder and Kemp are said to have much influence in the current Administration.

Lafferites appear to enjoy heaping praise on one another. Laffer, the hero of Wanniski's book, is quoted on the back of the paperbound edition as saying: "In all honesty, I believe it is the best book on economics ever written." Kristol, on the front cover, is more restrained. He thinks it is "the best economic primer since Adam Smith." Gilder asserts Wanniski "has achieved an overnight influence of nearly Keynesian proportions." Gilder has been greeted with similar euphoria. David Stockman, President Reagan's budget director, has hailed *Wealth and Poverty* as "Promethean in its intellectual power and insight. It shatters once and for all the Keynesian and welfare-state illusions that burden the failed conventional wisdom of our era."

How puzzled the President must be by the violent clash between his old friend Friedman and his Lafferite advisers! (The clash is not only over Friedman's monetary views but also over his distaste for the supply-side "gold bugs" who are urging an immediate return to the gold standard.) In the business section of *The New York Times* (Sunday, July 26) Wanniski's attack on Friedman was vitriolic. The burden of it is that although Friedman is "barely five feet tall," he "weighs" so much that he is now an enormous "deadweight burden" on the backs of Menachem Begin, Margaret Thatcher, Ronald Reagan and the U.S. economy.

Will the Lafferism of the Administration succeed or will it, as many economists fear, plunge the nation into higher inflation and higher unemployment? The fact is economists cannot know. The technosnarl is too snarly. The idle rich might not invest their tax savings, as Lafferites predict, but might spend it on increased consumption. The hardworking poor and middle class might decide to work less productively, not more. The corporations and conglomerates might do little with their tax savings except acquire other companies.

Of course, ideologues of all persuasions think they know exactly how the economy will respond to the Administration's mixture of Lafferism and monetarism. Indeed, their self-confidence is so vast, and their ability to rationalize so crafty, that one cannot imagine any scenario for the next few years they would regard as falsifying their dogma. The failure of any prediction can always be blamed on quirky political decisions or unforeseen historical events. It is inconceivable, for example, that Friedman would consider the triple-digit inflation in Israel or the recent riots in Britain or high U.S. stagflation in 1983 as suggesting the slightest blemish on his monetarist views even though he enthusiastically supported Begin, Thatcher and Reagan, and all three have in turn been strongly influenced by Friedman's brand of monetarism.

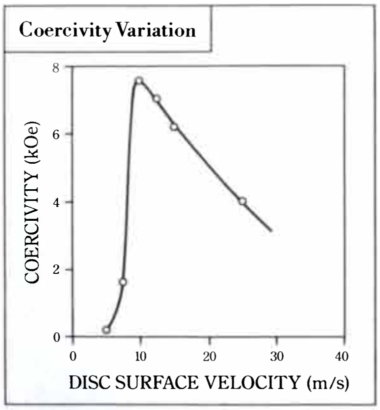
As for the Lafferites, they have all kinds of outs in case Reagan's policies lead to disaster. Some will blame it on Friedman. Others may follow an escape plan mapped out by William F. Buckley. Although the Administration's tax and budget cuts have been called the biggest in American history, Buckley thinks both cuts are not big enough. "The trouble with the Reagan tax cuts," he wrote in *National Review* (July 24), "is (*a*) they are insufficient, and insufficient-

© 1981 SCIENTIFIC AMERICAN, INC

© 1981 SCIENTIFIC AMERICAN, INC

The Critical Interval

There has long been a need in the industrial world for low-cost, high-performance permanent magnets. Recent discoveries at the General Motors Research Laboratories show promise of meeting this challenge by the application of new preparation techniques to new materials.



Coercivity of $Pr_{0.4}Fe_{0.6}$ plotted as a function of disc surface velocity.

TWO properties characterize desirable permanent magnets: large coercivity (magnetic hardness or resistance to demagnetization) and high remanence (magnetic strength). Higher-performance magnets are required to reduce further the size and weight of a wide variety of electrical devices, including d.c. motors. Such magnets are available, but the cost of the materials necessary to produce them severely limits their use. The research challenge is to select, synthesize, and magnetically harden economically attractive materials of comparable quality.

Prominent among alternative materials candidates are alloys composed of iron and the abundant light rare earths (lanthanum, cerium, praseodymium, neodymium). Investigations conducted by Drs. John Croat and Jan Herbst at the General Motors Research Laboratories have led to the discovery of a method for magnetically hardening these alloys. By means of a rapid-quench technique, the researchers have achieved coercivities in Pr-Fe and Nd-Fe that are the largest ever reported for any rare earth-iron material.

Drs. Croat and Herbst selected praseodymium-iron and neodymium-iron based upon fundamental considerations which indicate that these alloys would exhibit properties conducive to permanent magnet development. These properties include ferromagnetic alignment of the rare earth and iron magnetic moments, which would foster high remanence, and significant magnetic anisotropy, a crucial prerequisite for large coercivity.

That these materials do not form suitable crystalline compounds, an essential requirement for magnetic hardening by traditional methods, presents a major obstacle. Drs. Croat and Herbst hypothesized that a metastable phase having the necessary properties could be formed by cooling a molten alloy at a sufficiently

Color-enhanced transmission electron micrograph of melt-spun $Nd_{0.4}Fe_{0.6}$ having 7.5 kOe coercivity.

© 1981 SCIENTIFIC AMERICAN, INC

rapid rate. They tested this idea by means of the melt-spinning technique, in which a molten alloy is directed onto a cold, rotating disc. The cooling rate, which can be varied by changing the surface velocity of the disc, can easily approach 100,000°C per second. The alloy emerges in the form of a ribbon.

THE researchers found that variations of the cooling rate can dramatically affect the magnetic properties of the solidified alloys. In particular, appreciable coercivity is achieved within a narrow interval of quench rate.

Equally remarkable, synthesis and magnetic hardening, two steps in conventional processing, can be achieved simultaneously.

"X-ray analysis and electron microscopy of the high coercivity alloys reveal an unexpected mixed microstructure," states Dr. Croat. "We observe elongated amorphous regions interspersed with a crystalline rare earth-iron compound."

Understanding the relationship between the coercivity and the microstructure is essential. The two scientists are now studying the extent to which the coercivity is controlled by the shape and composition of the amorphous and crystalline structures.

"The development of significant coercivity is an important and encouraging step," says Dr. Herbst, "but practical application of these materials requires improvement of the remanence. Greater knowledge of the physics governing both properties is the key to meeting the commercial need for permanent magnets."

THE MEN BEHIND THE WORK

Drs. Croat and Herbst are Staff Research Scientists in the Physics Department at the General Motors Research Laboratories.

Dr. Croat (right) received his Ph.D. in metallurgy from Iowa State University. His research interests include the magnetic, magneto-elastic and catalytic properties of pure rare earth metals and their alloys and compounds.

Dr. Herbst (left) received his Ph.D. in physics from Cornell University. In addition to the magnetism of rare earth materials, his research interests include the theory of photo-emission and the physics of fluctuating valence compounds.

Dr. Croat joined General Motors in 1972; Dr. Herbst, in 1977.

GM General Motors
The future of transportation is here

© 1981 SCIENTIFIC AMERICAN, INC

ly targeted; and (*b*) the cuts in the budget are equally insufficient.... You cannot make long-range, significant cuts by concentrating on only a single one-third of the budget. It is the equivalent of saying you are going to lose weight by exercising only your right leg."

One can hope that President Reagan will not try to reconcile these conflicting conservative views by resorting to astrology. This possibility is not quite as remote as one might think. In an interview with Angela Fox Dunn the President said he followed the daily advice for his sign in the syndicated horoscope of Carroll Righter. Born on February 6, Reagan is an Aquarian. "I believe you'll find," he told Dunn (*The Washington Post*, July 13, 1980), "that 80 percent of the people in New York's Hall of Fame are Aquarians."

President Reagan and his wife Nancy have for many years been personal friends of both Righter (who advises Gloria Swanson and other Hollywood figures) and the astrologer Jeane Dixon, who lives in Washington. "I'm not considered one of his advisers," Dixon cryptically told Warren Hinckle (*San Francisco Chronicle*, July 19, 1980), "but I advise him." Joyce Jillson, who writes a syndicated astrology column for *The Chicago Tribune* and has among her clients several Hollywood studios and multinational corporations, says that last year Reagan aides paid her $1,200 for horoscopes on eight prospective vice-presidential candidates. The White House communications director has, however, called her a liar. Michael Kramer writes (*New York*, July 21, 1980): "Ronald Reagan, says Ronald Reagan, is a nice, well-intentioned man who loves his family, likes to consult his horoscope before making major decisions, and cries when he watches *Little House on the Prairie*."

Will the President seek help from the zodiac in trying to decide whether to follow Friedman or Laffer or someone else? One may never know. As the Yale economist William Nordhaus put it (*The New York Times*, August 9): "We can only hope that supply-side economics turns out to be laetrile rather than thalidomide."

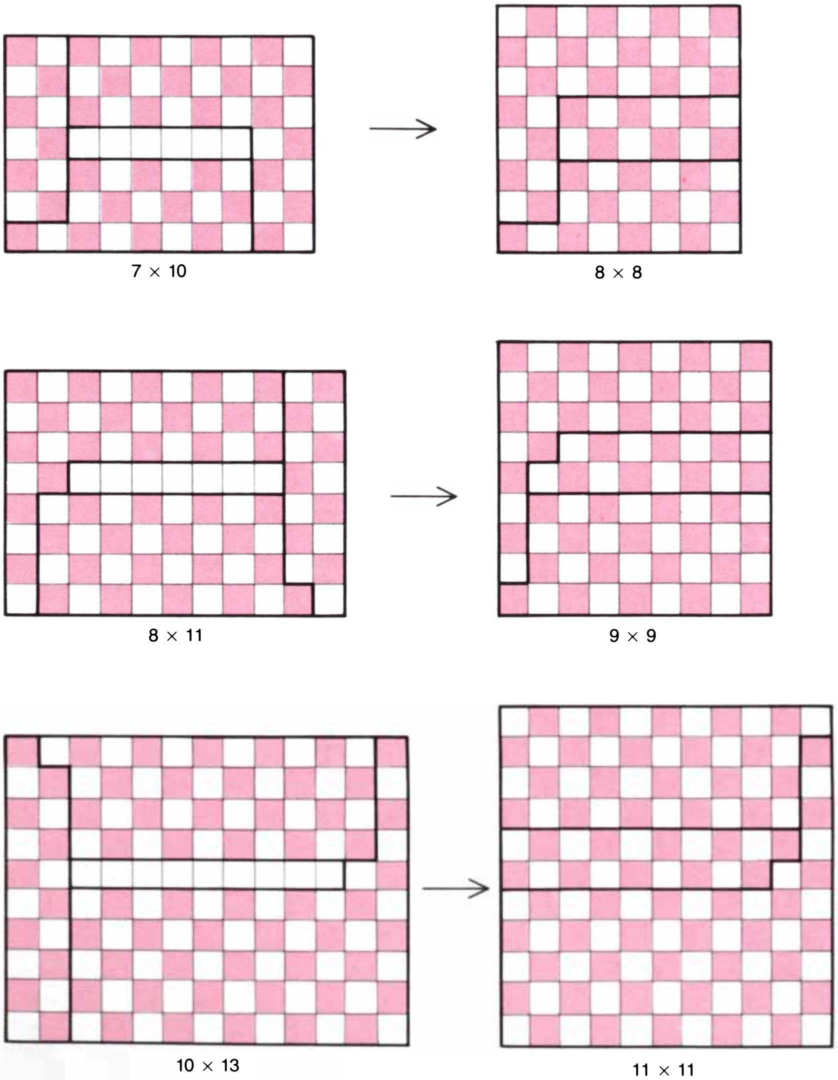
Last June I showed how a square sheet of paper can be folded obliquely along four sides to produce a shape that lacks any plane of symmetry yet is superposable on its mirror image. Paul Schwink of Carlisle, Iowa, and Piet Hein of Copenhagen pointed out that the solution is unnecessarily complicated. The same result can be obtained by folding just one pair of opposite sides, one up, one down.

In August I gave the best-known solution to Scott Kim's problem of placing the maximum number of queens on a chessboard so that each queen attacks exactly four other queens. Jeffrey E. Spencer went Kim one better by finding a solution with 21 queens. This unexpected pattern is shown on page 30. Is it maximal? No one knows.

Writing about the parabola in August, I said that if y equals x^2, the curve's vertex is on the directrix. The vertex can never be on the directrix. George Andrews was the first of many to catch this mistake. If y equals x^2, the vertex is at 0,0, the focus is at $\frac{1}{4}$,0 and the directrix is the line $x = -\frac{1}{4}$. I also said that as you lower a garden hose the tops of the parabolic jets trace a parabola. This is not so. It is the envelope of these curves that is a parabola, as Bernard M. Oliver was the first to point out.

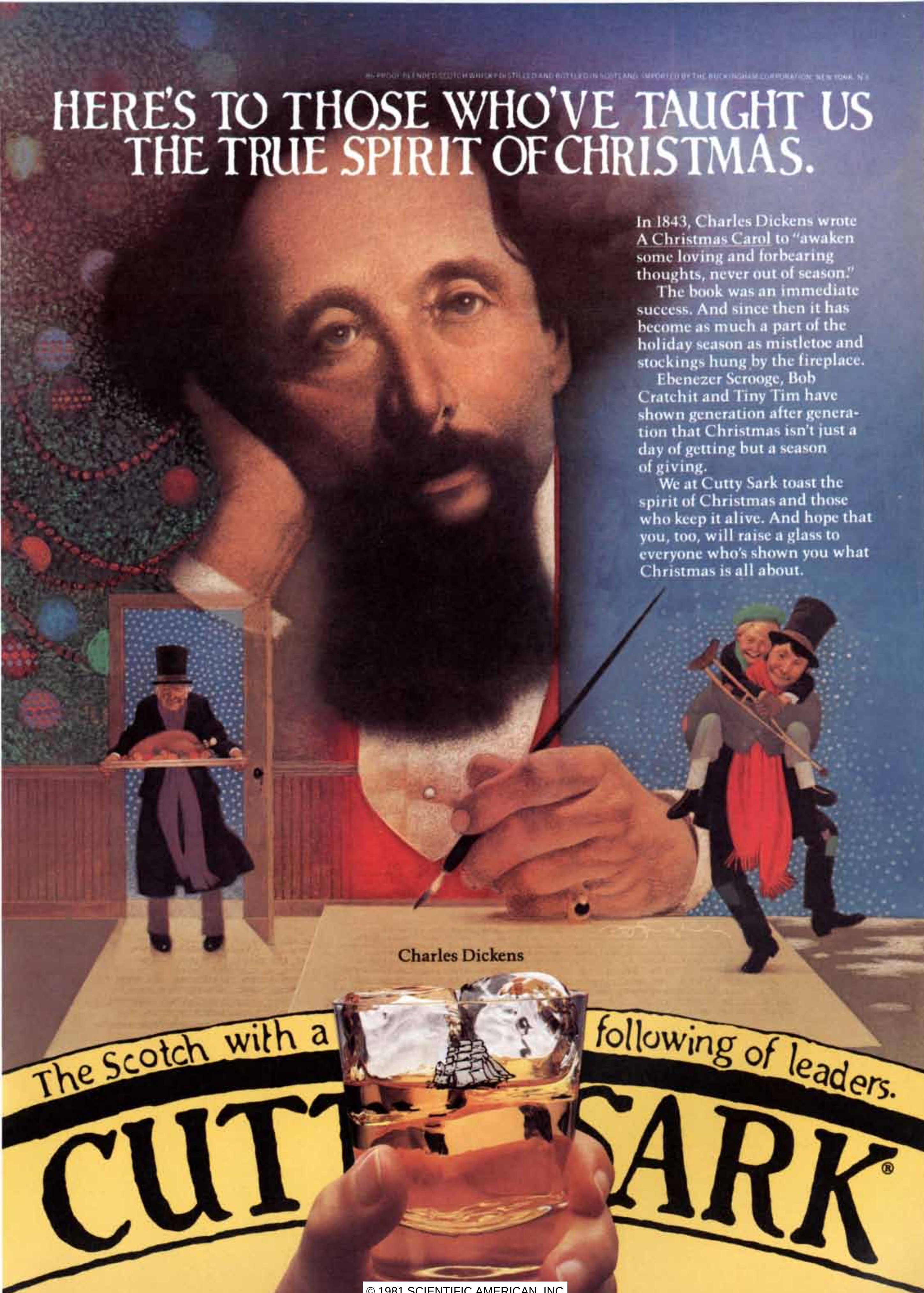
Many readers confirmed a conjecture reported in August that in the long run, using present Gregorian rules for Easter, April 19 is the commonest Easter date. Lawrence Joseph, Charles Kluepfel and Francis P. Larkin arrived at this result by reasoning from available data. Malcolm Baker, Robert B. Caldwell, Randolph J. Herber, Herman Sallé and Eryk Veshen were the first of many who worked with computer programs to test extremely long future spans. All found April 19 to be the most frequent date and March 22 the least frequent.

In October readers were asked to cut a chessboard-colored rectangle with a hole into three pieces that could be reformed (reflections allowed) to make a standard chessboard that would preserve the coloring. How it is done is shown at the top of the illustration at the left. The generalization to squares of even-numbered sides is obvious. For odd-sided squares of side n one must distinguish between $n = 1$ (mod 4) and $n = 3$ (mod 4). Examples of each are shown at the middle and bottom of the illustration. Again it is easy to see how the solution generalizes.



Solutions to mutilated chessboards

© 1981 SCIENTIFIC AMERICAN, INC



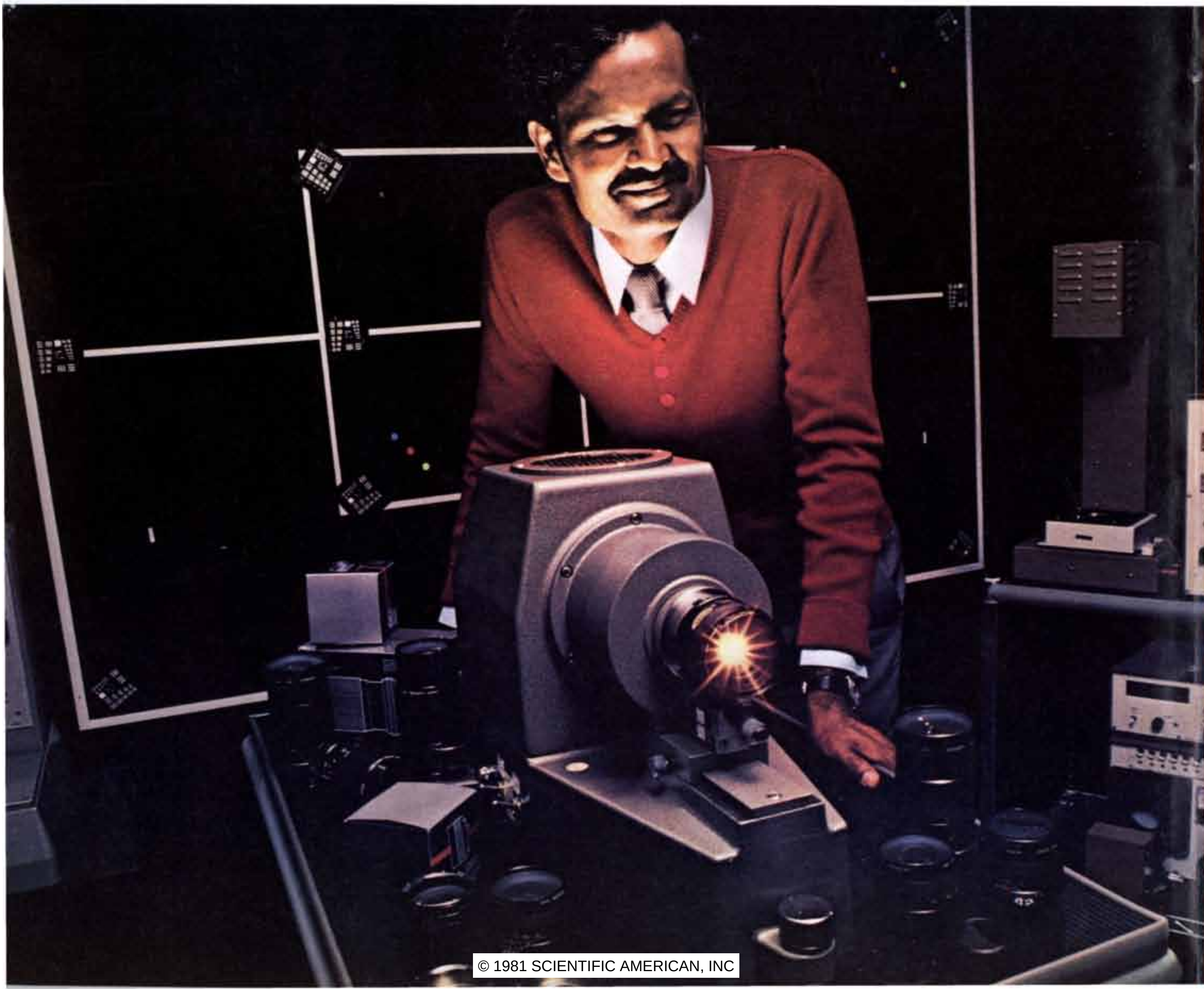
© 1981 SCIENTIFIC AMERICAN, INC

Reddy Chirra improves his vision with an Apple.

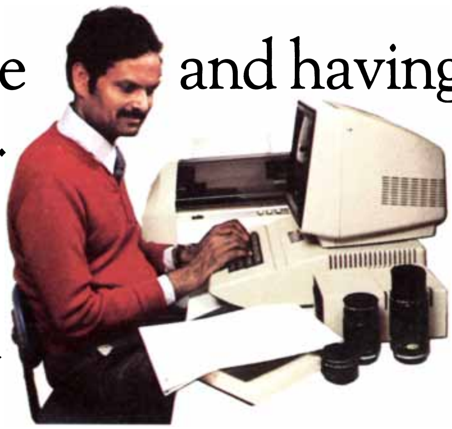
Reddy is an optical engineer who's used to working for big companies and using big mainframes.

But when he started his own consulting business, he soon learned how costly mainframe time can be. So he bought himself a 48K Apple II Personal Computer.

And, like thousands of other engineers and scientists, quickly learned the pleasures of



© 1981 SCIENTIFIC AMERICAN, INC

cutting down on shared time  and having his own tamper-proof data base.

His Apple can handle formulas with up to 80 variables and test parameters on 250 different optical glasses.

He can even use BASIC, FORTRAN, Pascal and Assembly languages.

And Apple's HI-RES graphics come in handy for design.

Reddy looked at other microcomputers, but chose Apple for its in-depth documentation, reliability and expandability.

You can get up to 64K RAM in an Apple II. Up to 128K RAM in our new Apple III. And there's a whole family of compatible peripherals, including an IEEE-488 bus for laboratory instrument control.

Visit your authorized Apple dealer to find out how far an Apple can go with scientific/technical applications.

It'll change the way you see things.

The personal computer. apple®

For the authorized dealer nearest you, call (800) 538-9696. In California, call (800) 662-9238. Or write: Apple Computer Inc., 10260 Bandley Dr., Cupertino, CA 95014.

© 1981 SCIENTIFIC AMERICAN, INC

hexa·photo·cybernetic
The Possibilities are Endless.

Shutter-Priority 1000 5.6

Six-mode exposure control.
System versatility. Newer electronics for wider applications.

The Canon A-1 is one of the world's most advanced automatic SLR cameras. Combining the finest in optical and mechanical engineering with the most sophisticated electronics, it's technology applied to give you the ultimate in creative control. At the touch of a button.

Depending on your subject, you can choose from six independent exposure modes to achieve the results you want:

1 Shutter-Priority: You select the shutter speed, to freeze the action and prevent camera shake or create an intentional blur. The A-1 automatically selects the appropriate lens opening.

2 Aperture-Priority: Control the area in focus by selecting the lens opening for the effect you want. The A-1 matches with the right speed.

3 Programmed: When you need to shoot fast, just focus. The A-1 will select *both speed and aperture* for great results.

4 Stopped-Down: For extreme close-up or specialized photography, a bellows, a microscope or almost anything can be attached to the A-1. It's still automatic.

5 Flash: Totally automatic flash photography, of course, with a wide variety of Canon Speedlites to choose from.

6 Manual: Yes. For those times when you absolutely want to do it all yourself. To experiment. To explore the possibilities.

There are over forty fine Canon lenses ranging from Fish Eye to Super Telephoto, plus accessories to meet every need. If you can't photograph your subject with a Canon A-1, it probably can't be photographed.

From the sophistication of its LED viewfinder display, to a ruggedness that allows up to five-frame-per-second motor drive, the Canon A-1 represents an incredible technology. At a price that makes owning one a definite possibility.

Canon A-1

Canon USA, Inc., One Canon Plaza, Lake Success, New York 11042 • 140 Industrial Drive, Elmhurst, Illinois 60126 • 6380 Peachtree Industrial Blvd., Norcross, Georgia 30071 • 123 Paularino Avenue East, Costa Mesa, California 92626 • Bldg. B-2, 1050 Ala Moana Blvd., Honolulu, Hawaii 96814 • Canon Canada, Inc., Ontario

© 1981 Canon U.S.A., Inc.

© 1981 SCIENTIFIC AMERICAN, INC

BOOKS

A Christmas collection of books about science for younger readers

by Philip and Phylis Morrison

Physical Sciences and Engineering

THE PRESIDENT'S CAR, written and illustrated by Nancy Winslow Parker. Thomas Y. Crowell ($8.95). JANE'S POCKET BOOK OF RECORD-BREAKING AIRCRAFT, compiled by Kenneth Munson. Collier Books, Macmillan Publishing Co., Inc. ($8.95). Theodore Roosevelt never rode in an automobile while he was in the White House. The Secret Service, formerly only the bane of counterfeiters, began its duty of protecting the president by following in its own open White Steamer Teddy's lacquered black two-horse brougham with its cockaded coachman. William Howard Taft was the first president to dispose of plenty of horsepower; he too had a White Steamer, a big touring car that cost the taxpayer $4,000. The armored limo called 200X is today's chosen vehicle, as it has been for seven years, complete with flashing red lights, holstered submachine guns, steel-reinforced tires and tie-down hooks welded to the frame for air shipment.

The father of our country sought a high profile. His state coach—the munificent London-made gift of the governor of Pennsylvania to Martha Washington—was a yellow-and-white gilded beauty, a few panels of which survive. The hammercloth (the droll pen-and-ink drawings that here cover every presidentiad include carefully labeled details to illustrate a fine technical glossary of horse and car) was of leopardskin "trimmed in red and gold lace." Thomas Jefferson, Democrat and democrat, rode horseback to his inauguration and back home to Monticello when his term had ended. The first American-made presidential carriage was a gift to Millard Fillmore; the coachmakers of London evidently were the Rolls-Royces of their day. Calvin Coolidge never allowed his drivers to exceed a thrifty 16 miles per hour in any of the dozen White House cars, all rentals. A couple of dozen presidential vehicles, from Washington's at Mount Vernon to two of Richard Nixon's, are now on public exhibition; a list of where to see them all closes this delightful and instructive book, open to young readers and readable for just about any American.

Such reviews of the past, visually setting a piece of technology in a single repetitive social context, share the virtues of coordinate paper for displaying a curve. They set change against a fixed lattice. The second of these books is as sober and deadpan as the first is artful and humorous, but its method is the same. An inexpensive pocket paperback, it presents photographs with elaborate (and overprecise) specifications for all the aircraft that have held official world records for absolute speed, height and distance. The first speed record was set by the 14-*bis,* whizzing around the Eiffel Tower in 1906 with its brave pilot, Alberto Santos-Dumont, standing upright in a wicker basket with the wind in his face at 26 m.p.h. The current speed record is held by Lockheed's all-titanium blackbird *SR-71A,* its record set in 1976 at about 2,200 m.p.h. (It holds the altitude record as well.)

The book is the treasury of facts enthusiasts enjoy, and it also offers a sharp look at aviation history, civil and military. The plateau of aircraft speed was reached in the early 1960's; that titanium speedster was built in 1964. Until then the speed record had risen with surprising smoothness from the days of wood and wire. Even the coming of the jets was not a sharp step; the Fairey delta-wing may have cut one in about 1954, although the effect is confused by a rules change that allowed the speed record to be set at higher altitude, where jets perform at their best. The maturing of Russian aviation, particularly in high-performance helicopters and heavy aircraft, is conspicuous in later years. The first mention of Andrei Tupolev goes back to 1933, when the plane he built flew from Moscow to California over the North Pole. Its designer under Tupolev's leadership was P. O. Sukhoi, a name still in the news. Some outlandish planes are seen: pilotless, piggyback, tiny. Louis Blériot, Charles Lindbergh, Billy Mitchell, Jimmy Doolittle, Howard Hughes or their planes all cross the stage.

THUNDER, SINGING SANDS, AND OTHER WONDERS: SOUND IN THE ATMOSPHERE, by Kenneth Heuer. Dodd, Mead & Company ($8.95). The whisper

The treasure is still there.
No one has yet unearthed the golden hare—
the treasure of Masquerade.
The challenge is still there.
The person who can find the golden hare
will be famous and rich.
An illustrated fantasy in glowing color containing a treasure hunt for a golden hare.


360,000 copies in print.
Over 30 weeks on The New York Times best-seller list.
And now there's a Masquerade Calendar for 1982
At all bookstores
Schocken Books
200 Madison Avenue, New York 10016

© 1981 SCIENTIFIC AMERICAN, INC

Wonders of the Universe 1982 Calendar

Galaxies, nebulae, star clusters, planets, the aurora, even the fiery launch of Space Shuttle. Every page a large color photograph of an astronomical spectacular from the world's greatest observatories including: Anglo-Australian, Kitt Peak, Lick, Palomar, U.K. Schmidt, U.S. Naval Observatories, and NASA spaceprobes.

These calendars make wonderful gifts; photographs are suitable for framing.

- ☐ **Enclosed is $7.95 (6.95 plus $1 postage) for one calendar**
- ☐ **Enclosed is $7.50 each for 2 or more calendars**
- ☐ **Enclosed is $1.00 for complete astronomical catalogs**

SHIPPED FIRST CLASS POSTAGE
ADD $5.00 PER CALENDAR FOR FOREIGN AIRMAIL POSTAGE

Send check or money order to:

Hansen Planetarium

15 South State Street, Dept. SAH-12
Salt Lake City, Utah 84111

The true story of the gorilla who can chat, tease, argue, joke, question, insult— and even lie.

"*The Education of Koko* is more than a charming story about animals; it is a valuable tool in our exploration of how we learn to communicate, how we, as well as apes, learn language."
—***Publishers Weekly***

THE EDUCATION OF
KOKO
by Francine Patterson and Eugene Linden

Main Selection of Book-of-the-Month Club/Science
Alternate Selection of Book-of-the-Month and Natural Science Book Clubs

$15.95 Holt, Rinehart & Winston

of the tree is its summed aeolian tones, eddies in the wind characteristic of the species, of the shape and size of its twigs. Just as the hum of a swarm of bees is pitched to that of the average bee, so is the whisper of a tree pitched to that of a single twig. Pines sigh in sibilant tones, the oak grumbles. Intensity adds, so that the forest murmurs loud; one can hear it a mile away. The mountain roars louder still, its sounds concentrated by the descending wind. The best time to listen is in winter, with the leaves gone. A dead tree lodged in the fork of some standing neighbor becomes a devil's fiddle, the sound arising from stick-and-slip motions, like the sound of a rosined bow. "If you are alone at night in a forest when a storm is gathering, you will jump to this music of the Prince of Darkness." It was the rustle of leaves one against another that gave voice to the oracle of Zeus at Dodona; the voice of Indian corn can be heard in windy autumn fields all over America.

This book for readers in the higher grades is perhaps the first one written on meteorological sounds in general: the clap and rumble of thunder, the patter of rain, the boom of ice-crusted lakes, the swish of the aurora, the sizzle of St. Elmo's coronal fires, the loud report of the snowquake. The book sustains the sense of wonder as it explores the subtleties of the physical world of motion that suffuses the air to stimulate our ears. The author recollects the cry of cold snow crystals breaking under his boots, the cracking of the rafter joints in his grandfather's country house on cold winter nights, the hum of the old telegraph wires. He has searched out the music and its causes from scientific journals and texts, but he has not forgotten to read the poets "who have always been interested in them."

Evocative, simple, its genuine learning lightly worn, this text itself plays a new variation on an old and universal theme. To his words Heuer has added a complement of pictures both fresh and apt. An avalanche roars down a cliff behind Zermatt, and the disastrous aftermath of another is shown in a little canton town, its tall houses standing waist-deep in snow. We do not understand it all yet; the singing sands of Massachusetts and those of the Mountain of the Bell on the coast of the Suez surely originate in the rubbing of grains of unusual uniformity of size, but just how? There are initial references for those who would explore. A stethoscope held against the floor of any house admits the listener to an unexpected concert.

THE HANDBOOK OF PHOTOGRAPHIC EQUIPMENT, by Adrian Holloway. Alfred A. Knopf, Inc. ($15.95). THE DARKROOM HANDBOOK, by Michael Langford. Alfred A. Knopf, Inc. ($25). All the top lens makers market telephoto magnifying lenses for 35-millimeter cameras. A fine lens of this sort, with a focal length of say 500 mm., will magnify about tenfold; the normal field of 46 degrees is reduced to about five degrees. A wide river scene with a distant boathouse on the far bank turns into a shot of an inviting white portico. Nowadays the same performance can be had with a stubby catadioptric system, folding up the light path with a system of elegantly figured lenses and mirrors. Such a piece of modern optics is not cheap, but it might weigh only a pound and a half compared with the standard long lens's six pounds. Its defects are different too; the light is a little dulled by the reflections, and the pale out-of-focus disks of the telephoto lens become vague rings in the hybrid system.

The Handbook of Photographic Equipment is a highly expert compilation that surveys in such a way the entire international marketplace of modern photography, from fixed-focus snapshot cameras to entire systems: lenses, cases, bodies, filters and radio remote control. It includes lights, studio gear, film processing, darkroom designs and printing. The available devices are drawn and diagrammed, their strong and weak points are discussed and often illustrated by sample images, and a series of manufacturers are named with price ranges. The tone is that of a consumer's guide, but final decisions are left to the reader; there are no rankings or best buys. Every interested high school library or club would find such a work valuable, both in the dollars and cents of proper choice and in the simple good sense of understanding purposes, compromises and results. It amounts to a knowing field guide to the glittering shops and the hyperbolic advertisements of this very popular activity for young people.

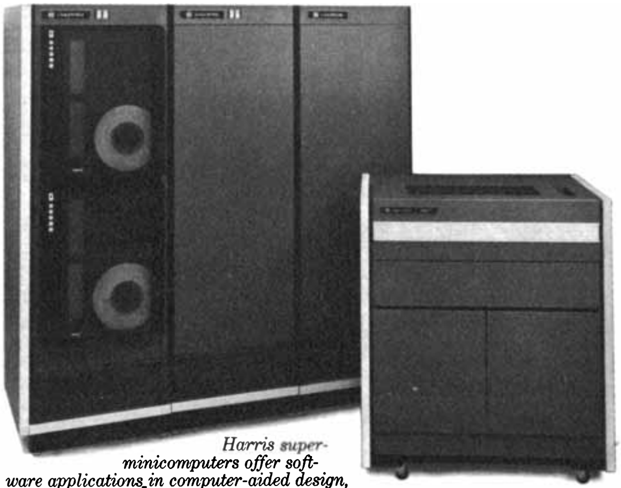
The Darkroom Handbook is even more widely interesting. It shares the mode of the first book: terse, factual pages, replete with diagrams, captioned sequences of steps in a process, sample images, careful comparisons in word and picture. About a third of the book is practical and explanatory, describing from the start a home darkroom and a big professional one, with detailed chapters on processing and printing in black and white and in color. The rest of the volume sticks to explaining how to do it, what tools to use and how they work. It goes beyond the straightforward darkroom, however, to manipulations of the photographic image, basic and advanced, and then beyond the darkroom to the artist's studio. Pushing or pulling the development of negatives that have been exposed defectively is only a start; you go on to airbrush retouching, masking, dodging, montages, multiple images, line prints and reliefs, bleaching and dying, and even hand embroidery on photolinen.

An entire gallery opens up as you turn these pages, from the cameraless shad-

© 1981 SCIENTIFIC AMERICAN, INC

HARRIS HAS A SOLUTION FOR YOUR COMPANY'S BIGGEST PROBLEM:

SOLUTIONS FOR YOUR COMPANY'S SMALLER PROBLEMS.



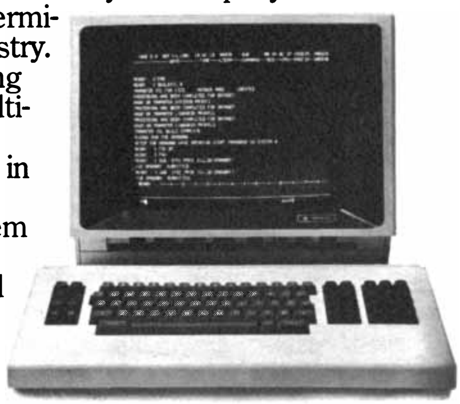
Harris super-minicomputers offer software applications in computer-aided design, simulation and some 300 other areas.

Most big companies are made up of a lot of smaller companies. They're called *departments.* And each has its own way of doing business.

It's the business of management to make sure that the efforts of each department work in concert with the rest. And that's a job Harris can make a whole lot easier.

We offer super-minicomputers for your R&D and technical people that are unmatched in power, performance and reliability.

The people who run your company's data center will appreciate our line of communications-oriented computer terminals (remote batch and interactive). It's the broadest in the industry.

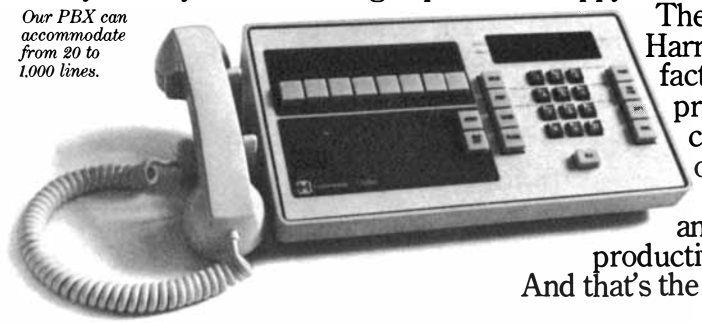


Our data terminals can grow into sophisticated distributed data processing systems.

Your MIS executives will value our distributed data processing systems for their speed, power and unique capabilities. Like multi-host support and word processing options.

Your communications managers will recognize the difference in bottom-line telephone costs our PBX's can make.

We also provide intelligent telephones, a unique private tandem networking capability and business satellite earth stations that can further reduce your telecommunications costs. And that will surely make your accounting department happy.



Our PBX can accommodate from 20 to 1,000 lines.

The fact is, Harris manufactures products that can improve the productivity of people in every one of your departments. What's more, because they're designed for future expansion and compatibility, they can maximize *corporate* productivity, too.

And that's the biggest contribution we can make.

HARRIS

For a copy of the Harris Integrated Information Processing Systems brochure, send your business card or write on your company's letterhead to Jack C. Davis, Group Vice President, Department 3, Information Systems, Harris Corporation, 1025 West Nasa Boulevard, Melbourne, FL 32919. Or phone 305-727-9100.

© 1981 SCIENTIFIC AMERICAN, INC

owgraphs of the Dada epoch to the most striking hybrids in today's color advertisements and serious works of art. The reader begins to understand the subtle nature of photographic evidence, the richness and variety of the visual mode of perception. It is a lesson in transformations, compelling even for one who will never enter the darkroom of ingenuity. Ansel Adams is not forgotten: the real world's fine detail as it was presented by the moment.

Both of these books originate in London; they were "conceived, edited and designed" by a firm there. Their amalgam of clarity and professionalism is not easy to match anywhere.

A Field Guide to the Atmosphere, text and photographs by Vincent J. Schaefer and John A. Day. Drawings by Christy E. Day. Houghton Mifflin Company ($13.95). Twenty years in gestation, this stout little volume draws on a lifetime—two lifetimes—of attentive thought and action. It is not in fact a handbook of introductory meteorology, although it has something in common with one. It is just what it says, a field guide to the atmosphere, in the sense that its topic is what anyone can see and feel here in the lower depths of the earth's sea of air.

What can you see? First of all clouds, with their kindred mist, fog, haze, drizzle, rain and a good deal more. Second, the glory of color, from twilight bands to the dawn rays, not to forget the less usual gifts of rainbow, glory, parhelia and the rest. Then there is snow, frost and hail, in motion and at rest in heaps and columns, or preserved as plastic replicas. These are the topics of the guide. Not one weather map is to be found; even the idea of the large-scale forces that cause the slow rotation of weather systems is relegated to one helpful page among the plentiful tables and diagrams of the appendixes.

There are explanations and numbers aplenty: it is the particles in the air by sea and land that are counted and catalogued. Clear blue sky is the ubiquitous sign of purity; the blue haze of the desert is the mark of terpenes from the chaparral; the gray haze records the soft nuclei of the seashore or the pollen of spring inland; browns and smoke blues are the signs of careless mankind. A couple of hundred clear and well-annotated photographs sample all the variety of clouds; it is not their names that are the center of interest but what clouds are and how they formed. For example, woolly puffs of a high convective layer show the formation of cloud droplets by cooling as the air rises, compensated in downward regions between the puffs, where the air stays clear.

These pleasures of the air are open to everyone, although it is true that the city, its views blocked, its skies soiled, is not the place these watchers would choose to be. Even there, however, remarkable things can be done. There are 15 experimental tasks described here; they sound as though they are not simply hopes but paths known by experience to lead somewhere. They call for tape and glue and polyethylene tubes and the like, the string and sealing wax of our time. Home and school laboratories can hold wonders once a cold chamber (one needs a freezer chest and a slide projector) or a vortex generator is built. To sample the sizes of raindrops, say, there are no fewer than four methods: one is catching them on a nylon stocking covered with powdered sugar. This is an active path to field science, well marked and wide open. High school students or their elders who want to watch the skies for meaning will profit from this uncommonly well-illustrated book. (Be sure to choose a window seat the next time you fly by day.)

Bridges: A Project Book, by Anne and Scott MacGregor. Lothrop, Lee & Shepard Books ($9.55). The three stands of great steel tubes that join hands to carry trains over the Firth of Forth are drawn large in strong line, shown in negative on the cover of this attractive book in white outline on dark blue ground and inside as ink on paper. In the same detailed style the authors of the book have described and pictured a series of a dozen or so bridges out of the worldwide history of bridge building, from a seventh-century stone arch in China to the Gladesville Bridge in Australia, whose main arch spans 1,000 feet with its prefabricated hollow concrete voussoirs. (Anyone who does not know this term of the art will find it clearly defined here in word and sketch.) More than that, the reader is invited to action. Careful instructions are presented for building a true arch bridge, with the option of matchboxes or of little blocks carved of Styrofoam for making the voussoirs. A workable bascule lift bridge is designed to be made of cardboard, with paper-fastener bearings and matchbox counterweights. The big suspension-bridge model proposed is not the Verrazano, but it can span the living-room space between two chair backs with folded sheets of newspaper serving both as cables and as decking. Patterns are given, and the clear, enthusiastic tone of the text encourages any reader to take his place in the noble line of bridge builders. (A small partnership of architect-engineers in the middle grades is just right for the slightly repetitive tasks of fabrication.)

Heavy Equipment, written, designed and illustrated by Jan Adkins. Charles Scribner's Sons ($8.95). "They are the big machines, the heavy equipment that chews at the earth and builds on it. They are so strong! The power of a thousand horses lives in their metal hearts and nothing can stand against them."

This sharply seen detailed set of ink drawings with shadow wash is a gallery of giants. They are today's earthy myth become real. Diesel-powered, hydraulic-muscled, they are under the easy control of their proud mahouts, although where and when they work, whether they leave behind a dead land or build roads to a better future, is not quickly judged. Adkins, himself a reflective hand-powered rigger and mover, is here in passive mode. He has watched the machines at work in order to put them down crisply and carefully, not forgetting to explain their hydraulics. The fork lifts and compactors, the huge crawler-dozers, such as the almost terrifying Caterpillar D 10's, rooting up "the landscape . . . like mechanical pigs," the pipe layers with big counterweights and the crawler drills are all here. Some of them tread softly; one crawls about the swamp on snowshoes, so to speak, its extra-wide treads spreading out the load 10 times more than wheels. The pincered Terex logger resembles a monster earwig. The awesome Big Muskie, the biggest of the land-borne machines, is draglining to strip the overburden from Ohio coal seams, 320 tons at a bite. Somehow the off-road trucks for ore and rock loom grandest; the Terex Titan hauls 350 tons on six very big wheels, its driver a good deal shorter than the tire diameter, its width too great for any ordinary highway. "The earth shakes when they pass." Younger children who favor monsters will certainly enjoy these.

Shadows: Here, There, and Everywhere, by Ron and Nancy Goor. Thomas Y. Crowell ($8.25). A tall giraffe casts a long shadow and a grasshopper a much shorter one. Sometimes people have more than one shadow: these ice skaters in center rink sport eight. Intricate shadows come from a dandelion or a high iron spiral staircase, and a kid's shadows can be long or short, depending. In some 40 striking photographs, crisp and convincing, the shadow and its variations are made visible in a small work of logic. Few pages have more than a couple of lines of easy text to describe the shadow features shown. Sundials are here, as are familiar shadows awry on the complicated surfaces of steps. One set of stairs climbs up the side of a big tank, leaving its shadow strangely behind. A few photographs show the shadow event stripped to a flashlight and a hand or a peg, tamed demonstration shadows, but most of them show shadows in the wild, at first only beautiful and then opening up for meaning.

This small book is a fine one for the keen eye, even if its owner is not an experienced reader. Texture is not forgotten; there are several hand shadows

© 1981 SCIENTIFIC AMERICAN, INC

The Ultimate Wagon

Imagine a station wagon that provides the security and traction of 4-wheel drive . . . yet still gets better EPA gas mileage than any full size 2-wheel drive wagon. Add to that the comfort and luxury you'd discover only in the finest automobiles . . . and you've got the ultimate wagon.

No conventional 2-wheel drive wagon can so deftly perform under pressure on snowburied highways, icy roadways, or in torrential downpours. And no conventional wagon lets you so freely follow your heart when the off-road calls.

Yet, while Wagoneer boldly meets the challenges of the rugged outside world, inside it presents an environment of ultimate comfort. An interior filled with supple leathers, plush carpeting, and the elegant touches and conveniences you'd expect in a luxurious setting. All with room and riding smoothness any wagon, any automobile, would be proud to claim.

There's a full range of Wagoneer models available. Owning one is surprisingly affordable. Driving one is an experience that'll spoil you for anything else.

Use these figures for comparison. Your results may differ due to driving speed, weather conditions and trip length. California figures lower. Jeep Corporation, a subsidiary of American Motors Corporation.

18 EST EPA MPG 25 HWY EST

Jeep® Wagoneer Limited

AT AMERICAN MOTORS

© 1981 SCIENTIFIC AMERICAN, INC

worth learning, and shadowless days are exhibited. The entire work induces the exercise of the eye and the mind, encourages looking closely and thinking to some purpose. One misses the notion that a shadow is not paper-thin but fills space; there is something left to learn. This is real physics without any ritual phrases or conventional abstractions.

People

SHADOW OF THE HUNTER: STORIES OF ESKIMO LIFE, by Richard K. Nelson. Illustrated by Simon Koonook. University of Chicago Press ($12.50). The flatlands of the North Slope face the Arctic Ocean. Our fellow citizens there, the Eskimo people near Wainwright, Alaska, are skillful users of outboard motors, binoculars, rifles and explosive harpoons. They wear blue jeans and drink soda, read by gasoline lantern and often crowd into villages. They also still hunt and fish, drive teams of eager dogs and keep the profound legacy of their ancestors. It is not the old tools alone that were their power and their pride; most of all it was their knowledge, the most powerful tool of the sea hunters, the ways of ice and sea, of bear and snowbird.

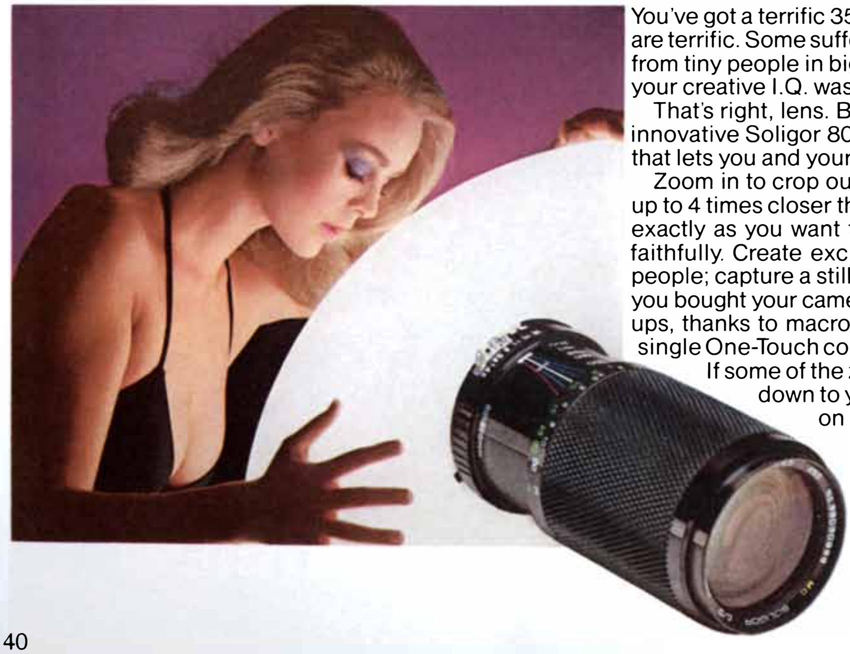
The author is a cultural anthropologist who studied the technique of these hunters, not only by interview and passive observation but also by daily sharing the hunt as an apprentice. That made another book; here he has ventured further. He seeks to share the mind of the hunter, by telling stories of 10 different days in the year's round. Most of them are days and nights in the hunt itself. Because the author wants to reach inward he has made his chronicle a kind of fiction; the individuals are fictional. "But the people, like the events, are collages based on what is real." This is still an ethnography, one way for a man to tell what he knows and respects of an old culture at the threshold of great change, not so far from the pipeline to Prudhoe Bay.

The book begins with Sakiak, an old hunter, alone on the sea ice hunting seals. It ends with the same man, returned from the ice with his kill. Sakiak dances; he had killed a bear on the ice that midwinter day. His dance to the pounding drums expresses "all that was Eskimo, in a land where none other could live." This sense of victory in an adaptation to the singular demands of the frozen sea glows through every story. Readers young and old can hardly fail to share in the pride of the hunter, and the game are not forgotten; the hunter's thoughts must merge with the seal's own. When the bowhead whales migrated, Sakiak stayed on the ice edge all day long. He was fascinated. The sea was not calm enough for hunting, and so that day he could only watch. Two hundred whales passed in an afternoon, and still he watched; "his passionate interest never diminished." Although he was old and wiser than anyone else, he never stopped increasing his knowledge.

The oldest men could name hundreds of landmarks, some features so subtle a stranger could not detect them at all. Wisdom comes with experience, and experience with game and weather comes only with age. That is why the Eskimo deferred to age. "This was true for men and women alike, but there was also a difference." Old men eventually become too weak for the hunt; then they have only their knowledge. Old women not only are wise but also remain adept with the skills of the hand; "perhaps this was why their personalities and assertiveness often strengthened with age." Young people, particularly teenagers, should find this book rewarding in its humanity. A few of the episodes treat of family matters, saying much more about women than the narratives of the hunt do; one scene sensitively evokes the situation of a young woman whose education has been outside the culture and what has befallen her.

THE NORSE MYTHS, introduced and retold by Kevin Crossley-Holland. Pantheon Books ($14.95). First and last things: the alpha and the omega. "Burning ice, biting flame; that is how life began." Iceland lies on the ocean ridge,

The Soligor 80-200mm Expand Your Horizons By Getting Close.



You've got a terrific 35mm SLR camera, but not all of your shots are terrific. Some suffer from too much unwanted scenery, some from tiny people in big frames... shots that didn't work because your creative I.Q. was more than your *lens* could handle.

That's right, lens. But, Soligor has a solution: the affordable, innovative Soligor 80-200mm One-Touch Zoom + Macro lens that lets you and your camera turn blah into beauty.

Zoom in to crop out extraneous details. Bring your subjects up to 4 times closer than a standard lens can. Frame your shots exactly as you want them, and Soligor quality captures them faithfully. Create exciting portraits, instead of just pictures of people; capture a still life or sports action as the kind of picture you bought your camera to get; experiment with amazing close-ups, thanks to macro ability. And it's all so easy with Soligor's single One-Touch control for zoom, focus and macro.

If some of the zip has gone out of your picture taking, zip down to your Soligor dealer and try our 80-200mm on your Canon, Minolta, Pentax, Olympus, Nikon or other fine camera. Or, write for full information.

SOLIGOR®
MAKES THE DIFFERENCE

AIC Photo, Inc. Carle Place, N.Y. 11514
In Canada: Kingsway Film Equipment, Ltd., Ontario

© 1981 SCIENTIFIC AMERICAN, INC

where magma and glacier both flow. When life first quickened, it took the form of an evil giant, Ymir. Ice melt became the cow Audumla, who licked men and gods from the ice. There were yet no sand, no sea, no grass, no earth, no heaven. It was Ymir's skull that was made into the vault of the sky by Allfather Odin and his brothers. Such was creation, in the first myth.

The 32nd myth, the last, is Ragnarok. "An axe-age, a sword-age, shields will be gashed: there will be a wind-age and a wolf-age before the world is wrecked." Parricide, incest and war will come, and then three winters without a summer. Men, elves, giants and gods will all die; the sun will darken and the stars vanish; the earth will sink into the sea. Only the cosmic axis remains, the ash tree Yggdrasill, that always was and is and will be. In that tree of life two human beings hide, and the dragon under the roots feeds on the dead. Then the earth will rise again, fair and green. Corn will ripen in fields never sown. There will be life everywhere. That was the end and this is the beginning, alpha and omega.

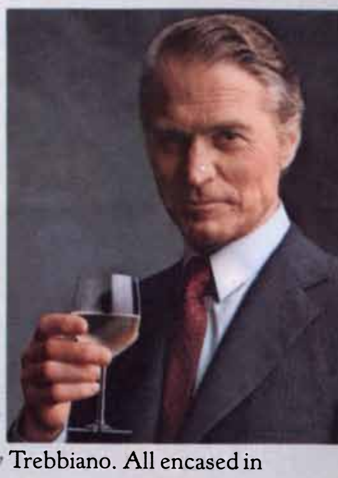
Rendered into a simple, modern fluent prose are these myths of the Norse cycle. Between creation and destruction the tales wind, cruel and deceitful, noble and courageous, compact with magic and art, love, jealousy, pride, terror and the poetic strangeness of northern peoples and their gods. The chief source of the tales is the 13th-century *Prose Edda,* with other works of Snorri Sturluson. The present author, an English poet and translator, has utilized the rich learning of our own day to surround these works with history and insight. A particularly helpful apparatus gives the reader sources and parallels, origins and uses. The author knows the land and the language of Iceland, and he applies that knowledge to good purpose. In myth No. 26, which also comes from the *Edda,* we touch the later *Volsunga Saga,* the source of Wagner's Ring. The passage from the island myths of the gods to the continental legends of heroes is complex and uncertain. The reader will nonetheless learn how the red gold and that twisted ring were accursed, to destroy whoever owned them.

This is an important and admirable volume; it can be read by anyone old enough to read it well. Like the more ancient, still sacred tales of Eden and Egypt and a land of milk and honey, rather than of ice and fire, it offers form and truth at many levels of understanding, easy for no one yet rewarding to everyone.

BO RABBIT SMART FOR TRUE: FOLKTALES FROM THE GULLAH, retold by Priscilla Jaquith. Drawings by Ed Young. Philomel Books, Putnam Publishing Group ($9.95). THE MAGIC PLUM TREE, by Freya Littledale. Illustrated by Enrico Arno. Crown Publishers, Inc. ($7.95). On the barrier islands of the Georgia and Carolina coast, the Sea Islands, there have lived for a long time a free people called the Gullah. They raise a little cotton and rice, and they hunt and fish expertly in the broom sedge and the piny woods. No one knows just how or whence they came, but they were free of the coast planters who once had bought them as slaves. They still speak a language of their own, perhaps West African in origin, influenced by English dialects of the time, and they have a rich spoken lore, lilting, expressive and racy. Albert H. Stoddard was born and raised there, and at 77 he recorded and transcribed for the Library of Congress the stories he had learned.

Priscilla Jaquith has retold four lively stories from Stoddard's work, with care to keep its rhythm and flavor. Ed Young has made many witty renderings in pencil, four to a page, characters sometimes breaking out of the neat frames, which enhance the story almost like a cartoon. Three of the stories are of Bo Rabbit, trickster and con artist. Pitting the elephant against the whale on a long rope, he could pass himself off as "one able little man." "No matter how little you are, if you're smart for true, you can beat the biggest crittuh on earth. It stands so." The partridge, though, was wiser than Bo and showed him how to

"HOW MANY OTHER GIFTS CAN BE OPENED FOUR TIMES?"
—Franco Bolla



"Deciding which delicious Bolla wine to give as a gift should never present a problem to you.

"Just give the Bolla Gift Selection, with its two red wines and two white wines. Each with its own distinctive taste. Full-flavored Valpolicella. Mellow Bardolino. Crisp, refreshing Soave. And light, dry Trebbiano. All encased in this handsome wooden giftbox.

"It's a gift that truly shows your good taste. And your generosity.

"After all, how many gifts can they open four times?"

YOU CAN ALWAYS TRUST THE TASTE OF A BOLLA.

To send the Bolla Gift Selection anywhere in the country, call toll free 800-528-6148. Arizona residents, dial 957-4923.

IMPORTED BY THE JOS. GARNEAU CO., N.Y., N.Y.

© 1981 SCIENTIFIC AMERICAN, INC

"Computer Chess checkmates the leading competitor."

— Bruce Pandolfini U.S. National Chess Master —

"I knew Mattel Electronics Computer Chess™ was a remarkable game. In fact, I was so confident it was one of the best electronic chess games, I encouraged Mattel Electronics to challenge their leading competitor, Fidelity Electronics' Sensory Chess Challenger "8," to a match. And as it turned out, my expectations were well founded. In more than 100 games, Mattel Electronics' Computer Chess beat Fidelity's game 62%* of the time.

"Computer Chess was programmed by International Chess Master Julio Kaplan, resulting in a game that plays more like a real person than a machine.

"It's portable and pocket-sized, and has no separate pieces to lose. Both the chessboard and the pieces are represented by a large easy-to-read liquid crystal display. And the game's three playing modes provide a variety of game play for the newcomer as well as the experienced player.

"If chess is your game, I highly recommend you make your next move to Mattel Electronics Computer Chess. But don't just take my word for it, compare for yourself. Once you do, I think you'll choose Computer Chess. The game that checkmates the leading competitor."

Games were played at the highest regular game level for each. Batteries not included.
*Based on International Chess Tournament rules.
©Mattel, Inc. 1981 All Rights Reserved.

MATTEL ELECTRONICS®
COMPUTER CHESS™

© 1981 SCIENTIFIC AMERICAN, INC

hide, without hard feelings. In Gullah too one finds folk themes of all the world. Young readers or the still-read-to will enjoy these tales and their dancing little sequences of drawings.

Artful in every line, the single quiet tale of *The Magic Plum Tree* and the three little princes who visit it in all seasons is a beautifully told tale from the *Jataka*, that treasury of folklore set down to commemorate, we are told, the former lives of Gautama Buddha. It is illustrated in a charming style that gains coherence as a version of the Mogul-court miniature of North India. Kites and flutes and dancers with graceful hand gestures fill these pages, all entirely appropriate in fancy.

HOW TO *REALLY* FOOL YOURSELF: ILLUSIONS FOR ALL THE SENSES, by Vicki Cobb. Illustrated by Leslie Morrill. J. B. Lippincott ($8.95). A one-eyed friend? Just put foreheads together, looking straight ahead. You will each find one. A mirage? On any summer day look along the surface of a brick wall in the sun. A dancing star? A flashlight kept in a shoe box with a pinhole will dance in a dark closet. (Flashing lights are standard on aircraft in part because they limit this autokinetic effect.) The sound of rain in your tape recorder? There are three ways to get it; one is to let sugar trickle down a chute of waxed paper. Make dry hands feel wet? Through rubber gloves cold water still feels wet; wetness is something like heat loss with evenly distributed pressure on the skin. (There are six or eight such "touch blends" listed that we still understand rather poorly.)

So it goes. This little book for grade school psychologists and philosophers presents a few dozen of these interesting but less familiar illusions, along with the arrow lengths, outline cubes, Eschers and three-pronged blivits of the standard optical-illusion list. The text is simple and direct, suitably lighthearted and more than once has the simple honesty to admit that nobody quite understands the perceptual problem. There are some big names attached to these simple puzzles; the current generation of fifth graders is likely to understand a good deal more about perception than any before it. This unpretentious account might just win over a couple of investigators of the future!

THE COLOR ATLAS OF HUMAN ANATOMY, edited by Vanio Vannini and Giuliano Pogliani. Translated and revised by Richard T. Jolly. Harmony Books/Crown Publishers Inc. ($6.95). Since the *Fabrica* of Andreas Vesalius himself the fabric of the human body has made many a striking volume. This handsome paperback is up to date. It comes from Milan, where it was produced two years ago not as a piece for medical instruction but as a reliable yet dramatic guide for the general reader. The core of the book is a set of careful anatomical drawings of the main systems of the body: muscle, bone, blood vessels, the endocrine glands, the nerves and the brain, the sense organs and the respiratory, digestive and urogenital systems, male and female. They are in no way bowdlerized, but they are in diagrammatic false color in a cutaway smooth-contoured style that might almost suit an instruction manual on aircraft hydraulic systems. This helps a nonmedical viewer a good deal by distancing the pages from bloody reality while revealing the essential structure. In this way one sees it all in context, trapezius, thymus and liver, lymph nodes and spleen, pituitary and prostate, even the look of a few malignancies.

This new atlas is also strong in showing what the physician sees now so well with instruments. Here are angiograms and CAT scans, bone scans, an ultrasonic survey of a fetus and the even more immediate views from endoscopic, corneal, retinal, bronchial and pelvic close-ups. The material is supported by interesting microscopic images, both real and redrawn, at a variety of scales. Not for every young reader, this inexpensive compilation takes a comprehensive look at the machinery of the body; high school reference shelves can certainly benefit.

Living Things

WHAT'S FOR LUNCH: ANIMAL FEEDING AT THE ZOO, by Sally Tongren. GMG Publishing, 25 West 43rd Street, New York, N.Y. 10036 ($12.95). Our National Zoological Park houses about 500 species of animals. They all have to eat. Peanuts for the elephants and bananas for the monkeys are certainly not enough. This well-informed and richly illustrated book by two authors who are quite at home in that land-borne ark is as much fun as it is full of information.

Nutrition is fundamental. Pink flamingos need a pink diet. (White flamingos will not breed.) In the wild they eat carotenoid-rich algae from broad salt lagoons. The zoo does not have a big tropical lagoon, but it found out how to substitute pink shrimp and other sources of pigment. Nor is an animal without its table manners. Toucans favor fresh fruit, but they needed supplements, and they took no interest in what was offered them. The zoo accordingly fed them special pellets with plenty of vitamins. The toucans tried them eagerly, but these big-billed birds pass their food back and forth between them, to eat finally by tossing it up and catching it. The pellets were too crumbly. Then the food was mixed with fruit and gelatin. Too sticky; it clung like peanut butter to the roof of the mouth. Now they are fed a frugivore gel: small, almost leathery cubes of gelatin loaded with fruit and meal. They pass up fresh fruit now for the delicious aspic. Feeding is an art, or a hundred arts.

Each of 60 species is shown here in an interesting photograph, and with it goes a compact statement of the natural diet of the animal and its daily zoo ration. The African elephant has a breakfast bucket of pellets, a noon snack of a couple of shovelfuls of timothy hay and a filling dinner of a bucket of pellets, two mats of hydroponic grass, a bale of timothy hay and a quarter bale of rich alfalfa hay.

Infants are special. The national zoo has plenty. The reptile and amphibian offspring are perhaps the hardest to care for. It is not tender loving care they need or get: their mothers ignore them, but they must have the right food in the right form. To this end the zoo runs a cockroach ranch, which offers live insects of almost any size. About a third of the mammal infants are hand-reared; mother's milk is not simple, and several different kinds of substitute milk must be worked out and produced. The black vultures that dine at the zoo are not boarders; they are local birds after a free lunch, mainly around the bears' fish and meat. Samuel Pierpont Langley built towers from which to photograph the vultures while he was working on his flying machine before the Wrights succeeded. Some animals have an easy feeding schedule; the Burmese python is content with a few rabbits or rats every other week.

Do not feed the animals; it does bring about a real bond between the two species involved, but it is dangerous for both.

SECRETS OF THE VENUS'S FLY TRAP, by Jerome Wexler. Dodd, Mead & Company ($6.95). The amazing carnivore in a flowerpot is worth attention, the more so because it presents a genuine but quite acceptable challenge for rearing, feeding and study even with the limited resources of a child's room. In dramatic black-and-white photographs, quite a few showing details larger than life, this experienced nature photographer has raised and answered the main questions about the Venus's-flytrap in a sequence of neatly posed experiments. The trap closes swiftly on a morsel once trigger hairs are touched. (On a very warm day one hair will spring the trap; in cold weather it takes many.) The plant does not eat hamburger; when it was fed some, the fatty morsel oozed out and rotted the trap, with an awful smell. The trap will spit out a captured seed or a small piece of gravel overnight. Give it a live fly, and two weeks later it will open, to reveal what looks like an intact insect. It is not; only the shell of the exoskeleton remains, the soft tissues having been digested by the plant.

Fed the right way, the plant can thrive

© 1981 SCIENTIFIC AMERICAN, INC


"IN JUST A FEW DAYS, I'LL SHOW YOU HOW TO DO
REAL MATH
ON YOUR CALCULATOR!"

$\int_a^b f \quad \sum_{n=1}^{\infty} a_n \quad \frac{df}{dx} \quad \lim_{n \to \infty}$

•Quick. •Guaranteed. •Easy. •Fun, too!

INTRIGUED BY CALCULATORS? Then you can step up your math skills *fast!* Use my *new method* in guidebook form. It's called *CALCULATOR CALCULUS.* This space-travel spinoff is sure-fire, so it has a simple guarantee — *just return it for an immediate refund if you are not astounded at the problems you're solving with it!*

But the point is - you won't want to send it back. For this is the *easiest, fastest shortcut* ever! The day you receive your copy in the mail you'll want to put it to work. It's that exciting and helpful.

My name is Dr. George McCarty. I teach math at the University of California. I wrote this guidebook to cut through the confusion. It does just that — with worked-out examples, simple exercises and practical problems — all designed to work with precision and magic on your calculator!

POWER METHODS. Need to evaluate functions, areas, volumes — solve equations — use curves, trig, polar coordinates — find limits for sequences and series? It's all here!

If you're in the biological, social or physical sciences, you'll be doing Bessel functions, carbon dating, Gompertz' growth curves, half-life, future value, marginal costs, motion, cooling, probability, pressure — and plenty more (even differential equations).

Important numerical techniques? Those algorithms are here, too: rational and Pade approximation, bracketing, continued fractions, Euler's method, Heun's method, iteration functions, Newton's method, predictor-corrector, successive substitutions, Simpson's method and synthetic division.

LOOK AT WHAT USERS SAY: Samuel C. McCluney, Jr., of Philadelphia writes: *"CALCULATOR CALCULUS IS GREAT! For ten years I have been trying to get the theory of calculus through my head, using home-study courses. It was not until I had your book that it became clear what the calculus was all about. Now I can go through the other books and see what they are trying to do. With your book and a calculator the whole idea becomes clear in a moment, and is a MOST REFRESHING EXPERIENCE. I program some of the iterative problems you suggest and it always GIVES ME A THRILL to see it start out with a wild guess and then approach the limit and stop."*

Professor John A. Ball of Harvard College (author of the book *'Algorithms for RPN Calculators'*) writes: *"I wish I had had as good a calculus course."*

Professor H. I. Freedman of the U. of Alberta, writing in *Soc. Ind. Appl. Math Review,* states: *"There can be no question as to the usefulness of this book...lots of exercises...very clearly written and makes for easy reading."*

C.B. of Santa Barbara says: *"Your book has given me much instruction and pleasure. I do not hesitate to recommend it!"*

I WANT YOU TO TRY THIS. *Get my complete kit,* with a TI-35 calculator, a 200 p. Student Math Book, *AND* the guidebook, *ALL* for $44.95 (for shipping to USA add $2, or $5 by AIR; Foreign $5, or $10 AIR), in Calif. add $2.70 tax.

If you already have a scientific calculator, you can invest in *'CALCULATOR CALCULUS'* for only U.S. $19.95 (to USA or foreign: add $1 for shipping, or $4 by AIR; in Calif. add $1.20 tax).

As pennywise Ben Franklin said, *"An investment in knowledge pays the best dividends."* GET STARTED NOW — Tax deductible for professionals.

NO RISK WHATEVER! Send for it today. Be sure to give me your complete mailing address with your check or money order. If you want to charge it (Visa or MC), tell me your card no. and exp. date. Prompt shipment guaranteed. Thank you! *George McCarty*

EduCALC Publications, Dept. AN
Box 974, Laguna Beach, California 92652
In Calif. (also AK and HI), call 714—497-3600; elsewhere TOLL FREE 24-hour Credit Card orders: 800—854-0561, Ext. 845; Dept. AN

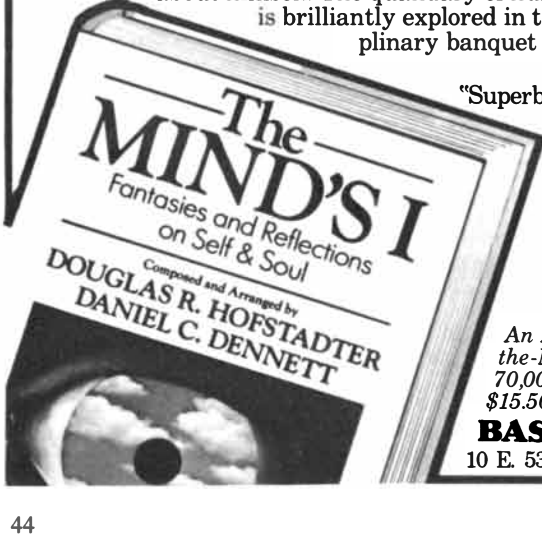
TEAR OUT AND MAIL TODAY

"Philosophical fun and games... of a very high order from the authors of *Gödel, Escher, Bach* and *Brainstorms*"*

Pulitzer Prize-winner Douglas Hofstadter and the philosopher Daniel Dennett take you on a mind-jolting exploration of art and science, humor and philosophy, to probe the meaning of self and consciousness. "The authors supply extracts from literature (Borges, Lem) and scientific reports (A.M. Turing, John Searle) that reveal the complexities, idiosyncracies, and sheer brilliance (and folly) of man thinking about himself. The quandary of human self-representation is brilliantly explored in this cunning, interdisciplinary banquet of food for thought."
—*ALA Booklist*

"Superb...with equally wondrous commentaries."
—*Martin Gardner*

*Kirkus Reviews



An Alternate of the Book-of-the-Month Club (Science)
70,000 copies in print
$15.50 at bookstores

BASIC BOOKS, INC.
10 E. 53 Street, New York 10022

on bits of lean beef It can be grown from leaves, rhizomes, even tiny seeds. Local or mail-order suppliers will provide a seedling or a rhizome. An aquarium or a pot with a plastic container will properly house the plants, indoors or out. The plants may not do well on tap water; rainwater is better. This is a good book to read and ponder, and an even better one as a guide to husbandry. Any 10-year-old with enough patience can manage the task; older students would be by no means patronized by this serious small work.

A PENGUIN YEAR, written and illustrated by Susan Bonners. Delacorte Press ($9.95). A million Adélie penguins make up a big rookery of the species there on the icy summer shores. All spring the dinner-jacketed birds file inland in lines miles long across the ice shelf, to nest and rear their young. The author-artist has painted the entire year of the Adélie on white paper in the blues and blacks of the loneliest continent. There are scenes of a few birds, of the two parents bobbing and bowing in courtship, of many waddly penguins in their soaring submarine flight, catching their staple food, the shrimplike krill, and a striking two-page spread of the rookery, thousands of birds visible.

One meets the appealing chicks, fuzzy and ill-formed, huddling in day-nursery groups against summer snow squalls (and the hungry skua gulls) while the parents forage all day at sea for krill by the pound. By fall the old birds leave at last for a distant ice floe, and the chicks mature from fuzz to sleek oily feathers. Three months old, the young birds enter the sea for the first time. All of this is on the pages in easy text and images as clean and shiny as the Antarctic itself, where on a hot day for penguins the temperature may rise almost to the freezing point. Any young reader will enjoy the true dramatic narrative.

CLASSIFICATION OF THE ANIMAL KINGDOM: AN INTRODUCTION TO EVOLUTION, by Kenneth Jon Rose. David McKay Company, Inc. ($8.95). The title is dull and the pages are full of outrageously long words one could call barbarous if they were not Greek. This modest book is nonetheless absorbing to read, and it is very simply prepared for grade school readers. What is presented is the conventional list of the great divisions of the animal kingdom, some 14 living phyla from the protozoa to the chordates. There is an account of the Linnaean hierarchy, how it arose and what it does. Each phylum receives a brief description of the nature of its members; for most of them certain classes, orders, families and a few genera and species are called out as well.

The etymologies for the bigger divisions are translated (not always an easy task), and all the hard words are spelled

© 1981 SCIENTIFIC AMERICAN, INC

DEVELOP YOURSELF.

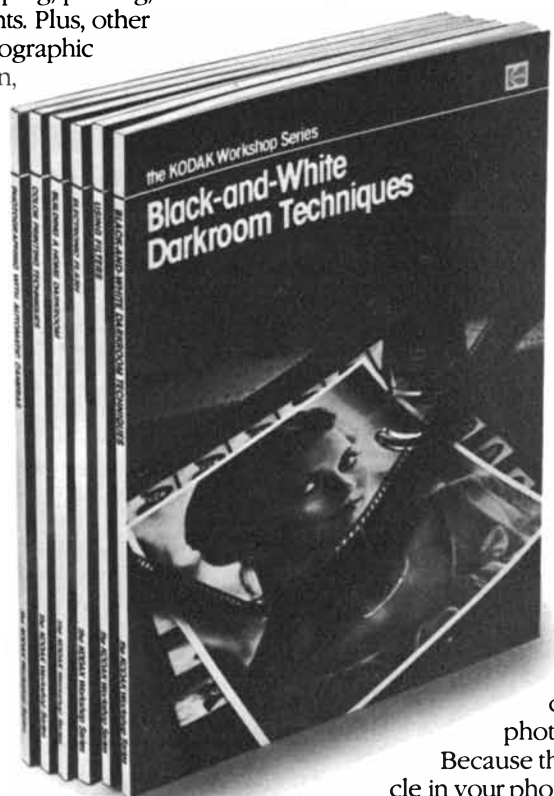
Pick your area of interest. And *teach yourself* with six easy-to-follow books in the new *KODAK Workshop Series.*

Each volume contains 96 pages of step-by-step pictorial instructions and costs only $8.95.

Black-and-White Darkroom Techniques details all the steps for developing, printing, and finishing black-and-white prints. Plus, other sections cover choosing photographic paper, dodging and burning in, mounting prints, and more.

Using Filters gives creative advice that helps you see and capture extraordinary images in color and black-and-white. It shows you how to create mood with color filters, add dazzle with special-effects filters, and render more natural colors and tones with correction filters.

Photographing with Automatic Cameras shows you how to get the most from your automatic camera. Especially useful for newcomers to 35 mm photography, it looks at how automatic cameras work and how to best use one. It offers special tips for capturing landscapes, portraits, and other subjects with an automatic camera.



Building a Home Darkroom tells you how to plan, what you'll need, and where to locate. From planning to construction to electrical work to plumbing, this book shows the step-by-step completion of a prototype darkroom in photographs and easy-to-understand illustrations.

Electronic Flash starts with the basics, giving thorough coverage of how, when, and where a flash can be used to enhance your photographs. Advanced techniques such as bounce and multiple flash are discussed.

Color Printing Techniques explains the basic procedures for making color prints from color negatives and color slides (including the new KODAK EKTAFLEX PCT Color Printmaking Products). Also included is information on equipment, darkrooms, retouching, and framing.

Choose one or all six titles in the new *KODAK Workshop Series* at your camera store or wherever fine photography books are sold.

Because the best way to put some muscle in your photographic development is to work out with the experts.

When it comes to photography, Kodak wrote the book.

Kodak

© Eastman Kodak Company, 1981

© 1981 SCIENTIFIC AMERICAN, INC

out in a rather ugly-looking but workable phonetic scheme. Any big biology text has the same kind of catalogue, but there is no other source for such a simple and understandable version, the rough roster of our planetary ark. For example, the pink-and-blue Portuguese man-of-war of summer seas is of the genus *Physalia* (a bubble), family Siphonophora (hollow float); it is a colonial mass of five types of modified medusans, mutually bound into an organism of the class Hydrozoa within the phylum Coelenterata, seh-lentuh-'rayd-uh, the hollow-guts.

JOURNEY INTO A HOLLOW TREE, by Donald R. Perry with Sylvia E. Merschel. Enslow Publishers, Bloy Street and Ramsey Avenue, Hillside, N.J. 07205 ($7.95). The aim was to go up, high into the living green canopy of the rain forest, 100 feet and more. Spikes and a belt around the tree might work, but the trees are large to grasp, are too hard or too soft to spike and are home to wasps, ants and snakes in plenty. One scheme might work for a solo biologist. Fire a weighted string over a high, strong branch with a crossbow. Pull a rope into place, tie it down and climb the rope with mountaineer's step-by-step ascender clamps.

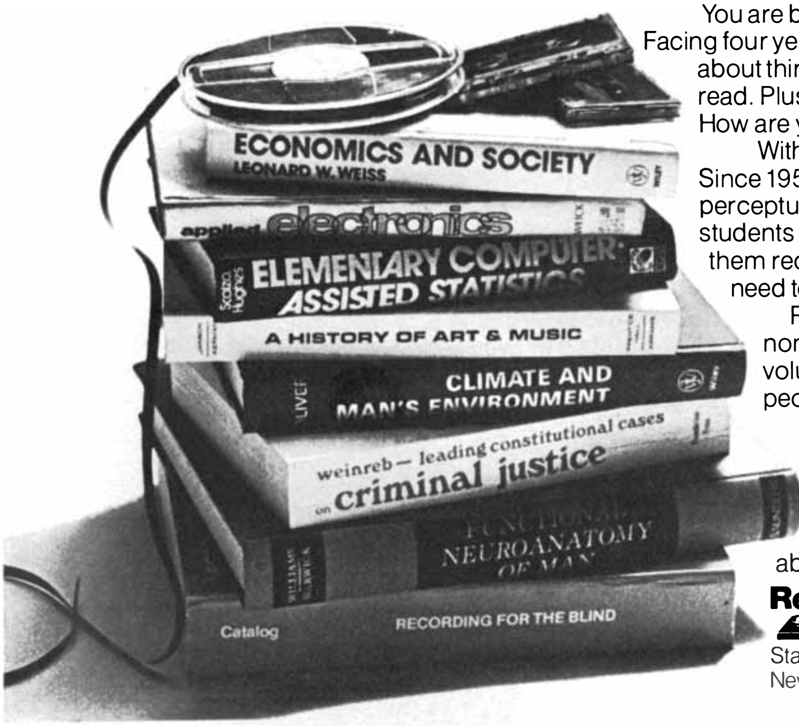
This little story of humor and horror recounts Donald Perry's first tree climb, in Costa Rica. (Some of the evidence comes from later trips, when a friend was along to snap the pictures.) The chosen tree was big, yards wide even after he got up a little. Hanging 50 feet up, considering a re-roping to get over an obstructing limb, Perry unintentionally kicked the tree hard. It sounded like a drum; the big tree was one huge chimney. The next day, with fresh gear and a head lamp, he let himself down on a rope inside the dark living tree, never before entered. Into the hot, humid, stinking air he went, past scorpions and snakes, onto a soft, oozing floor churning with insects. Eerily, he could look out through a small chink in the trunk to see his guide waiting outside near the base of the tree, but he could not make himself heard. And below the mushy floor, down in the hollow old roots...

If you can stand the rest of the journey, it is a brave small adventure. It is traveling into night by broad day, into a place where jungle night life could not evade the biologist (and vice versa). This true tale is a creepy-crawly story become altogether real. Watch out for the fungus-ridden whip scorpion and the vampire bats. Dungeons and dragons are tamer stuff.

AFTER MAN: A ZOOLOGY OF THE FUTURE, by Dougal Dixon. St. Martin's Press ($14.95). A paleontologist and model- and film-maker, the British author has conceived an imaginative tour de force, a fictional pictorial natural history of the world 50 million years from now, absent all hominids. The continents have drifted a bit. South America is a great island and the other continents have fused: North America with Asia across the Bering Sea, Australia with a chunky South Asia. The book begins with a review of evolution in text and diagram and proceeds to the "world after man," described in about 30 spreads. For each spread there is a full-page painting of a number of animals, shown in lively poses within a single habitat, and a page of summary natural history: the origins and the curious life histories of the forms shown. Most of these vivid paintings from nonlife (based on Dixon's careful sketches) are by Diz Wallis, with help from John Butler and Philip Hood.

The general scene is clear; each broad environment is mapped worldwide. The hoofed animals have gone. The domestication of horses and cattle proved irreversible; the deer never recovered from the loss of the woodlands to city and farm. Their niche was slowly filled by the rabbit kind, become like llamas, antelopes or spotted white-tailed near-deer. Here is a serious drawing, very familiar in another form, showing the foot of the rabbit in stages from its ancestral long toes to the present two-toed hoof. The older carnivores have all but vanished; the new predators are rodents in

Close your eyes.
Now have someone read this to you.



You are blind. A student. Facing four years of college. With about thirty-two textbooks to read. Plus fifty supplemental texts. How are you going to manage?

With Recording for the Blind. Since 1951, we've helped over 53,000 blind, perceptually and physically handicapped students get through school. By sending them recordings of the books they need to read. Free.

Recording for the Blind is non-profit, and supported by volunteers and contributions from people like you who can imagine what it's like to be blind.

Your tax-deductible donation will help our students meet their educational goals. We'd all be grateful.

If you want to know more about us, write:

Recording for the Blind, Inc.
an educational lifeline.
Station E, 215 East 58th Street
New York, New York 10022, (212) 751-0860.

© 1981 SCIENTIFIC AMERICAN, INC

the Temperate Zone and mainly primates in the Tropics. The wily ground-hunting neo-ape ambushes the massive wood antelope in the African grass.

At the species level (there are close to 100 imaginary forms) the detail is impressive. The method of extrapolation is not hard to see: most of the changes are rather close to well-known cases of today, transferred to quite different originating forms. The tiniest of broad-footed insectivorous mammals walks on the surface film of fresh water, with a tooth-tipped hairless snout to spear mosquito larvae at the surface and suck them dry. The last of the cats is a monkey-form tree carnivore, with grasping paws and a prehensile tail, a predator on the social monkeys, whose fierce males have chest armor of horn. Another primate hangs by an armored tail whenever the cat is near. The great Southern Ocean teems with life; its ruler is the largest creature on the earth, whalelike in bulk and form. But the animal is a fully marine bird, which bears its single egg internally until hatching; it is a plankton eater, a fine feeding sieve of bone plates having developed out of the beak of the ancient penguins.

This book should be a pleasure for any older young reader who takes a serious interest in the diversity of life. The book is instructive, handsomely made and harbors many small surprises, although somehow the evolutionary truth remains stranger than even well-informed fiction.

Words and Figures

HIEROGLYPHS: THE WRITING OF ANCIENT EGYPT, by Norma Jean Katan with Barbara Mintz. Atheneum ($8.95). In fewer than 100 brief pages, with plenty of photographs to bolster the text, this small book lays out clearly and attractively the basis of the writing found both carved and painted along the Nile. The level is an entirely workable one for readers from the fourth grade or so on up. There are a few pages of the history of ancient Egypt, with a map, and a few pages more to tell the wonderful tale of Jean François Champollion and the Rosetta stone. (It was the names of rulers ringed in a cartouche that gave him his first clue.) There is a discussion of the beliefs of the ancient Egyptian people, particularly their awe of the written word, and of the kind of texts we have: the pyramid texts, the coffin texts, the Book of the Dead.

At this stage we are ready for the disclosure of the script itself. It takes the form of many simply drawn hieroglyph signs, first the phonetic signs and their pronunciation, then the ideograms and then a few determinatives. Only a dozen or two signs are shown in addition to the phonograms. It is enough to allow writing your name in hieroglyphs, naturally within a royal cartouche! Numbers are not omitted, and a few much used formulas are cited, such as "a boon which the king gives." The last pages show single signs used as amulets, with examples. It is altogether a thrill to see a carved limestone tablet from the Eighteenth Dynasty, plain in a good photograph, and to read clearly on it the very hieroglyphs interpreted on the opposite page. There is even more material in this book that is a model of how to open a door into a world of abstract learning.

MORE THAN ONE, by Tana Hoban. Greenwillow Books, a division of William Morrow & Company, Inc. ($7.95). A stack of collective nouns, 10 of them, label these two dozen fine black-and-white photographs, the work set in giant bright blue letters bound to catch the eye of a would-be reader. The pictures have that visual energy typical of this well-known author: a row of four dazzle-painted zebras, a domestic herd of elephants, a group of children all jumping at once, a crowd of bathers at Coney Island and more. There is also more than one way of looking at any picture; for example, there is a pile of rocks behind the herd of goats. The book declares itself to be at once a counting book, a word book and a shape book. It is a good book to be led through while you still hope to learn to read, and a fine one for new readers.

© 1981 SCIENTIFIC AMERICAN, INC

The protest we have in mind is against prestigious luxury cars that succeed as symbols, but disappoint as cars.

Cars whose underlying engineering seems to have lagged behind their considerable reputations.

Luxury car buyers dissatisfied with this state of affairs will find a perfect vehicle for dissent in the BMW 733i—the $35,000 luxury car engineered to lead where others have lagged.

INTRODUCING
DIGITAL MOTOR ELECTRONICS.

The 733i is the first automobile in America to offer Digital Motor Electronics—a system that illustrates the difference between technology and gadgetry.

"DME" measures, reports on and, most importantly, governs engine efficiency.

It assures that the optimum mixture of fuel and air is ignited at the optimum time in the ignition cycle. It adjusts idling speed, cuts off fuel flow to cylinders when they're not needed, and even helps report back, through a fuel economy indicator, your actual mpg figures as you drive.

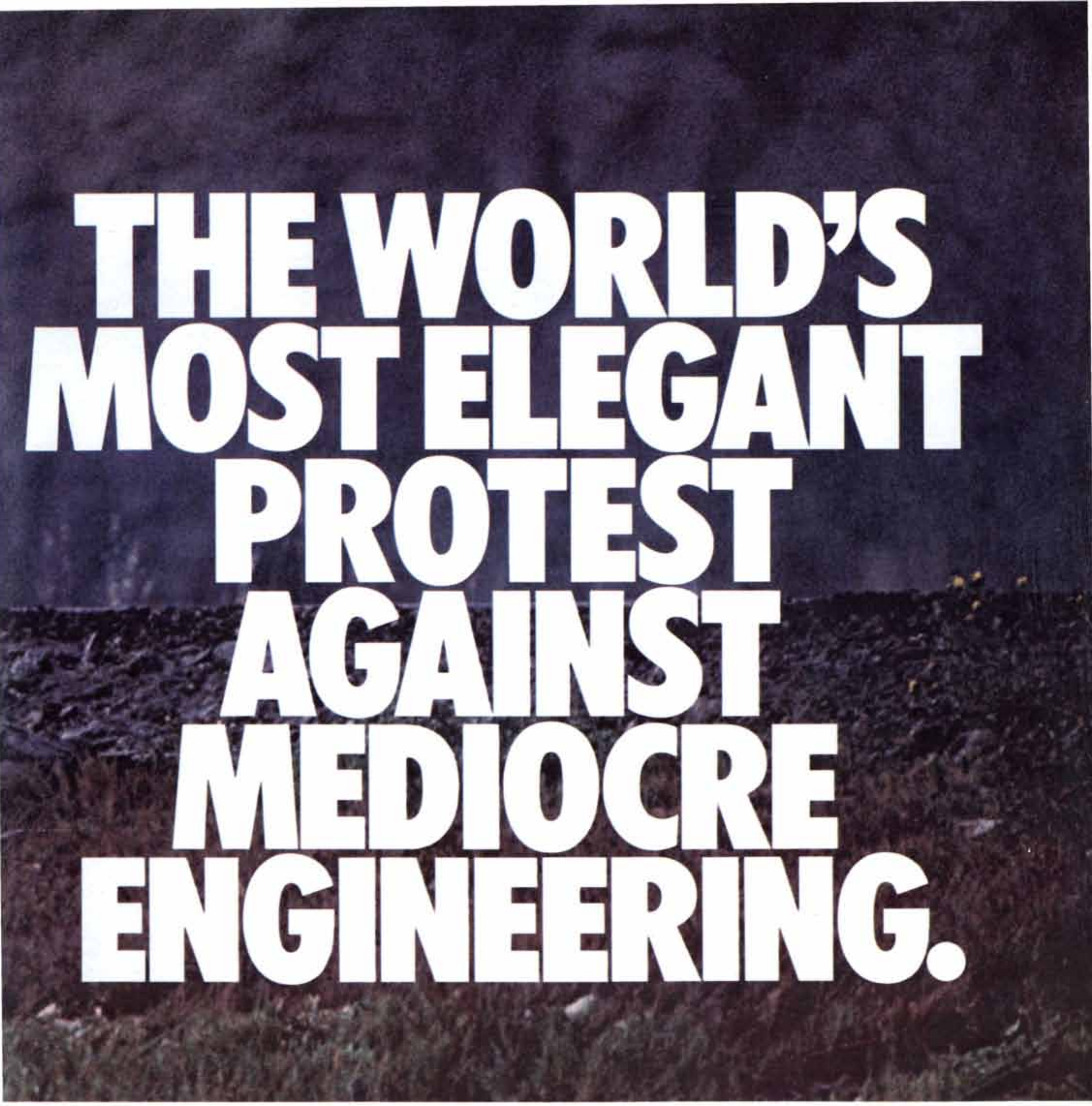
The figures will make interesting reading. The 733i with standard five-speed transmission now delivers a pleasantly surprising [19] EPA estimated mpg, 29 mpg highway. Automatic is also available.

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

Inside, an onboard computer provides such useful functions as anti-theft protection and speed monitoring—and even helps control the weather. A special climate con-

© 1981 BMW of North America, Inc. The BMW trademark and logo are registered trademarks of Bayerische Motoren Werke, A.G.

© 1981 SCIENTIFIC AMERICAN, INC



trol adjusts temperatures to a preset level, going so far as to warn you of potential icing conditions.

All these technological advances accompany a car that's fairly steeped in amenities.

Its molded bucket seats are upholstered in wide rolls of fine leather. Carpeting is thick and plush. And the attentiveness to comfort throughout caused Car and Driver to single out the 733i as "the height of refined elegance."

PERFECTION IS UNATTAINABLE. SUPERIORITY ISN'T.

Of course, the true measure of any machine is how well it performs—an axiom that confers an almost unfair advantage on the 733i.

Its 3.2-liter, electronically fuel-injected engine has been called "without a doubt, the most sophisticated production in-line six in the world" (Road & Track magazine), delivering the exhilarating performance that's conspicuously absent among cars in its class.

Its revolutionary double-pivot front suspension is so advanced it has been awarded an international patent.

And its amazingly agile steering reflects the precision inherited from over six decades of building high-performance vehicles.

The sum, according to Car and Driver, is a car whose "parts and pieces...work so well together they must have been melded in another world."

If your present luxury sedan suggests more mundane origins, you might contact your nearest BMW dealer, who will be happy to arrange a test drive at your convenience.

THE ULTIMATE DRIVING MACHINE.

BMW, MUNICH, GERMANY.

© 1981 SCIENTIFIC AMERICAN, INC

© 1981 SCIENTIFIC AMERICAN, INC

Established 1845 SCIENTIFIC AMERICAN December 1981 Volume 245 Number 6

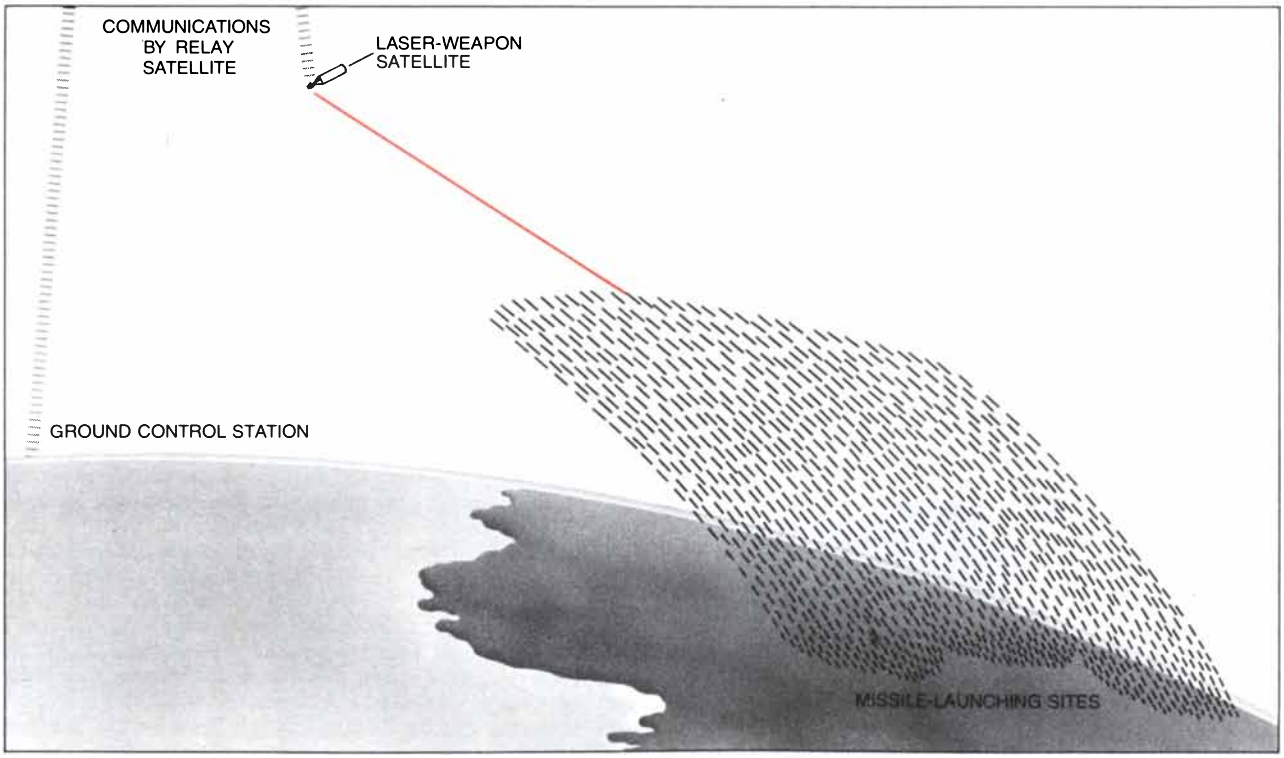
Laser Weapons

Could orbiting lasers defend a nation against missile attack? The technological obstacles are insurmountable; furthermore, such weapons would be vulnerable to simple countermeasures

by Kosta Tsipis

A high-energy laser can readily burn a hole through a metal plate of considerable thickness; indeed, the laser serves as a cutting tool in industry. This capability has naturally led to speculation that the laser might serve as a weapon of war. What is envisioned by some military planners is a weapon rather like the ray gun of science fiction. The laser beam would be pointed at an attacking missile or aircraft or at some other target and would almost instantly destroy it. Because the beam propagates with the speed of light there would be no possibility of outrunning or evading it. In preliminary tests under controlled conditions lasers have destroyed small, remotely guided aircraft.

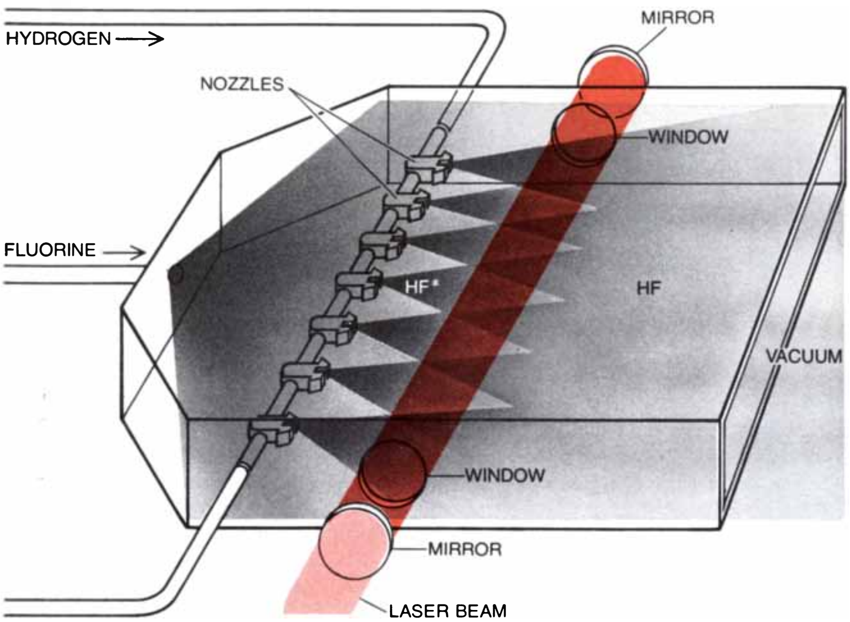
Recently a small group of people in the U.S. Congress, the Department of Defense and the aerospace industry



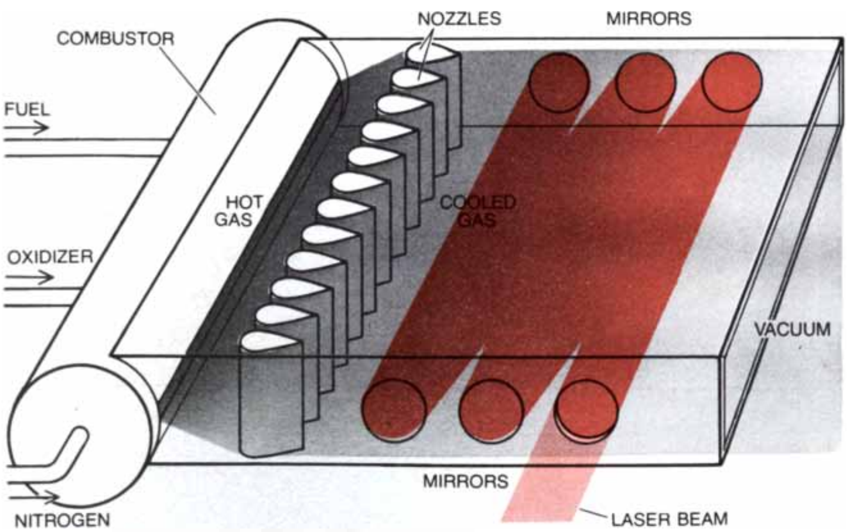
PROPOSED MISSION for a laser weapon is to defend a nation against intercontinental ballistic missiles. The laser would be mounted on a satellite in an orbit at least 1,000 kilometers above the earth. The missiles would be attacked during the boost stage of their flight, which lasts for about eight minutes. To ensure that at least one satellite would be in range of the missile-launching sites at all times about 50 satellites would be needed. Each satellite would have to be capable of dealing with as many as 1,000 missiles in the eight-minute period because all the other satellites would be over some other part of the earth. Infrared sensors or radar would detect and track the missiles. Additional sensors would measure the miss distance or assess the damage if the missile were hit by the beam. A relay satellite in a higher orbit would provide a communications link with the ground. No countermeasures that might be employed to overcome the laser weapon are shown here, but even under these conditions physical and technological constraints would make the weapon impractical.

© 1981 SCIENTIFIC AMERICAN, INC

have contended that high-energy lasers have the potential for destroying intercontinental ballistic missiles in flight. Maintaining that the U.S.S.R. has already mounted a large effort to develop lasers as antimissile weapons and that the U.S. therefore confronts a "laser gap," these people are urging the Reagan Administration to greatly expand the U.S. laser-weapons program, which is now receiving about $300 million per year. The main objective would be to deploy a network of very large laser weapons in earth orbit within about 10 years. The orbiting weapons would have the mission of destroying Russian intercontinental missiles soon after they were launched. Another objective would be to develop laser weapons that would be fired from the ground to attack enemy satellites or to defend valuable targets against aircraft and tactical missiles.



CHEMICAL LASER is one of three kinds of laser being considered as potential weapons. In each case the working medium is a gas in which many molecules are raised to an excited state, creating a "population inversion." Light is amplified as it passes through the medium repeatedly in an optical "cavity" formed by two mirrors. In the laser shown the chemical reaction between two gases creates the active medium. Fluorine and hydrogen issuing from a row of nozzles combine to create hydrogen fluoride molecules in an excited state (HF*). To prolong the lifetime of the excited molecules the density is kept low by exhausting the combustion products into a vacuum. Light is emitted as the HF* molecules return to their ground state (HF).



GAS DYNAMIC LASER achieves a population inversion by generating a hot gas and then cooling it abruptly. Fuel is burned with an oxidizer to form carbon dioxide at high temperature. Light emission in carbon dioxide results from transitions between two excited states. In the hot gas many molecules occupy the excited states, but laser action is not possible because the population of the upper laser energy level is not markedly greater than the population of the lower level; at high temperature the molecules in the lower level do not vacate it readily by cascading to the ground state. When the gas is rapidly cooled by being expanded through nozzles, the ground state becomes accessible and transitions from the upper laser level to the lower one become possible. Nitrogen added to the mixture transfers energy to the carbon dioxide molecules.

The effects of such hypothetical weapons on the world military balance and on the prospects for nuclear-arms limitation might someday merit detailed appraisal. For now, however, a more fundamental question must be addressed: Is it technically feasible to build an effective laser-weapon system? I shall argue here that the objectives set forth for laser-weapons development could not possibly be achieved in 10 years. Indeed, unless a number of fundamental impediments to the use of lasers as weapons are overcome, the objectives could never be achieved. Several of the difficulties arise from the physics of the propagation of a laser beam over long distances. Other difficulties are technological and economic.

The potential of lasers as weapons has been assessed in a series of workshops organized by the Program in Science and Technology for International Security of the physics department of the Massachusetts Institute of Technology. Participants in the workshops have included some of my colleagues and me from M.I.T. and investigators from other universities, from industry and from the national weapons laboratories. We have concluded that lasers have little or no chance of succeeding as practical, cost-effective defensive weapons.

A laser generates an intense stream of electromagnetic waves, all of which have exactly the same frequency, phase and direction of motion; the waves are said to be coherent. The property of coherence is essential to weapons applications of the laser because in order to cause damage a beam of laser light must be intense and well collimated and the waves that make up the beam must be in phase. In principle the light intensity of a laser is unlimited; in practice it depends on the size of the laser and the properties of the material in which the coherent light is generated.

The working medium of a laser can be a solid, a liquid or a gas, but high-energy lasers generally employ a molecular gas. To initiate laser action external energy must be supplied to the molecules of the gas. A fraction of the energy increases the kinetic energy of the molecules and therefore simply heats the gas, but some of the energy is absorbed into the internal vibrational and rotational motions of the molecules. A molecule excited in this way leaves its lowest vibrational or rotational energy state (the ground state) and occupies a higher one. As a result the low energy states are depopulated and a significant number of mole-

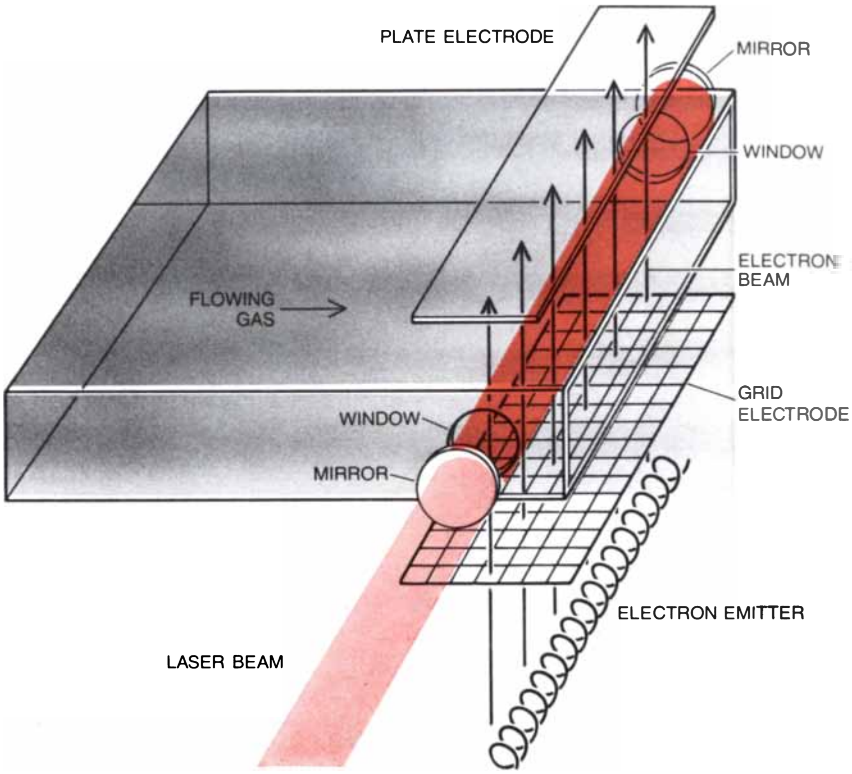
© 1981 SCIENTIFIC AMERICAN, INC

cules enter an excited state. The condition is called a population inversion.

A molecule in an excited state can return to a state of lower energy by emitting a photon, or quantum of electromagnetic radiation. The frequency of the radiation is determined entirely by the difference in energy between the two states. The operation of a laser depends on a peculiarity of the interaction of photons with matter. When a photon emitted by one excited molecule impinges on another molecule in the same excited state, the photon can stimulate the second molecule to emit an additional photon of the same phase and frequency as the stimulating photon. Both photons can then stimulate similar emissions from other molecules, so that the number of identical photons moving through the collection of molecules grows exponentially. The nature of this process is suggested by the word laser, which was coined as an acronym for "light amplification by stimulated emission of radiation."

In a laser a collection of molecules subject to a population inversion is enclosed in an optical "cavity" with parallel mirrored surfaces at the ends. Photons emitted by the excited molecules travel back and forth through the laser medium, reflected by the two mirrors, and stimulate additional molecules to emit photons with the same frequency and phase. Because only the photons that follow a path exactly perpendicular to the mirrors remain in the cavity long enough to be amplified, the light is formed into a well-collimated beam. A portion of the beam can be allowed to leave the cavity by making one of the mirrors partially transparent.

A photon with a frequency in the visible region of the electromagnetic spectrum has little energy: less than 10^{-19} joule, or watt-second. Nevertheless, the energy output of a laser can be many thousands of joules, emitted in an exceedingly brief period, sometimes as short as a few millionths of a second. The reason is that enormous numbers of atoms (perhaps 10^{23}) can be stimulated to radiate many times during this short interval.



ELECTRON-DISCHARGE LASER achieves a population inversion in the molecules of the working gas by means of an electron beam. Collisions of electrons with molecules impart energy to the molecules, raising them to an excited state. The electrons are emitted by a hot filament or an electric discharge and are accelerated through the cavity by a pair of electrodes.

Three kinds of high-energy laser have been considered as potential weapons. They are classified according to the mechanism that creates the population inversion in the working medium. In the gas-dynamic laser a gas such as carbon dioxide is generated by combustion. The gas is formed at high temperature, with the result that most of the molecules are in excited states. Then the gas is cooled suddenly by expansion through a series of nozzles; the cooling is so rapid that the molecules occupying excited states do not have time to return to the ground state. A population inversion is thus created, and laser radiation is emitted immediately after the expansion.

An electron-discharge laser achieves a population inversion by means of an electron beam directed through the gaseous working medium. The electrons give up part of their energy through collisions with molecules of the gas, causing transitions to higher vibrational or rotational energy states. By this mechanism the population inversion can be sustained continuously.

In a chemical laser two elements or chemical compounds are combined to form molecules of a new compound; for example, the gases hydrogen and fluorine can be combined to form hydrogen fluoride. The molecules are created in an excited state, and by controlling their environment it is possible to achieve the stimulated emission of radiation before they return to the ground state by dissipating their energy as heat.

These three methods can generate a population inversion in a large collection of molecules with good efficiency. There are practical limits, however, to the size of an efficient optical cavity for a laser and to the amount of power it can handle. Much of the research and development now under way in the field of high-energy lasers has the aim of pushing back those limits.

A laser weapon would differ in three important ways from all weapons that have been deployed up to now. First, it would transport destructive energy to the target in the form of an intense beam of electromagnetic waves rather than in the form of an explosive charge carried in a missile or a shell. Second, the energy would move with the speed of light, roughly 300 million meters per second; a supersonic missile, in comparison, has a speed of between 1,000 and 2,000 meters per second. Third, the laser beam must actually strike the target in order to damage it, whereas an explosive warhead can be effective at a considerable distance. Hence for a laser weapon to destroy its target the position of the target must be known to within a distance equal to the shortest dimension of the target, and the laser must be pointed with the same precision.

Given these characteristics of a laser weapon, one can think of three kinds of mission it might perform. Mounted on a satellite orbiting the earth it could attack intercontinental ballistic missiles during their boost phase, which lasts for about eight minutes, or it could attack enemy satellites in their orbits. Mounted on the ground it could attack aircraft or enemy satellites as they passed overhead, or mounted on a naval ship it could defend against missiles homing on the vessel. A laser weapon mounted on an aircraft could attack enemy aircraft or missiles.

In any of these missions the laser-weapon system would have to complete

© 1981 SCIENTIFIC AMERICAN, INC

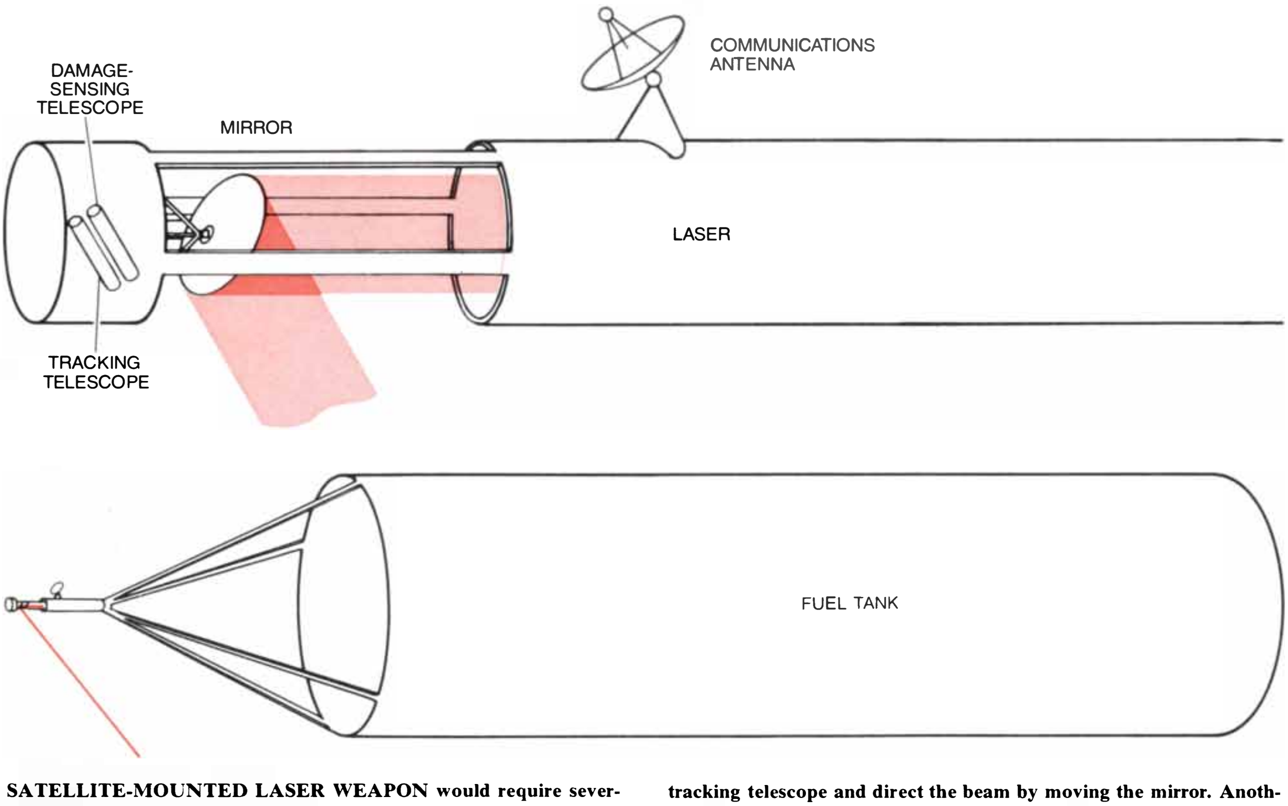
successfully an entire sequence of operations. The system would have to detect the target and distinguish it from possible decoys or other objects in the background. The system would have to point the laser beam at the target, follow its motion and fire the beam through the intervening medium. After each firing of the laser it would be necessary to determine whether or not the target was hit. In the case of a miss the system would have to determine by how much and in what direction the beam was misdirected, then correct the aim and fire again. After a hit the weapon system would have to determine whether or not the target had been destroyed; if it had not been, the aiming and firing would have to be repeated. Ultimately the system would have to communicate the results to a central command post and engage a new target if necessary.

To do these things the system would need several devices in addition to the laser. One device is a large mirror that could be moved under precise control to point the beam at the target. Another is a complement of sensors capable of detecting, identifying and determining the position of the target with the requisite precision and stability. Control devices would be needed to couple the output of the sensors to the aiming mirror. An additional, specialized set of sensors would be needed to assess the damage to the target or the distance by which the beam missed the target. Of course the system would also require a means of generating and storing energy and a mechanism for supplying the energy to the laser in intense pulses at the appropriate times.

A laser-weapon system operating in space and attacking targets that are also above the earth's atmosphere could send its beam over long distances, because light propagates without impediment in a vacuum. The beam would, however, diverge somewhat owing to diffraction, which is a consequence of the wave nature of light. Assuming that the mirror has a perfect surface and shape, the angle at which the beam diverges is inversely proportional to both the frequency of the laser light and the diameter of the mirror. Because one would want to keep the spreading of the beam to a minimum, a laser intended to serve as a weapon would work best if it generated light with a high frequency and if it were equipped with a large aiming mirror.

A laser beam traveling through the atmosphere is attenuated and dispersed by a number of processes. The molecules of the air and the particulate matter in it (dust, water droplets and smoke particles) both scatter and absorb light. An infrared beam from a carbon dioxide laser would lose half of its intensity after traveling four kilometers in cool, dry air or 1.5 kilometers in hot, humid air. Clouds, smoke, dust, fog or thick haze would absorb a beam almost completely. In short, the efficacy of a laser weapon operating in the atmosphere would depend on the weather. Such dependence is a serious drawback in any weapon, but it is particularly troublesome in a defensive weapon, which would have to respond to an attack launched at a time (and therefore in weather conditions) of the enemy's choice. Even in clear weather a laser beam can be deflected, dispersed or completely interrupted by atmospheric phenomena. Turbulence causes rapid local changes in the density of the air, which can deflect a beam of light or make it diverge. The twinkling of stars and distant lights is a manifestation of this effect.

A considerable fraction of the energy in a laser beam is absorbed by the atmosphere. As a result the air in the path of the beam is heated; the heated air expands, creating a channel of low-density air. Light waves bend away from the



SATELLITE-MOUNTED LASER WEAPON would require several components in addition to the laser itself. An infrared or optical telescope would detect and track a missile during the boost stage of its flight, and a hinged mirror would point the laser beam at the target. The mirror would have to be large, rugged, highly reflective and optically perfect. A control system would receive the signals from the tracking telescope and direct the beam by moving the mirror. Another system of telescopes and sensors would measure the miss distance or assess the damage to the target. A communications link with the ground would transmit information about the target and receive commands. By far the largest component of the laser weapon is a reserve of stored fuel and a system to manage it and supply it to the laser.

© 1981 SCIENTIFIC AMERICAN, INC

hotter, less dense regions of a medium, and so the beam diverges. The phenomenon is called thermal blooming; it is a common reason for the defocusing and divergence of a laser beam in air.

A final difficulty in propagating a laser beam through the atmosphere is the risk of creating a plasma. Since light waves are a form of electromagnetic radiation, an intense light beam is accompanied by a strong electric field. At an intensity of about 10 million watts per square centimeter (the exact value depends on the frequency of the radiation) the field is so strong that it removes electrons from atoms in the air, thus ionizing the air and creating a plasma. The plasma absorbs the beam and interrupts its transmission. The effect sets an upper limit on the intensity of a beam of laser light that can propagate through the atmosphere.

A laser weapon would damage a target by overheating it, that is, by concentrating on it more thermal energy than it could withstand without malfunctioning. Damage arises only from the fraction of the energy that is absorbed by the surface of the target. For example, a target of shiny aluminum would absorb only 4 percent of the radiation from an infrared laser that reached the target. The rest would be reflected and would cause no damage.

The proportion of the laser energy that would be absorbed by a target depends on the frequency of the radiation, the material of the target and the condition of the target's surface. Visible and infrared radiation are mostly reflected from a polished metal surface, so that in general much less than 10 percent of the energy carried by the laser beam would be absorbed and cause damage. The absorption of ultraviolet radiation by a metallic surface is much higher; more than half of the ultraviolet energy reaching a target would cause damage.

Overheating might destroy or incapacitate a target such as a missile by any of several mechanisms. The amount of energy per unit area that would have to be delivered to the target in order to damage it would depend on the mechanism chosen and the vulnerability of the target to that mechanism. For example, the electronic circuits of an unprotected satellite would probably malfunction if the craft were illuminated continuously for several minutes by a laser beam with an intensity of about one watt per square centimeter. This is roughly 10 times the intensity of sunlight at the top of the atmosphere. The absorption of 1,000 watts per square centimeter for one second (a total absorbed energy of 1,000 joules per square centimeter) would melt a metal surface a few millimeters thick. To deposit that much energy, however, an infrared laser would have to provide about 20,000 joules per square centimeter, since most of the energy would be reflected by the target.

A laser that sends out its energy in brief but powerful pulses might reach an instantaneous intensity of a million watts per square centimeter, even though the average power would be much lower. The surface of a target struck by such pulses would rapidly lose its shininess, and the fraction of the beam's energy absorbed would increase with each pulse. It is therefore possible in principle to burn a hole in a target with a pulsed laser beam.

When the target is in the atmosphere, a beam intensity of roughly 10 million watts per square centimeter would cause the air immediately in front of the target to ionize, creating a layer of plasma where the beam strikes the surface. The plasma would absorb the energy of the beam and grow incandescently hot (to about 6,000 degrees Celsius). The plasma would rid itself of this energy in two ways: by emitting ultraviolet radiation and by expanding explosively. These two mechanisms could increase the proportion of the beam energy coupled to the target to about 30 percent and thereby reduce the amount of energy the laser would have to generate.

A pulsed beam of extreme intensity could evaporate the metal at the surface of the target. The evaporated metal would fly away from the surface at a high velocity, and its momentum would be balanced by an equal and opposite momentum impinging on the target. The impulse generated in this way could tear or crack a metallic target.

From the physics of these effects it is possible to arrive at a good estimate of the capabilities a laser weapon would need in order to carry out a particular mission. The mission I should like to consider in some detail is that of an orbiting laser weapon intended to destroy enemy intercontinental ballistic missiles during their boost stage. Although this mission is the most remote application of laser weapons in terms of development time and practicality, it is conceptually the most interesting mission. It is also the one most often mentioned in public discussions of laser weapons.

The missile-defense lasers would be deployed on satellites in orbits some 1,000 kilometers above the earth. At this altitude a satellite would be within striking distance of launching sites in the U.S.S.R. for only a short period during each orbit. To ensure that at least one satellite would be within range at all times the total force would have to include about 50 satellites. A single satellite would have to be capable of destroying an entire force of perhaps 1,000 missiles during the boost stage, which lasts for about eight minutes. Therefore the satellite could devote about half a second to each missile.

My colleagues and I have found that an efficient damage mechanism for a ballistic-missile interceptor would be to crack the surface of the missile by impulsive loading. Cracking would result from the absorption of about 1,000 joules per square centimeter during each of several brief pulses. The energy would be delivered by a beam with an intensity at the target of about a million watts per square centimeter and a pulse duration of a few hundred-millionths of a second. Laboratory experiments indicate that about 10 pulses would be needed to punch a hole in the missile.

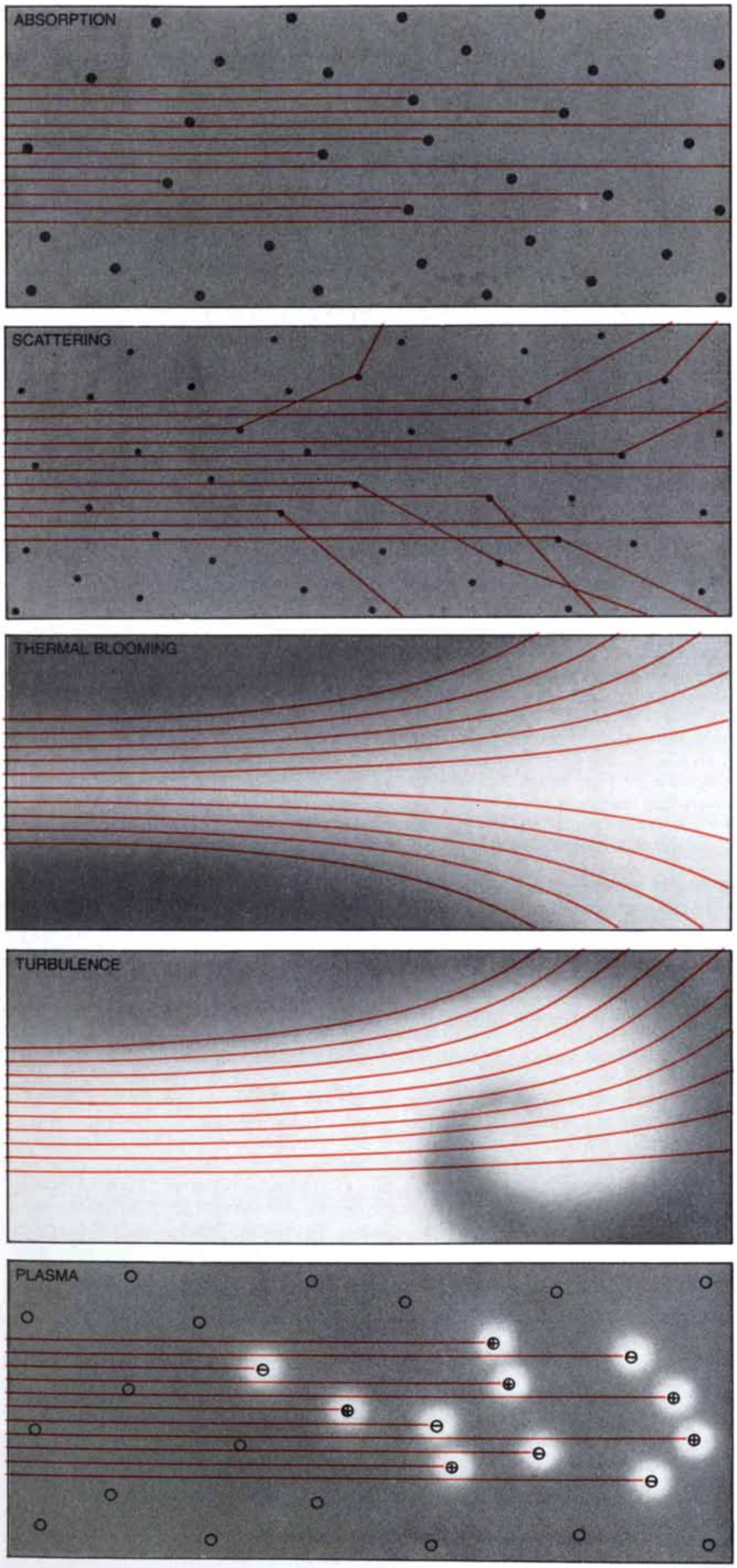
How much energy must such a laser develop? Assume that the weapon is a pulsed hydrogen fluoride laser and its beam-directing mirror is optically perfect and measures one meter in diameter. Since only about 10 percent of the light that strikes the target is absorbed and contributes to the damage, the laser must deliver 10,000 joules per square centimeter per pulse at the target. The area covered by the beam 1,000 kilometers away would be about the same as the area of the mirror: almost 8,000 square centimeters. To achieve an energy flux of 10,000 joules per square centimeter over this area the total energy of the beam would have to be almost 80 million joules per pulse. If the pulses were to last for roughly 100 microseconds, the power of the laser would be almost a million megawatts, which is quite unattainable. (A large commercial power station has a generating capacity of a little more than 1,000 megawatts.)

A lesser amount of absorbed energy from a continuous laser beam might damage a distant target by melting a hole in its skin instead of fracturing the skin. For example, an aluminum skin two millimeters thick would melt when it had absorbed about 400 joules per square centimeter. If the reflectivity of aluminum is assumed to be 90 percent, a 100-megawatt carbon dioxide laser would need about 100 seconds to inflict such damage on a target 1,000 kilometers away. This rate of damage is clearly inadequate, since the laser weapon has only half a second at best in which to deal with each rising missile.

One way of alleviating these difficulties might be to enlarge the pointing mirror. With a mirror four meters in diameter a 100-megawatt hydrogen fluoride laser could damage the target by melting in about a second. Making such a mirror sufficiently rugged and of the necessary optical quality, however., is beyond the technical capabilities of the U.S. or any other nation. There are scant prospects for constructing an optically precise four-meter mirror.

The fuel requirements of a laser-weapon system represent another insurmountable obstacle. Even if the laser itself and its energy-staging system op-

© 1981 SCIENTIFIC AMERICAN, INC



erated with perfect efficiency, such a continuous-wave hydrogen fluoride laser would consume some 660 kilograms of fuel for each missile destroyed. In order to shoot down 1,000 missiles, then, each satellite would have to be supplied with 660 metric tons of fuel, which represents about 20 loads for the U.S. space shuttle. The 50 satellites needed to ensure continuous coverage of Russian launching sites would require 1,000 shuttle flights for their energy stores alone. Four shuttle craft, each making two trips per year, would take 125 years to deliver the fuel.

The assumptions that underlie this discussion of a hypothetical missile-defense system are unrealistically optimistic. It should be pointed out first that a 100-megawatt hydrogen fluoride laser does not exist, and there is no indication that such a device could be developed in the foreseeable future. Furthermore, the efficiency of the laser and of the energy-staging system will never approach 100 percent. The efficiency of existing lasers is a few percent, and it might someday attain 30 or 40 percent. An energy-staging system can at best reach 30 percent efficiency. Hence the total energy store for each satellite would have to be increased by a factor of at least 10 and more likely 30.

It is conceivable that a laser weapon suitable for deployment in space could eventually be constructed. Even so, I doubt that it could be exploited successfully because it would be vulnerable to a number of relatively simple and inexpensive countermeasures. During the long time it would take to assemble each platform in space the system would be extremely vulnerable to attack by an antisatellite weapon exploded nearby. Even a completed network could be temporarily incapacitated at crucial times by blinding its sensors, by jamming its communications or by confusing its detection and tracking system.

The other conceivable use of a space-based laser weapon is as an antisatellite system. The practicality of the concept is highly questionable. In the first place satellites in orbit are already vulnerable to explosive weapons, which can be placed accurately in space or even made to home in on a warm object in orbit. A

ATMOSPHERIC INTERFERENCE could deflect or reduce the intensity of a laser beam being propagated through the air. The beam would be absorbed by particulate matter and scattered by dust, smoke and water droplets; even molecules of the air could absorb and scatter the beam. Thermal blooming results from heating of the air in the beam, creating a region of low density that causes the beam to diverge. Turbulence leads to local variations in both density and refractive index that would deflect and diffuse the beam unpredictably. Very intense laser light could ionize molecules of the air, creating a plasma that would absorb and thereby interrupt the beam.

© 1981 SCIENTIFIC AMERICAN, INC

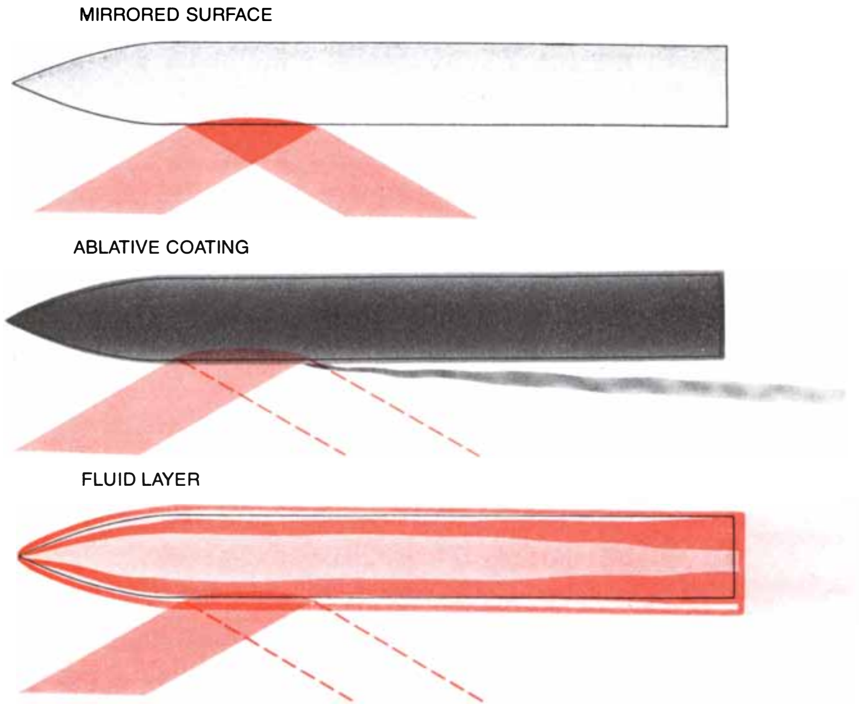
space-based antisatellite laser would itself be vulnerable to the same weapons. The laser system would also be complex and fragile and therefore expensive and difficult to maintain. It is highly unlikely that antisatellite lasers will ever become more cost-effective than mechanical satellite killers launched from the earth.

I turn now to the potential of high-energy lasers as weapons operating in the earth's atmosphere. Missions such as the protection of aircraft and ships from enemy missiles and the destruction of enemy aircraft might in principle be carried out by a laser weapon. Several weapon systems that can accomplish the same tasks already exist, however, including supersonic self-guided missiles and rapidly firing cannon. The question, then, is whether a laser would be a superior weapon. Could it provide such short-range protection more cheaply or more effectively?

The first thing to consider is the physics of the propagation of a laser beam in the atmosphere. I have already described blooming, absorption and atmospheric ionization. Blooming and absorption alone would reduce the intensity of an infrared laser beam by a factor of from 100 to 300 over a distance of five kilometers. If the size of the beam at the target is about equal to the size of the transmitter mirror, the intensity of the beam at the mirror would have to be from 100 to 300 times what it is required to be at the target. From this requirement another arises: if the laser light is to destroy the target without damaging the mirror, the mirror must be from 200 to 300 times more reflective than the target. If the opponent protected his missiles or aircraft with a reflective coating, however, the target would be almost as shiny as the mirror.

One could attempt to overcome this difficulty by building a large mirror that could focus the laser beam on a target a few kilometers away. The cross section of the beam at the target would then be smaller than the cross section at the mirror. This solution is impractical, however, because a mirror much larger than a meter in diameter is awkward to operate and point and is vulnerable to simple projectiles. Moreover, very large focusing mirrors would be ineffective because atmospheric turbulence would disturb and defocus a wide beam. An effort to build more reflective mirrors and to cool them could be countered by painting the target missiles with several coats of an ablative material that would burn off and carry away most of the incident energy from the laser beam. In a contest between improved lasers and countermeasures the laser is at an intrinsic disadvantage, since even in good weather the atmosphere works against it.

Another tactic for a laser weapon engaged in defense against missiles would be to wait until the target was only about



DEFENSIVE MEASURES could protect a missile from the effects of laser light at small cost. The most obvious approach is to make the surface of the missile highly reflective so that little of the light is absorbed. Alternatively the missile could be covered with an ablative coating, which would burn off and so carry away the energy of the laser radiation. A layer of fluid continuously secreted from the nose of the missile would have the same effect. The missile could also be made to spin, thereby spreading the energy of the beam over a larger area.

a kilometer away before attacking it with a laser. The intensity of the beam would then be degraded by a factor of about 10 instead of 300, and a reasonably reflective mirror could perhaps withstand the energy flux required to destroy the target. The weakness of this plan is a lack of time. A missile approaching at, say, twice the speed of sound covers the last kilometer of its flight in about 1.5 seconds. A laser weapon would not have enough time to engage more than one attacking missile. In the same length of time a rapidly firing cannon could direct several explosive shells at the target.

Even though laser light travels almost a million times faster than an ordinary projectile, a laser weapon would have no intrinsic operational advantage over a fast-firing cannon for close-range protection from missiles. On the contrary, the laser has several disadvantages. An attacking missile can be protected from laser light (particularly a continuous-wave beam of low intensity) by a thin film of a substance that is constantly excreted at the nose of the missile to absorb the energy of the beam and carry off the heat. Another defense would be to make the missile rotate so that it spread out the heat over the entire surface area. Furthermore, even over a range of one kilometer bad weather can completely neutralize a laser weapon.

A final consideration is that the process of detecting and tracking a target is more demanding with a laser weapon than it is with other defensive weapons, since the beam must actually hit the target if it is to have an effect. The standard of accuracy for the tracking system of a cannon that fires projectiles is much less stringent, particularly if the projectiles carry an infrared seeker that enables them to home in on the target.

On balance, then, laser weapons operating in the atmosphere offer no clear advantage over existing weapons for close-range defense. In addition they can be impeded by weather, they cannot operate effectively beyond a range of a few kilometers, they are easier to neutralize by countermeasures than ordinary projectiles or supersonic missiles and they require a much better tracking system. Under these circumstances it is difficult to see how the development and deployment of such fragile, complex and expensive weapons would improve the military capability of a nation.

It does not necessarily follow that research on high-energy lasers has no worthwhile objectives. Although lasers are decidedly unpromising as weapon systems, they may have valuable applications in industry, particularly in chemical engineering and in energy systems based on nuclear fusion. For these reasons rather than for unrealizable military applications the U.S. would do well to continue research on the many aspects of the technology of high-energy lasers.

© 1981 SCIENTIFIC AMERICAN, INC

Magnetic Navigation in Bacteria

Certain aquatic bacteria are magnetotactic: they have tiny internal compasses that orient them in the earth's magnetic field. Swimming along the inclined magnetic field lines directs them toward the mud

by Richard P. Blakemore and Richard B. Frankel

Bacteria are among the simplest of organisms. Nonetheless, they have evolved a variety of sensory and motor adaptations, called tactic responses, by means of which they interact with their environment. Many bacteria are chemotactic: they tend to move toward either a higher or a lower concentration of a particular substance. Other bacteria exhibit phototaxis: they accumulate in an illuminated region.

In the past few years a novel tactic response in bacteria has come under investigation. Certain aquatic bacteria are now known to be magnetotactic: they tend to swim along magnetic field lines and are accordingly influenced by the earth's magnetic field. It has been shown that the magnetotactic bacteria synthesize and thereafter carry within them small crystals of magnetite (Fe_3O_4), the oxide of iron known to early navigators as lodestone. Particles of magnetite have also been found in various other organisms, and so the discovery of magnetotaxis in bacteria suggests that man is not the only organism to have mastered the art of magnetic navigation.

The magnetic properties of magnetite were recognized by the ancient Chinese and Greeks more than 1,000 years before the invention of the magnetic compass in the Middle Ages. The working material in the first compasses was an elongated piece of magnetite with a large natural magnetization. Later it was found that an iron needle magnetized by rubbing it with magnetite could serve the same purpose.

The idea that the earth itself is a magnet was not proposed until 1600, when William Gilbert published *De magnete magneticisque corporibus et de magno magnete tellure* (*On the Magnet and Magnetic Bodies and on the Great Magnet the Earth*). Gilbert, who served as physician to Queen Elizabeth I of England, based his treatise on 16 years of studying the interaction of magnetized needles with spheres made of magnetite. He called the spheres terrellas, or little earths.

A few decades earlier Robert Norman, an English compass maker, had found that if a magnetized needle is allowed to pivot freely in the vertical north-south plane, the north-seeking end of the needle dips below the horizon. In London, for example, the angle of inclination is approximately 70 degrees. Gilbert explained the inclination as an effect of the geometry of the earth's magnetism. He explored the geometry by measuring the orientation of magnetized needles placed near the surface of a terrella. The magnetic field set up by a magnetized sphere, he found, is radial (vertical) at the poles, tangential (horizontal) at the equator and between these extremes is inclined at an angle that increases with latitude. (It is now known, of course, that the magnetic poles of the earth do not exactly correspond to the geographic ones, but in our work the discrepancy is unimportant and we shall ignore it here.)

By convention the direction of a magnetic field is the one indicated by the north-seeking end of a magnetic compass needle. Hence the geomagnetic field points straight up at the South Pole, straight down at the North Pole and horizontally northward at the Equator. In the Northern Hemisphere the field is inclined downward; in the Southern Hemisphere it is inclined upward.

The first indication that bacteria are sensitive to the geomagnetic field was noted in 1975 by one of us (Blakemore), then a graduate student in microbiology at the University of Massachusetts at Amherst. In the course of a microscopic study of bacteria commonly found in the mud of brackish marshes, some microorganisms were observed to swim persistently in one direction across the field of view. They accumulated at one edge of a drop of muddy water. Evidently the response was not a phototactic one because the bacteria swam toward the same edge regardless of the distribution of the light falling on the microscope slide. Even when the microscope was covered with a box, turned around or moved to another room, the bacteria continued to swim in the same geographic direction. It appeared they were directed by some pervasive cue, possibly the earth's magnetic field.

That the behavior of such bacteria is indeed magnetotactic was easily demonstrated. When a droplet of muddy water was examined microscopically at low magnification (about 80 times) with dark-field illumination, the motile, light-refracting bacteria appeared as moving points of light. In the absence of any magnetic field except the geomagnetic one some of the bacteria swam persistently northward and accumulated at the northern edge of the droplet. When a bar magnet was brought near, the bacteria swam toward the pole that attracts the north-seeking end of a compass needle. Conversely, they swam away from the pole that attracts the south-seeking end of the needle.

At first small permanent magnets and electromagnets were used to observe the organisms' response to magnetic fields and to separate them from the sediments for further study. Later, at the Woods Hole Oceanographic Institution, Adrianus J. Kalmijn, a specialist in the sensory biophysics of marine animals, joined the effort to explore the magnetotactic behavior of the bacteria in magnetic fields roughly equivalent in strength to the geomagnetic field. (The earth's field has a strength on the order of one gauss.) For these experiments uniform magnetic fields were set up by a pair of Helmholtz coils, which allowed the direction and the intensity of the fields to be controlled [*see illustration on page 60*].

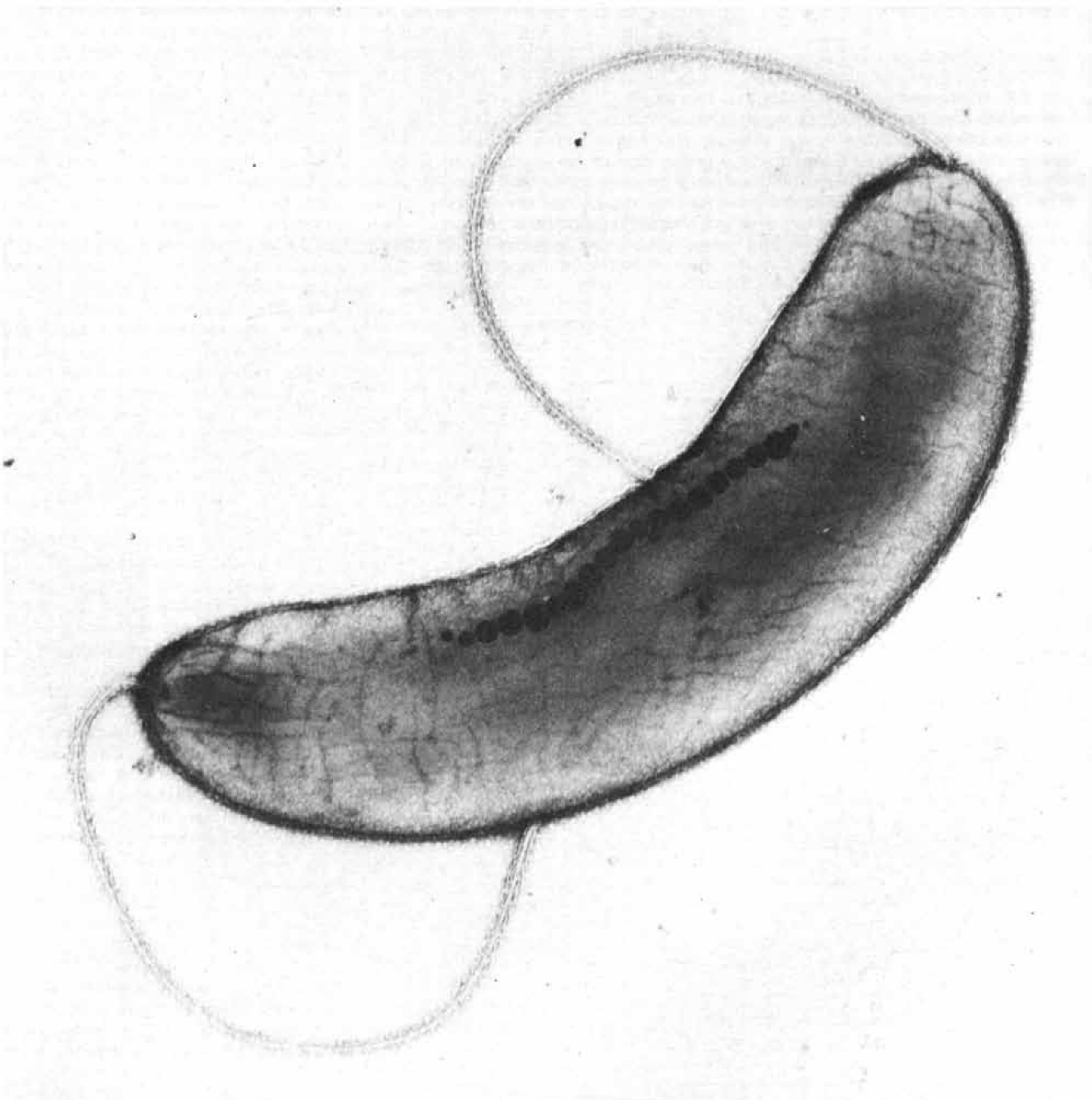
When the axis of the Helmholtz coils is aligned north-south, the intensity of the horizontal field acting on the bacteria is the sum of the field generated by the coils and the horizontal component of the geomagnetic field. If the field generated by the coils is somewhat stronger than the geomagnetic field, the net direction of the combined fields is effectively the same as that of the applied field. The bacteria swim along the magnetic lines of force in the direction of the field (that

© 1981 SCIENTIFIC AMERICAN, INC

is, in the direction indicated by the north-seeking end of a compass needle). When the electric current in the coils is reversed, the magnetic field reverses direction; the bacteria then make a 180-degree turn and swim in the opposite direction. Each time the field is reversed the bacteria make a U-turn, so that they are always swimming in the direction of the field. Thus the organisms themselves can be said to be north-seeking.

The persistent swimming of magnetotactic bacteria along magnetic field lines is in marked contrast to the run-and-tumble motility characteristic of chemotactic bacteria such as *Escherichia coli.* Even when magnetotactic bacteria have been killed, they assume a consistent orientation in the magnetic field and rotate by 180 degrees when the current in the coils is reversed. (The killed bacteria do not migrate either north or south, however.) In short, the bacteria act as biological magnetic dipoles.

In sediments taken from bogs, marshes, sewage-treatment ponds or similar places the concentration of magnetotactic bacteria is usually between 100 and 1,000 cells per milliliter. When the sediments are stored in jars in the laboratory, the concentration increases in a few weeks to between 100,000 and a million cells per milliliter. The high population density often persists for as long as two years without added nutrients. One can take advantage of the magnetotactic re-



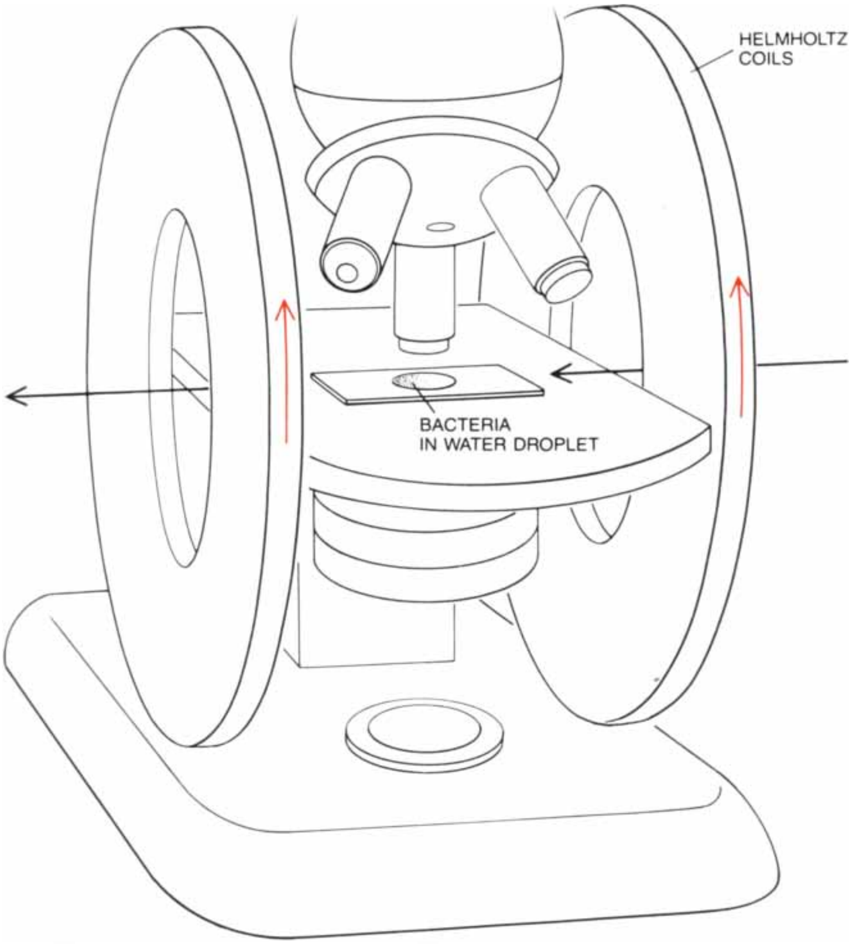
MAGNETOTACTIC BACTERIUM is seen in a transmission electron micrograph, which reveals a striking feature of its internal structure: a chain of particles that are opaque to the electron beam (*black spots*), aligned more or less parallel to the long axis of the cell. The particles are called magnetosomes and consist of the oxide of iron known as magnetite (Fe_3O_4). The chain functions as a compass, orienting the bacterium in the same direction as the lines of force of the earth's magnetic field. The species shown here has a flagellum (a filamentous propeller) at each end; it is capable of swimming either forward or backward. (The tips of the two flagella are doubled back under the body of the bacterium and hence are out of sight in this view.) The magnification is approximately 56,000 diameters.

© 1981 SCIENTIFIC AMERICAN, INC

sponse of the bacteria to make them swim away from sediments and other debris into a droplet of clean water, where they can be collected and examined with a microscope. More than a dozen morphologically distinct types of bacteria have been found in samples prepared in this way; they include cocci (spherical bacteria), bacilli (rod-shaped bacteria) and spirilla (helical bacteria). This observation, together with the fact that magnetotactic bacteria are found in both freshwater sediments and marine ones, indicates that magnetotaxis is shared by diverse bacterial species.

One such species, a freshwater magnetotactic spirillum that has been given the name *Aquaspirillum magnetotacticum,* has been isolated and grown in an artificial culture medium by one of us (Blakemore) and Ralph S. Wolfe of the University of Illinois. Bacteria of this species have a flagellum (a filamentous propeller) at each end and can swim either forward or backward. This ability distinguishes them from many other magnetotactic bacteria, which have their flagellar apparatus at only one end of the cell and appear to swim persistently forward.

Closer examination of the internal structure of a bacterium such as *A. magnetotacticum* by means of a transmission-type electron microscope reveals a striking feature: approximately 20 particles, opaque to the electron beam and commonly either cubic or octahedral in form, arranged in a chain parallel to the cell's long axis. Every kind of magnetotactic bacterium that has been examined so far by this technique has turned out to have such particles in the cytoplasm of the cell. The particles are most often arranged in a single chain or two chains, and they are remarkably uniform in size and shape. Each particle is surrounded by a sheath, or membrane, that is always adjacent to (and may be contiguous with) the cytoplasmic membrane that envelops the cell as a whole. The enclosed particles, which are about 500 angstrom units across, are referred to as magnetosomes.



EXPERIMENTAL SETUP employed by the authors' group to study the behavior of magnetotactic bacteria in an applied magnetic field consists essentially of a microscope fitted with a pair of Helmholtz coils. The electric current in the coils (*colored arrows*) creates a uniform magnetic field along their axis (*black arrows*). When the current is reversed, the axial magnetic field also reverses. Varying the magnitude of the current changes the strength of the field.

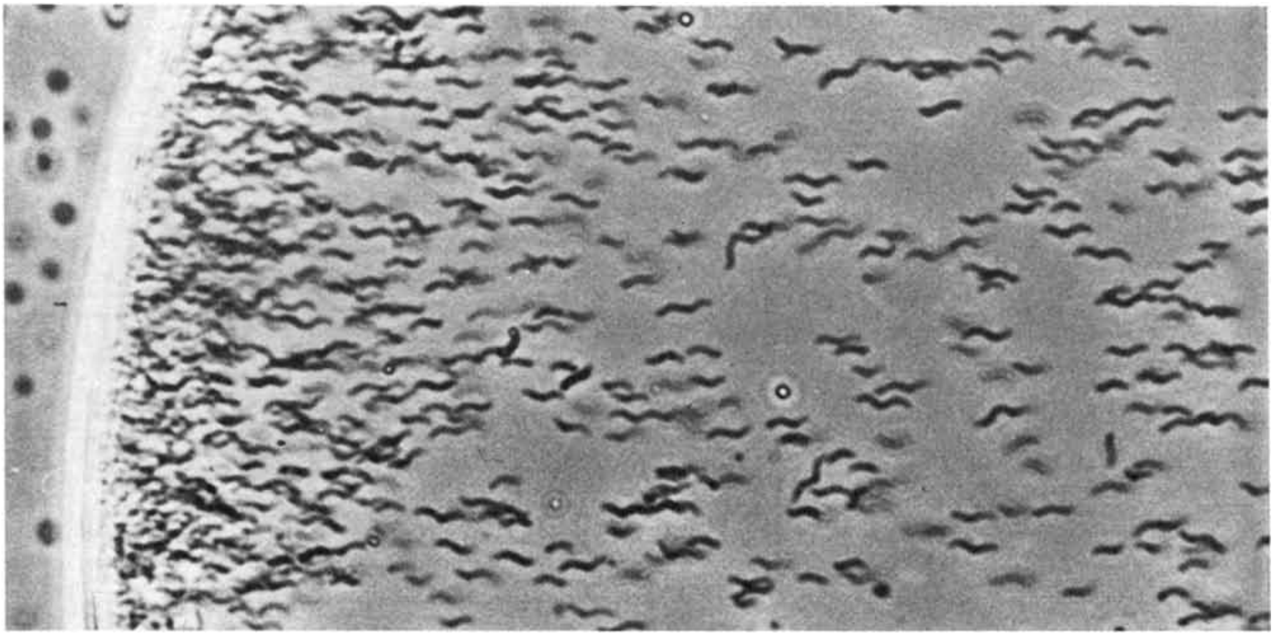
Electron micrographs made by David L. Balkwill and Denise Maratea of the University of New Hampshire revealed that in *A. magnetotacticum* the sheath of a magnetosome consists of a thin electron-opaque layer separated from the particle itself by an electron-transparent space. In other species of magnetotactic bacteria three layers can be perceived in the membrane that encloses each particle. The chemical composition of the envelope of the magnetosomes is currently under study. One of its functions may be to hold each particle in a fixed position in the cell.

The elemental composition of the magnetosome particles can be determined by observing the X rays that are emitted when a sample is struck by the electron beam of the electron microscope. The high-energy electrons collide with and displace electrons in the atoms of the sample; the subsequent rearrangement of the atomic electrons is accompanied by the emission of X rays that have a spectrum of energies characteristic of the element from which they emanate. When the magnetosomes of *A. magnetotacticum* are stimulated in this way, X rays characteristic of iron predominate. When regions of the cell that do not contain magnetosomes are similarly exposed, the spectrum of X rays emitted does not include those characteristic of iron. It follows that the particles must be composed of iron in some form. Indeed, the element appears to account for as much as 2 percent of the cells' dry weight.

A connection between the magnetosomes and the magnetotactic response can be shown by the following experiment. If iron is supplied to the culture medium of *A. magnetotacticum* in the form of a soluble organic complex at a concentration of one or two milligrams of iron per liter, the bacteria grow, they synthesize magnetosomes and they are magnetotactic. If the same strain of bacteria is inoculated into a culture medium containing no more than half a milligram of iron per liter, the bacteria grow as before, but they do not form magnetosomes and they are not magnetotactic. The total concentration of iron in the nonmagnetotactic cells is only about 10 percent of that in the magnetotactic ones. Evidently only bacteria with magnetosomes exhibit magnetotaxis. The iron required for the synthesis of magnetosomes is readily available at concentrations of a milligram or so per liter in many of the natural environments in which magnetotactic bacteria are found.

The chemical form of the iron in the magnetosomes can be ascertained by Mössbauer spectroscopy. This technique makes it possible to detect in the spectrum of Doppler-shifted gamma rays absorbed by an atomic nucleus the subtle shifts caused by the configuration

© 1981 SCIENTIFIC AMERICAN, INC



NORTH-SEEKING BACTERIA swim in the direction of an applied magnetic field and accumulate at the edge of a drop of water in this demonstration of magnetotaxis. In the absence of the applied field the bacteria would swim persistently northward under the influence of the geomagnetic field. The bacteria have been named *Aquaspirillum magnetotacticum*. They are enlarged here about 1,700 diameters.

of the electrons surrounding the nucleus. Because the electronic configuration is determined by the chemical environment of the atom, the Mössbauer spectrum gives an indication of the chemical form an element has in a particular specimen.

In this case the chemical form of the iron was determined by measuring the Mössbauer spectrum of the isotope iron 57 in freeze-dried magnetotactic cells of *A. magnetotacticum* and in magnetosomes isolated from the cells. The spectrum turned out to be almost identical with that of a pure laboratory sample of magnetite [*see top illustration on page 64*]. It follows that the iron in *A. magnetotacticum* is primarily in the form Fe_3O_4. As one might expect, spectral lines corresponding to magnetite are absent in the Mössbauer spectrum of nonmagnetotactic cells.

In addition to the lines corresponding to magnetite in the Mössbauer spectrum of the magnetotactic cells there is a pair of lines in the middle of the spectrum that corresponds to another iron compound apparently present in substantial amounts. Since the iron in the culture medium was supplied in the form of a soluble organic complex, the magnetite in the particles is clearly a product of bacterial synthesis. We now think the material responsible for the additional lines in the Mössbauer spectrum is an iron-containing precursor in the biochemical pathway by which the bacteria synthesize magnetite.

Knowing that the magnetosome particles are made of magnetite enabled us to elucidate the mechanism of magnetotaxis. The form of magnetism observed in magnetite is called ferrimagnetism. As in all magnetic materials the ultimate source of the magnetism is the magnetic moment associated with the spin angular momentum of each iron atom. Interactions among the atoms result in the parallel alignment of the spins in a region of the material. The macroscopic magnetic properties of a magnetite particle depend on its size and shape. If it is large, it will include multiple magnetic domains: regions in which the spin axes are oriented antiparallel. In a ferrimagnetic material the antiparallel configuration is favored because it lowers the overall magnetic energy of the particle; it also reduces the remanent, or net, magnetic-dipole moment.

Magnetic domains are separated by transition regions called domain walls. The width of such a wall is determined by certain intrinsic magnetic properties of the material and hence is independent of the size of the particle. If the dimensions of the particle are smaller than the width of the domain wall, separate domains cannot form and the particle constitutes a single magnetic domain. In such a particle the remanent magnetic moment is unchanging in time and approaches the theoretical maximum for the material.

A still smaller magnetic particle also forms a single domain, but its effective magnetic moment can be reduced by another phenomenon, known as superparamagnetism. There are several possible orientations of the magnetic moment favored by the crystallographic structure of the material, all of which have the same energy. In a very small particle the magnetic moment can fluctuate among the orientations as a result of thermal disruption. In other words, the remanent magnetic moment is not permanent in such a particle. At a given temperature the time required for the magnetic moment to reorient itself is an exponential function of the volume of the particle. If the particle is large enough, the thermal reorientation time is essentially infinite.

From these considerations it is evident that a single-domain particle with a volume too large to be superparamagnetic at room temperature has a permanent magnetic-dipole moment that corresponds to the maximum magnetization for the substance. For magnetite the maximum superparamagnetic dimension is between 300 and 400 angstroms, whereas the minimum dimension for the formation of multiple domains is between 800 and 1,200 angstroms. The particles produced by *A. magnetotacticum* and other species of magnetotactic bacteria fall precisely in the size range within which magnetite exists as thermally stable single-domain particles: between 400 and 1,200 angstroms. In the laboratory it is difficult to make magnetite particles in the single-domain size range. How the bacterial cell does so is not yet clear. We think the maximum size of the particles is somehow constrained by the magnetosome envelope and hence is under biological control.

What about the configuration of the magnetite particles within the cell? As we mentioned above, many species of magnetotactic bacteria have a

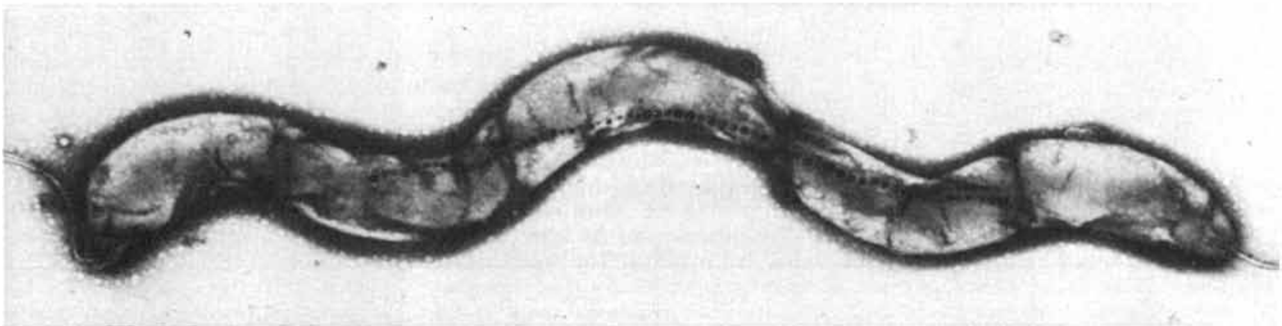
© 1981 SCIENTIFIC AMERICAN, INC

single chain or two chains of magnetosomes. The magnetic interactions of the particles in a chain tend to orient their magnetic-dipole moments parallel to one another along the axis of the chain. This phenomenon was noted by Charles P. Bean and Israel S. Jacobs of the General Electric Research and Development Center, who considered the properties of a chain of single-domain magnets in a different context two decades before the discovery of magnetotactic bacteria. Because of the parallel orientation of the moments the total moment of the bacterium is the sum of the moments of the individual particles. The moment per unit volume of magnetite is well known, and so the total moment per bacterium can be estimated from the size and the number of its magnetosomes, which can readily be observed in electron micrographs.

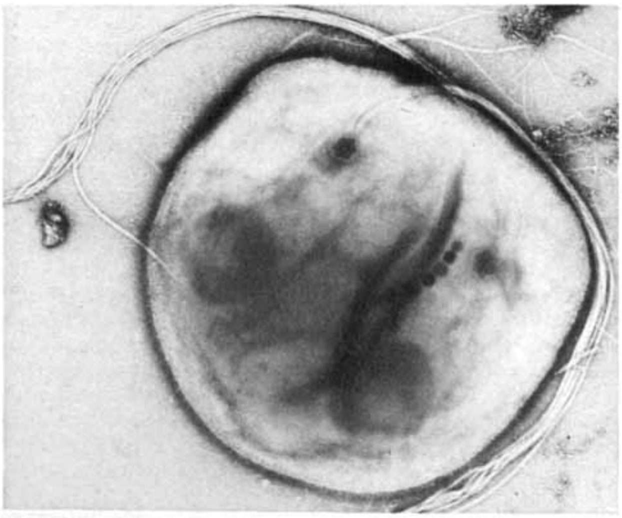
The orientation of a magnetotactic bacterium in water at room temperature is determined by competition between the torque exerted on the magnetic-dipole moment of the bacterium by the geomagnetic field and the randomizing forces resulting from the thermal motion of the water molecules (the phenomenon known as Brownian motion). The average degree of orientation of an ensemble of freely rotating magnetic dipoles in thermal contact with their environment was calculated at the turn of the century by the French physicist Paul Langevin. He showed that as the ratio of the magnetic energy to the thermal energy increases, the average orientation of the ensemble increases; for ratios greater than 10 the ensemble approaches complete orientation.

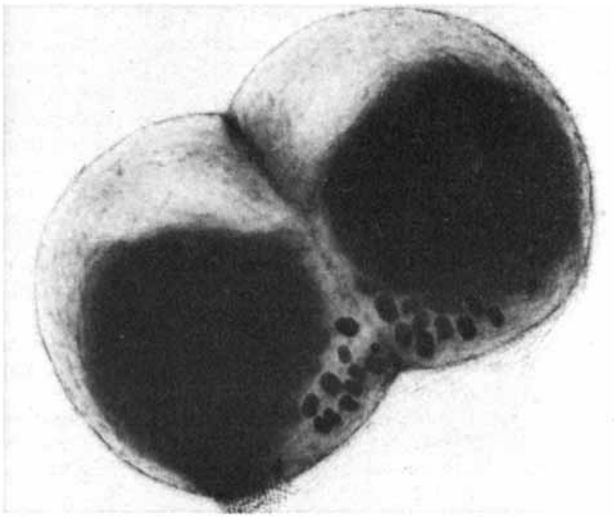
In *A. magnetotacticum* the ratio is approximately 16, so that the average orientation is virtually at the maximum. Furthermore, increasing the number of magnetite particles per bacterium would only marginally increase the degree to which the bacteria are oriented along the direction of the magnetic field. On the other hand, if the bacteria contained only enough magnetite to make their total concentration of iron comparable to that of other common bacteria, such as *E. coli,* their orientation would be barely distinguishable from a random distribution. Thus the single-domain magnetite particles arrayed in a chain constitute a biomagnetic compass of sufficient strength for the bacterium in water at room temperature to be efficiently oriented in the direction of the geomagnetic field.

The simplest explanation of the mechanism of magnetotaxis is that a swimming bacterium is passively steered by the torque exerted on its biomagnetic compass by the geomagnetic field. This hypothesis has been confirmed by measurements of the velocity of the migrating cells as a function of the strength of the magnetic field. When the field is strong (several gauss), the bacteria are well oriented in the direction of the field and their migration velocity in that direction is comparatively high. When the field is weak, the bacteria are more disoriented by thermal agitation, their swimming is more random and their migration velocity in the direction of the field is low. The speed of the migration



HELICAL BACTERIUM of the species *A. magnetotacticum* is magnified some 25,000 diameters in a transmission electron micrograph. Members of this freshwater magnetotactic species have been isolated and grown in an artificial culture medium. The particular specimen shown has an exceptionally long chain of magnetosomes strung out along its axis and appears to be in the process of cell division.

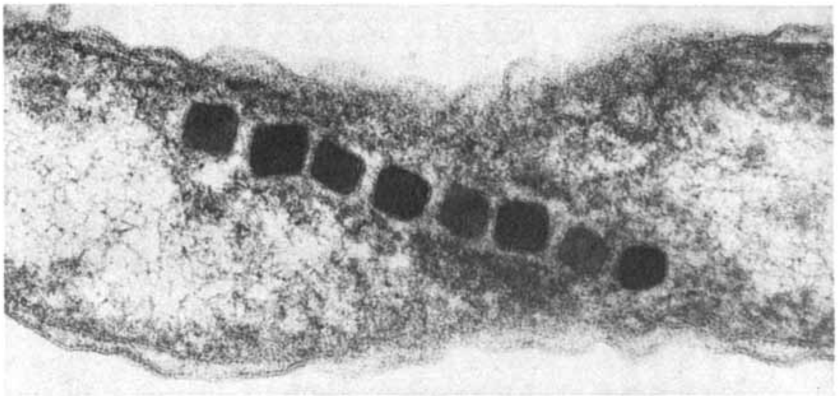




SPHERICAL BACTERIA, known as cocci, also exhibit magnetotaxis and have particles of magnetite in their cytoplasm. In some cocci the magnetosomes are arranged in chains (*left*); in others they are in clusters (*right*). Both of the species shown have paired bundles of flagella on one side and swim in only one direction. The large electron-opaque bodies in the coccus at the right have a high concentration of phosphorus and potassium; their role in the life of the organism is not known. This cell is apparently also just about to divide.

© 1981 SCIENTIFIC AMERICAN, INC

should depend on the strength of the field in the way described by Langevin; if it does, analysis of the data should yield the magnetic-dipole moment of the bacteria. Recent experiments at Woods Hole by Kalmijn and his colleagues B. D. Teague and M. K. Gilson on individual bacteria have confirmed the Langevin field dependence and have yielded magnetic moments for individual bacteria consistent with the analysis presented above.



THIN MEMBRANE surrounding each particle of magnetite is barely visible in this greatly enlarged transmission electron micrograph of a thin section cut from a magnetotactic bacterium. One function of the envelope may be to hold each particle in a fixed position in the cell.

The fact that bacteria with unidirectional motility collected from sediments in the Northern Hemisphere swim consistently northward is attributable to the forward orientation of the north-seeking pole of their magnetic-dipole moment with respect to the cell's flagellar apparatus. If the magnetic moment were reversed (that is, if the south-seeking pole were oriented forward with respect to the flagellum), the bacteria would swim in the opposite direction (southward).

South-seeking bacteria have been created in Kalmijn's laboratory. Following a suggestion by Edward M. Purcell of Harvard University, north-seeking bacteria were exposed to brief but intense pulses of a magnetic field directed opposite to the ambient field. When the pulsed field was strong enough, it reversed the magnetic-dipole moment of the magnetosome chain. The bacteria whose moment had been reversed became south-seeking. They made a U-turn and swam opposite to their initial direction, that is, opposite to the steady ambient field. Their north-seeking orientation could be restored by a second pulse delivered antiparallel to the first.

The magnetic moment could also be redirected by a standard "degaussing" procedure. A group of north-seeking bacteria was exposed to and then slowly removed from a magnetic field alternating at 60 hertz with a peak magnitude of more than 1,000 gauss. Whereas all the bacteria had initially swum toward the north pole, after the degaussing approximately half swam north and the other half swam south. The experiment showed that the magnetic-dipole moments of individual bacteria can be reversed, but the organisms cannot be demagnetized, which is exactly what one would expect for a chain of single-domain magnetic particles.

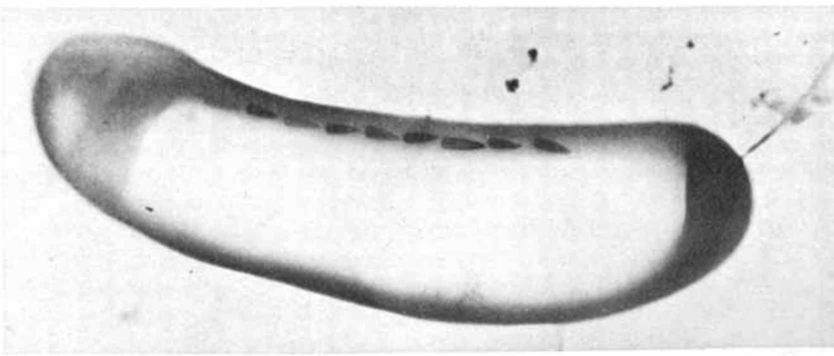
The behavior of microorganisms, including their movements in response to chemicals or light, provides an adaptive advantage for their survival. Magnetotaxis presumably confers some such survival value, but what is it? To answer this question we return to Gilbert's model of the inclination of the geomagnetic field.

As noted above, the geomagnetic field points north and down in the Northern Hemisphere and north and up in the Southern Hemisphere, with the absolute value of the angle of magnetic inclination increasing as one moves from the geomagnetic equator toward either of the poles. Because of the inclination of the geomagnetic field north-seeking bacteria in the Northern Hemisphere migrate downward and south-seeking bacteria migrate upward. In New England the magnetic inclination is about 70 degrees with north down; hence the predominantly north-seeking population of magnetotactic bacteria found there is effectively directed downward. The bacteria thereby keep to the sediments and away from the surface water.

The magnetotactic bacteria are bottom-dwelling organisms that are either anaerobic (capable of living only in the absence of oxygen) or microaerophilic (surviving best in an environment with little oxygen). A tendency to migrate downward could be advantageous in that it would help them to avoid the toxic effects of the greater concentration of oxygen in the surface water.

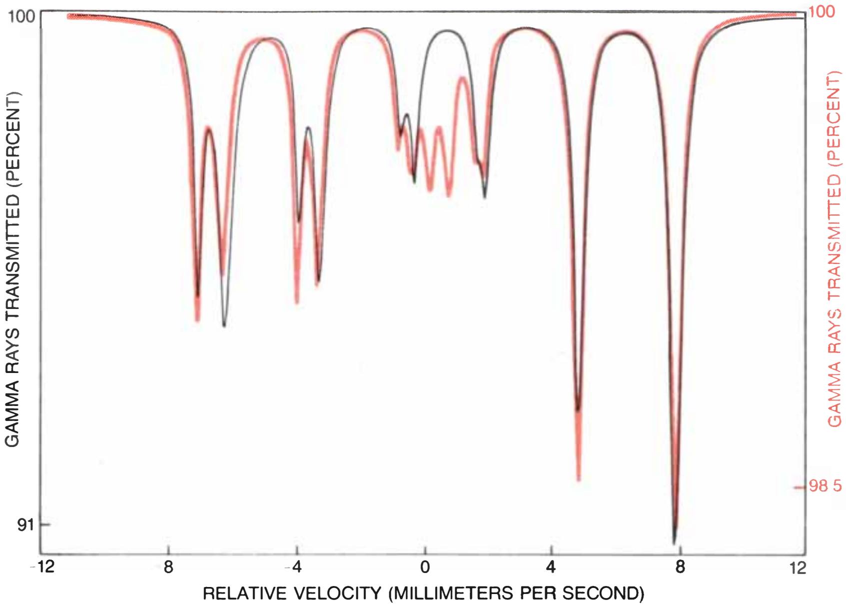
On the basis of this hypothesis one would expect magnetotactic bacteria in the Southern Hemisphere to be predominantly south-seeking; they would then also migrate downward, staying in the sediments and away from the surface water. In January, 1981, together with Nancy Blakemore and Kalmijn, we undertook an expedition to New Zealand and Tasmania to search for magnetotactic bacteria and to test the hypothesis. The sites were chosen because they are ecologically diverse and share many physical characteristics with New England, such as absolute latitude, magnetic field strength and climate. Moreover, the magnetic inclination in New Zealand and Tasmania has the same absolute value as it has in New England, although it has the opposite sign.

Sediments were collected from salt marshes, ditches, rivers, ponds, mountain lakes, thermal springs and caverns. They were all examined with portable microscopes equipped with Helmholtz coils. Most of the sediments included magnetotactic bacteria, and as predicted they were predominantly south-seeking. Like their counterparts in the Northern Hemisphere, the bacteria had magnetosomes in their cytoplasm, and their po-

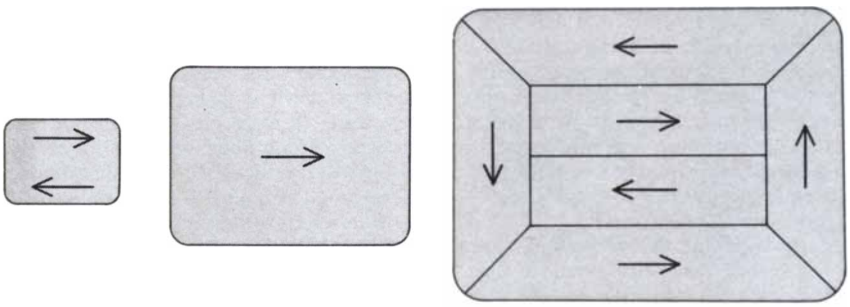


SOUTH-SEEKING BACTERIUM was collected by the authors and their colleagues near Christchurch, New Zealand. Magnetotactic bacteria of various types from New Zealand and Tasmania were found to swim predominantly southward, in agreement with the authors' hypothesis that magnetotaxis in bacteria is a mechanism for migrating down to and remaining in sediments. In most of the species collected in the Southern Hemisphere the magnetosomes had shapes similar to those found in the Northern Hemisphere. In this species, however, a novel pointed shape was observed for the first time. The cell is enlarged by about 33,000 diameters.

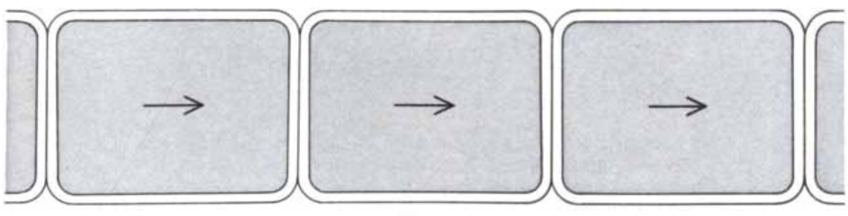
© 1981 SCIENTIFIC AMERICAN, INC



MÖSSBAUER SPECTRUM of the isotope iron 57 in freeze-dried cells of *A. magnetotacticum* (*colored curve*) is almost identical with that of a pure laboratory sample of magnetite (*black curve*), thereby demonstrating that the iron in this magnetotactic species is primarily in the form Fe_3O_4. To measure the spectrum gamma rays with an energy of 14.4 keV (thousands of electron volts) were passed through each sample. By moving the source with respect to the sample the wavelength of the gamma rays could be shifted in proportion to the relative velocity. At particular relative velocities the iron-57 nuclei in the sample could absorb the gamma rays by making a transition to an excited state with an energy of about 14.4 keV. At each absorbed wavelength a detector placed behind the sample recorded fewer transmitted gamma rays. The record of the spectrum shows the relative intensity of gamma rays striking the detector as a function of the velocity of the source with respect to the sample. The exact velocities at which absorption is observed in a sample are indicative of the chemical form of the iron in the sample.



SIZE OF A PARTICLE of magnetite determines its effective magnetic moment. The very small particle represented at the left is superparamagnetic: it consists of a single magnetic domain (a region in which the spin axes of all the iron atoms are oriented in the same direction), but the orientation of its magnetic moment (*black arrows*) can fluctuate as a result of thermal disruption. The large particle at the right has multiple magnetic domains in which the spin axes are oriented antiparallel; accordingly it has a low remanent, or net, magnetic moment. The intermediate-size particle at the center measures between 400 and 1,200 angstrom units across, the range in which magnetite exists as thermally stable, single-domain particles. The particles produced by magnetotactic bacteria, the authors have found, fall in this size range.



MAGNETIC MOMENTS ARE ALIGNED in the same direction in the chains of magnetosomes found in most species of magnetotactic bacteria. The total magnetic moment of such a chain is therefore the sum of the moments of the individual magnetite particles in the chain.

larity could be reversed by the degaussing procedure. Thus magnetotactic bacteria in the two hemispheres are similar except that the populations have opposite polarities.

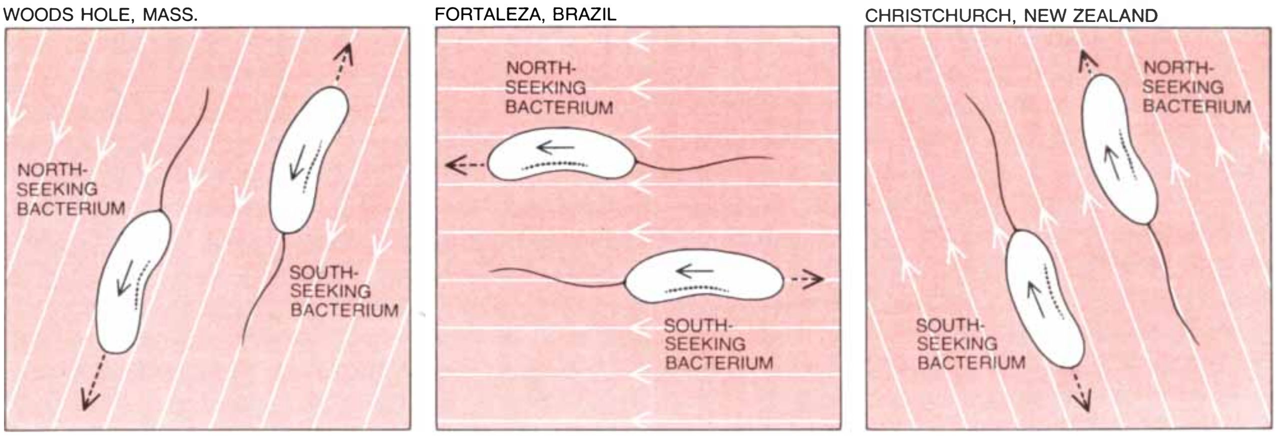
Laboratory experiments also indicate the role of the sign of the magnetic inclination in selecting the predominant polarity. Samples of sediment from New England, where the bacteria were initially north-seeking, were placed in a system of electrical coils that inverts the vertical component of the ambient magnetic field. The coils therefore reproduce the upward-inclined orientation of the geomagnetic field in the Southern Hemisphere. Control samples were placed in coils carrying no current, and therefore they remained in the ambient downward-inclined geomagnetic field. The samples were periodically examined and records were kept of the number and polarity of the magnetotactic cells over a period of a year.

Whereas the control populations remained north-seeking, the polarity reversed in the magnetotactic populations exposed to the inverted field. South-seeking bacteria increased detectably within six days; after three weeks these cells were predominant, and after eight weeks the population reversal was virtually complete. This result is entirely consistent with the hypothesis that the vertical component of the geomagnetic field is the relevant factor determining the polarity of bacterial populations in natural environments. Moreover, the experiment suggests that the response to changes in the vertical component takes place over many generations.

Another confirmation of the importance of the vertical component of the geomagnetic field comes from observations of magnetotactic bacteria at the geomagnetic equator, where the vertical component is zero and the geomagnetic field lines are horizontal. Since all magnetotactic bacteria are directed horizontally there, neither polarity is directed downward. On the other hand, horizontally directed motion could be advantageous for bacteria in the sediments by reducing potentially harmful upward excursions. Of course, magnetization of either polarity would be equally advantageous and neither would be favored.

Both north- and south-seeking magnetotactic bacteria have been found in sediments from Fortaleza in Brazil, a site near the geomagnetic equator. This observation was made in collaboration with F. F. Torres de Araujo of the Federal University of Ceará and D. M. S. Esquivel and J. Danon of the Brazilian Center for Physics Research. In Rio de Janeiro, where the inclination is 25 degrees upward, south-seeking bacteria predominate. It remains to be determined how the relative numbers of each polarity in a population of bacteria depend on the magnetic inclination for in-

© 1981 SCIENTIFIC AMERICAN, INC



SURVIVAL VALUE OF MAGNETOTAXIS to a bottom-dwelling bacterium is shown for three latitudes. In the Northern Hemisphere (*left*) a north-seeking bacterium is directed downward toward the sediments, whereas a south-seeking bacterium heads upward toward the more oxygenated (and hence toxic) surface water. In the Southern Hemisphere (*right*) south-seeking bacteria tend to swim downward and north-seeking ones upward. Near the geomagnetic equator (*middle*) both types of bacteria are found and both are directed horizontally, thereby reducing potentially harmful upward excursions. White arrows indicate direction of the geomagnetic field in each location.

clinations between zero and 25 degrees.

Laboratory experiments done with Wendy O'Brien, Randy Caplan and Nancy Blakemore have corroborated and extended these findings. Sediments from New England (where the bacteria are north-seeking) were placed in small vials sealed with rubber stoppers somewhat permeable to oxygen and stored in a magnetically shielded box. Over several weeks the samples underwent changes resulting in equal numbers of north- and south-seeking cells. Moreover, magnetotactic bacteria of both polarities could even be observed in equal numbers in the oxygen-depleted surface waters of the sealed vials. If the stoppers were removed, allowing more air into the vials, within several days no magnetotactic bacteria could be found in the surface water, whereas large numbers of both polarity types were present at the boundary between the sediment and the water. Accordingly both field and laboratory studies show that in the absence of a vertical magnetic field component the two polarity types coexist. The laboratory experiments also show that factors such as oxygen concentration can influence the distribution of magnetotactic bacteria in natural environments.

A relation between several behavioral responses is illustrated in *A. magnetotacticum*. Because this bacterium has a flagellum at both ends it can swim either forward or backward. Consequently, once the cells are passively aligned in the geomagnetic field, they can swim upward or downward along the inclined field lines. The direction chosen is determined at least in part by the local gradient of oxygen concentration.

Cells of this microaerophilic organism are also aerotactic: they tend to accumulate in bands at regions of appropriate oxygen concentration. Magnetotaxis makes aerotaxis more efficient by reducing random excursions and promoting straight-line motility.

Although the ability to synthesize magnetite is certainly genetically encoded, the polarity of magnetotactic bacteria cannot be genetically encoded. If a bacterium without magnetosomes begins to make them, it has an equal probability of being either north- or south-seeking. The polarity of a bacterium that already has magnetosomes can be conserved in each of its daughter cells, however, because the chain of magnetosomes is partitioned during cell division. If each daughter cell inherits some of the parental magnetosomes, it inherits the parental polarity; as the daughter cell synthesizes new magnetosomes at the ends of its inherited chain they become magnetized in the same direction by their interaction with the magnetized particles in the chain.

In every generation, however, a few bacteria can end up with the opposite polarity, possibly as a result of not receiving any magnetosomes in the cell division and subsequently synthesizing magnetosomes that fortuitously become magnetized in the opposite direction. Under normal circumstances bacteria with reversed magnetization are continually discriminated against by being directed upward to regions less suited to their growth, and the population in the sediments retains its original polarity. If the vertical component of the magnetic field is inverted, however, the former misfits are favorably directed downward and their progeny take over the sediments. In such an event natural selection acts in a matter of only weeks or less.

This laboratory experiment has presumably been duplicated on a global scale during reversals of the geomagnetic field. Because the geomagnetic field is not purely dipolar it does not go completely to zero in the course of such a reversal but instead changes in magnitude and rotates through zero inclination everywhere on the surface of the earth during a transition period of several thousand years. In the process the polarity of the magnetotactic bacteria in both hemispheres presumably becomes inverted as well.

Life has evolved in a magnetic field. Magnetotactic bacteria provide the first unambiguous demonstration that organisms respond to the geomagnetic field by means of a biomagnetic compass made of the inorganic mineral magnetite, which they synthesize from soluble iron in their environment. Moreover, their compass appears in several respects to be highly adapted for interacting with the earth's magnetic field. It consists of single-domain magnetic particles, each one with a high magnetic remanence, often arranged in an elongated chain along the cell's axis of motility. In spite of the efficient functioning of the magnetosomes as a navigational device, they probably also serve an additional purpose in the life of magnetotactic bacteria. They may be a repository for excess iron, or they may assist cells in ridding themselves of hydrogen peroxide, a toxic product of oxygen metabolism that is decomposed by iron. These possible physiological roles are under study.

The most exciting possibility arises from the fact that over the years magnetite has been found in many organisms besides bacteria. So far the list includes chitons (a class of marine mollusks), honeybees, butterflies, homing pigeons and, added just recently, dolphins. The elucidation of the role of bacterial magnetotaxis therefore provides a basis for searching for a comparable magnetic sense in higher organisms. The outcome of that search may give the old notion of animal magnetism a new reality.

© 1981 SCIENTIFIC AMERICAN, INC

The Recumbent Stone Circles of Scotland

These megalithic monuments, like many others, have been seen as ancient astronomical observatories. It seems clear that although they are astronomically aligned, their purpose was purely ritual

by Aubrey Burl

Any scholar worth his salt tries to avoid prejudging the results of a line of inquiry, but such prejudgment can occur even when the scholar is investigating the remote past. To cite one example, in 1909 Sir Norman Lockyer, the astronomer who directed Britain's Solar Physics Laboratory some 70 years ago, published the second edition of his book *Stonehenge and Other British Stone Monuments Astronomically Considered.* In it he listed his findings with regard to 29 ancient stone circles of a kind peculiar to northeastern Scotland and southwestern Ireland. There were once at least 120 of these distinctive monuments in Scotland, and 50 of them remain relatively intact today.

The Scottish circles Lockyer examined are all architecturally similar. They are also found only in a limited area; none is more than 40 miles from Aberdeen on the east coast of Scotland. For both reasons one might expect that they were linked by some common purpose. Lockyer failed to detect this purpose because he had prejudged what it would be. He had made the assumption that instead of having a single purpose the 29 monuments served a variety of astronomical purposes. Standing outside each circle and sighting across a large horizontal stone in it, he deduced that 15 of the circles were aligned on one of two stars: Arcturus or Capella. Three other circles, he thought, were aligned on the midsummer sunrise and two on the May Day sunrise. Five more he decided were special instances of astronomical alignment; for the remaining four he found no evidence for such alignment. His final tally—more than six astronomically oriented circles for every circle that was not so oriented—seemed impressive. The fact is that he had consistently looked in the wrong direction.

The Scottish monuments Lockyer surveyed belong to the group known to archaeologists as recumbent stone circles because the largest stone in each of them is not upright but lies flat on the ground with a flanking upright set at each end. The builders of the circles set the recumbent stone in place with care so that its upper surface was horizontal. They also placed it on the south side of the circle, in a position somewhere between south-southeast and southwest.

The uprights diminish in height according to their distance from the recumbent stone. The circles are not uniform in circumference, and the number of standing stones that outline the circle is not the same in each one; there may be as few as eight or as many as 16. The builders did, however, favor certain numbers. Among the 31 best-preserved circles 22 (or more than 70 percent) have either 10 or 11 uprights.

The number of uprights was not determined by the size of a circle. For example, the circle known as the Hill of Fiddes is 44 meters in circumference and the circle known as Sunhoney is nearly 80 meters in circumference; both have 11 uprights. Garrol Wood is some 56 meters in circumference and Old Rayne is 86; both have 10 uprights. The number 10 was evidently preferred by the builders of the earliest circles; they positioned the uprights in five opposing pairs. The circles with 11 uprights were built later. Perhaps the 11th stone marked the place where an observer should stand to look across the circle toward the recumbent.

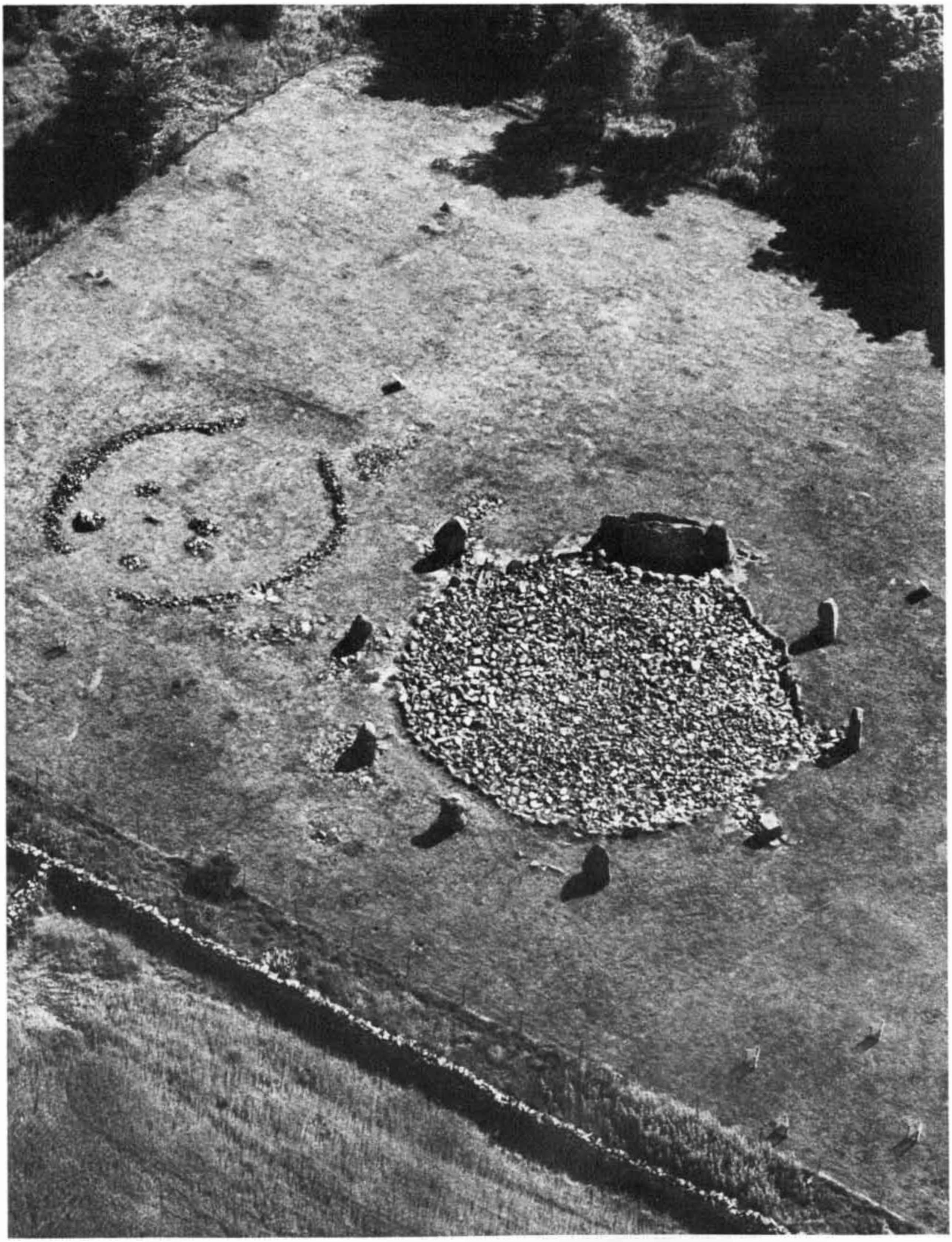
Another evident preference was for the site to be above a valley or some other expanse of low-lying ground. To achieve this kind of site the builders selected a place such as the side of a hill or the end of a ridge. If the site was not naturally level, the builders sometimes made it so. For example, at Druidsfield a level shelf was dug into a hillside, and at Loanhead of Daviot a level platform was built of rubble. At Berrybrae, which I excavated between 1975 and 1978 with the help of volunteers from the U.S., we found that the flat arena where the circle stood had been leveled by heaping up a thick layer of clay.

Where several sites were available to the builders the one nearest a good source of stones was chosen. It must have been rare, however, for the builders to find a block nearby that was big enough to serve as the recumbent stone. Many of these great slabs are of a kind of stone different from that of the uprights. For example, at Easter Aquorthies the circle stones, which weigh on the average about 1.5 tons, are a whitish porphyry of local origin, and the recumbent, which weighs 12 tons, is a red granite brought from some distance away. The siliceous recumbent of Old Keig, a monster that weighs more than 50 tons, was apparently hauled to the site from a river valley several miles distant.

Just as nearly all the Scottish circles overlook lower ground, so too have virtually all the recumbents been set in place so that their upper surface is exactly horizontal. When the stones are examined, it can be seen that their long bottom surface is not straight but forms a shallow *V*. Evidently this configuration allowed the builders, once the recumbent was roughly in place, to tilt the ends up or down until the top was horizontal. (They could have used a water-filled trough as a level.) With the recumbent finally in position the builders chocked it with bulky stones, jamming them in so tightly that the great blocks have barely shifted since.

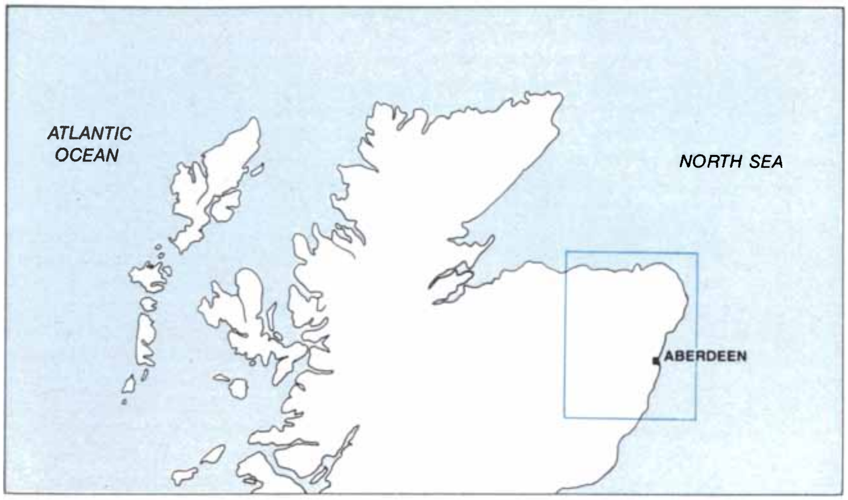
It is not uncommon to find what is called a ring cairn, a low dome of stones with an open center, near the middle of a recumbent stone circle. Pits were sometimes dug in the open center to receive burnt human bones. One of the earliest and probably the most inept of the excavations of a ring cairn was noted by James Garden of the University of Aberdeen in a letter written in 1692 to John Aubrey, the well-known author of *Brief Lives* and an eager antiquary: "Many years since, they did see ashes of some burnt matter digged out of the bottom of a little circle, set about with stones

© 1981 SCIENTIFIC AMERICAN, INC

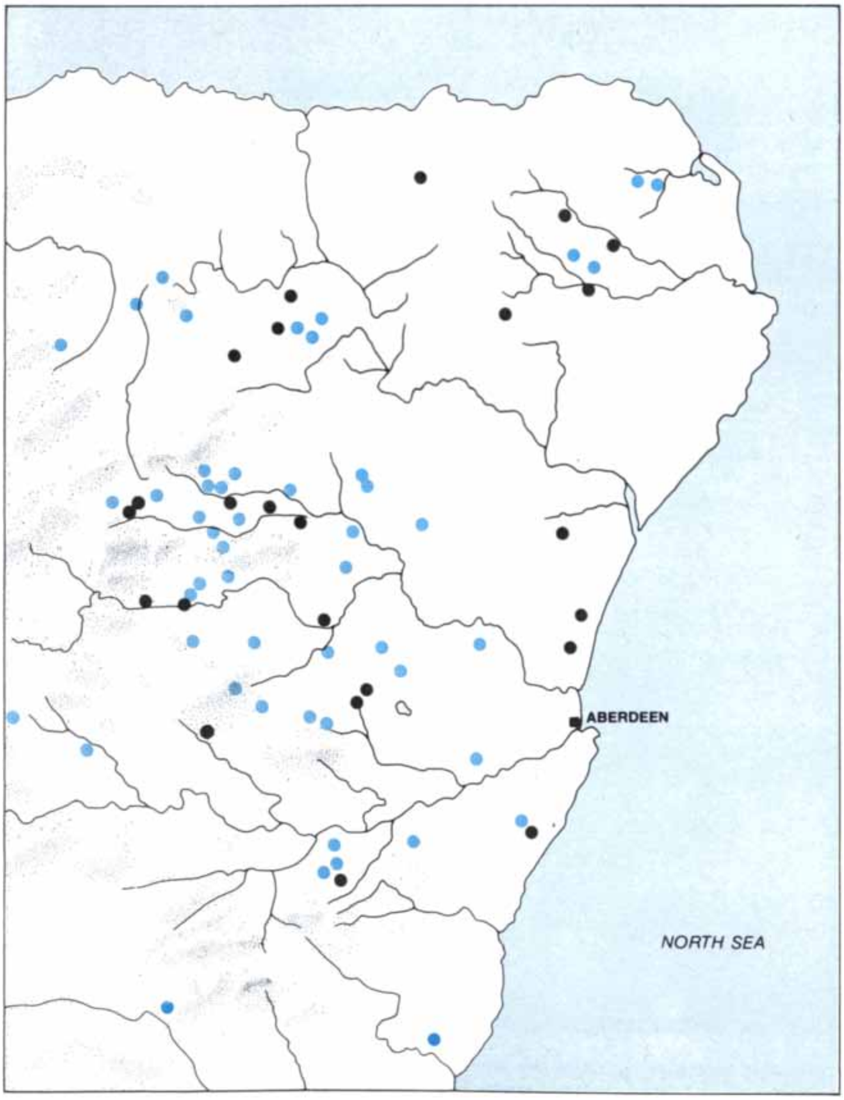


TEN UPRIGHT STONES, including those at each end of a large level recumbent stone, outline the Scottish stone circle known as Loanhead of Daviot, 20 miles northwest of Aberdeen. The rock-strewn area inside the circle is the remains of a ring cairn; the center of the area was originally empty. Customarily the center of a ring cairn held pits where cremated human bones were buried. The pits here held five pounds of bones, among them some 50 fragments of children's skulls. The view in this aerial photograph is toward the south. The incomplete rubble circle to the left marks an enclosed cremation cemetery that came into use after the recumbent stone circle itself was abandoned some 4,000 years ago. Loanhead of Daviot is one of the oldest of the more than 120 recumbent stone circles in Scotland.

© 1981 SCIENTIFIC AMERICAN, INC



ABERDEENSHIRE and adjacent counties in northeastern Scotland (*boxed area*) are the setting for Bronze Age recumbent stone circles. They are found elsewhere only in Ireland.



LOCATION OF 74 CIRCLES is shown; many are only a few miles apart. Those in color are the 50 best-preserved ones for which the author determined the azimuth of a line of sight passing across the middle of the recumbent stone from a position on the opposite side of the circle.

standing close together, in the center of one of those monuments... near the church of Keig." Nearly 200 years later, in the course of an enthusiastic but calamitously haphazard investigation, Charles Elphinstone Dalrymple, a Victorian antiquary, unearthed cremations at several other Scottish recumbent stone circles. Since then better excavations at Loanhead of Daviot, at Old Keig and at Berrybrae have also uncovered cremated human remains.

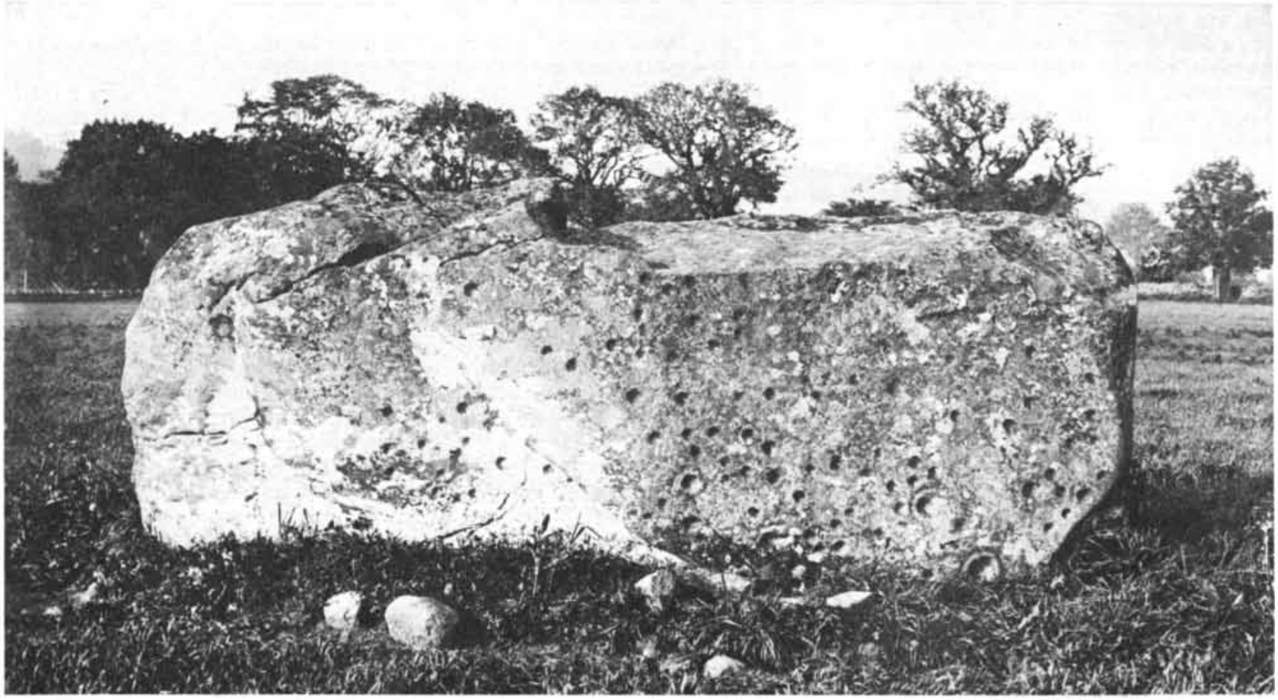
Broken pottery has been unearthed at the foot of some of the upright stones, in a few instances accompanied by lumps of charcoal and rather characterless flint artifacts but never by human bones. The pottery is crude and characteristic of that made in the centuries around 2200 B.C. The recent excavations have also revealed scatterings of broken quartz pebbles close to the recumbent stones. The white fragments were piled thickly beside the recumbent at Berrybrae.

The stones of perhaps one Scottish recumbent stone circle in 10 bear what are known as cup marks: depressions about as wide as a drinking cup and about half as deep, formed by grinding the stone with a hard pebble. Only the recumbent itself, its flanking stones or the stones next to them are so marked. Even there the markings are few. At most of the circles there are only two or three cup marks, although many more are found at Balquhain and at Sunhoney, and more than 100 have been counted at Rothiemay. These laboriously ground hollows tantalize the imagination. Since most of them are on the sides of the stones rather than on the top, they cannot have been meant primarily as receptacles. An investigator of the 1920's, a Major Tilney, noted that certain of the cup marks at Rothiemay duplicated the constellation Ursa Major, the "Big Dipper," except that the figure is reversed. No other constellation can be picked out among the cup marks, reversed or otherwise, and Tilney's ingenious interpretation must be considered more imaginative than perceptive.

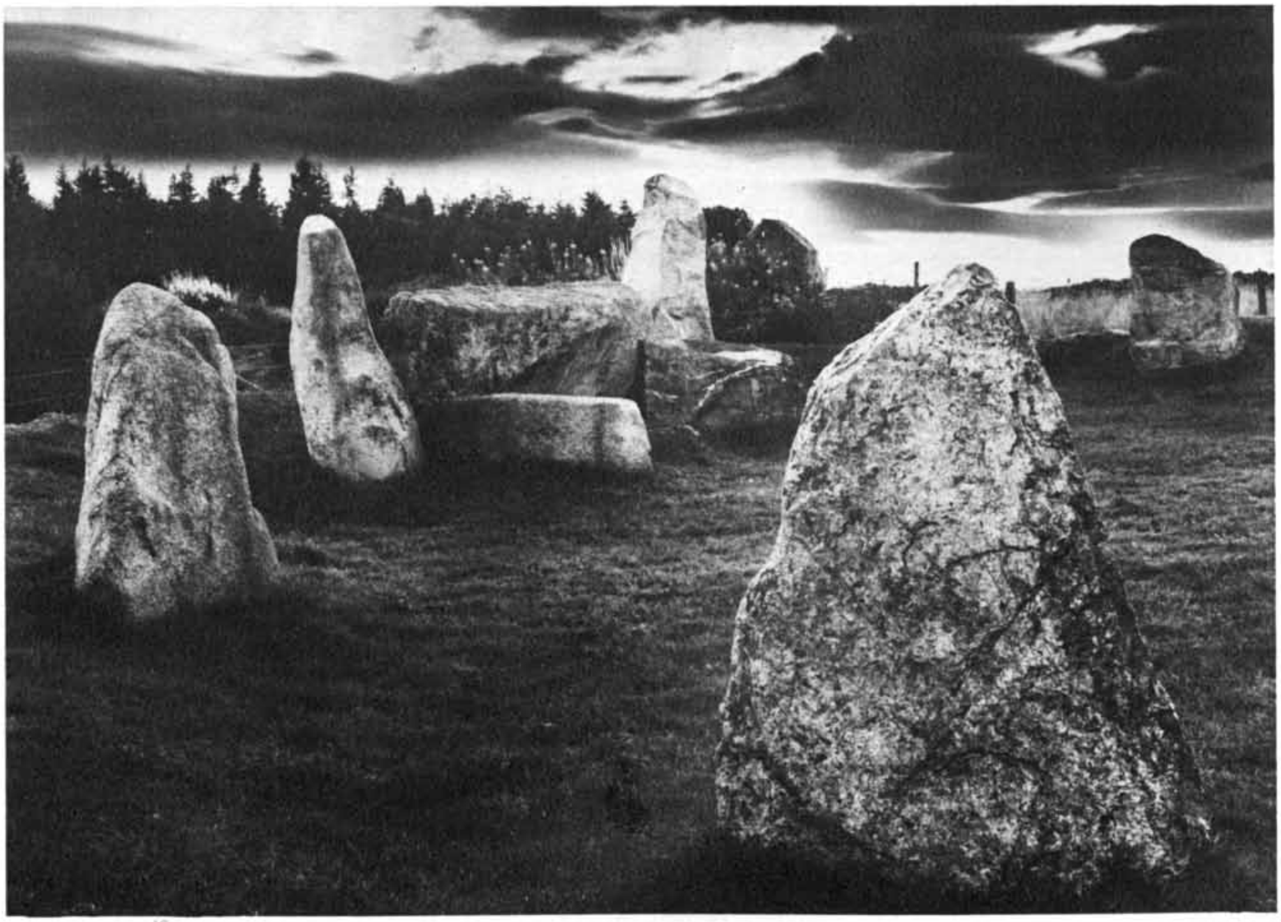
Until recently the only clues to when the recumbent stone circles were put up came from artifacts such as potsherds (and one archer's wrist guard) found buried in them. The artifacts could be assigned to the beginning of the Bronze Age in Britain, and so it has been assumed that the circles were erected between 2500 and about 1700 B.C. Our Berrybrae excavation has confirmed this assumption with carbon-14 dates.

Berrybrae had been dismantled by prehistoric vandals. Charcoal associated with their activities furnished samples for two carbon-14 determinations: 3450 ± 80 B.P (before the present) and 3310 ± 90 B.P. When these dates are properly calibrated, they put the approximate time of the circle's destruction at 1750 B.C We calculate that the

© 1981 SCIENTIFIC AMERICAN, INC



"CUP MARKS," hollows ground into the surface of a recumbent stone or an upright stone, are found at roughly one of every 10 recumbent stone circles. Seen here is the recumbent stone of Rothiemay, the circle with the most cup marks in Scotland. There are more than 100 marks, some of them large cup-and-ring marks (*lower right*). The upright stones that normally flank the recumbent stone are missing.



EASTER AQUORTHIES is a circle whose uprights are of porphyry of local origin; they have an average weight of 1.5 tons. The recumbent stone, at the left center between a pair of flanking uprights, is red granite and came from some distance away. It weighs 12 tons.

© 1981 SCIENTIFIC AMERICAN, INC

ring was probably built in about 1800 B.C., a date late in the record of the construction of recumbent stone circles. The early circles, such as Loanhead of Daviot, must by then have been hundreds of years old.

Carefully leveled recumbents, generally consistent numbers of uprights graduated in height, cup marks, sparkling white quartz and incinerated human bones—none of these characteristics by itself does much to explain what the Scottish circles were. Standing or fallen, flooded with sunlight or hidden in forest, the stones today occupy a stillness as empty of human life as the snows of Siberia. Yet slowly their mystery is dissipating, even though what is not known continues to outweigh what may be surmised.

So far not a single dwelling of this phase of the British Bronze Age has been discovered in the recumbent circle region. As a result almost nothing is known about the builders of the circles. The monuments lie within two or three miles of each other, which is far too close for each of them to have been some kind of tribal center. Probably each lay within the home territory of one family; four to six square miles would have been land enough to support 10 to 20 people who would have grazed cattle and raised crops on the hillsides above the wooded lowlands. Garden reported in his 17th-century letter to Aubrey the local folk belief that pagan priests had "caused earth to be brought from other adjacent places" to the Auchquhorthies circle, "which is given for the reason why this parcel of land, though surrounded with heath and moss on all sides, is better and more fertile than other places thereabouts." This was good observation on the inhabitants' part. Modern soil maps show that the circles are alongside, if rarely on, large patches of rich, well-drained soil. This suggests at least one thing about the circle-building families: they were astute farmers.

If each circle "belonged" to a single family, however, that few men and women could not have built the monument. To move a recumbent stone weighing 20 tons or more, whether it was two miles or two yards, would have called for at least 50 adults and probably 100. The easiest explanation is that when the time came to build a circle, neighboring families helped, as at a barn raising.

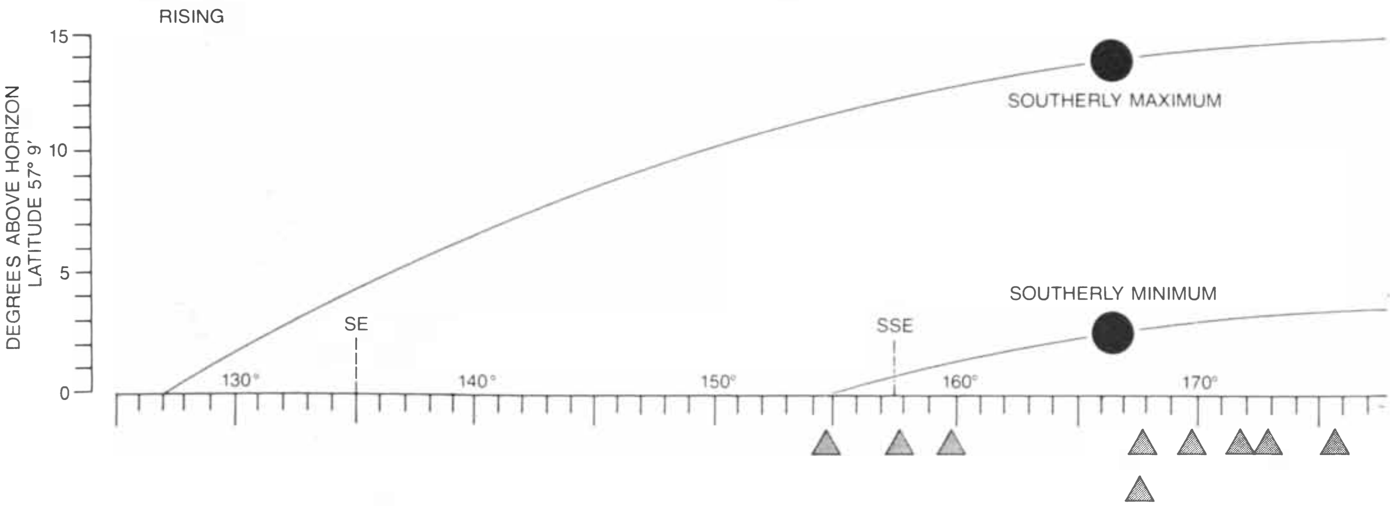
To take a negative approach, what could the Scottish circles not have been? They could not have been homes: they lack any trace of domestic rubbish. By the same token they were not workshops for the manufacture of stone tools, pottery or metal artifacts. Lacking substantial banks of earth, they would not have been suitable as forts or cattle pens.

James Fergusson, an early student of Britain's megalithic monuments, wrote in 1872 that since cremations were found in the Scottish circles, the circles were "the graves of chiefs, or sometimes, it may be, family sepulchres." The human remains are too few, however, for the circles to have been family burial plots; in most of the circles the bones of no more than one or two individuals are found. If any circle had served as a cemetery, even if only for a century, successive generations of a family of 20 would have had some 40 deaths in that length of time. Moreover, men, women and children are not equally represented among the remains. For example, at Berrybrae only two partial cremations were found, both of children. At the other extreme Loanhead of Daviot has yielded five pounds of human bones. Most of them were the remains of adults, but they included more than 50 fragments of children's skulls.

There is a smell of ritual death about all of this. The atmosphere of the circles is better conveyed by the word "shrine" than by "graveyard." In later folk belief the circles were places of evil; the circle at Innesmill was called the Devil's Stanes, and another circle, known as Chapel o'Sink, was taken to be the remains of an unfinished church that had been dragged halfway down into the earth one night by the devil. In 1527 Hector Boece, first principal of the University of Aberdeen, described the purpose of the circles as follows: "Huge stones were erected in a ring and the biggest of them was stretched out on the south side to serve for an altar, whereon were burned the victims in sacrifice to the gods."

Boece's statement about burnt offerings may possibly reflect some folk memory of pyres and burnt bones that had endured over a span of 4,000 years. He must also be given full credit for emphasizing the southerly position of the recumbents; it was a fact that was to lack either much attention or any explanation for more than four centuries after his day. There was no common lay of the land to account for this positioning. The answer almost certainly had to be astronomical. That, however, does not alter the fact that the astronomical answers proposed in the past do not hold water.

I have described Lockyer's astronomical analysis made early in this century. Sixty years later Alexander Thom, a retired professor of engineering at the



CYCLE OF MOTIONS OF THE MOON across the sky, when related to the recumbent stones, indicates that they were aligned with the moon. In this diagram the two extremes of the 18.6-year cycle, as observed at the latitude of Aberdeen, are shown as arcs above the horizon. At the most southerly extreme the moon rises near south-southeast (154 degrees), reaches a maximum height of three degrees

© 1981 SCIENTIFIC AMERICAN, INC

University of Oxford, also investigated the Scottish circles. Of the 30 he analyzed for precise astronomical alignments only four (and possibly a fifth) survived his scrutiny. Moreover, of the nine alignments that Thom detected, none passed over the recumbent stone of a circle. They were directed instead toward inconspicuous outlying stones or toward other rings. Like the targets perceived by Lockyer, those chosen by Thom were implausible in their variety: a northerly setting of the moon, sunset in November and sunrise in midsummer, in midwinter, in May, in October and in November.

My colleague John Barber (who studied 30 of the recumbent stone circles in Ireland) and I (in my own analysis of the Scottish circles a few years ago) at least sought out lines of sight that passed over the recumbents. Our findings, however, were no more convincing than Thom's. They included risings and settings of the sun or the moon or certain stars and even the almost unpredictable cycle of the planet Venus. Such results imply a casualness on the part of prehistoric sky watchers that is plainly belied by the symmetry and sophistication of the circles' construction.

The solution to the puzzle proved to be a simple one. Of the Scottish rings 50 are still in a condition good enough to allow an estimate of their azimuth (as measured by compass bearing) clockwise from true north to the midpoint of the recumbent. When I compiled a series of such estimates, I found that every azimuth fell between 155 degrees (south-southeast) and 235 degrees (southwest). The great majority, 42 in all, fell between 155 and 204 degrees, well south of the rising and setting of the sun and the moon, and seven more fell between 229 and 235 degrees. Only a single alignment, and that a questionable one, was anywhere near the midwinter sunset; it was an azimuth of 221 degrees for the ravaged ring of Stonehead.

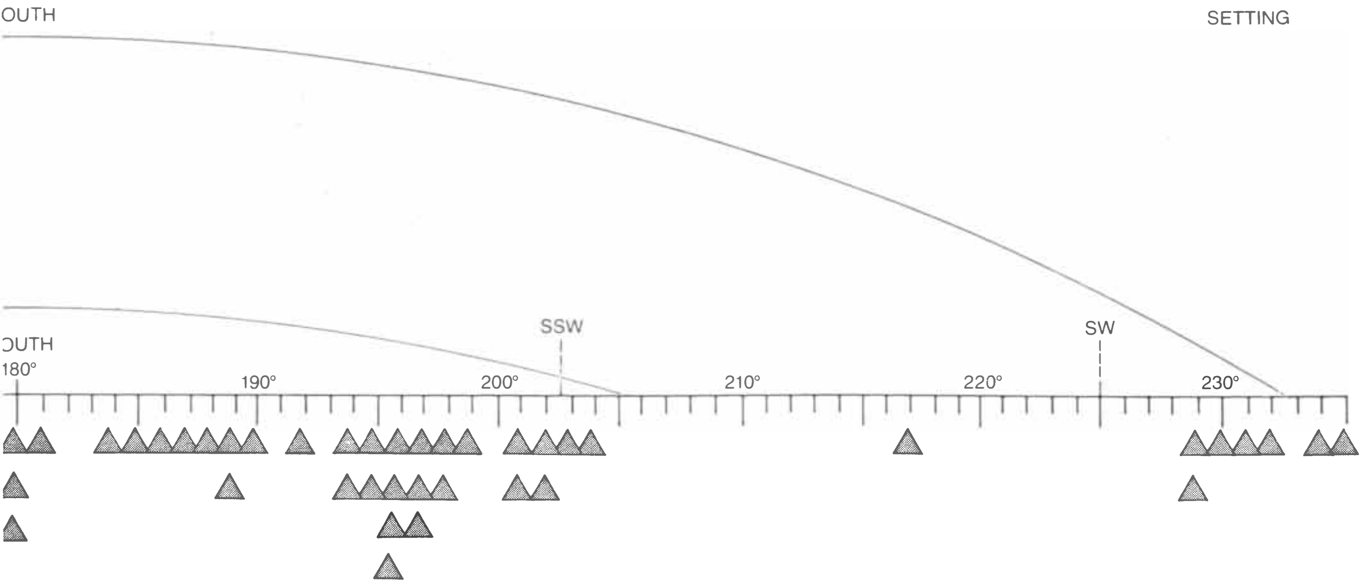
Not only did the rising and setting of the sun and the moon fail to coincide with the alignments of the recumbents but also the movements of no one star or planet could be fitted to them. Hence it was necessary to search for some other celestial phenomenon that would fit with the meticulously leveled recumbents. One possibility was that the orientation involved a celestial target not at the moment of its rising or setting but when it was moving high in the sky. This proved to be the case. The target was an obvious one: the moon.

Unlike the annual cycle of the sun, the cycle of the moon is a complex one. For example, in the Northern Hemisphere the sun rises more and more to the south of 90 degrees in the fall until at the winter solstice it reaches its most southerly rising position: 139 degrees (at the latitude of Aberdeenshire, about 57 degrees north), or roughly southeast on the compass. (It sets that same day at 221 degrees, or roughly southwest.) Six months later, at the summer solstice, it has reached its most northerly rising position and the cycle is complete. This is not the case with the moon. The moon's southerly risings and settings shift over a period of not a year but about nine years. At the southerly maximum at the latitude of Aberdeenshire the moon's arc across the sky measures only 52 degrees. It rises at about 154 degrees (a little east of south-southeast) and sets at about 206 degrees (a little west of south-southwest). A hilly skyline would reduce this arc still further.

In the ensuing nine years the southern moon will rise and set successively farther from the south until it reaches its southerly minimum, covering an arc more than twice as long as the southerly maximum: 106 degrees. The moon now rises at about 127 degrees (eight degrees east of southeast) and sets at about 233 degrees (eight degrees west of southwest). Thereafter the march toward the southern maximum begins again; the full lunar cycle is completed at the end of 18.6 years.

Now assume that a sight is taken from the side of the circle opposite the recumbent stone, grazing the top of the stone at the middle. For 42 of the 50 recumbent stones the line of sight lies at an azimuth of between 154 and 204 degrees, with the majority of the lines of sight clustered within an even narrower arc, between 180 and 204 degrees. The obvious inference to be drawn is that the circles were aligned on the moon, and that they were aligned on it primarily at the time of its maximum southerly risings and settings. They were not, however, aligned on it at the particular moment of moonrise or moonset. The observers must have been interested not in the moon's rising and setting but in its path across the sky. Indeed, the azimuth of three of the recumbents is 180 degrees, or due south, and that of 16 others is within 12 degrees of due south. This is where the moon would have been at its highest in its path across the sky.

Seven of the Scottish recumbent stone circles are oriented quite differently. Their azimuth lies between 229 and 235 degrees, to the west of southwest. That is where the moon sets during the minimum southerly extreme of the 18.6-year lunar cycle, well to the west of where it



above the horizon and sets near south-southwest (206 degrees). At the least southerly extreme, 9.3 years later, the moon rises east of southeast (127 degrees), reaches a height of 13 degrees above the horizon and sets west of southwest (about 233 degrees). Of the 50 circles analyzed by the author the azimuths of 42 lay between 155 and 204 degrees; the azimuths of seven clustered around 233 degrees.

© 1981 SCIENTIFIC AMERICAN, INC

disappears at its maximum southerly extreme. Thus it is evident that at least some observers were not primarily concerned with the moon when it was high in the sky. It is also worth noting, even though the data are negative, that not one recumbent stone azimuth points to 139 degrees or (excepting the questionable instance of Stonehead) to 221 degrees, the rising and setting points of the midwinter sun. It is as though the builders deliberately avoided setting any recumbent in line with this turning of the solar year.

My analysis of the recumbent stone azimuths, embracing a large group of similar monuments, shows how misleading the study of single sites can be. For example, the recumbents at Tomnagorn and at Loanhead of Daviot have azimuths that point south-southwest toward the descending moon. Yet Lockyer thought Tomnagorn was oriented toward Capella because a short stone happened to stand exactly in line with that star's rising. And Thom saw at Loanhead of Daviot an alignment with the midwinter sunset.

The Scottish recumbent stone circles form a cohesive group, all with a similar architecture, all with the same kind of leveled stone as a sighting element and all with the same target: the moon. In them one finds an archaeological and astronomical unity that is persuasive in its consistency, even though their alignments are too coarse to have been of service to any postulated astronomer-priests of archaeoastronomy. For example, looking across the 20 meters of the average circle toward a recumbent stone measuring 4.5 meters from end to end, an observer would have found the arc between the two stones flanking the recumbent to be 13 degrees. This arc is far too large for any kind of astronomical observation. It is ideal, however, for people engaged in long ceremonies performed by moonlight. At Sunhoney, for instance, it would have taken the moon more than an hour to cross the space between the two flanking stones, its light shining all the while past the recumbent onto the ring cairn where Dalrymple found fire-marked stones and burnt bones in 1868.

So dramatic must the passing moon have seemed, framed between the silhouetted flankers, that this may well have been the chief effect sought by the builders of the Scottish circles. In fact, at most of the circles an even more dramatic spectacle would have been seen whenever the moon was at its southerly extreme. In *Stonehenge Decoded,* Gerald S. Hawkins points out that the southern moon rises barely one degree above the skyline at Callanish, a famous stone circle in the Hebrides. The same would be true of the Scottish circles that lie just above or below the latitude of Callanish. At the southernmost extreme of the moon's 18.6-year cycle it would have seemed to drift along the very top of the recumbent.

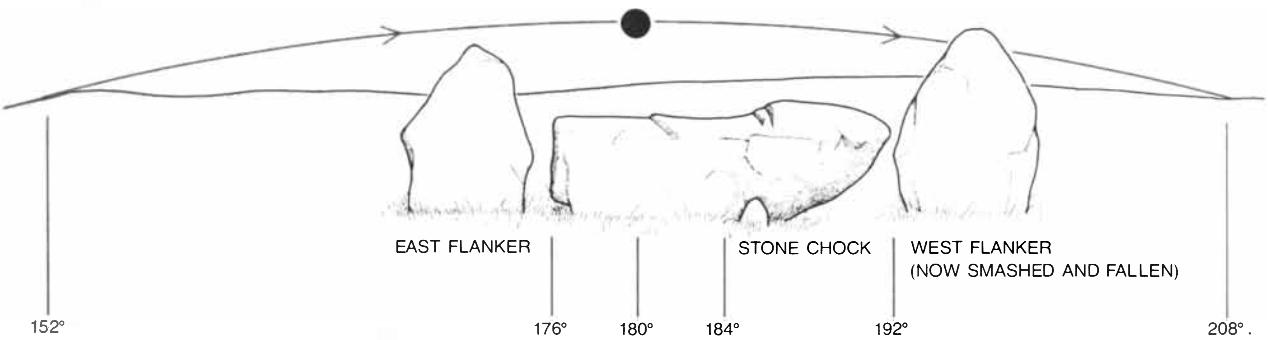
One wonders what symbolism lay in the cup marks on the level stone or in the quartz flakes gleaming in the moonlight. Fire, death and the moon are the quintessence of the Scottish circles. The soil at their center is often reddened where pyres blazed before the scorched bones were picked out, the ashes were raked away and the ring cairn was built. Sometimes objects were also "killed" (that is, smashed) to accompany the dead. Near the center of the circle that Thom judged to be aligned with the midwinter sunset, namely Loanhead of Daviot, a curved setting of stones has been found, much like the crescent of the new moon in outline. Inside the points of the stone crescent were a splinter of human bone, a lump of charcoal and a piece of a broken pot.

What the moon meant to these distant people we may never know. Quite clearly it was as vital to them as the sun was to other communities in Britain. As one example, where the rings of wood posts, now called Woodhenge, once stood in Wiltshire not far from Stonehenge, someone killed a little girl 4,000 years ago. Was it done ceremonially? Whatever the occasion, her skull had been cleaved completely in two. She was then buried within the henge, positioned so that her remains were in line with the midsummer sunrise.

In the Scottish recumbent stone circles the children whose remains have been found (as at Loanhead of Daviot) may have died in the same way. Was it done so that their spirit might merge with the potent moon? One must return to Aberdeen's postmedieval commentator, Boece. In his 1527 commentary he not only mentioned burnt offerings but also added that the pagan rituals inside the circles demanded a monthly offering and that "that is why the new moon was hailed with certain words of prayer."

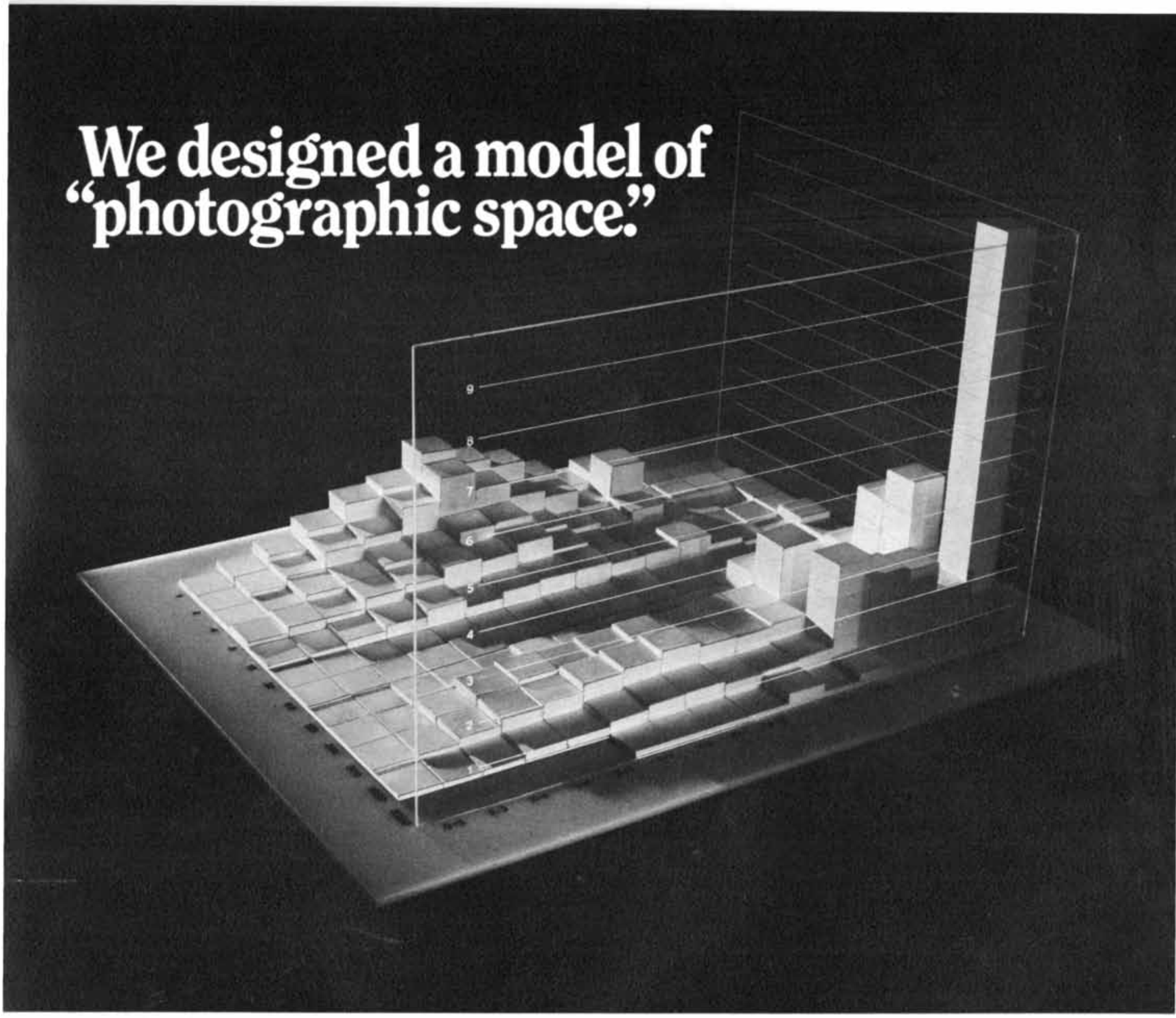
Whether Boece was repeating folk tradition or not, it is possible that the builders of the Scottish circles constructed likenesses of the new moon inside their rings. Crescent-shaped arrays of stones similar to those at Loanhead of Daviot are found at Loudon Wood and at Whitehill Wood, a circle now blurred with mildew, moss and the soft green corruption of antiquity. At Berrybrae the quartz-littered platform uncovered along the interior of the recumbent had a crescent-shaped outline. At Strichen, a circle damaged in prehistoric times and mindlessly destroyed only some 20 years ago, American investigators have unearthed opposite the recumbent a crescent formed with heavy stones, lavishly strewn with lumps of quartz.

Are these crescents symbols of the new moon? Are the enigmatic cup marks symbols of the full moon? Does the gradation in height of the standing stones in the Scottish circles symbolize the moon's ascending and descending journey across the sky? The answers to these questions and many more remain unknown. It is nonetheless a measure of progress that we no longer think of the recumbent stone circles as being enclosures for cattle. Nor can one any longer seriously classify them as astronomical observatories. Years of study have yielded to the archaeologist a better knowledge of their design, even though we may never have more than a dim picture of the rituals that were acted out within the circles some 4,000 years ago.



ASTRONOMICAL SPECTACLE that would have been visible on any clear moonlit night at the time of the moon's most southerly extreme is diagrammed for Aikey Brae, a site at about the latitude of Aberdeen. Rising no more than two degrees above the horizon, the moon would have seemed to drift along the top of the recumbent. The spectacle would have been particularly dramatic at or near full moon.

© 1981 SCIENTIFIC AMERICAN, INC



Then built a model camera around it.

"Photographic space" is a concept Kodak engineers developed that tells more than just the lighting conditions and distances at which average people take pictures.

Its vertical third dimension graphically shows the *percentage* of times photographs are taken at any given light/distance range.

Plotting data gathered from an extensive sample, encompassing all kinds of amateur films (110, 126, 135, and instant), the study produced some surprising results. When graphed on three axes, our engineers were able to learn as much from the valleys and plateaus as from the high peaks.

They soon hypothesized that the lack of significant photographic activity in the ideal close-up range (2 to 4 feet) was more due to shortcomings in the cameras themselves than a lack of consumer interest.

If a simple camera could produce quality close-up images, both at outdoor and indoor (flash) light levels, it could provide substantial consumer benefits.

One result of our studies is now on sale. The Kodak Colorburst 350 instant camera is the culmination of years of computer design and market research. Not to mention product refinement.

This instant camera lets anyone buy more "photographic space" at the touch of a button. And at reasonable cost.

If you'd like to learn more about "photographic space," a report by Terry Faulkner and Tom Rice is available by writing Eastman Kodak Company, Dept. PS, 343 State Street, Rochester, N.Y. 14650.

Kodak

© Eastman Kodak Company, 1981

© 1981 SCIENTIFIC AMERICAN, INC

SCIENCE AND THE CITIZEN

Caught off Base

Discussions of the proposed new intercontinental ballistic missile designated the MX have focused less on the missile itself than on questions of where and how it should be deployed. Now that the leading candidate among various basing plans has been abandoned by the Reagan Administration it may be possible to see more clearly what effect the MX itself would have on the security of nations.

The problem the MX was intended to solve is the supposed vulnerability of the existing Minuteman ICBM's to a "counterforce" strike by Russian missiles. Concern about the vulnerability of land-based strategic missiles can be traced to improvements in missile accuracy and to the development of multiple independently targeted reentry vehicles (MIRV's), which enable a single missile to launch several warheads. With such weapons, it has been suggested, the U.S.S.R. could mount an attack with only a fraction of its own missiles and destroy almost all the 1,052 Minuteman and Titan missiles now installed in fixed silos. The U.S. could respond only with submarine-launched missiles, which are not currently accurate enough to destroy the remaining Russian ICBM's, or with manned bombers, which are too slow to do so. Hence the only military option would be a retaliatory attack on Russian cities, which would surely bring on the ruin of American cities in turn.

The MX was to solve this quandary with a basing plan that would make it difficult for the Russians to know exactly where each missile would be at the time of an attack. Over the years some 30 basing schemes were considered by the Department of Defense. In the one favored by the Air Force and adopted by the Carter Administration multiple concrete shelters and a network of connecting roads would have been provided for each missile; when warning of an attack was received, the missile could be moved into any one of the shelters. As a result the U.S.S.R. could be certain of destroying all the missiles only if it could be certain of destroying all the shelters.

In rejecting this "shell game" President Reagan noted that "no matter how many shelters we might build, the Soviets can build more missiles more quickly and just as cheaply." Although the major motive for deploying the MX was thereby nullified, the Administration has nonetheless proposed to build 100 of the missiles. The first of them would be installed in existing Minuteman or Titan silos, which might be "reconstructed for much greater hardness to nuclear effects." The Administration has conceded, however, that the hardening of the silos would provide little added protection and would be only an interim measure. Indeed, a report on Russian military strength issued just two days before the President's announcement points out that at least one Russian ICBM, the SS-18, is "capable of destroying any known fixed target with high probability."

If building the MX will not create an invulnerable weapon, what will it accomplish? Herbert Scoville, Jr., of the Arms Control Association has pointed out that the "second-strike, 'counter-ICBM'" role suggested for the missile was never a plausible one, no matter what the basing plan. A first strike directed exclusively against American land-based missiles could be a rational strategy only if the U.S.S.R. could have great confidence that no retaliation would follow. Because even a "limited" nuclear attack would devastate large areas of the continent and cause substantially more than 10 million deaths, such restraint seems unlikely. Indeed, the U.S.S.R. would have to consider the possibility that the land-based missiles would be launched on warning of an attack to avoid their destruction.

Even if the MX could survive a first strike and be launched in a retaliatory action, it would not be aimed at Russian missiles. Once nuclear weapons had been exploded on U.S. territory, Scoville notes, the U.S.S.R. would "launch every missile it can get off the ground as soon as its warning radar and satellites tell it that the United States' retaliatory strike is under way." The second-strike forces would find only empty silos.

There is only one remaining strategic role for which the MX would be well suited. Most descriptions of the missile specify that it would carry 10 warheads (compared with three in the most advanced models of the Minuteman), and each warhead might be almost twice as powerful as those in the Minuteman. The accuracy of the MX would also be twice that of the Minuteman (and at least twice that of the SS-18): the MX would be able to place each warhead within a circle of probable error having a radius of 300 feet. A weapon with these capabilities, Scoville writes, is a first-strike weapon, and it would be perceived as such by the U.S.S.R.

Since the rationale offered for building the MX has relied almost entirely on the need for an invulnerable basing plan, the decision to build the missiles but not the multiple shelters seems quite inconsistent with earlier analyses by the Department of Defense. One interpretation of the decision is that the Administration no longer intends to build the MX at all. William H. Gregory, editor of *Aviation Week & Space Technology*, writes in an editorial: "Without a basing mode, MX is headed for ultimate cancellation, either by Congress now or later by the Administration if Capitol Hill does not take the bait. If that is the case, the Reagan plan is pointing U.S. strategic doctrine toward a dyad of manned bombers armed with cruise missiles and submarine-launched ballistic missiles instead of a triad with these two and land-based ballistic missiles."

Fourth Arm

The conviction that the Milky Way is a spiral-armed galaxy comes mostly from the observation that it has certain large-scale features (a disk of bright stars, a central bulge and a lane of dust) like those seen in other spiral-armed galaxies, such as the one in the constellation Andromeda. The arms of the spiral in the Milky Way itself have proved difficult to trace. With increasing distance from the solar system the light from the stars in the arms grows fainter, and estimates of the distance grow less certain. Moreover, because the solar system lies in the disk of the Milky Way nearby arms must obscure more distant ones. Three arms in the neighborhood of the solar system have been recognized; now Marc Kutner and Kathryn Mead of the Rensselaer Polytechnic Institute report observations that lead them to suspect they have found a fourth arm farther away.

Kutner and Mead surveyed the arc of the Milky Way that extends across the constellations Vulpecula and Cygnus. The arc amounts to an eighth of the galaxy's longitude. The disk of the galaxy is warped near its edges, and so Kutner and Mead made their measurements 1.5 degrees above the plane defined by the central part of the disk. In that direction they detected radiation at a radio wavelength of 2.6 millimeters; such radiation is characteristic of carbon monoxide molecules.

The Doppler shift of the radiation suggests the carbon monoxide and the solar system are approaching each other. The apparent approach of interstellar matter from that direction in the sky is thought to signify that the solar system is overtaking the matter as both the solar system and the matter revolve at different rates about the center of the galaxy. This circumstance in turn is thought to signify that the matter is farther from the galactic center. Kutner and Mead calculate that the carbon monoxide is 15 kiloparsecs from the center, which makes it at least five kiloparsecs more distant than the solar system is. (A kiloparsec is about 3,260 light-years.) In contrast, the Perseus arm is

© 1981 SCIENTIFIC AMERICAN, INC

© 1981 SCIENTIFIC AMERICAN, INC

The new Ac
Will they dri
back to the
board again

©1981 American Honda Motor Co., Inc.

cords.
ve everyone
drawing

The Honda Accord 4-Door Sedan has always had tremendous drawing power.

Both in the way it attracts loyal owners. And draws favorable comparison between itself and cars costing much more.

For 1982, the Accord draws ahead. We've upgraded the interior to make it even more elegant. It's roomier inside and more comfortable. It's quieter, too. The trunk has more interior space. And so does the gas tank.

The mileage story is also drawn out this year. With the 5-speed, a gallon of gas takes you an EPA estimated [30] miles, and estimated 41 miles highway.

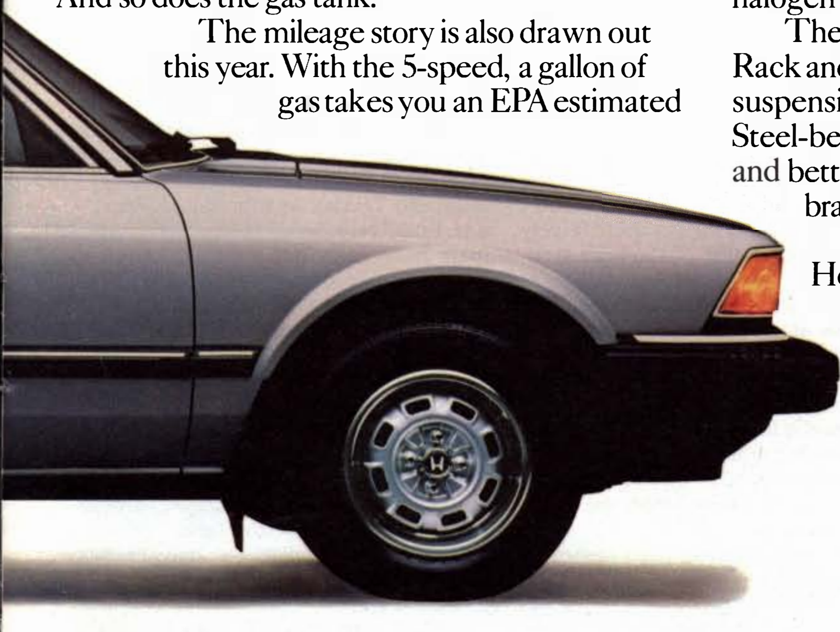
Use 30 mpg for comparison. Your mileage may vary according to weather, speed or length of trip. And you can expect actual highway mileage to be less. California mileage will be lower.

You can expect the list of standard equipment to be more, however. Cruise control is new and standard. As are instrument warning lights. And now a warning chime alerts you when the halogen headlights are left on.

There's still our proven front-wheel drive. Rack and pinion steering. 4-wheel independent suspension. And variable-assist power steering. Steel-belted radials are wider for a smoother ride and better handling. And the power-assisted brakes have larger discs up front.

Something few others can copy is Honda's simple philosophy of building cars that work the way they're designed to work. Which may account for Honda's impressive resale value.

On that, we draw the line.



HONDA

We make it simple.

© 1981 SCIENTIFIC AMERICAN, INC

two kiloparsecs farther from the center than the solar system is, the Sagittarius-Carina arm is two kiloparsecs closer to the center than the solar system is and the Orion arm includes the solar system.

What seems to place the carbon monoxide in a newly found spiral arm (perhaps to be called the Cygnus arm) is that Kutner and Mead can trace the concentration of carbon monoxide over a region in space some 15 kiloparsecs long. Moreover, when the region is observed at high resolution, it becomes a chain of clouds, each cloud being from 60 to 80 parsecs long. The pattern seems typical of the edge of a spiral arm.

In general the distribution of carbon monoxide in the disk of the Milky Way is correlated with the distribution of cold molecular hydrogen, a substance hard to detect because its characteristic spectral lines lie in parts of the spectrum that are absorbed by the atmosphere of the earth. In some instances the molecular hydrogen turns out to be a thousand times more abundant than the carbon monoxide. Thus the carbon monoxide seems to show up in places occupied by cold, placid clouds of matter. They are called giant molecular clouds. According to a widely accepted hypothesis, such clouds are piled up in a spiral pattern by waves of density that traverse the disk of a galaxy such as the Milky Way; then the condensation of matter in the clouds gives rise to stars that populate the spiral arms. Kutner and Mead's discovery suggests stars arise throughout a much larger part of the galaxy than had been thought.

One thing distinguishes the giant molecular clouds that Kutner and Mead have found. The clouds less distant from the center of the galaxy have a temperature of 12 degrees Kelvin. The newly discovered clouds are six degrees colder. The difference is explained if giant molecular clouds are heated mostly by cosmic rays, which become sparse with increasing distance from the galactic center. In any case the low temperature of the newly discovered clouds means they are intrinsically less luminous at radio wavelengths than the more central clouds. The peripheral clouds are therefore harder to find, which further increases the difficulty of tracing the Milky Way's spiral-arm structure.

Inadmissible Evidence

A comprehensive theory of cancer causation was abuilding last spring. It was supported by a figurative arch. One side of the arch was evidence from tumor virology; the other side was evidence from the biochemistry of tumor cells. An elegant keystone, also derived from tumor-cell biochemistry, gave promise of making the structure complete. Now the integrity of the keystone is in question. Some of the experimental results from which it was fashioned may have been faked; at best they have not been reproduced so far.

The virologists' side of the developing theory is essentially the discovery of a family of genes (oncogenes) that can transform some animal cells, causing cancer. The genes are carried by retroviruses: viruses whose genetic material is RNA, which is transcribed "backward" into DNA after the virus infects a cell. A remarkable feature of the oncogenes is that they do not seem to be peculiar to the viruses; there is genetic evidence that they originated in animal cells (as proto-oncogenes) and were captured and perhaps modified by the retroviruses.

Another remarkable finding is that oncogenes in several retroviruses (which infect different animals and induce different kinds of cancer) all encode a specific kind of protein. It is an enzyme called a protein kinase that transfers a phosphate group from one molecule to another. In each case the source of the phosphate is adenosine triphosphate, or ATP, the cell's major energy currency, which is converted by the transfer into adenosine diphosphate, or ADP; the destination of the phosphate is a particular amino acid unit in a cellular protein. Unlike other kinases, the oncogene-encoded enzymes phosphorylate the amino acid tyrosine.

These facts suggested that proto-oncogenes might be found in animal tumor cells and that there too the genes might encode a kinase that phosphorylates tyrosine. The exciting news last spring was that biochemists had found evidence of proto-oncogenes and phosphorylated kinases in tumor cells. Efraim Racker of Cornell University had earlier established that glycolysis, the fermentation of glucose to lactic acid, is enhanced in malignant cells by the increased availability of ADP and phosphate. He had found that these substances are produced in excess in a particular line of mouse tumor cells because an enzyme called an ATPase that serves as a pump in the cell membrane is inefficient.

Last year Racker and his colleagues showed that the inefficiency is due to the presence of a phosphate group on one amino acid of the ATPase and that the phosphorylated amino acid is a tyrosine. In a series of experiments done largely by Mark Spector, one of Racker's graduate students, the phosphorylation of the ATPase was shown to be the end result of the activity of a cascade of four protein kinases, all of which phosphorylate tyrosine. Then came the apparent clincher. Immunological evidence indicated that the first kinase of the cascade is very similar to and perhaps the same as the kinase encoded by *src*, the oncogene of Rous sarcoma virus, the most-studied retrovirus.

News of the apparent proto-oncogene in a tumor cell spread quickly (see "Science and the Citizen," June), even before the findings were published in the journals *Science* and *Cell* last summer. Soon, however, there were reports that workers in other laboratories were unable to reproduce some of the results. Volker M. Vogt, a colleague of Racker's and a coauthor of one of the papers, asked Spector and a co-worker to repeat a typical experiment. It was an unpublished one in which antibodies to a cascade kinase were alleged to have precipitated a protein, labeled with radioactive phosphorus, from cells that had been transformed by a retrovirus, the Moloney mouse-sarcoma virus. The result suggested that the precipitated protein was the long-sought product of the Moloney-virus oncogene and was very similar to the cascade kinase. Vogt found that the precipitated protein had been labeled not with radioactive phosphorus but with radioactive iodine; the protein was not a kinase but another protein chosen to appear to be one.

That discovery, along with discrepancies found in other laboratories, convinced Racker and Vogt that the immunological characterization of the cascade kinases, and in particular the identification of one of them with the *src* gene product, may be wrong and must at least be considered doubtful. They are now repeating the experiments. In a letter of retraction to *Science* Racker wrote that he had so far confirmed a few of the published results, including the phosphorylation of tyrosine on the tumor-cell ATPase.

Meanwhile the concept of oncogenes as transforming genes stands unchallenged, as does the commonality of tyrosine phosphorylation by oncogene-encoded proteins. The importance of phosphorylation in tumor-cell metabolism is suggested by several lines of evidence, but the keystone of the edifice will have to be set in place all over again.

Mesozoic Milk Teeth

The Age of Mammals is generally reckoned to begin at the end of the Mesozoic era, some 63 million years ago, but the first known mammals actually appeared 120 million years earlier in the Mesozoic, at the boundary between the Triassic and the Jurassic periods. Fossil remains of the earliest mammals have been quite scarce, however, and until recently were known only from deposits in Britain and China. Now evidence has emerged that similar mammals were present at roughly the same time in the New World.

For many years a mouse-size animal assigned to the genus *Morganucodon* held the exclusive position of first mammal. Evidently resembling the Triassic reptiles of the order Therapsida, which were the Mesozoic forebears of the mammals, *Morganucodon* had cheek teeth with three cusps each, arrayed in a line from front to back.

Fifteen years ago teeth representative

© 1981 SCIENTIFIC AMERICAN, INC

© 1981 SCIENTIFIC AMERICAN, INC

of a second early mammal were uncovered in the same fossil deposits in England and Wales that had yielded *Morganucodon*. In the new specimens the three cusps of the cheek teeth formed a triangle rather than a line. Only isolated teeth were found, but it was estimated that the animal, assigned to the new genus *Kuehneotherium*, had been about the same size as *Morganucodon*. The more advanced shape of the teeth, however, suggested to paleontologists that *Kuehneotherium* could have been ancestral to the two advanced orders of living mammals, the marsupials and the placentals. *Morganucodon's* place in the evolutionary sequence was reduced to that of the forebear of the primitive egg-laying mammals, the monotremes. (The duckbill platypus and spiny anteater of Australia are the only living monotremes.)

The latest discoveries were made in deposits dating to the Triassic-Jurassic boundary in the Kayenta Formation of Arizona. A team of paleontologists headed by Farish A. Jenkins of Harvard University has been at work in the Kayenta Formation for the past four years. During the first three years the fossil beds yielded only the remains of reptiles, including several small dinosaurs, one of the earliest known turtles and a late, mammal-like therapsid.

In November of last year William Downs of the Museum of Northern Arizona found a number of *Morganucodon* teeth. Turning their attention to the part of the formation Downs had quarried, the team extended their time at the site. Late in July, on their next to last working day, Kathleen Smith of Duke University found in a lump of sedimentary rock a centimeter-long fragment of lower jaw bearing four cheek teeth.

In the new specimen the cusps of three of the teeth are intact; like those of *Morganucodon*, they lie in a line from front to back. Unlike the cusps of *Morganucodon* teeth, however, the central cusp rises far above the two flanking ones. Moreover, the wear pattern indicates that the upper and lower teeth rubbed together during chewing, as the teeth of *Kuehneotherium* did. The discovery of this third mouse-size early mammal, Jenkins suggests, will require paleontologists to reexamine hypotheses about the relations of the earliest known mammals to their descendants.

The Nobel Prizes

The selection of the 1981 Nobel prizes in the sciences confirms the continued preeminence of the major U.S. research universities, not only as centers for the creation of knowledge but also as magnets for scientific workers from other countries. Of the nine investigators who won the awards this year seven are faculty members at institutions of higher learning in the U.S.; of those seven, three were born and educated abroad. A fourth came to the U.S. at the age of 11 and a fifth, although born in the U.S., earned his university degrees in Canada. Each of the prizes this year is valued at about $180,000. They will be presented by King Karl Gustaf of Sweden in Stockholm on December 10.

Half of the prize in physiology or medicine was awarded to Roger W. Sperry of the California Institute of Technology. The other half was shared equally by David H. Hubel and Torsten N. Wiesel of the Harvard Medical School. Sperry, whose research over the past four decades has covered various aspects of the central nervous system, was cited for his discoveries concerning "the functional specialization of the cerebral hemispheres." The work that led to the award was begun some 30 years ago at the University of Chicago and has been carried on since 1954 at Cal Tech, where Sperry is Hixon Professor of Psychobiology.

The possibility of exploring the separate functions of the two halves of the cerebrum (the top part of the brain) was originally suggested by the experience of neurosurgeons, who many years earlier had made a surprising discovery: The main link between the hemispheres—the bundle of nerve fibers known as the corpus callosum, or the great cerebral commissure—could be cut into with little or no perceptible change in the patient's mental faculties. Following a series of experiments on animals, which tended to confirm the harmlessness of the procedure, surgeons tried cutting all the way through the corpus callosum to prevent the spread of epileptic seizures from one hemisphere to the other. The operation proved remarkably successful, and beginning in the late 1930's it became an accepted practice in cases of severe epilepsy. The seeming irrelevance of the corpus callosum in such circumstances, however, remained a mystery until the early 1950's, when Sperry and his colleagues took up their investigation.

That the bisected brain is not entirely normal in its functioning was first demonstrated by Ronald E. Myers, one of Sperry's graduate students at the University of Chicago. Myers severed all the major pathways connecting the hemispheres of a cat's brain and found that behavioral responses learned by one side of the brain were not transferred to the other side. Sperry later wrote of this work: "It was as though each hemisphere were a separate mental domain operating with complete disregard—indeed, with a complete lack of awareness—of what went on in the other. The split-brain animal behaved in the test situation as if it had two entirely separate brains" (see "The Great Cerebral Commissure," by R. W. Sperry; SCIENTIFIC AMERICAN, January, 1964).

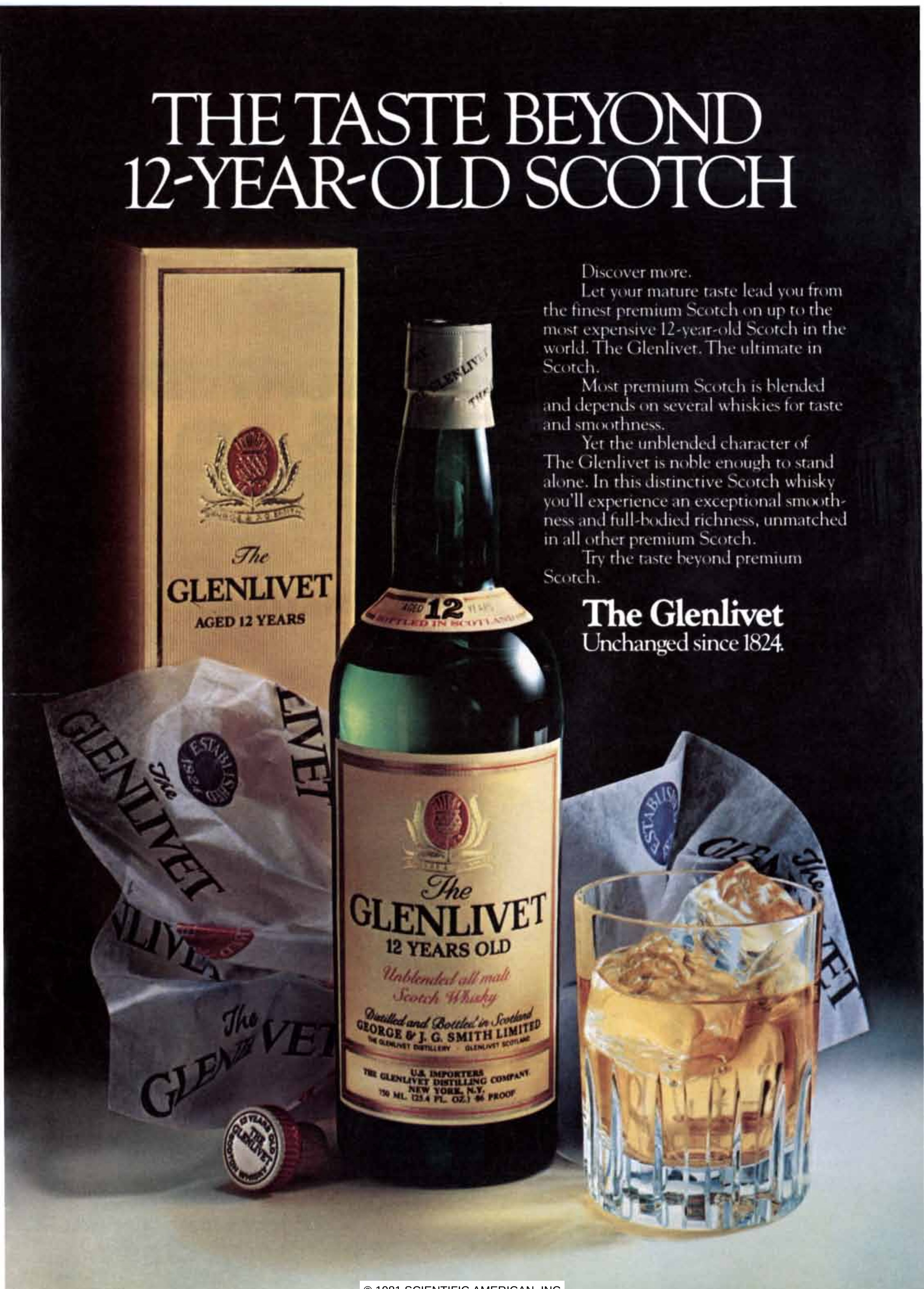
The line of inquiry that began with this demonstration was pursued by Sperry and his co-workers through a wide-ranging series of animal studies, designed to analyze the separate organization and operation of the brain's hemispheres. Beginning in the 1960's the basic experimental techniques worked out in detail with cats, monkeys and chimpanzees were applied to human patients who had undergone the brain-splitting operation for the control of intractable epilepsy. The latter experiments were done mainly by Sperry and Michael S. Gazzaniga (see "The Split Brain in Man," by Michael S. Gazzaniga; SCIENTIFIC AMERICAN, August, 1967).

In summarizing what has been learned from these investigations the Nobel selection committee of the Karolinska Institute stated that Sperry had "brilliantly succeeded in extracting the secrets from both hemispheres and in demonstrating that they are highly specialized." There is now substantial evidence that whereas the left hemisphere (which in general controls the right side of the body) tends to be the dominant one for speech and abstract reasoning, some other mental functions, such as spatial perception and musical ability, are centered in the right hemisphere (which is mainly responsible for the left side of the body). In the course of exploring the functional specializations of the cerebral hemispheres in the split brain the role of the corpus callosum in the intact brain has finally been clarified: it serves as a communications channel for combining and integrating the perceptions and the knowledge of the two hemispheres.

The contributions of Hubel and Wiesel to brain science have been on a much finer scale. They were honored for their discoveries concerning "information processing in the visual system." For more than two decades Hubel and Wiesel have applied variants of a basic experimental strategy they describe in their own words as "(in principle) simple. Beginning, say, with the fibers of the optic nerve, we record with microelectrodes from a single nerve fiber and try to find out how we can most effectively influence the firing by stimulating the retina with light. For this one can use patterns of light of every conceivable size, shape and color, bright on a dark background or the reverse, and stationary or moving. It may take a long time, but sooner or later we satisfy ourselves that we have found the best stimulus for the cell being tested.... We note the results and then go on to another fiber. After studying a few hundred cells we may find that new types become rare. Satisfied that we know roughly how the neurons at this stage work, we proceed to the next stage... and repeat the process."

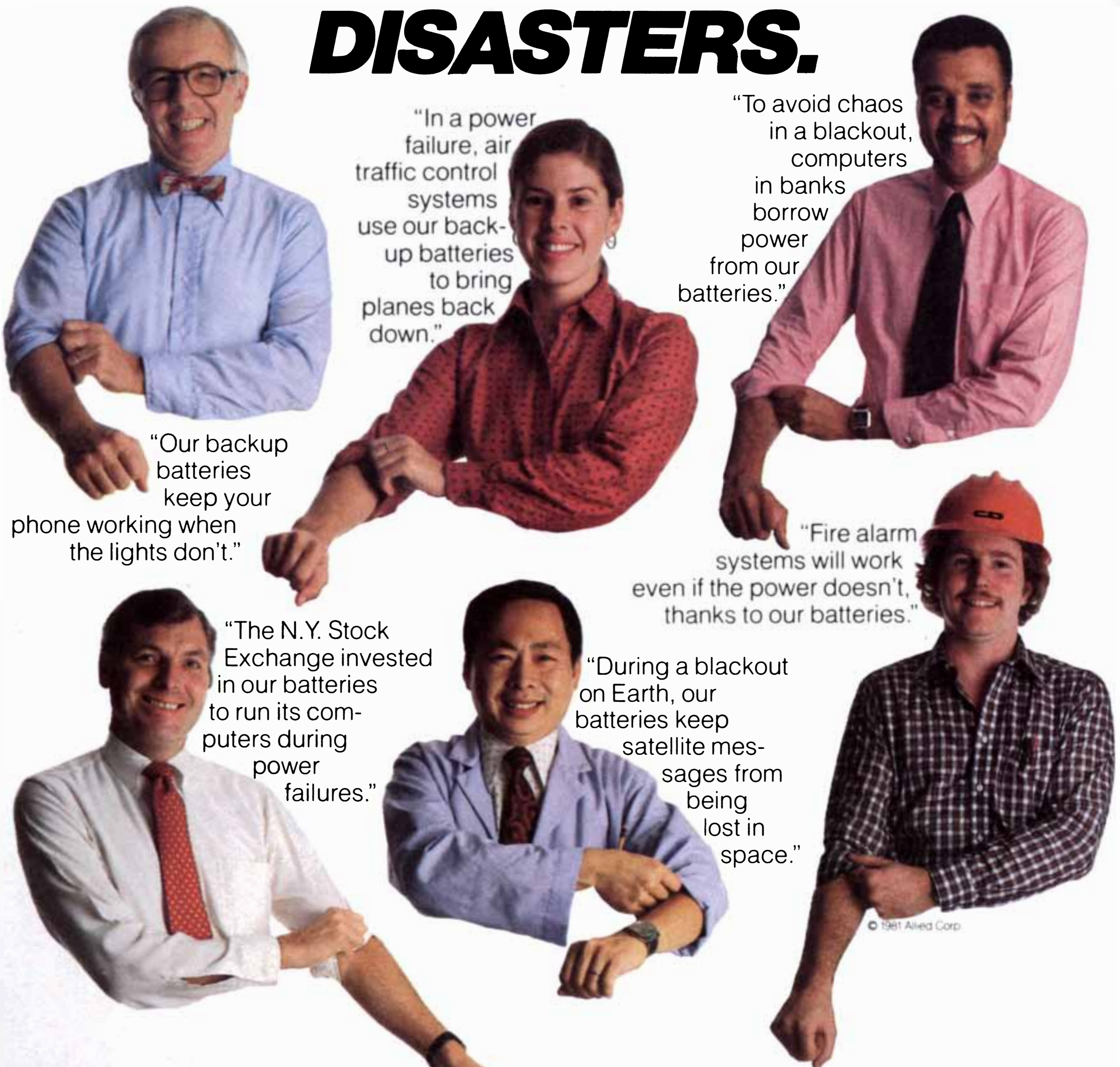
Working in this way (mainly with the

© 1981 SCIENTIFIC AMERICAN, INC



© 1981 SCIENTIFIC AMERICAN, INC

ALLIED ON THE PREVENTION OF CALAMITIES, CATASTROPHES, CATACLYSMS, AND OTHER ASSORTED DISASTERS.



It's the business of a backup battery to keep the power going in systems that shouldn't ever stop. At the C&D Batteries division of Eltra Corporation, we mean business with some of the most advanced backup power systems in the world, as well as an electrifying array of other industrial batteries.

Eltra's electrical products connect with other major businesses like fibers and plastics, oil and gas, and chemicals, to power Allied Corporation.

It's no accident that an Allied company makes such dependable backup systems. When we say we prevent disasters, we mean business.

ALLIED Corporation

We mean business.

© 1981 SCIENTIFIC AMERICAN, INC

brain of anesthetized cats and monkeys), Hubel and Wiesel have followed the visual impulses from the eye to the various layers of cells in the primary visual cortex, at the back of the cerebrum. They have demonstrated that the message representing the image on the retina is analyzed in the cortex by a system of neurons arrayed in small columns. Within each column nerve cells respond preferentially to specific details of contrast and motion in the retinal pattern (see "Brain Mechanisms of Vision," by David H. Hubel and Torsten N. Wiesel; SCIENTIFIC AMERICAN, September, 1979).

Hubel was born and educated in Canada (M.D., McGill University, 1951) and Wiesel was born and educated in Sweden (M.D., Karolinska Institute, 1954). They began their collaboration in the late 1950's while they were both postdoctoral fellows working under the direction of the late Stephen W. Kuffler at the Johns Hopkins School of Medicine. When Kuffler moved to Harvard in 1959, Hubel and Wiesel followed him, and they have been there since. Hubel is now George Packer Berry Professor of Neurobiology, and Wiesel is Robert Winthrop Professor of Neurobiology and chairman of the department.

The prize in physics was also divided into three parts. Half was awarded jointly to Nicolaas Bloembergen of Harvard and Arthur L. Schawlow of Stanford University "for their contribution to the development of laser spectroscopy." The other half went to Kai M. Siegbahn of the University of Uppsala "for his contribution to the development of high-resolution electron spectroscopy."

Spectroscopy, broadly defined, is the study of the characteristic frequencies at which the resonating particles of matter absorb and emit energy. In atomic and molecular spectroscopy the energy is absorbed and emitted primarily in the form of electromagnetic radiation. The advent of the laser in the 1960's provided spectroscopists with a powerful new tool for probing the energy states of gases. Because laser light is highly monochromatic (that is, confined to a narrow range of frequencies) it is ideally suited to the task of resolving fine spectral lines.

One of Bloembergen's major contributions to laser spectroscopy was to supply the theoretical foundation for greatly extending the range of frequencies accessible to spectral analysis. This advance grew out of his work on nonlinear optics: the study of interactions of light with matter in which the light beam is intense enough to generate harmonic frequencies, or overtones, in the resonating particles. (The effects are said to be nonlinear because the relation of the input to the output cannot be represented in a graph by a straight line.) The only light source capable of producing

Public Service Canada
Fonction publique Canada

Open to both men and women

International Year of Disabled Persons
1981
Année internationale des personnes handicapées

CHIEF, INVERTEBRATE & MARINE PLANTS DIVISION

Salary: $37,703 – $47,448 (under review)
Ref. No.: 81-PSCH-DFO-12

Department of Fisheries & Oceans
Halifax, Nova Scotia

Plans, directs and manages the Invertebrates and Marine Plants Division; organizes and administers activities aimed at maintaining the welfare of marine invertebrates and plant resources and maximizing continuing biological production from stocks; co-ordinates work of the Division with that of industry, provincial departments and other units within the Fisheries organization.

Qualifications
Either graduation with an acceptable doctoral degree from a recognized university in Biology or an equivalency. (Equivalency refers to graduation with an acceptable Master's Degree or an acceptable Bachelor's Degree from a recognized university in Marine Biology coupled with acceptable research training and experience in which the capability has been clearly demonstrated to do independent research equivalent to that required for a doctoral degree.); evidence of authorship of published or unpublished reports or papers resulting from research in the field of fisheries; and recognition by the scientific community of achievement in fisheries research; experience in carrying out research projects related to marine invertebrates and plant resources and in the management of research resources, including supervision and financial budgeting and control.
Knowledge of the English language is essential.

Clearance No.: 331-259-001

Additional job information is available by writing to the address below:
Toute information relative à ce concours est disponible en français et peut être obtenue en écrivant à l'adresse suivante:

How to apply
Send your application form and/or résumé to:
Mrs. B.J. Firth, Staffing Officer
Public Service Commission of Canada
4th Floor Royal Bank Building
5161 George Street
Halifax, N.S. B3J 1M8
902-426-5878
Closing date: December 31, 1981

Please quote the applicable reference number at all times.

Canadä

© 1981 SCIENTIFIC AMERICAN, INC

SCIENCE/SCOPE

Medical imaging and airport baggage inspection are but two uses of electronic devices called digital image processors. The equipment converts data or information from various devices into pictures for display on standard TV screens. In medicine, the digital image processors (often called scan converters) are used with ultra high frequency sound to display live or stored pictures of the heart, other body parts, and unborn babies. In medical X-ray, it is possible to subtract from the display image those areas which are not associated with the area of interest. For airport inspections, carry-on baggage is exposed to a very short burst of X-rays. A solid-state detector senses this energy, and the digital image processor creates a picture for display on a TV monitor.

Satellite pictures have helped the state of California study its land resources more closely than ever. The state government and NASA's Ames Research Center used data from Landsat 2 in a series of projects. The list includes an inventory of irrigated land, crop identification, classifying land cover, and storing data on farmlands in a computer to provide information on conservation. Landsat 2's electronic camera, a multispectral scanner, was developed by Hughes.

Better and timelier weather forecasts will be possible when a microwave sensor is launched aboard a military satellite in the mid-1980s. The instrument will tell how hard rain is falling in a specific area rather than simply how much has fallen over a wide area within 24 hours. It also will determine wind speed, atmospheric water content, soil moisture, and sea ice conditions. Because the satellite will follow a low polar orbit, the sensor will gather important data on the little-studied polar regions and oceans. Hughes will soon deliver the prototype Special Sensor Microwave/Imager to the U.S. Air Force.

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 your resume to Engineering Recruitment, Hughes Aircraft Company, P.O. Box 11337, Dept. SE, Tucson AZ 85734. Or call (602) 746-8925. Equal opportunity employer.

A device that directly converts electrical input signals into output images could be used for optical data processing and the projection of very bright TV pictures on a large screen. The device, a CCD liquid-crystal light valve, uses a charge-coupled device array and a metal oxide semiconductor readout structure to transfer signal charges to a liquid-crystal layer. The readout source can be common white light or a laser in the spectral range from near ultraviolet to infrared. Hughes has demonstrated a fully operational 64x64-element device.

Creating a new world with electronics

HUGHES

HUGHES AIRCRAFT COMPANY
CULVER CITY, CALIFORNIA 90230
(213) 670-1515 EXTENSION 5964

© 1981 SCIENTIFIC AMERICAN, INC

such effects is the laser. Bloembergen showed how, by mixing three intense laser beams in certain materials, one could generate a fourth beam that could be "tuned" over a wide range of frequencies, extending far beyond the visible part of the spectrum into both the infrared and the ultraviolet regions.

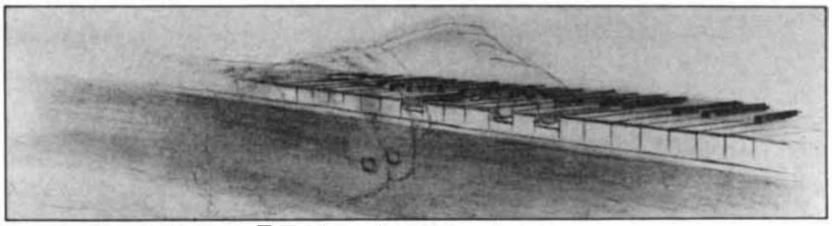
Bloembergen, who was born in the Netherlands and received his Ph.D. from the State University of Leiden in 1948, has also made important contributions to the study of nuclear magnetic resonance and to the development of the maser (the microwave precursor of the laser). A member of the faculty at Harvard since 1951, he became Gerhard Gade University Professor last year.

Schawlow, who is J. G. Jackson–C. J. Wood Professor of Physics at Stanford, is perhaps best known as one of the coauthors of the 1958 paper in *Physical Review* that provided the conceptual basis for the laser. (His coauthor, Charles H. Townes, won part of the 1964 Nobel prize in physics for his role in this development.) Schawlow was born and raised in upstate New York and was educated at the University of Toronto, getting his Ph.D. there in 1949. He spent a decade at the Bell Telephone Laboratories before moving to Stanford in 1961.

Schawlow was awarded his share of this year's physics prize for his role in the development and application of methods in laser spectroscopy that depend for their effectiveness on nonlinear "saturation" effects caused by the absorption of intense laser light. The methods serve as the basis of Doppler-free laser spectroscopy, in which the broadening of the spectral lines caused by the motion of the particles in a gas is overcome. Schawlow and his co-workers at Stanford have applied their methods to precise measurements of the spectrum of the simplest atom: hydrogen (see "The Spectrum of Atomic Hydrogen," by Theodor W. Hänsch, Arthur L. Schawlow and George W. Series; SCIENTIFIC AMERICAN, March, 1979).

Siegbahn has devoted much of his scientific career to the development of an alternative to a basic analytic technique for which his father, Manne Siegbahn, received the 1924 Nobel prize in physics. The elder Siegbahn, who was director of the Nobel Institute for Physics of the Royal Swedish Academy of Sciences from 1937 to 1975, died three years ago at the age of 92. The younger Siegbahn obtained his doctorate from the University of Stockholm in 1944 and has been on the faculty at Uppsala since 1954.

Electron spectroscopy is a technique for studying the energy states of the electrons bound in the atoms or molecules of a substance by dislodging some of the electrons and then measuring their energy. The emitted electrons (or photoelectrons) are usually pried loose



Roger Williams can play *your* piano...like magic.

Without those awkward piano rolls! In fact, you can surprise your guests with performances by many of the world's great pianists, in your living room, on *your* piano. That's the magic of the PIANOCORDER® reproducing system, a musical breakthrough that makes the *rinky-tink* sound of the "old fashioned player piano" disappear.

Hidden away inside your piano, the PIANOCORDER uses computerized cassette tapes to bring the keys and pedals to life, recreating the original performer's style with unbelievable accuracy.

You can even record your own songs and play them back instantly, note for note, a feature that makes the PIANOCORDER invaluable for learning *and* entertaining.

What's more, our extensive tape library contains over 3,000 superb performances, from classical to jazz, ragtime to pop. And we're constantly adding new music by today's top pianists—Roger Williams, Peter Nero, George Shearing and many others.

The PIANOCORDER system can be installed in almost any existing piano. If you're considering a new piano, you can also purchase our fine **MARANTZ** reproducing piano with the system already built in.

Write or dial toll-free 1-800-447-4700 (in Illinois, 1-800-322-4400) for information on the remarkable PIANOCORDER system from **MARANTZ.**

ROGER WILLIAMS TAPE NOW AVAILABLE

Pianocorder® Reproducing System

marantz® reproducing piano

Marantz Piano Company, Inc. • Post Office Box 460 • Highway 64-70 • Morganton, North Carolina 28655 • (704) 437-7135

Speak French like a diplomat!

What sort of people need to learn a foreign language as quickly and effectively as possible? *Foreign service personnel,* that's who. America's diplomatic corps assigned to U.S. embassies abroad must be able to converse fluently in every situation.

Now you can make a start on learning to speak French just as these diplomatic personnel do — with the Foreign Service Institute's Basic French Course.

The U.S. Department of State has spent thousands of dollars developing this course. It's by far *the most effective way* to learn French at your own convenience and pace.

The Basic French Course consists of a series of cassettes and an accompanying textbook. Simply follow the spoken and written instructions, listening and repeating. By the end of the course you'll be learning and speaking entirely in French!

This course turns your cassette player into a "teaching machine." With its unique "pattern drill" learning method, you set your own pace—testing yourself, correcting errors, reinforcing accurate responses.

The FSI's Introductory Basic French Course comes in two parts. Part A provides an introduction to the simpler forms of the language plus a basic vocabulary. Part B introduces more complex structures and additional vocabulary.

You may order one or both parts of the Basic French Course:

☐ **Basic French, Part A.** 12 cassettes (17 hours) and 200-page text, $115.

☐ **Basic French, Part B.** 18 cassettes (25½ hours) and 300-page text, $149.

(Conn. and N.Y. residents add sales tax.)

Shipped in handsome library binders.

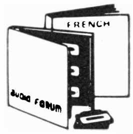
TO ORDER, JUST CLIP THIS AD and mail it with your name and address, and a check or money order. Or, charge to your credit card (American Express, VISA, MasterCard, Diners Club) by enclosing card number, expiration date, and your signature.

The Foreign Service Institute's French course is unconditionally guaranteed. Try it for three weeks. If you're not convinced it's *the fastest, easiest, most painless way to learn French,* return it and we'll refund every penny you paid. Order today!

Many other FSI language courses also available. Write us.

audio-forum®

Audio-Forum
Dept. T-14
On The Green,
Guilford, CT. 06437
(203) 453-9794



Or visit our New York sales office: 145 E. 49th St., New York, N.Y. 10017 (212)753-1783

© 1981 SCIENTIFIC AMERICAN, INC

THE JOURNAL

OF

CLASSICAL PHYSICS

This new journal is intended for Scientists and knowledgeable laypersons who feel Quantum Wave Mechanics is non-predictive and ultimately counterproductive and that classical model development is preferred.

Seminal papers are invited from individuals within and without the academic establishment. The only criteria for publication are succinctness and some degree of engagement pro or con with the journal's philosophy.

The inaugural issue features a reprint of Ralph Sansbury's 1978 book, *Electron Structure,* a brief summary of which follows.

1) A simple analogy can be drawn between the magnetic force and the force between electrostatic dipoles; Ampère's formula for the magnetic force between two current-carrying wire segments equals the force between two electrostatic dipoles whose moments are proportional to the average electrons' speeds, v_i, along the two wires and whose orientations are roughly perpendicular to the respective wire segments. 2) As electrons approach the speed of light, c, further elastic dilations of charge are nonlinear and proportional to $v(1-v^2/c^2)^{1/2}$. Hence pair production etc., not infinite mass, results from the speed, c. The electron and most nucleons contain quark-like particles orbiting each other at speeds that can exceed c. 3) Em. waves, photons and matter waves are misleading descriptions of rapidly changing instantaneous electrostatic forces-at-a distance. Starlight, for example, is shown to reach earth fractions of a second, not years, after its emission. 4) Atomic orbital periods are mutiples of nuclear charge fluctuation periods; spectral radiation frequencies are averages of pairs of such semistable frequencies defining transitions; an analogous explanation holds for nuclear spectra. 5) With each circular orbit are associated many elliptical orbits with the same semiminor axes as the circular radius and the same orbital frequency but with different coefficients of precession that give rise to different radiated frequencies. 6) Mach's gravitation principle, electron structure and the classical electron radius imply the gravitational constant and that gravity is a residual electrostatic force. 7) Electron structure implies a tendency of orbital planes in non-ferromagnetic solids to line up parallel to the lines of force of an applied magnetic field.

A one year/two issue subscription is $25. Unsolicited papers and checks in U.S. dollars should be sent to The Journal of Classical Physics, Box 2212, Mount Vernon, New York 10550.

from the surface of a solid sample by irradiating it with either X rays or ultraviolet rays. (In the related technique of X-ray spectroscopy, pioneered by the elder Siegbahn, the X rays are absorbed by the target substance, exciting the electrons from a lower energy state to a higher one; the electrons then return to the lower state, emitting their excess energy in the form of secondary X rays.)

The study of photoelectrons for clues to the electronic structure of atoms and molecules goes back many years, but because of energy losses incurred by the photoelectrons on their way out of the irradiated sample the technique was unable to compete with X-ray spectroscopy for precise measurements. Interest in electron spectroscopy revived in the 1950's when Siegbahn and his colleagues at Uppsala began to analyze photoelectrons with the aid of an improved device called the high-resolution double-focusing spectrometer, which had originally been designed for the study of electrons emitted in the beta decay of atomic nuclei. Later their technique was adapted for chemical analyses, and it is now in use in laboratories throughout the world.

The chemistry prize was shared by Kenichi Fukui of the University of Kyoto and Roald Hoffmann of Cornell University "for their theories, developed independently, concerning the course of chemical reactions." Fukui, who has held the post of professor of physical chemistry at Kyoto since 1951, is the first Japanese to win the Nobel prize in chemistry. He studied engineering as an undergraduate and graduate student at Kyoto before embarking on his scientific career as an experimental chemist. Hoffmann, who is John A. Newman Professor of Physical Sciences at Cornell, was born in Poland but came to the U.S. as a boy and was educated in this country, receiving his B.A. from Columbia College in 1958 and his Ph.D. from Harvard in 1962.

The work of Fukui and Hoffmann is based on the concepts of quantum mechanics, according to which the components of matter can be viewed as either particles or waves. More than 25 years ago, the Nobel citation states, Fukui showed that the chemical reactivity of molecules is greatly influenced by certain wave properties of their most loosely bound orbital electrons. His "frontier orbital" theory attracted little attention from chemists at the time, however, owing in part to its difficult mathematical formulation. It was not until the mid-1960's, the citation says, that "Fukui and Hoffmann discovered—almost simultaneously and independently of each other—that the symmetry properties of frontier orbitals could explain certain reaction courses that previously had been difficult to understand."

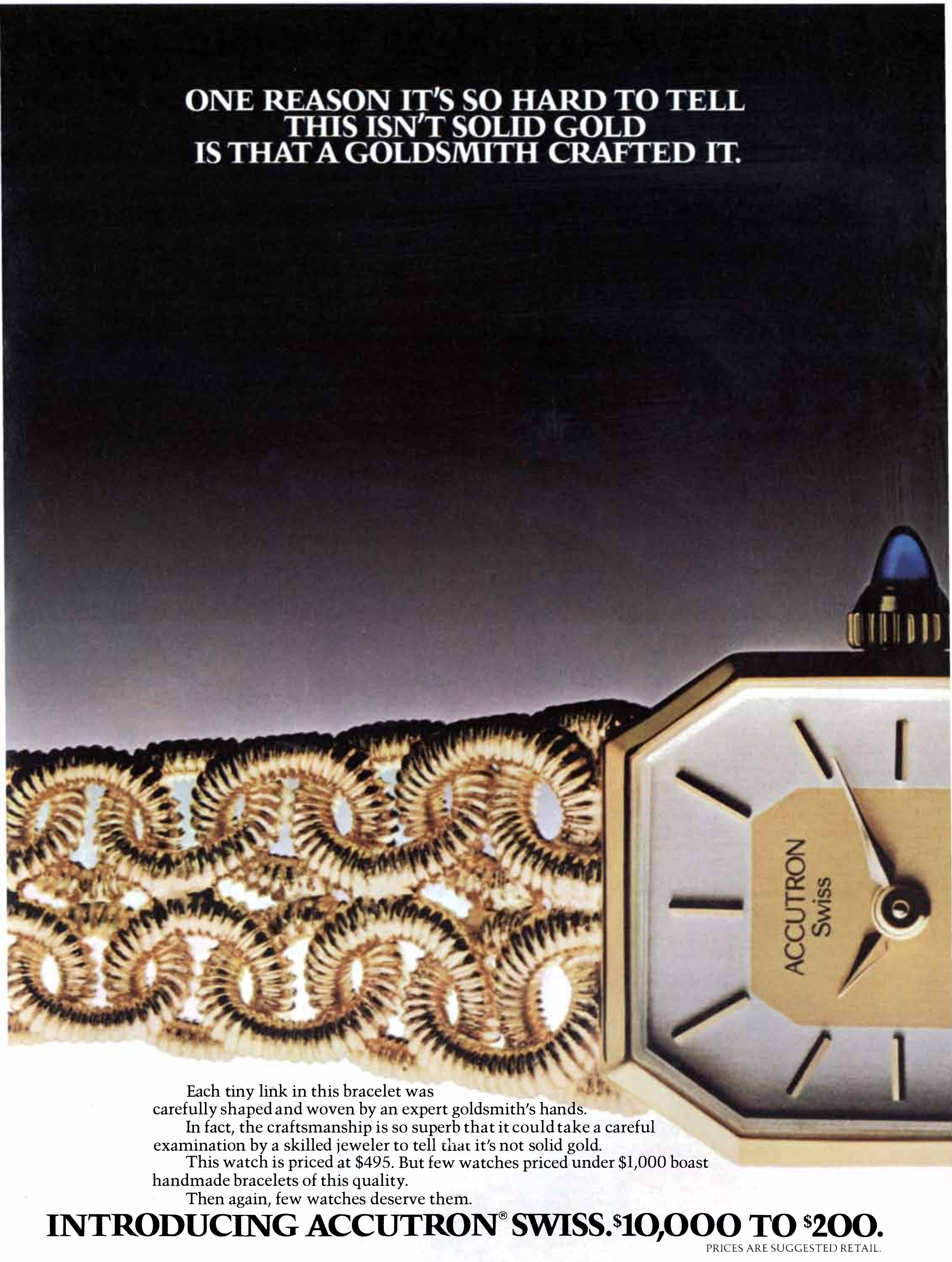
Much of Hoffmann's research on the conservation of orbital symmetry in chemical reactions was done in collaboration with the late Robert B. Woodward of Harvard, who won the 1965 Nobel prize in chemistry for the synthesis of various organic compounds. The main product of their joint work, known as the Woodward-Hoffmann rule, predicts in general terms which reactions of organic molecules can proceed easily and which can proceed only with difficulty. In recent years Hoffmann has been extending these ideas to inorganic chemistry.

The Alfred Nobel Memorial Prize in Economic Sciences, which was established in 1968 with financing from the Central Bank of Sweden, was awarded this year to James Tobin, Sterling Professor of Economics at Yale University, "for his analysis of financial markets and their relations to expenditure decisions, employment, production and prices." Tobin, who received his Ph.D. from Harvard in 1947, has been on the faculty at Yale since 1955. During the Kennedy Administration he was a member of the President's Council of Economic Advisers.

According to the statement on the economics prize issued by the Royal Swedish Academy of Sciences, Tobin's most important contributions to economic science have stemmed from his role in the formulation of "portfolio selection theory," a method for describing how individual households and businesses determine the composition of their assets by balancing the risks between financial assets (such as stocks and bonds) and real assets (such as real estate, industrial equipment and other tangible goods). The statement goes on to explain that Tobin "has developed these ideas into a general equilibrium theory for financial and real assets and analyzed the interaction between financial and real markets." An essential component of the analysis is the study of the "transmission mechanisms" whereby changes in financial markets are reflected in the expenditures of households and businesses. Noting that "this classic problem in economic research had thus far not been dealt with satisfactorily," the statement adds that "Tobin's studies constitute a major breakthrough in the integration of real and financial conditions in central economic theory."

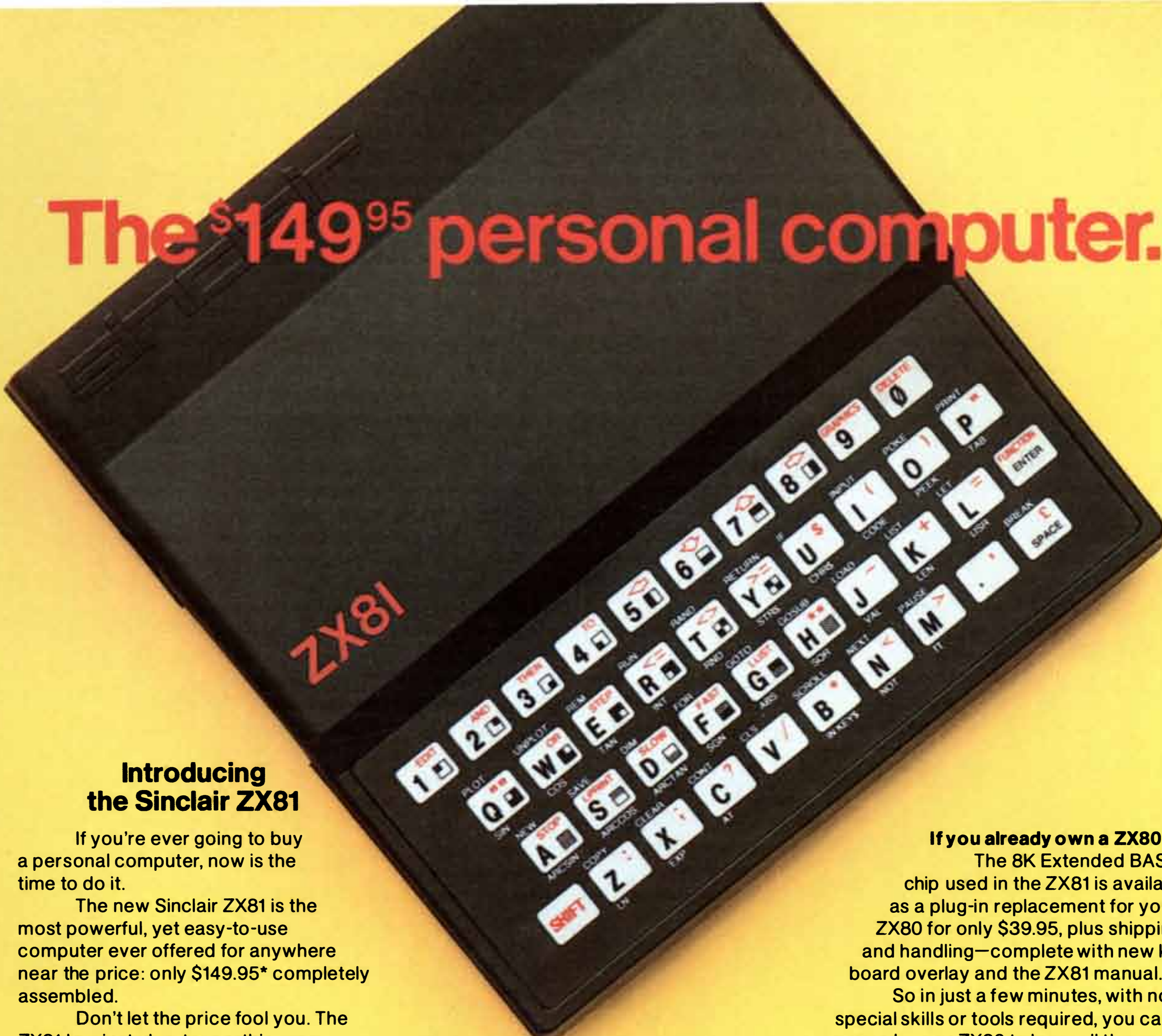
Often described as a "neo-Keynesian" (although he himself prefers "post-Keynesian"), Tobin is a political economist in every sense of the term. He has not hesitated, for example, to draw attention to his differences with the economic and social policies of the Reagan Administration, characterizing those policies as efforts to "redistribute wealth, power and opportunity to the wealthy and powerful and their heirs."

© 1981 SCIENTIFIC AMERICAN, INC



© 1981 SCIENTIFIC AMERICAN, INC

The $14995 personal computer.



Introducing the Sinclair ZX81

If you're ever going to buy a personal computer, now is the time to do it.

The new Sinclair ZX81 is the most powerful, yet easy-to-use computer ever offered for anywhere near the price: only $149.95* completely assembled.

Don't let the price fool you. The ZX81 has just about everything you could ask for in a personal computer.

A breakthrough in personal computers

The ZX81 is a major advance over the original Sinclair ZX80—the world's largest selling personal computer and the first for under $200.

In fact, the ZX81's new 8K Extended BASIC offers features found only on computers costing two or three times as much.

Just look at what you get:

■ Continuous display, including moving graphics

■ Multi-dimensional string and numerical arrays

■ Mathematical and scientific functions accurate to 8 decimal places

■ Unique one-touch entry of key words like PRINT, RUN and LIST

■ Automatic syntax error detection and easy editing

■ Randomize function useful for both games and serious applications

■ Built-in interface for ZX Printer

■ 1K of memory expandable to 16K

The ZX81 is also very convenient to use. It hooks up to any television set to produce a clear 32-column by 24-line display. And you can use a regular cassette recorder to store and recall programs by name.

If you already own a ZX80

The 8K Extended BASIC chip used in the ZX81 is available as a plug-in replacement for your ZX80 for only $39.95, plus shipping and handling—complete with new keyboard overlay and the ZX81 manual.

So in just a few minutes, with no special skills or tools required, you can upgrade your ZX80 to have all the powerful features of the ZX81. (You'll have everything except continuous display, but you can still use the PAUSE and SCROLL commands to get moving graphics.)

With the 8K BASIC chip, your ZX80 will also be equipped to use the ZX Printer and Sinclair software.

Warranty and Service Program**

The Sinclair ZX81 is covered by a 10-day money-back guarantee and a limited 90-day warranty that includes free parts and labor through our national service-by-mail facilities.

*Plus shipping and handling. Price includes connectors for TV and cassette, AC adaptor, and FREE manual.

**Does not apply to ZX81 kits.

NEW SOFTWARE: Sinclair has published pre-recorded programs on cassettes for your ZX81, or ZX80 with 8K BASIC. We're constantly coming out with new programs, so we'll send you our latest software catalog with your computer.

ZX PRINTER: The Sinclair ZX Printer will work with your ZX81, or ZX80 with 8K BASIC. It will be available in the near future and will cost less than $100.

16K MEMORY MODULE: Like any powerful, full fledged computer, the ZX81 is expandable. Sinclair's 16K memory module plugs right onto the back of your ZX81 (or ZX80, with or without 8K BASIC). Cost is $99.95, plus shipping and handling.

ZX81 MANUAL: The ZX81 comes with a comprehensive 164-page programming guide and operating manual designed for both beginners and experienced computer users. A $10.95 value, it's yours free with the ZX81.

© 1981 SCIENTIFIC AMERICAN, INC

The 99^{95} personal computer.

Introducing the ZX81 kit

If you really want to save money, and you enjoy building electronic kits, you can order the ZX81 in kit form for the incredible price of just $99.95.* It's the same, full-featured computer, only you put it together yourself. We'll send complete, easy-to-follow instructions on how you can assemble your ZX81 in just a few hours. All you have to supply is the soldering iron.

How to order

Sinclair Research is the world's largest manufacturer of personal computers.

The ZX81 represents the latest technology in microelectronics, and it picks up right where the ZX80 left off. Thousands are selling every week.

We urge you to place your order for the new ZX81 today. The sooner you order, the sooner you can start enjoying your own computer.

To order, simply call our toll free number, and use your MasterCard or VISA.

To order by mail, please use the coupon. And send your check or money order. We regret that we cannot accept purchase orders or C.O.D.'s.

CALL 800-543-3000. Ask for operator #509. In Ohio call 800-582-1364. In Canada call 513-729-4300. Ask for operator #509. Phones open 24 hours a day, 7 days a week. Have your MasterCard or VISA ready.

These numbers are for orders only. For information, you must write to Sinclair Research Ltd., One Sinclair Plaza, Nashua, NH 03061.

sinclair

AD CODE 12SA	PRICE†	QTY.	AMOUNT
ZX81	$149.95		
ZX81 Kit	99.95		
8K BASIC chip (for ZX80)	39.95		
16K Memory Module (for ZX81 or ZX80)	99.95		
Shipping and Handling	4.95		$4.95
To ship outside USA add $10.00			
		TOTAL	

MAIL TO: Sinclair Research Ltd., One Sinclair Plaza, Nashua, NH 03061.

NAME ______________________

ADDRESS ______________________

CITY/STATE/ZIP ______________________

† U.S. Dollars

© 1981 SCIENTIFIC AMERICAN, INC

Jupiter and Saturn

Competing models seek to describe the sun's two giant companions. In one model the winds are confined to a thin layer at the surface; in another the winds extend through the fluid depths of each planet

by Andrew P. Ingersoll

There were many exciting moments during the encounters of the Voyager spacecraft with Jupiter in 1979 and with Saturn in 1980 and 1981, but to me the most memorable ones came early in the first encounter, when we viewed the time-lapse images of Jupiter's swirling clouds made by *Voyager 1* on its long approach to the planet. The sequence compressed a 30-day history of the Jovian weather into a one-minute motion picture. As a scientist who studies the atmospheres of the planets, I was familiar with Jupiter's brown belts and white zones: the colored cloud bands some thousands of kilometers wide that circle the planet at constant latitude. And I had come to accept the hypothesis that Jupiter's Great Red Spot is a storm as large as the earth that has lasted for centuries.

I was not prepared, however, for the intricate motions revealed in the time-lapse sequence. The sequence was synchronized to the rotation of Jupiter, so that the Great Red Spot appeared to be stationary, with the adjacent atmosphere swirling around it. Bright, small-scale features appeared and then were torn apart, all in a few days. Small spots encountering the Red Spot from the east seemed to be drawn into its counterclockwise, rotatory flow, to circle it in one or two weeks and then to divide, a part of each one merging with the spot and the other part returning eastward. Elsewhere spots were forming, merging and dividing every few days. On scales less than 1,000 kilometers everything seemed to be chaos. How the larger structures could endure and retain their distinct colorations in such a well-mixed atmosphere was more of a mystery than it had been before the spacecraft arrived.

It is still a mystery today. Nevertheless, an analysis of the images made by *Voyager 1* and *Voyager 2* reveals order in the chaos. Indeed, it shows that many aspects of the atmospheric circulation on Jupiter and Saturn resemble patterns in the atmosphere and oceans of the earth. A number of theoretical models and laboratory experiments are now invoked to explain the circulation. The models differ in their assumptions about a basic unanswered question. Are the motions in the atmosphere of Jupiter and Saturn confined to a thin sunlit layer 100 or 200 kilometers thick where clouds form and the atmospheric pressure is only a few times the sea-level pressure on the earth? Or do the motions extend tens of thousands of kilometers down to the top of a metallic hydrogen zone where the pressure is three million times the earth's sea-level pressure?

In considering these questions I shall focus on Jupiter and Saturn themselves, to the exclusion of their moons and rings. I shall begin with bulk planetary properties: the mass, the density and the composition of Jupiter and Saturn. This leads to a discussion of the internal structure of each planet and of the origin of the internal heat each is radiating into space. Next I shall describe the structure and chemistry of the atmosphere of Jupiter and Saturn. Alternative explanations of the dynamics of the atmosphere I shall take up last. Here the challenge is to find out why features of atmospheric flow can persist for decades or centuries on Jupiter and Saturn and only for days or weeks on the earth.

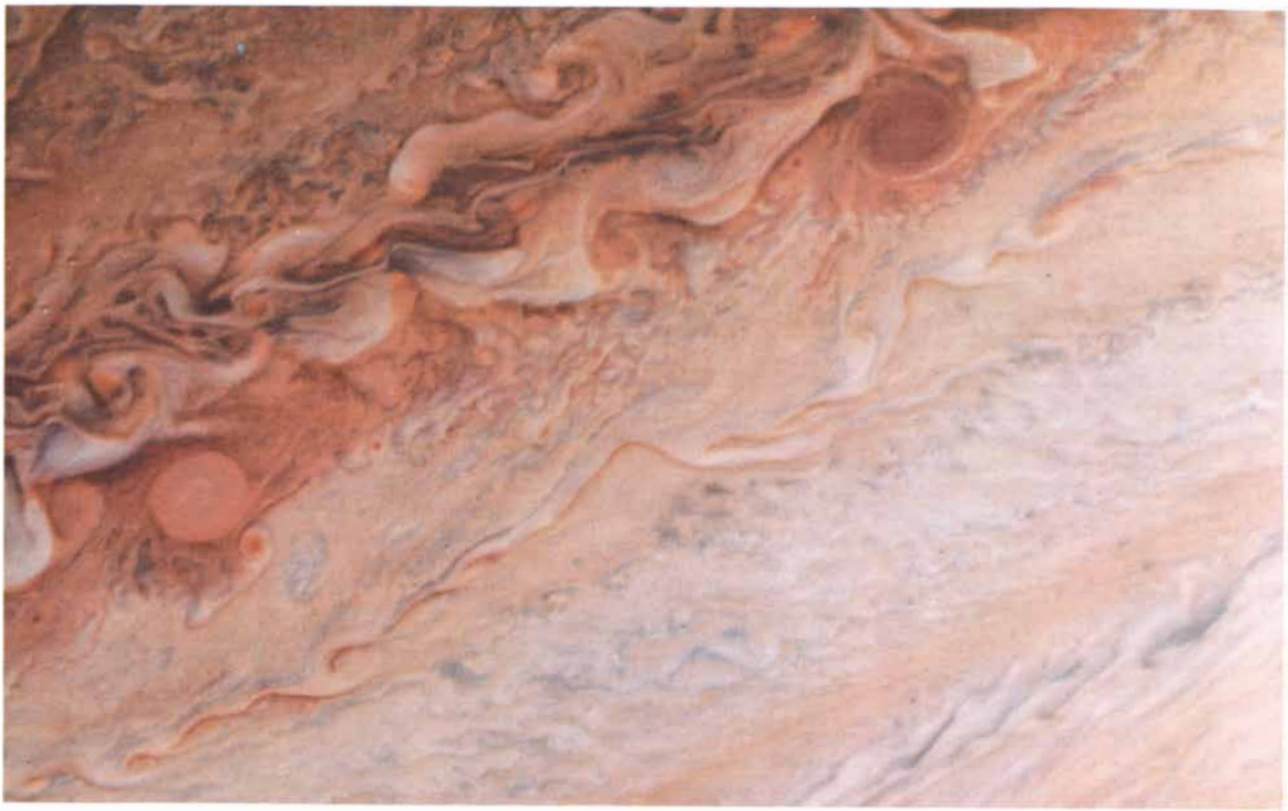
Mass, Density and Internal Structure

No theory is available that accounts precisely for the mass of the sun's two principal companions. The mass of Jupiter is 318 times the mass of the earth, or about a thousandth the mass of the sun. The mass of Saturn is 95 times the mass of the earth. Presumably these values reflect the amount of matter left in orbit around the sun soon after it formed. Moreover, no theory is available that accounts precisely for the relative abundances of the various chemical elements constituting Jupiter and Saturn. The abundances do, however, resemble those in the sun. Specifically, Jupiter and Saturn are the only planets in the solar system that consist mostly of hydrogen and helium. No other substances could give Jupiter its bulk density of only 1.33 grams per cubic centimeter at the pressures and temperatures that characterize the planet. The density of Saturn is even less—.69 gram per cubic centimeter—because Saturn's smaller mass entails a lesser degree of gravitational self-compression.

Mercury, Venus, the earth and Mars are made of heavier stuff: their densities are from 3.9 to 5.5 grams per cubic centimeter, or several times the density of Saturn. In general they are made of rocks: the most abundant metals and their oxides. The densities of Uranus and Neptune are twice as great as Saturn's, although their self-compression is less. Their most likely constituent elements are therefore oxygen, carbon and nitrogen: the third, fourth and fifth most abundant elements in the solar system. (The first two are hydrogen and helium.) At the temperatures that characterize the outer solar system oxygen, carbon and nitrogen should combine with the available hydrogen to form water, methane (CH_4) and ammonia (NH_3). On the surface of Uranus and Neptune these compounds are ices; in the interior they are liquids. The enrichment of ices with respect to hydrogen and helium on the planets beyond Saturn is hard to explain. The depletion of gases and ices in the inner solar system probably reflects the high temperatures close to the sun in the early life of the solar system.

Given the mass and composition of a planet such as Jupiter or Saturn one may seek to infer its internal structure. The size and density of the planet adjust themselves so that the outward pressure of the compressed material exactly balances the inward pull of gravity at any given place in the planet's interior. The result is a state of hydrostatic equilibrium. If the planet is rotating, a further force enters the balance. It is the outward centrifugal force that results from the planet's rotation. The outward force on a rotating mass is proportional to the square of the distance of the mass from the axis of rotation. Hence a rotating planet is flattened: its polar radius is less than its equatorial radius. The degree of flattening will depend on the internal distribution of mass. For example,

© 1981 SCIENTIFIC AMERICAN, INC



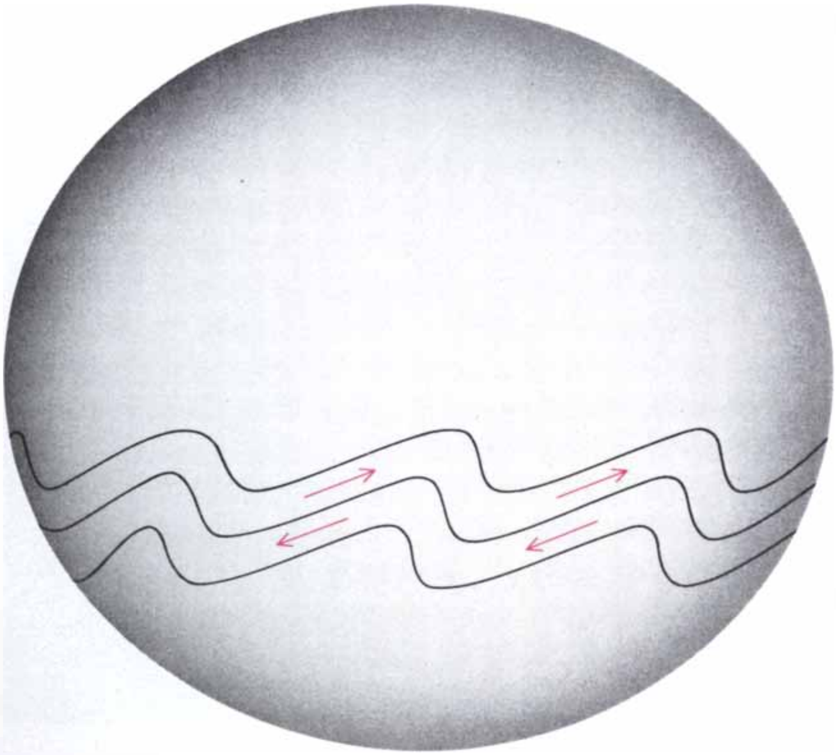
EDDY CURRENTS in the atmosphere of Jupiter and Saturn are deviations in patterns of flow that otherwise consist of sustained, alternating ribbons of eastward and westward wind. The northern mid-latitudes of Jupiter (*top*) were photographed in exaggerated color by the spacecraft *Voyager 1* on March 2, 1979. The orange ribbon cutting diagonally across the bottom right corner represents a steady eastward wind whose speed is some 130 meters per second. The sinuous lines toward the top represent eddies whose speeds are about 30 meters per second with respect to the steadier currents. The northern mid-latitudes of Saturn (*bottom*) were photographed in exaggerated color by *Voyager 2* on August 19 of this year. The sinuous line inside the light blue ribbon is a pattern moving eastward at 150 meters per second. The dark oval and the puffy white features below it are eddies drifting westward at speeds as high as 20 meters per second.

© 1981 SCIENTIFIC AMERICAN, INC

two planets of the same mass and rate of rotation will differ in the degree to which they are flattened if matter is concentrated near the center in one and farther from the center in the other. The latter will be the more flattened of the two. Clearly the degree of flattening is a sensitive probe of a rotating planet's internal structure.

Both Jupiter and Saturn have a rotational period of about 10 hours. Moreover, both planets are somewhat flattened. Jupiter's equatorial radius is 6.5 percent greater than its polar radius; Saturn's is 9.6 percent greater. Measurements of the planets' gravitational field imply a corresponding degree of concentration of mass toward the equatorial plane. An incorporation of the measurements into models of the internal structure of Jupiter and Saturn have led William B. Hubbard, Jr., of the University of Arizona and V. Zharkov and V. Trubitsyn of the Institute of the Physics of the Earth in Moscow to a further conclusion. Both Jupiter and Saturn have a dense core that cannot consist of compressed hydrogen and helium. The pressure inside each planet is simply not great enough to produce the required central densities from a mixture of those two elements. Apparently Jupiter has a core of rock and ice that constitutes about 4 percent of its mass, and Saturn has a similar core that constitutes about 25 percent of its mass. Each core may be the "seed" on which the rest of the planet condensed from gases when the solar system formed. Or perhaps the cores formed later as the result of a redistribution of matter inside the planets.

Knowledge of the internal structure of Jupiter and Saturn also comes from the quantum-mechanical description of how atoms and molecules behave as they are compressed. According to the exclusion principle of modern physics, the electrons bound to protons in a compressed assemblage of hydrogen molecules can occupy the same shrinking volume only by climbing to higher levels of energy. At a certain compression (and thus a certain amount of energy) they are no longer bound to individual protons but become free to wander in an electrically neutral mixture of protons and electrons. The hydrogen then becomes a metal. Calculations made by Edwin E. Salpeter of Cornell University and David J. Stevenson, who is now at the California Institute of Technology, show that the transition from molecular hydrogen to metallic hydrogen comes at nearly the same critical pressure (three million earth atmospheres) on both Jupiter and Saturn. Since Jupiter is more massive than Saturn, the critical pressure is attained closer to the surface. On Jupiter the distance from the center of the planet to the metallic-molecular transition is in the range of .75 to .80 times the distance from the center to the surface. On Saturn it is .45 to .50.



TRANSFER OF MOMENTUM from eddy currents to sustained eastward and westward winds was documented for the earth by Victor P. Starr and his colleagues at the Massachusetts Institute of Technology; the Voyager images suggest that similar transfers feed momentum into the east-west winds on Jupiter and Saturn. In the illustration eddies on a model planet are shown to feed eastward momentum toward the north and westward momentum toward the south. This augments the velocity difference between the planet's mean east-west currents.

Sources of Internal Heat

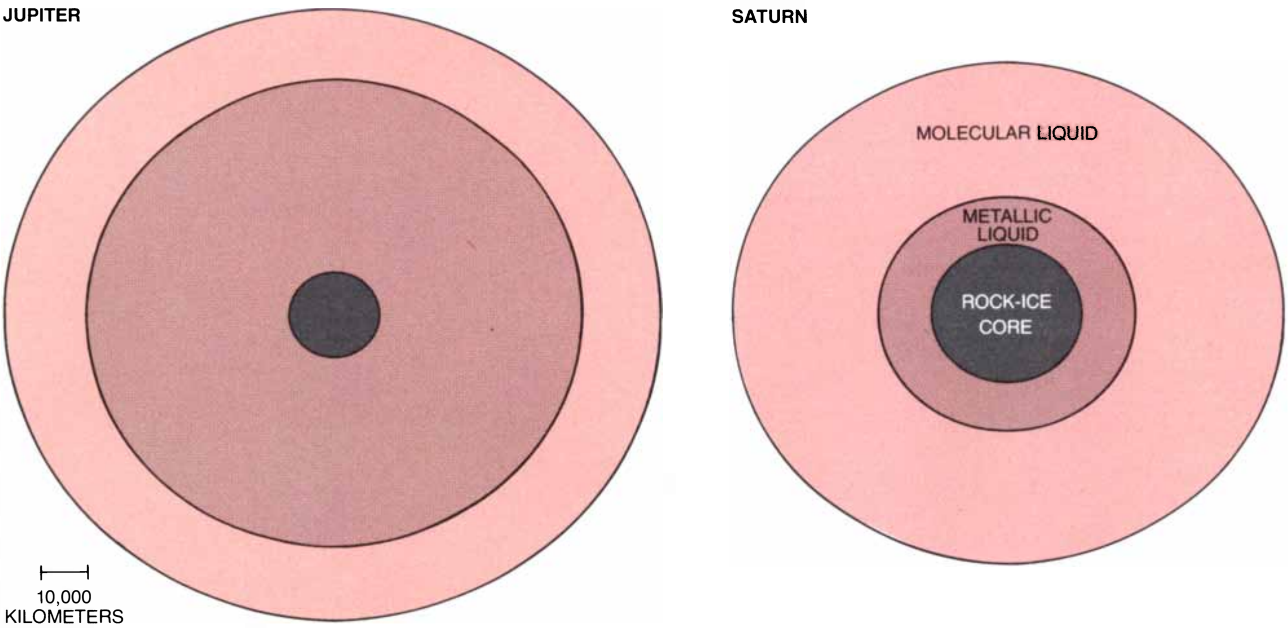
Measurements made by instruments on the Voyager spacecraft, and also the Pioneer spacecraft that reached Jupiter as early as 1973, imply that the power Jupiter gives off (as infrared radiation) is 1.5 to 2.0 times the amount it absorbs (as sunlight). The power Saturn gives off is 2.0 to 3.0 times the amount it absorbs. Hence both Jupiter and Saturn have internal sources of heat. Yet neither planet is massive enough for gravitational self-compression to have initiated nuclear fusion. In short, neither planet is a star. Instead their internal heat must represent the conversion of the gravitational potential energy that became available as each planet contracted from a cloud of gas beginning some 4.6 billion years ago. James B. Pollack and his colleagues at the Ames Research Center of the National Aeronautics and Space Administration have developed models of the history of the giant planets and conclude that the interior of Jupiter and Saturn is still hot today.

How hot? The answer follows from the thermodynamic law that heat flows from warmer places to colder. Specifically, a mixture of hydrogen and helium in Jupiter or Saturn (even a metallic mixture) cannot conduct heat away from the center of the planet unless the rate of temperature decrease with distance from the center is significant. The rate of decrease is limited, however, by convection: the overturning of a fluid in which warm parcels of the fluid rise and cooler parcels sink.

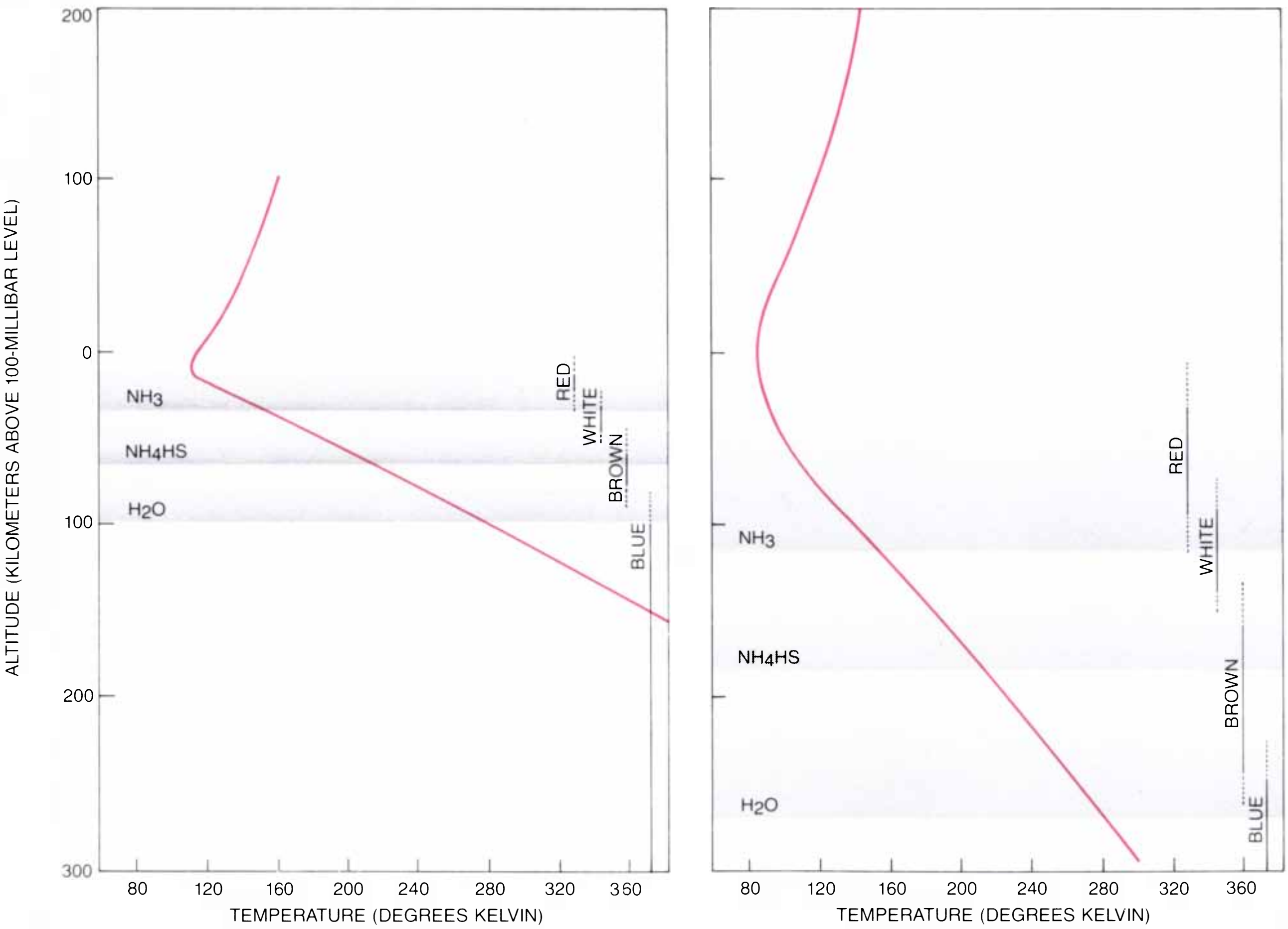
Briefly, convection mixes a fluid until its temperature decrease with altitude matches the adiabatic lapse rate: the rate at which a rising fluid parcel will cool when no heat is exchanged with its surroundings. Instead of losing energy by heat flow the parcel loses energy by pushing on its surroundings as it expands. On this basis it can be shown that the temperature gradient in Jupiter and Saturn's interior is close to adiabatic and that the central temperatures are in a range of 20,000 to 30,000 degrees Kelvin. At such temperatures a mixture of hydrogen and helium does not solidify. Thus the metallic hydrogen inside Jupiter and Saturn is liquid. At an intermediate level, where the pressure is three million earth atmospheres, the metallic liquid abruptly gives way to a molecular liquid. At still higher levels the molecular liquid gradually gives way to a molecular gas: the atmosphere of Jupiter and Saturn.

Models of the cooling of Jupiter over

© 1981 SCIENTIFIC AMERICAN, INC

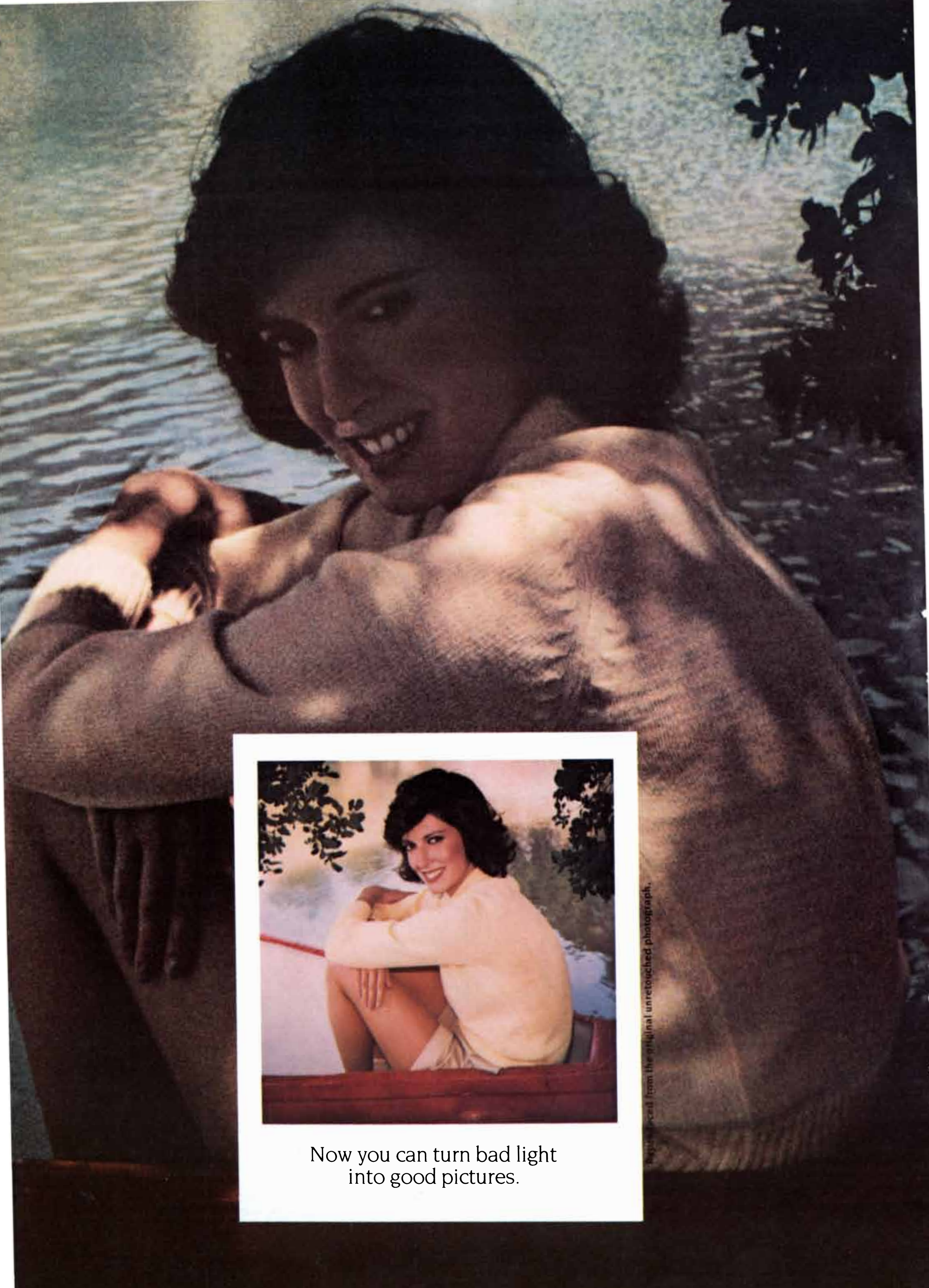


INTERIOR of Jupiter (*left*) and Saturn (*right*) consists of three layers. The outermost layer is a liquid mixture of hydrogen and helium; the hydrogen is molecular. The innermost layer is a core of rock and ice. In the middle layer a pressure in excess of three million earth atmospheres transforms the hydrogen into a liquid mixture of protons and wandering electrons. Thus the hydrogen in the middle layer is a metal. The rotation of each planet makes it somewhat flattened toward the poles. The degree of flattening is greater on Saturn.



ATMOSPHERE of Jupiter (*left*) and Saturn (*right*) is assumed to have proportions of the various chemical elements much like the proportions in the sun; on that basis each atmosphere can be assumed to include stratified clouds of ammonia (NH_3), ammonium hydrosulfide (NH_4HS) and water. These compounds all form white particles; hence the colors in each atmosphere must have other causes, which have yet to be identified. In the charts each color is assigned a range of altitudes in accord with measurements of cloud-top temperatures. Red clouds, for example, are the coldest and therefore the highest. The cloud tops on each planet lie no higher than the level at which the temperature (*colored curves*) begins to increase with altitude, so that convection currents no longer carry solid (or liquid) particles upward.

© 1981 SCIENTIFIC AMERICAN, INC



© 1981 SCIENTIFIC AMERICAN, INC

The Polaroid Sun Camera. A Revolutionary New Camera and Film System.

The light you use on every shot.

We've put a piece of the sun into this amazing new system to make beautiful pictures possible in any kind of light. Look at the way it brought this beautiful girl out of the shadows.

Indoors and out, the Sun Camera adds proportional "fill" lighting wherever it's needed—extra electronic "sunshine" that fills the shadows and yet mixes with natural light to avoid a harsh flash look.

And it's all automatic. All lighting and exposure decisions are made by electronic "logic" circuits when you press the button to shoot.

The invention behind the invention: The fastest color print film made—600 ASA!

The Sun Camera came from our invention of a new highly light-sensitive color film. It records detail in far less light than ordinary color film and permits use of a very small aperture to give your pictures far more detail throughout.

Colors are deep, brilliant and the pictures very sharp—and virtually developed in 90 seconds.

Revolutionary new use for sonar.

In our Autofocus Model 660, focus is set automatically by our sonar ranging invention. Controlled by sonar, an ingenious rotating disc of four interchanging lenses locks in place to put you in precise focus from 2 feet to infinity.

And the Sonar Autofocus system has also been coupled to the electronic circuitry to balance the Sun Camera's light with the ambient light. You've never been so sure of an instant picture.

Super power for the Sun Camera.

We've also made a new super battery with far more capacity than our previous batteries. Built into our film packs, it's the only battery this camera needs, running everything from motor to "sunshine." And it recharges the "sunshine" in as little as 5 seconds after each shot.

How the system can save you money.

Film savings should be substantial, since you no longer worry about wasting shots in bad light. And you never buy flash or extra batteries. The "sunshine" is built into the camera, and you get a new battery in every pack of film.

The Sun Camera is light, motor-driven and easy to use. Just press the button and the picture's developing in your hand. Our Autofocus Model 660 is $95.* And our fixed-focus Model 640 gives you Sun Camera technology for $70.* If you have any questions, call us any weekday, 9a.m. to 5p.m., toll free at 800-343-5000. In Massachusetts call collect 617-494-8266.

© 1981 Polaroid Corporation. "Polaroid"®, "Sun"™
*Suggested retail price. Initial quantities limited.

© 1981 SCIENTIFIC AMERICAN, INC

the history of the solar system account for all the power that Jupiter is radiating today in excess of the amount it absorbs. Similar models fail, however, to account for about a third of the excess that Saturn radiates. Apparently Saturn has a source of internal heat not included in the calculations, a source Jupiter lacks. In the mid-1970's Salpeter and Stevenson proposed an explanation that is now supported by the Voyager data. A planet incorporating a mixture of hydrogen and helium has two types of energy: thermal and gravitational. If the mixing ratio (that is, the ratio of hydrogen to helium) is constant throughout the mixture, the two types of energy are released together in constant proportions. As the planet cools it contracts. If, however, the mixing ratio changes (for example, if the helium falls through the hydrogen), an additional quantity of gravitational energy is released. Such a process is likely on Saturn because the planet has already cooled to the extent that helium is precipitating at the top of the metallic hydrogen zone.

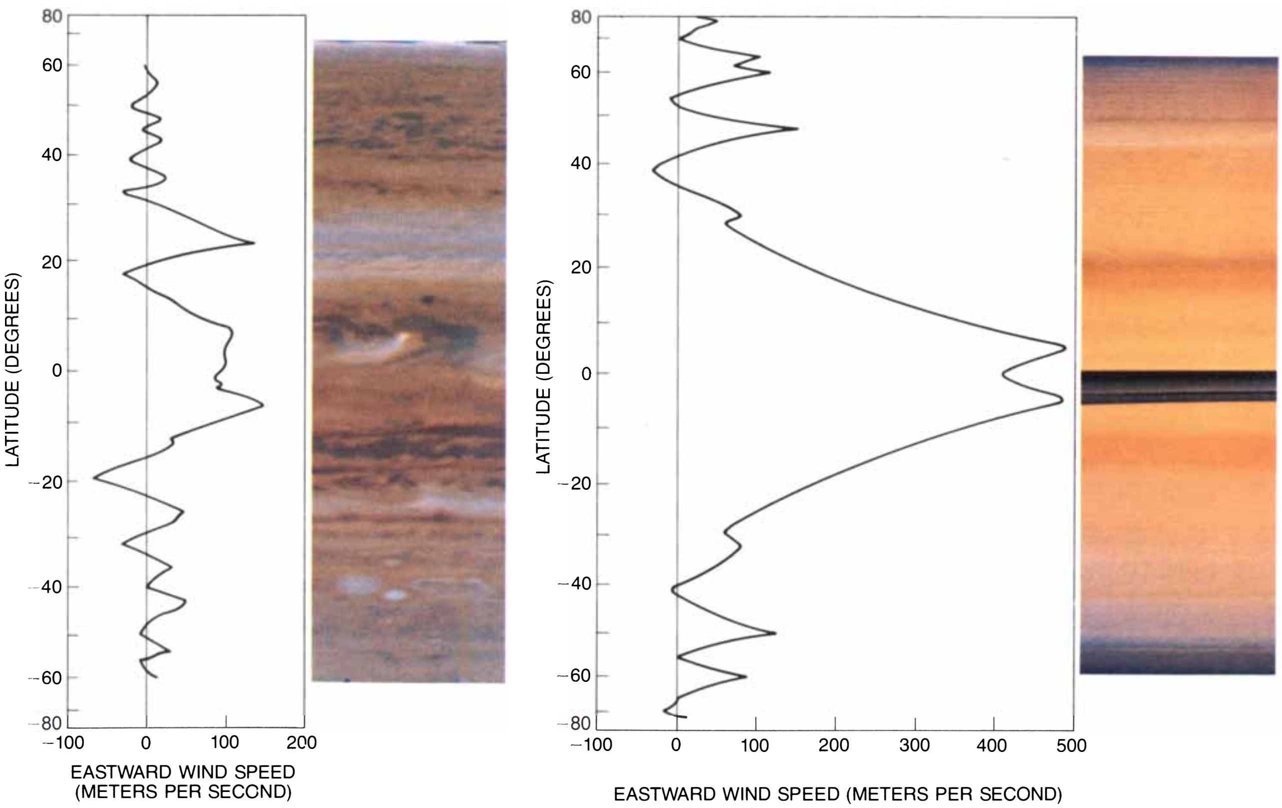
According to Salpeter and Stevenson, the process is much like ordinary rainfall. When a parcel of the earth's atmosphere is cooled below its saturation point, water condenses and raindrops fall. The condensation releases the heat that had been added to the water to make it a vapor, and the rate of atmospheric cooling slows. On Saturn the raindrops are helium, and energy is released as the raindrops rub against the hydrogen fluid through which they fall. The process began on Saturn some two billion years ago. Jupiter, being more massive, has not yet cooled to a point where the planet at any level is saturated with helium. Perhaps it is just now reaching that point.

Evidence in support of the hypothesis that helium rain releases energy on Saturn has come from measurements of the atmospheric helium abundance. It is not an easy measurement to make. Helium does not absorb radiation in the infrared, and so the spectrum of the radiation emitted by Jupiter and Saturn does not reveal helium directly. The presence of helium does, however, affect the absorption of infrared radiation by hydrogen. By this means a group led by Rudolph A. Hanel of the Goddard Space Flight Center of NASA and Daniel Gautier of the University of Paris has determined the relative numbers of helium atoms and hydrogen molecules from measurements made by the Voyager spacecraft.

Above the zone of metallic hydrogen Jupiter turns out to be 10 percent helium, a value not significantly different from the 11 percent of helium in the sun. Saturn turns out to be less than 6 percent helium. If the missing helium has rained downward from the molecular zone to deep in the metallic zone, the heat that would have been released could indeed have maintained Saturn's internal heat source at its present value for the past two billion years. Thus the various inferences about the bulk composition, the internal structure and the history of the cooling of the giant planets all seem to hold together.

Atmospheric Chemistry

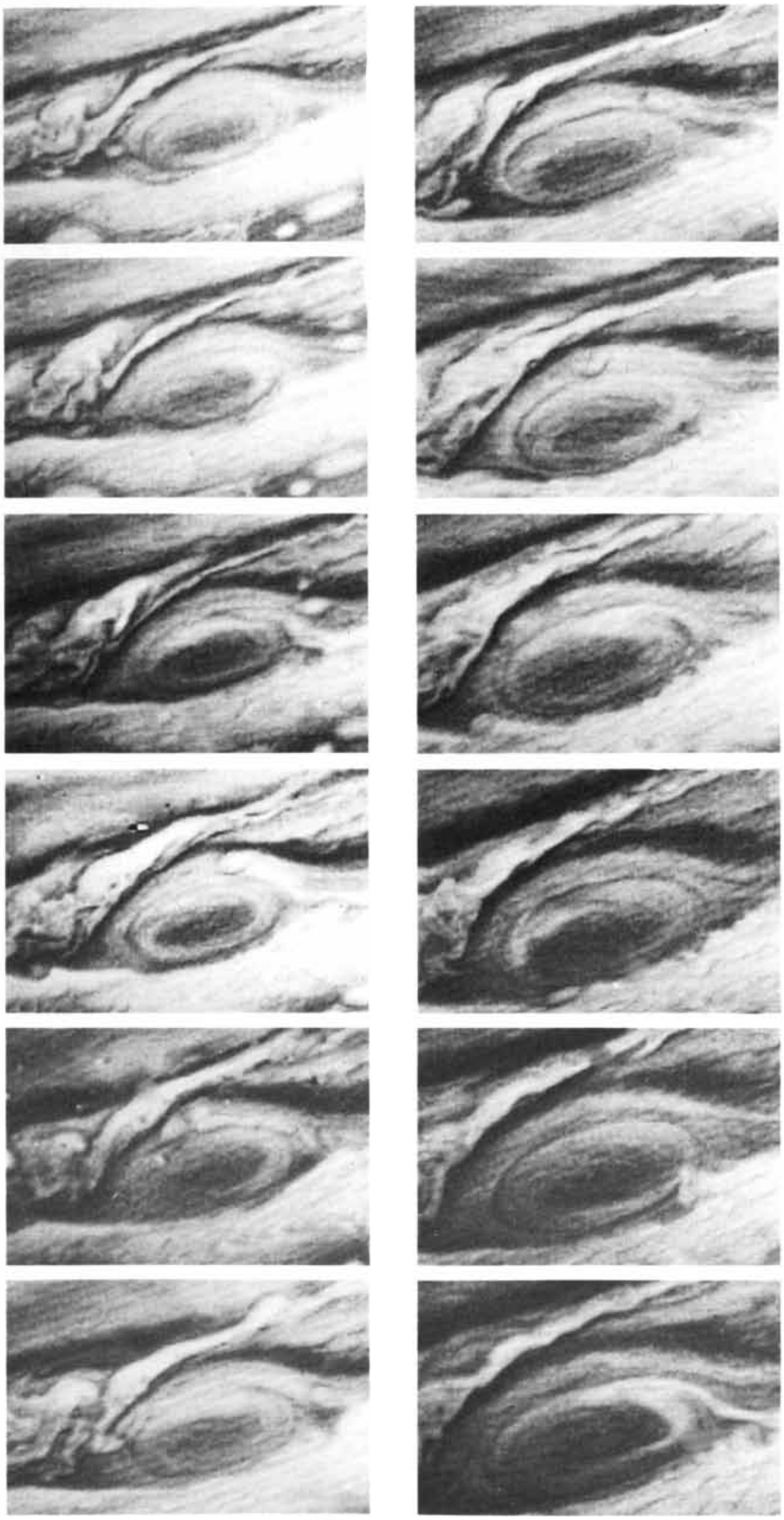
As early as the 1930's investigators were identifying lines in the spectrum of sunlight reflected from Jupiter due to the absorption of light by gaseous methane and ammonia. The hydrogen molecule has only weak absorption lines; hence its presence was confirmed only some 30 years later even though its abundance was then inferred to be 1,000 times greater than that of methane and ammonia. The calculated abundances of hydrogen, carbon and nitrogen in the atmosphere of Jupiter and Saturn support the hypothesis that the giant planets



MEAN WIND SPEEDS on Jupiter (*left*) and Saturn (*right*) are compared with images of each planet. Positive numbers are eastward velocities; negative numbers are westward ones. The numbers are wind speeds with respect to the speed of the planet's rotation; they were measured by tracking the motion of cloud features in successive images of each planet made by *Voyager 2*. It emerges from the measurements that each hemisphere of Jupiter has several alternations of eastward and westward currents. Saturn's pattern is simpler but the currents are stronger; in the atmosphere of Saturn 500 meters per second is two-thirds the speed of sound. Eighty years of observations from the earth and recent observations from spacecraft suggest that the cloud colorations at any latitude are changeable but that the winds are much more persistent. The dark band across the equator of Saturn is the ring system of the planet and its shadow on the surface.

© 1981 SCIENTIFIC AMERICAN, INC

© 1981 SCIENTIFIC AMERICAN, INC



GREAT RED SPOT of Jupiter is shown in a sequence of images made by *Voyager 1* every fourth rotation of the planet, or about once every 40 hours. The spot itself has been observed for three centuries from the earth. It rolls counterclockwise between a westward current to its north and an eastward current to its south. It is some 25,000 kilometers long. In the Voyager sequence structure on a scale of 1,000 kilometers is revealed. Small clouds approach the spot from the east. They circle the spot in six to 10 days. They are partially swallowed. Smaller spots return to the east. In addition to the Great Red Spot, Jupiter has several white ovals.

are composed of material much like that which condensed to form the sun.

Other gases, however, should also be detected in a mixture of solar composition. Notable among them are water vapor and hydrogen sulfide (H_2S). In the 1970's spectral lines due to the absorption of infrared radiation by water vapor on Jupiter were detected by Harold P. Larson and Uwe Fink of the University of Arizona. Such lines have not been detected on Saturn. Moreover, hydrogen sulfide has escaped detection on both Jupiter and Saturn. Still, both water vapor and hydrogen sulfide gas must have a rather low concentration at the top of the clouds on Jupiter and Saturn, where the temperature is 150 degrees K. (-123 degrees Celsius) or less. Ultimately the vapors may turn out to be present in solar abundances at levels below the clouds.

The infrared spectra of Jupiter's hot spots (holes in the clouds) reveal a rich chemical mixture. In addition to water vapor, phosphine (PH_3), germane (GeH_4), hydrogen cyanide (HCN) and carbon monoxide (CO) have all been detected, and so has heavy methane, that is, methane molecules incorporating the heavy isotope of either hydrogen (hydrogen 2, called deuterium) or carbon (carbon 13). Moreover, ethane (C_2H_6) and acetylene (C_2H_2) have been detected all over the disk of Jupiter and on Saturn as well. Most of these compounds would not be present in an atmosphere rich in hydrogen if the atmosphere were in chemical equilibrium. For example, the various carbon compounds would revert to methane, and the nitrogen would form ammonia.

The obvious source of the chemical disequilibrium is the sun. Specifically, the sun's ultraviolet radiation can break down the dominant chemical species such as methane and liberate free radicals such as CH_2 and CH_3. Lightning in the clouds of Jupiter and Saturn and the impact of electrically charged particles can have the same effect. (The charged particles rain down into the atmosphere from the magnetosphere, the zone above the planet where they are confined by the planet's magnetic field.) The radicals can react with methane molecules to form ethane and acetylene and liberate hydrogen. The composition of the atmosphere of Jupiter therefore reflects a balance between the production and the breakdown of these higher hydrocarbons.

The presence of carbon monoxide in Jupiter's hot spots is more problematic, since water, the potential source of oxygen, is scarce above the clouds, where ultraviolet photons (quanta of ultraviolet radiation) are plentiful. On the other hand, water may be abundant below the clouds, and there it may combine with methane to form carbon monoxide. The conditions of temperature and pressure well below the clouds favor such a reac-

© 1981 SCIENTIFIC AMERICAN, INC

Who moves more people than VW for less money? It's Ram Tough Dodge's new Mini Ram Wagon

Compare Dodge Mini Ram 250 to VW Vanagon—passenger seating, gasoline mileage, fuel capacity and range, horsepower and rear loading area. Mini Ram gives you more.

Then compare standard features like power steering and factory-installed options like air conditioning and your choice of 6 sound systems: all available in Mini Ram. Not in Vanagon

Now compare price. Mini Ram costs $1,995 less than Vanagon For panel-side van buyers, there's a Dodge Van with the same performance, efficiency and interior dimensions as Mini Ram Wagon at a price VW hasn't seen in years—just $6,928*

Here's how Mini Ram beats Vanagon

	Dodge Mini Ram Wagon 250	VW Vanagon
Sticker Price (MSRP)	**$9,365.00***	**$11,360.00***
EPA EST. MPG	19 MPG**	17 MPG**
Horsepower	95	67
Passenger Seating	8	7
Overall Length	178 9"	179 9"
Wheelbase	109 6"	95.8"
Fuel Capacity	36 gal	15 9 gal
EPA Est Range	684 miles**	270 miles**
Side Door Width	49"	42"
Removable Rear Seat	Yes	No
Power Steering	Standard	Not Available
Color-Keyed Carpeting	Standard	$410 with int pkg
Factory-Installed Air Conditioning	Option	Not Available

Underneath it all, Mini Ram is a Ram Tough Dodge Wagon. With the best rust protection of all wagons. There's 100% electrocoating, plus 370 sq. ft. of galvanized steel in critical areas . . . compared to VW's 4 sq. ft.

New Dodge Mini Ram Wagon It does more than VW Vanagon and it does it for less. As a pure people mover, it just might be the best buy on the road today.

Now get $300 to $1000 cash.† *Depending on the model you buy or lease, get a Chrysler savings certificate for $300 to $1000 on new '81 and '82 Dodge trucks. See your participating dealer for full details*

Dodge Trucks

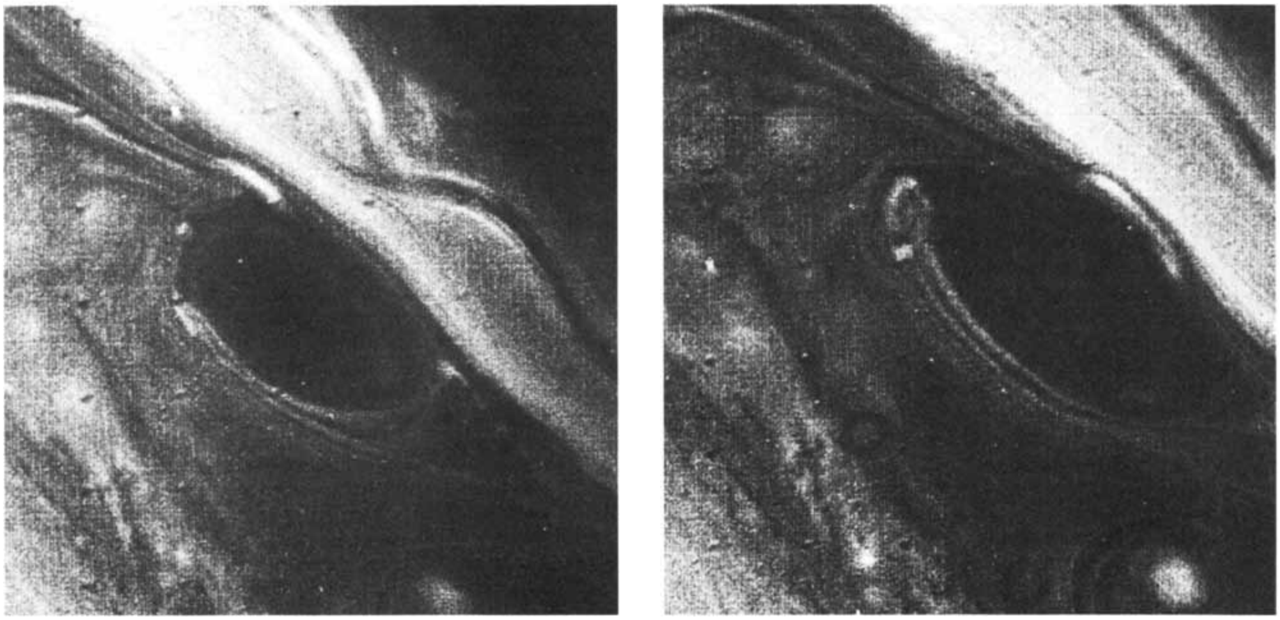
DODGE TRUCKS ARE RAM TOUGH

**Sticker price comparison, excluding title, taxes and destination charges, unadjusted for different levels of standard equipment Whitewall tires $85 extra. Prices and specifications as of October 15, 1981*

***Use these numbers for comparison. Your mileage and range may differ depending on speed, distance and weather. Calif est lower*

†Savings program differs in Texas

© 1981 SCIENTIFIC AMERICAN, INC



LONG-LIVED SPOT ON SATURN is a brown oval in the northern hemisphere that was photographed on August 23 (*left*) and one rotation of the planet (10 hours) later (*right*) by *Voyager 2*. It is a fourth the size of the Great Red Spot. Its rotation is clockwise.

tion. Another possibility is that the oxygen above the cloud tops comes not from Jupiter but from sulfur dioxide ejected from the volcanoes of Jupiter's satellite Io, whose activity was revealed in images made by *Voyager 1*.

The solid and liquid particles that constitute the clouds of Jupiter and Saturn give further evidence of chemical disequilibrium. The most abundant condensable vapors in a mixture of solar composition are water, ammonia and hydrogen sulfide. At chemical equilibrium they form crystals of water ice, of ammonia and of ammonium hydrosulfide (NH_4HS). Liquid drops of water and of ammonia-water solutions are also conceivable, as John S. Lewis and his colleagues at the Massachusetts Institute of Technology have noted. The problem is that all these condensates are white, whereas the clouds of Jupiter and Saturn are colored.

Ronald G. Prinn of M.I.T. has suggested some possible coloring agents. For one thing, molecular sulfur (S_n, where n can take several values greater than 1) forms brown and yellow particles. It therefore becomes all the more vexing that hydrogen sulfide, the parent molecule of the elemental sulfur, has not yet been detected. The challenge for theorists championing sulfur as a coloring agent is to hide the hydrogen sulfide in the clouds from spectroscopic view but still expose enough of it to solar photons so that S_n can form. Prinn notes that elemental phosphorus has a red color resembling that of the Great Red Spot, and it could be formed when ultraviolet photons strike molecules of phosphine gas. Given the affinity of carbon atoms for one another, complex organic compounds are also a possible source of color. Unfortunately the spectroscopic identification of compounds in the solid state is difficult because the pattern of vibrations (and the associated absorption of certain wavelengths of light) by the molecules in a solid is blurred by the collisions between neighboring molecules. Hence the sources of color on Jupiter and Saturn remain uncertain.

It can be said, however, that clouds of differing color on Jupiter and Saturn are associated with different levels in the atmosphere. A comparison of images made in visible light and in infrared radiation reveals this correlation. The visible images show the colors; the infrared images distinguish cool (and therefore high) clouds from warm (and therefore low) ones. On Jupiter the highest cloud tops are red; the next-highest are white, the ones lower than that are brown and the lowest ones (or perhaps the atmosphere below the clouds) are blue. Presumably the various compounds responsible for these colors form at different levels in response to different temperatures and amounts of sunlight. The white particles that form the major constituents of the clouds should also be layered. Ammonia should be uppermost, then ammonium hydrosulfide and finally water.

Atmospheric Circulation

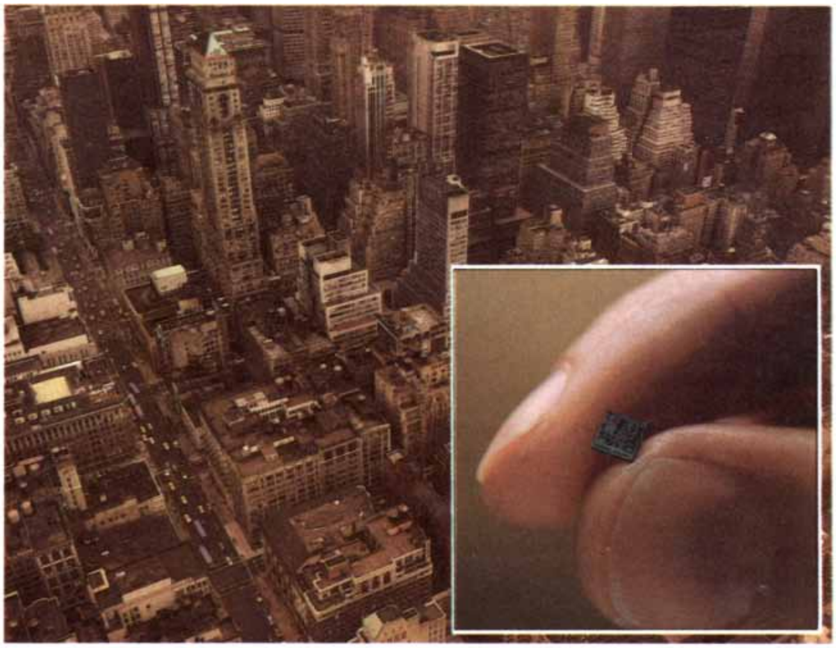
In the atmosphere of the earth horizontal gradients of temperature are the reservoir from which the winds get their energy. The gradients arise because the sun heats the Tropics more than the poles; then the warm tropical air slides over the colder polar air. This converts gravitational potential energy into kinetic energy and also transports heat upward and poleward.

On Jupiter and Saturn horizontal temperature gradients may be less important than they are on the earth. First of all, the gradient of temperature from the equator to the pole is small on Jupiter and Saturn, at least at the cloud-top levels where the Pioneer and Voyager spacecraft could measure it. On Jupiter, for example, the difference in temperature between the equator and the pole is less than three degrees C. On the earth the difference is 10 times greater, and it is compressed into a distance from the Equator to the pole that is 10 times smaller.

In the second place the atmosphere of Jupiter and Saturn gets half or more of its heat from the interior of the planet. In that regard Jupiter and Saturn resemble stars more than they resemble the earth. According to theories of convection employed in stellar models, an internal heat source should produce an adiabatic temperature gradient that is the same along any radius from the center of the planet to a point on its surface. Moreover, since the part of the atmosphere of Jupiter or Saturn receiving sunlight has only a millionth the mass (and therefore a millionth the heat-carrying capacity) of the planet's interior, one can expect the atmosphere to be in essence short-circuited by the interior. It is as if all points on the surface of the planet were wired to the center by strong conductors, and weak conductors connected points on the surface to each oth-

© 1981 SCIENTIFIC AMERICAN, INC

DESIGN AUTOMATION HELPS US CREATE VERY LARGE SCALE INTEGRATED CIRCUITS AS DENSELY POPULATED AS MANHATTAN.



WITHOUT DESIGN AUTOMATION, DESIGNING A VLSI CHIP WOULD BE AS DIFFICULT AS CREATING A WORKING MODEL OF A MAJOR METROPOLITAN AREA IN THE SPACE OF A POSTAGE STAMP.

At Honeywell, we use computers to design integrated circuit chips for computers. In fact, design automation has played a key role in the development of Honeywell computers, from the smallest to the largest. But our research in very large scale integrated circuits has presented some new challenges to our design automation capabilities.

Our design automation system is one of the tools we're using to populate a CMOS chip with close to a million features which form 300,000 transistors. Design automation is also helping us develop a bipolar microcircuit with 1.25 micron feature size and 30,000 gates for Phase 1 of the Department of Defense's VHSIC program.

But in order to develop VHSIC chips with sub-micron feature size, our researchers will need the support of even more sophisticated design automation tools. So, we're in the process of building an Advanced Integrated Design Automation (AIDA) system to answer those needs.

By late 1984, AIDA will give Honeywell engineers access to a total electronics design and documentation system that will free them to create complex circuits with immense functionality at a relatively low cost per function.

We're working on a symbolic layout module that will allow designers to place and interconnect transistors and small logic functions in symbolic representation, without concern for physical design rules.

Computer simulation will let Honeywell designers analyze dense chip design in the future without the astronomical investment of time and money that breadboard simulation would require.

And the module we're developing for synthesis at the logic block and logic gate level is expected to dramatically reduce the time and cost of designing both chips and systems.

Automatic test generation is another one of the capabilities we're developing for the AIDA system. The challenge is devising a module that will automatically generate tests, not only at the chip level, but at the printed circuit board and systems level as well.

Soon our Advanced Integrated Design Automation system will be used throughout Honeywell to support electronic design. The development of this capability is vital to the continued advancement of control and computer technologies and the creation of the new products on which our future depends.

If you have a degree and experience in solid state electronics, mathematics, integrated circuit design, design automation development, or computer sciences, opportunities exist in Minneapolis, Boston, Phoenix, and Santa Clara.

For more information on this challenging assignment, write to Dr. Eugene E. Yore, Corporate Director, Design Automation, Honeywell Plaza, Minneapolis, MN 55408.

Honeywell

The research environment at Honeywell is further enhanced by our affiliations with universities across the country. We have an ongoing program of seminars with Berkeley, MIT, Stanford, Carnegie Mellon, the University of Illinois, Cornell, Purdue, Oregon Graduate Center, and the University of Minnesota.

© 1981 SCIENTIFIC AMERICAN, INC

REPLAY IT ON SCOTCH® VIDEO TAPE. THE NETWORKS DO.

If the networks don't tape that big game, the game that will live forever is gone forever.

The networks tape for delayed broadcast just like you. They know that no other brand outshines Scotch® video tape in the brilliance and clarity of its picture. And that no other video tape shows the true colors of a colorful athletic event better. That's why all three major networks use Scotch video tape.

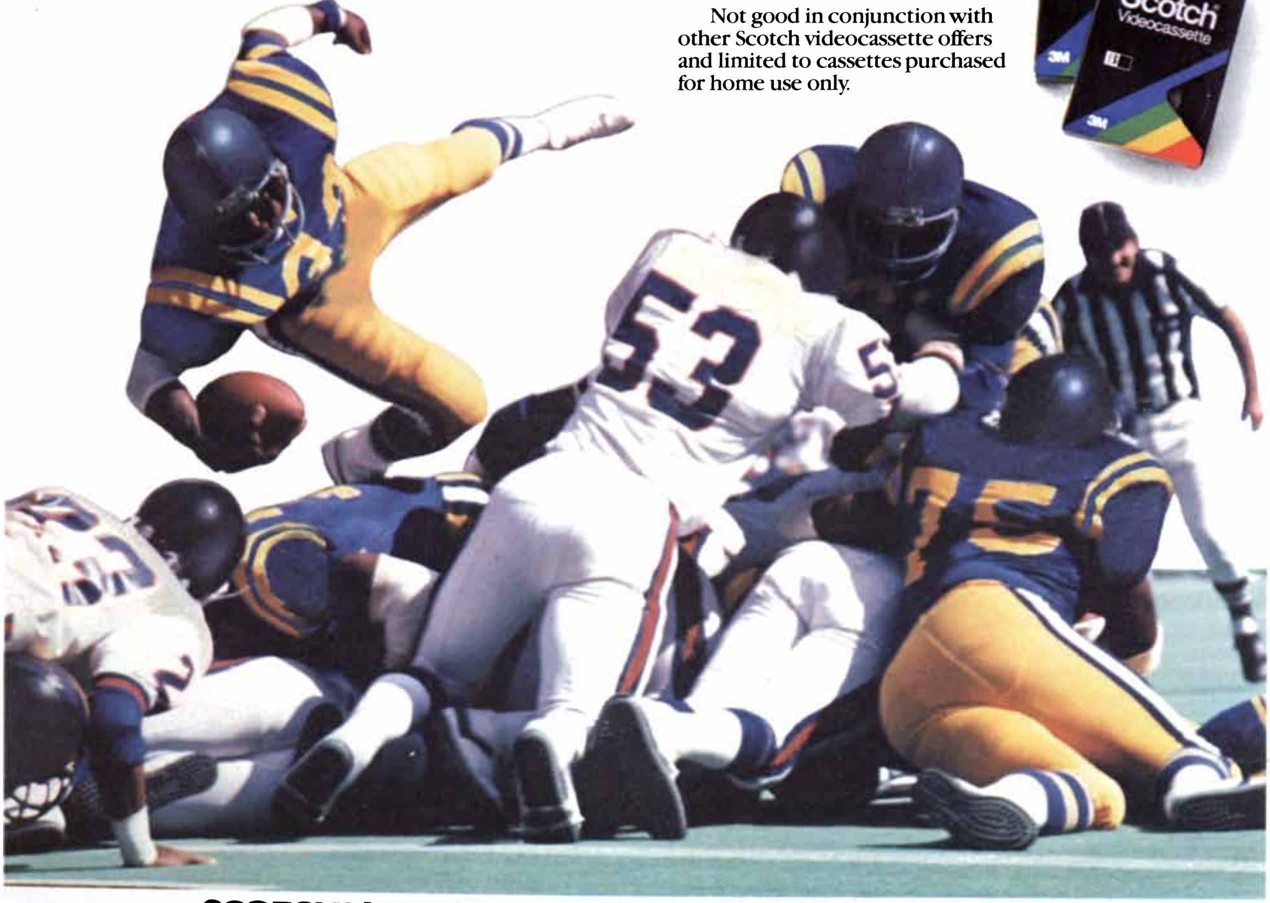
That's why you should use Scotch Videocassettes for your permanent replays at home. Scotch Videocassettes are engineered to give you all the color and clarity your VCR can deliver.

So when you record at home, do as the networks do. Get Scotch Videocassettes.

$2.00 REBATE OFFER.

Good on Scotch T-120 and L-500 videocassettes purchased from September 28, 1981, thru January 9, 1982. Limit of ten per household. Details at participating dealers.

Not good in conjunction with other Scotch videocassette offers and limited to cassettes purchased for home use only.



SCOTCH® VIDEOCASSETTES. THE TRUTH COMES OUT.

3M

© 1981 SCIENTIFIC AMERICAN, INC

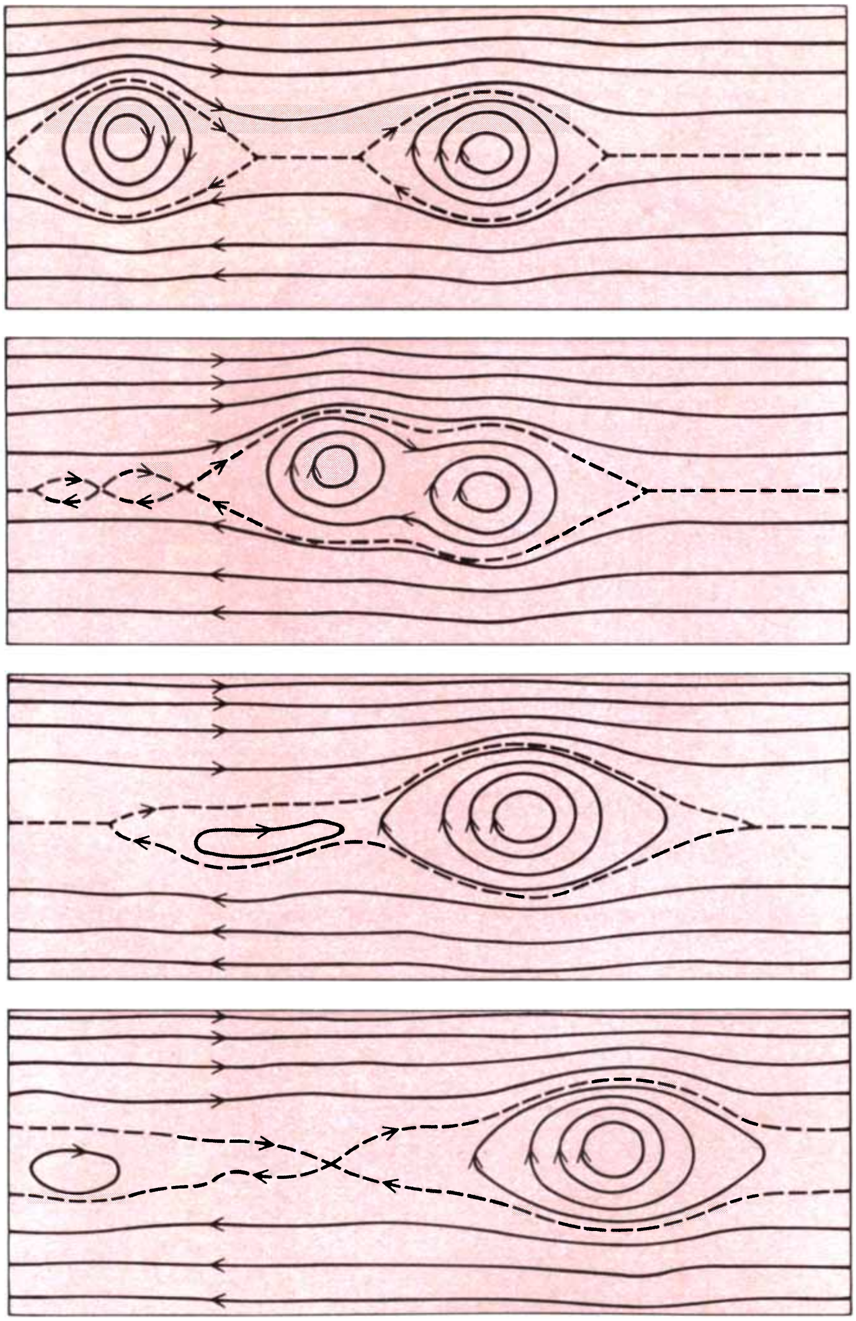
er. On this reasoning horizontal temperature gradients should be small.

Still, more sunlight is deposited at the surface of Jupiter and Saturn than at the poles, and measurements made by the Pioneer and Voyager spacecraft show that the rate of infrared emission is roughly independent of latitude and is greater than the rate of absorption of sunlight at all latitudes. Heat is therefore transported poleward. The argument that the interior of each planet is in effect a strong conductor implies that the entire fluid interior of each planet is involved in the poleward transport. A computer model that I and Carolyn Porco have devised at Cal Tech suggests how the transport is maintained. In response to the uneven distribution of sunlight at the surface of the planet small differences in temperature develop in the interior. The differences modulate the rate at which internal heat arrives from below. According to the model, the poleward decrease in the solar heating of the thin sunlit layer is offset by a poleward increase in the upwelling of internal heat. Poleward heat transport in the thin sunlit layer is negligible.

A model based on entirely different assumptions has been published by Gareth P. Williams of the Geophysical Fluid Dynamics Laboratory of the National Oceanic and Atmospheric Administration at Princeton University. Williams began with a mathematical formalism employed in predicting the weather on the earth. The mathematics describes the motions that arise in a fluid atmosphere much thinner than the planet's radius in accord with physical laws such as the conservation of momentum and energy. Williams scaled the radius and the rotation rate of the model planet so that they would characterize Jupiter or Saturn, and he reduced what are called the dissipation parameters, which represent the rate at which an atmosphere loses heat and momentum because of forces such as friction. The reduction of the parameters can be justified on the ground that Jupiter and Saturn have no solid surfaces that winds can rub against. Moreover, a deep, cold atmosphere loses heat extremely slowly, as Peter J. Gierasch, now at Cornell, and Richard Goody of Harvard University pointed out 15 years ago.

Williams also assumed that the atmosphere below the level to which sunlight penetrates on Jupiter or Saturn has negligible effects on the circulation above. In other words, the upwelling of heat from the interior was neglected or assumed to be independent of latitude. In addition the lower boundary of the sunlit layer was assumed to act like a solid surface in that it is undeformable and impermeable. This assumption would be justified if the density of the sunlit layer were substantially less than that of the layer below it. Such a decrease is found between the warm water at the surface of the earth's oceans and the cooler water below it. The decrease is less likely to be found, however, in a fluid that is convecting heat upward from below.

In short, Williams' model of the atmosphere of Jupiter or Saturn resembles in many ways a model of the atmosphere of the earth. Yet his model proves able to generate the most notable feature of the meteorology of Jupiter or Saturn: an alternating pattern of east and west winds. Indeed, the model entails a prediction of how the winds are maintained. In the atmosphere of the earth the sustained low-latitude winds blow to the west and the sustained middle-latitude winds blow to the east. Both are maintained by large-scale eddies that transport eastward momentum away from the equatorial latitudes. The eddies include the cyclones and anticyclones that give rise to much of the



MERGING OF SPOTS on Jupiter and Saturn was simulated with a computer by the author and Pham Giem Cuong at the California Institute of Technology. They propose that each spot is a more or less permanent vortex above an underlying pattern of east-west flow. On their hypothesis the small transient spots on Jupiter and Saturn are buoyant; thus the small spots store gravitational potential energy. The large spots are maintained by swallowing the small ones. The broken lines mark boundaries between each vortex and the atmosphere's laminar flow.

© 1981 SCIENTIFIC AMERICAN, INC

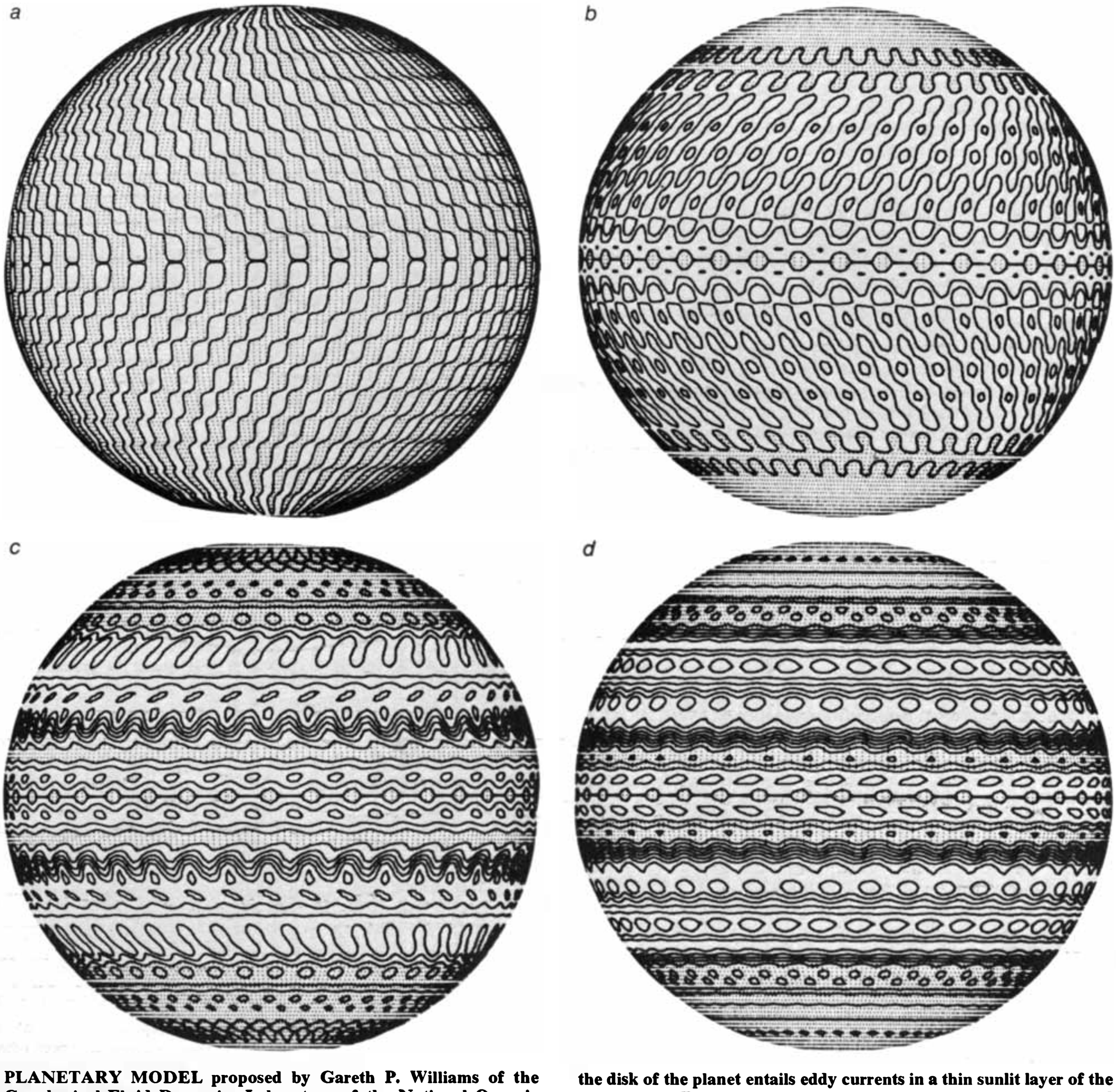
earth's weather. On Jupiter and Saturn the bands of alternating winds are more numerous. Nevertheless, in Williams' model it is eddies that put energy into the east-west winds. Furthermore, the energy driving the eddies on Jupiter, Saturn and the earth comes ultimately (Williams proposes) from the same source: the temperature gradient from the equator to the poles that is maintained by solar heating.

Voyager Measurements

The best measurements of the winds on Jupiter and Saturn come from tracking the position of cloud features in successive images made by the Voyager spacecraft. The investigators responsible for making these measurements included Reta Beebe, Garry E. Hunt, Jim L. Mitchell and me. For Jupiter our first goal was to define the mean wind velocity at each degree of latitude by averaging the velocities of all the features we could identify at that latitude. At most latitudes 50 to 100 high-contrast features could be tracked. Saturn has fewer such features and so fewer measurements could be made.

One remarkable result was the agreement between the measurements based on the Voyager images of Jupiter and the measurements based on some 80 years of observations from the earth. The changes over the 80 years seem to have been mostly in the coloration of the clouds at given latitudes. At times the east-west winds were unobservable from the earth, but apparently they did not change.

A second result has to do with how the winds deviate from their mean velocity at a given latitude. On Jupiter the mean eastward velocities are no greater than 130 meters per second. The deviations from this mean, which correspond to eddies, are typically 20 meters per second. The deviations have a systematic tilt. For example, at places where the mean eastward velocity increases with lati-



PLANETARY MODEL proposed by Gareth P. Williams of the Geophysical Fluid Dynamics Laboratory of the National Oceanic and Atmospheric Administration assumes that the processes shaping the weather on the earth also shape the weather on Jupiter and Saturn. Specifically the uneven distribution of solar radiation across the disk of the planet entails eddy currents in a thin sunlit layer of the atmosphere. The momentum of the eddies then fuels eastward and westward currents. Trains of spots arise in the model but isolated ovals do not. The illustration shows the state of Williams' computer simulation after 4.6 days (*a*), 23 days (*b*), 46 days (*c*) and 73.3 days (*d*).

© 1981 SCIENTIFIC AMERICAN, INC

THIS IS WHAT WE GET FOR NOT FOLLOWING THE CROWD.

A camera with a combination of features you won't find on any other 35mm SLR in its class.

A camera so extraordinary that in just a few short months it has become one of the best-selling in America.

More than a camera. An achievement. The Minolta XG-M.

What kinds of features make a camera this outstanding?

Optical precision for sharp, clear pictures.

Convenience features like automatic exposure to make taking pictures as easy as point, focus, shoot.

Important features like metered manual and exposure override that let you give full rein to your creative instincts.

Electronic features to help prevent mistakes.

Handling features like a built-in, textured grip shaped to fit the curve of your hand.

Even professional features like the optional motor drive that automatically advances the film. One frame at a time. Or at a blistering 3.5 frames per second to capture fast action. Like a touchdown pass rifling into the end zone.

And when you want to unleash your imagination, there are more than 45 Minolta computer-designed interchangeable lenses to help you do it. Along with a full system of accessories.

The Minolta XG-M is only the latest in our over 50-year tradition of creating cameras that are not simply cameras, but outstanding achievements.

See it at your Minolta dealer. To find the XG-M, just follow the crowd.

WAIT 'TIL YOU SEE HOW GOOD YOU CAN BE.

MINOLTA

For more information, write Minolta Corporation, 101 Williams Drive, Ramsey, N.J. 07446. In Canada: Minolta, Ontario, L4W 1A4.

Product appearance and/or specifications are subject to change without notice.

© 1981 Minolta Corporation.

© 1981 SCIENTIFIC AMERICAN, INC

tude, the vectors that represent the velocity (and therefore the momentum) of the deviations tend to be tilted toward the northeast. Hence they feed velocity and momentum northward into latitudes where the mean velocity and momentum are already greater. This is precisely the mechanism by which eddies sustain the mean winds on the earth, and it is also the mechanism that underlies Williams' model. Jupiter's seemingly chaotic eddies have more order than one might suspect.

There are nonetheless some important quantitative differences between Jupiter and the earth. On the one hand, the mean velocities of the winds and the velocities of the eddies are greater on Jupiter. Indeed, the rate at which kinetic energy is transferred from eddies to sustained east-west winds is 10 times greater on Jupiter than it is on the earth per unit area on the surface of the planet. On the other hand, the rate at which thermal energy is made available to the atmosphere of Jupiter for possible conversion into kinetic energy of winds is 20 times less than it is on the earth, again per unit area, because Jupiter is cooler. Thus the efficiency with which the atmosphere converts thermal energy into kinetic energy seems to be much greater on Jupiter than on the earth.

And yet one must be careful in making any general conclusion about the efficiency of Jupiter or Saturn's energy cycle because these cycles involve transformations of energy that have not yet been measured. For example, a mass of cold air above a mass of warm air represents a certain amount of gravitational potential energy, which is released when the cold air sinks. Such releases occur inside the clouds of Jupiter and Saturn, and thus they are hidden from view. On the earth the net efficiency of the atmosphere's energy cycle is about 1 percent. That is, about 1 percent of the solar power absorbed by the earth fuels the large-scale motions of the atmosphere before friction in the atmosphere converts it back into heat that the earth radiates into space. The rest is radiated into space without ever being converted into kinetic energy. The net efficiency of Jupiter and Saturn is unknown.

Coaxial Cylinders

I myself suspect that the great depth of the fluid interior cannot be neglected in modeling the atmospheric dynamics of Jupiter or Saturn. Laboratory experiments, including those done by Geoffrey I. Taylor at the University of Cambridge in the 1920's and those being done by F. H. Busse at the University of California at Los Angeles today, show that small-scale turbulent motions (that is, eddies) in a rapidly rotating fluid align themselves in columns parallel to the axis of rotation. At any level in each column the motion in a plane perpendicular to the axis is the same. The columns span their container and resist stretching or compression along the axis. Therefore if the container is spherical, each column remains at a fixed distance from the axis of rotation. Busse's experiments and calculations suggest that a sustained pattern of flow develops in the fluid as a result of the columns. In a liquid of constant density and low viscosity the pattern turns out to be one in which coaxial cylinders of fluid rotate at different velocities about their common axis, which is the axis of the fluid's mean rotation. In a liquid of greater viscosity or stratification into layers of varying density other patterns are possible.

The relevance of these laboratory experiments to Jupiter and Saturn depends, then, on the distribution of density in each of the planets. A marked increase in density below the sunlit layer of the atmosphere, as postulated by Williams, implies that each planet is the large-scale analogue of a stratified laboratory fluid. Columns of the type found by Taylor and Busse do not cross the interface between two layers of differing density, and so the sunlit layer can be decoupled from the interior. On the other hand, the convection of heat in the interior of Jupiter and Saturn should lead to an adiabatic gradient of temperature and a well-mixed interior. This implies that each planet is the analogue of a laboratory fluid of constant density.

According to most models of Jupiter and Saturn's interior, the adiabatic zone ends in the clouds. Hence the steady eastward and westward winds we have measured in the clouds of Jupiter and Saturn may turn out to be the visible sign of the motion of coaxial cylinders that extend all the way through each planet's fluid interior. To be sure, the winds might get their energy from eddies, as is suggested by Williams' model and supported by data from the Voyager spacecraft. If the winds do represent the motion of cylinders, however, the inertia that supports the winds would be immense. Once the coaxial cylinders are set in motion they might well remain in undisturbed rotation throughout the 80 years of observations made first by earth-based astronomers and then by the Voyager instruments.

The coaxial cylinders do imply that the profiles of wind velocity v. latitude in the northern and southern hemispheres of Jupiter and Saturn should be symmetrical about the equator. The symmetries need not, however, extend to high latitudes, because the jump in density at the interface between molecular and metallic hydrogen inside each planet decouples the inner coaxial cylinders. For Jupiter the decoupling should affect latitudes greater than 40 to 45 degrees North and South. For Saturn it should affect latitudes greater than about 65 degrees. In profiles produced from Voyager data the requisite symmetries are present: the northern and southern hemispheres of Jupiter and Saturn each show about three complete cycles of alternating eastward and westward winds between the equator and the latitudes affected by decoupled cylinders. Small departures from symmetry, such as the ones at 25 degrees north and south on Jupiter, where eastward jets are found, may be due to a nonadiabatic temperature gradient in the cloud layers. Larger departures would imply a nonadiabatic interior and would constitute a disproof of the hypothesis.

It is difficult at present to choose between a model of Jupiter and Saturn in which the great depth of the fluid interior is immaterial and one in which the depths are crucial. After all, even the data recorded by the Voyager spacecraft pertain only to the cloud tops. The spacecraft *Galileo,* which is scheduled for launching in the late 1980's, will probe the atmosphere of Jupiter more deeply. It is hoped the probe will measure winds at the level of the cloud bases and will determine if the adiabatic zone extends that high. Meanwhile some indirect strategies may prove useful.

One such strategy exploits the differences between Jupiter and Saturn. In particular, the winds at the cloud tops on Saturn are three to four times stronger than the winds on Jupiter. (The eastward wind speeds at the equator of Saturn are almost 500 meters per second, or more than 1,000 miles per hour.) The eastward and westward currents are broader than on Jupiter, and fewer large oval structures are found. The possible causes of these differences cannot be many. Perhaps, for example, it is significant that the zone of metallic hydrogen lies much deeper in Saturn than in Jupiter. The corresponding increase in the depth of the molecular hydrogen zone might give coaxial cylinders that rotate in opposite directions a greater spacing and greater relative velocities. On the surface of Saturn (as compared with the surface of Jupiter) gravity is weaker, the flux of heat is lower and seasonal changes are greater. (The last follows because Saturn's axis of rotation is more inclined than Jupiter's with respect to the plane of its orbit around the sun and because the rings of Saturn cast a shadow on the surface that changes its position seasonally.) As a result of the weaker gravity Saturn's clouds are thicker and as a result of the lower flux of heat the small-scale convective motions of the atmosphere might be weaker. The implications of the differences at the surface of each planet for large-scale motions in the atmosphere are, however, unclear.

Long-lived Ovals

Another strategy is to examine Jupiter and Saturn's atmospheric flow patterns other than the eastward and westward winds and see what assumptions

© 1981 SCIENTIFIC AMERICAN, INC

IT CAN ACTUALLY MAKE 55 M.P.H. INTERESTING.

If you think that's impossible, you've never driven the Volvo Turbo.

A car whose handling equipment can turn a curve in the road or a trip to the supermarket into a driving adventure.

Its turbocharged 4-cylinder engine can dust a V-8 off the line. Automotive writers have described it as "A blast." "Spectacular." "Like cutting in an afterburner."

Maybe you think speed limits, emissions controls and government mileage requirements have made driving humdrum. But that's only because you don't own an interesting car.

THE TURBO
By Volvo.

© 1981 SCIENTIFIC AMERICAN, INC

about the deep interior are compatible with the observations. In particular, the Great Red Spot of Jupiter and other long-lasting ovals on Jupiter and Saturn are a unique and possibly diagnostic feature of the giant planets. The ovals themselves are relatively slow-moving. For example, the Great Red Spot moves westward only a few meters per second, although the winds around it reach speeds of 100 meters per second. In fact, all the ovals on Jupiter and Saturn seem to rotate like ball bearings between adjacent eastward and westward currents. Each rotation takes only a few days.

The ovals are also enduring: they can last for decades and even centuries. The eddies in the oceans and the atmosphere of the earth are less enduring by orders of magnitude. For example, the eddies in the Atlantic tend to drift westward until they merge with the Gulf Stream off the east coast of North America. Their lifetimes are measured in months and sometimes years. The eddies in the atmosphere of the earth are of several types. The most enduring ones seem to be trapped in place near features of the surface such as mountain chains or boundaries between a continent and an ocean. On Jupiter and Saturn there is no such topography.

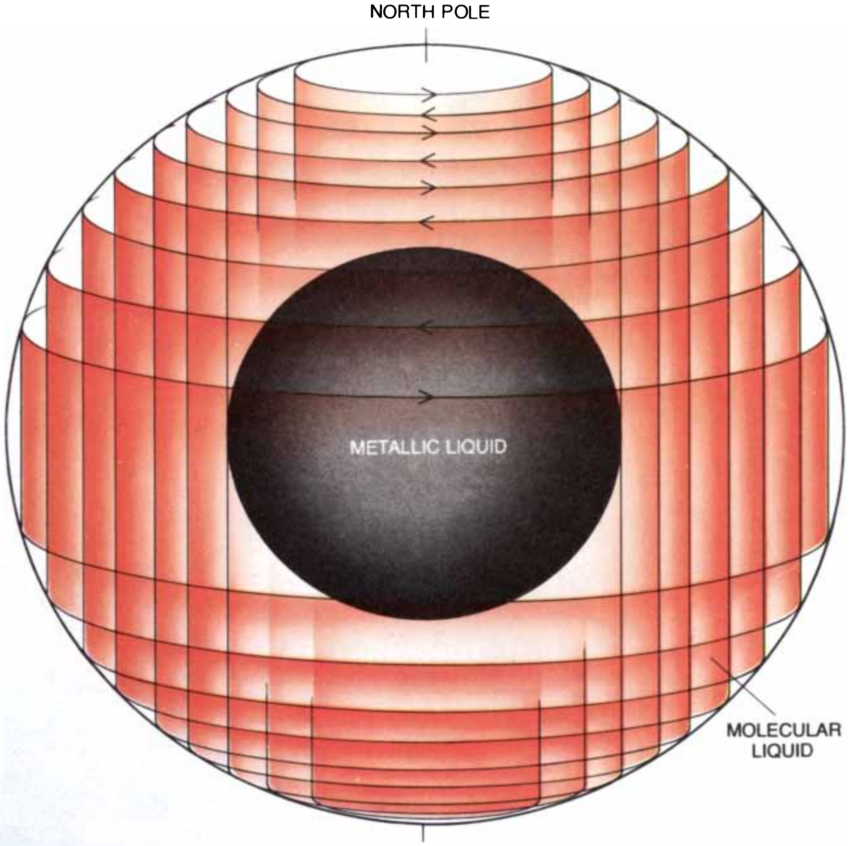
At least two proposals have been put forward that account for many of the properties of the ovals. Each proposal seeks only to show how an isolated vortex can endure in the midst of a pattern of alternating eastward and westward currents. It seeks, in other words, to show that the configuration is stable even if small perturbations of the configuration occur. The proposals do not account for how the vortexes arise.

Tony Maxworthy and Larry G. Redekopp of the University of Southern California have proposed that a long-lived oval represents a "solitary wave," that is, a self-sustaining wave with a single crest instead of a train of crests and troughs. Such a wave is a fluid-dynamical curiosity dating back to the 19th century; in Maxworthy and Redekopp's hypothesis it is a single north-south displacement of flow lines that otherwise lie east-west. The models Maxworthy and Redekopp have published often bear a striking resemblance to the Great Red Spot. Moreover, those models imply that a planetary solitary wave can exist only in a pattern of east-west flow that is unstable to certain perturbations. This may explain why isolated ovals do not spontaneously appear in Williams' models, in which the east-west flows are not unstable. In Williams' models the closest analogues to isolated ovals are trains of spots strung out at constant latitude. Such patterns do appear on Jupiter, but they are distinct from the large, isolated ovals. When two solitary waves meet, however, they simply pass through each other. When two ovals meet on Jupiter or Saturn, they sometimes merge.

The second proposal, made by me and Pham Giem Cuong of Cal Tech, depends on assuming that the east-west pattern of flow in the clouds is part of a much deeper pattern, perhaps one of rotating coaxial cylinders. On that hypothesis it can be shown that stable vortexes can exist in an east-west flow that is also stable. According to this proposal, such a vortex extends downward only to the top of the adiabatic zone, wherever that may lie. We tested the stability of the ovals in our computer model by introducing large and small perturbations, by forcing two ovals to collide and by feeding small ovals to the larger ones. Given the right east-west flow under them, the ovals are quite robust: they survive rather large perturbations. Moreover, the large spots can grow by consuming the smaller spots. It is likely that on Jupiter and Saturn the smaller, transient spots derive energy from their buoyancy.

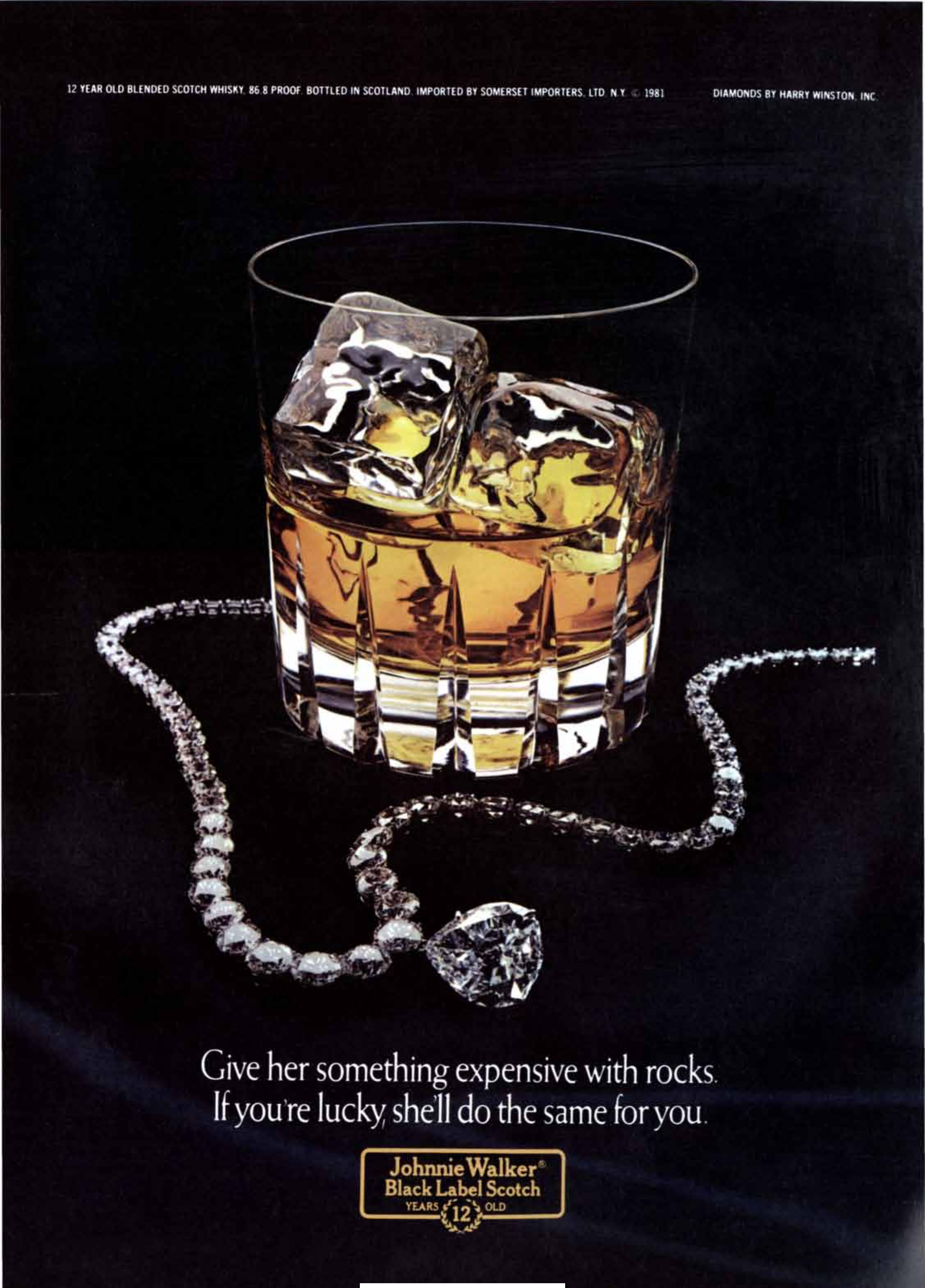
So far Williams' model of Jupiter and Saturn, which derives from models of the earth, is the only proposal that is complete, in the sense that it has sources and sinks of energy and the eastward and westward currents arise spontaneously. To varying degrees the other models take much of the pattern as presupposed. For example, the models of the long-lived ovals presuppose the basic east-west flows.

The fundamental issues remain unresolved. How deep do the visible patterns of flow on Jupiter and Saturn extend? How important is solar heating of the atmosphere, as opposed to internal heating? How is the density of the atmosphere stratified below the cloud tops? The issues are particularly challenging because an all-encompassing computer model of Jupiter or Saturn is impractical. One simply cannot incorporate into the same mathematical description of a planet the small, transient atmospheric eddies that are crucial in Williams' hypothesis and the slow, large-scale internal responses to uneven solar heating that occur in the hypothesis advanced by Porco and me. The scales of size and time for the two phenomena are just too different. Computer models will be important, but as we come to understand the giant planets clever thinking and insight will be needed even more.

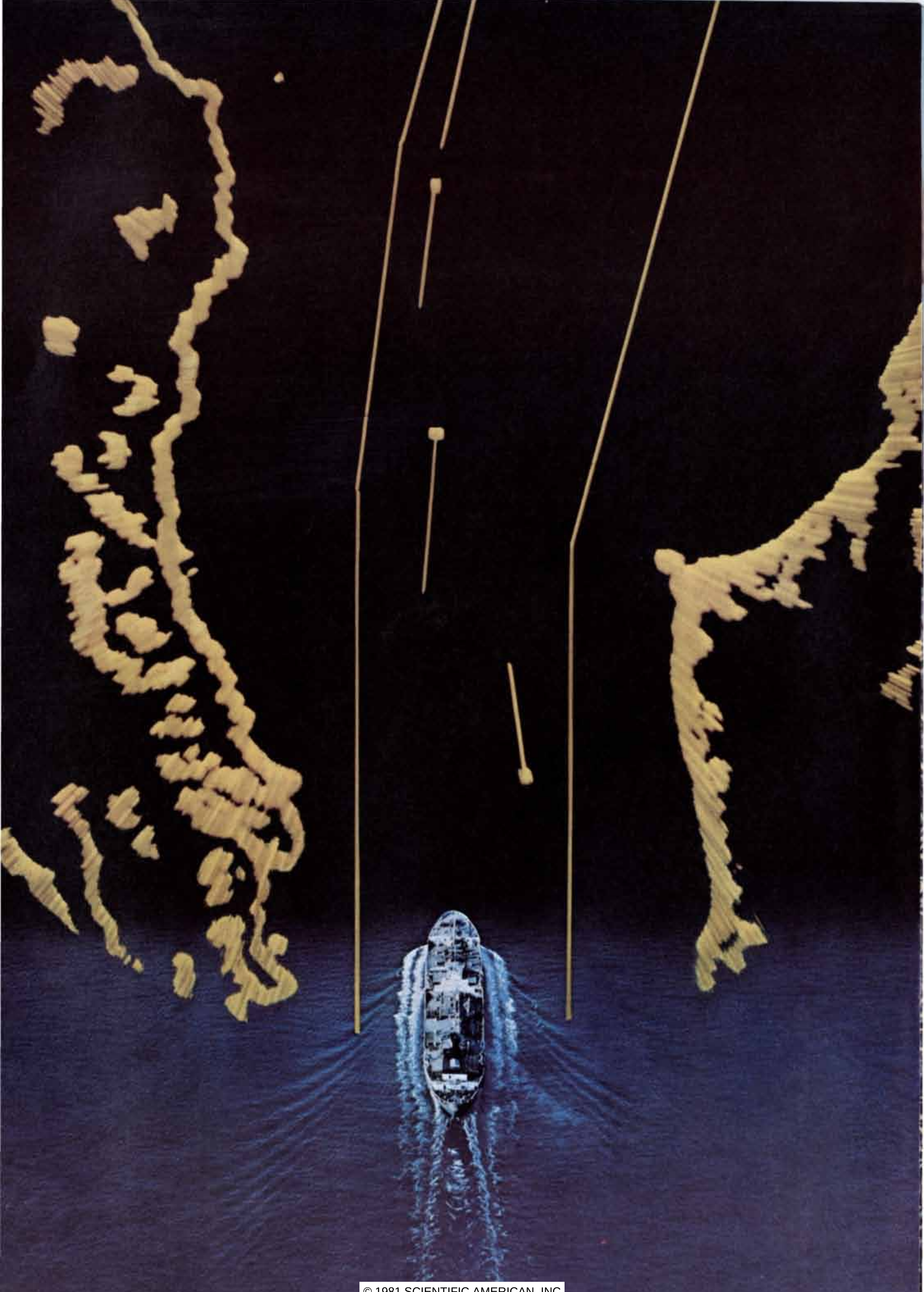


ALTERNATIVE MODEL advanced by F. H. Busse of the University of California at Los Angeles and supported by the author proposes that the east-west winds in the cloud decks of Jupiter and Saturn are the visible sign of a pattern of rotation extending through the fluid interior of each planet. The model is based on the experiments of Geoffrey I. Taylor at the University of Cambridge and those of Busse, which suggest that in a rotating fluid planet that has been well mixed by convection the sustained motions are those of nested fluid cylinders. A discontinuity in the density of the planet's interior at the top of the zone of metallic hydrogen interrupts the innermost cylinders. The small asymmetries between the northern and southern hemispheres in the wind profiles shown on page 96 are not inconsistent with the model.

© 1981 SCIENTIFIC AMERICAN, INC



© 1981 SCIENTIFIC AMERICAN, INC



© 1981 SCIENTIFIC AMERICAN, INC

We designed an intelligent radar that predicts collisions at sea, so they won't happen.

Consider, for a moment, what confronts a ship's officer on the bridge of a large, oceangoing vessel. His job, to navigate the ship safely and efficiently from port to port. Simple enough in theory, but in actual practice, vastly complicated.

Today's sea-lanes are crowded with more and more ships. Larger ships that are sluggish to maneuver and slow to stop. There is radar on the bridge, of course, but often that's not enough. Not because the radar can't "see" what's out there. But because often it can take too long to interpret what's on the radar screen.

That's why Raytheon developed RAYCAS (Raytheon Collision Avoidance System). It tracks up to 20 individual targets automatically and gives both visual and audible warnings when ships are on a collision course. It also allows the officer to create a safe channel on the radar scope for his own ship. Or even to display a trial maneuver so he can evaluate the effect of a proposed course change.

The RAYCAS system is designed around a Raytheon Mariners Pathfinder® radar with a patented system for processing incoming radar signals in digital form. This not only provides an extremely bright radar display, but allows the same data to be fed to a high-performance microcomputer, where it is processed along with own ship's speed, course, and similar information. Thus, the system provides a continuous update of bearing, range, course, and speed of target ships—together with related navigational information—both in digital readout form or as a visual display on the radar screen.

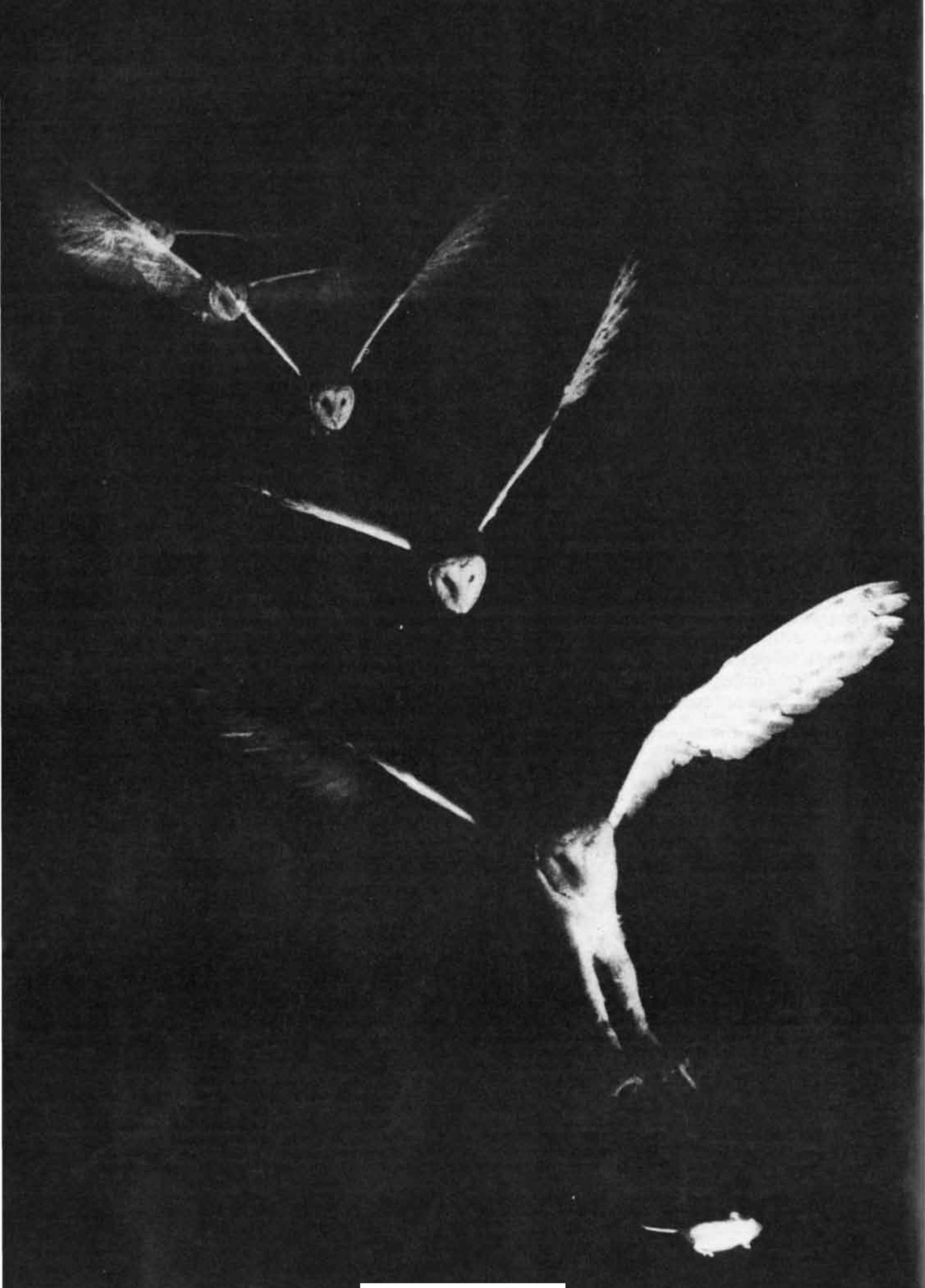
RAYCAS is just one of Raytheon's major achievements in radar technology, and a typical example of how we constantly strive for new and better solutions to difficult problems through advanced technology.

Raytheon...a $5 billion company in electronics, aviation, appliances, energy, construction, and publishing. For further information, write Raytheon Company, Public Relations, Section 2-3, 141 Spring Street, Lexington, Massachusetts 02173.

RAYTHEON

Candidates interested in technical employment opportunities with Raytheon Company, An Equal Opportunity Employer, should forward a resume to Manager, Executive Placement, at the above address.

© 1981 SCIENTIFIC AMERICAN, INC



© 1981 SCIENTIFIC AMERICAN, INC

The Hearing of the Barn Owl

The bird exploits differences between the sound in its left and right ears to find mice in the dark. It can localize sounds more accurately than any other species that has been tested

by Eric I. Knudsen

For the barn owl life depends on hearing. A nocturnal hunter, the bird must be able to find field mice solely by the rustling and squeaking sounds they make as they traverse runways in snow or grass. Like predators that hunt on the ground, the barn owl must be able to locate its prey quickly and precisely in the horizontal plane. Since the bird hunts from the air, it must also be able to determine its angle of elevation above the animal it is hunting. The owl has solved this problem very successfully: it can locate sounds in azimuth (the horizontal dimension) and elevation (the vertical dimension) better than any other animal whose hearing has been tested.

What accounts for this acuity? The answer lies in the owl's ability to utilize subtle differences between the sound in its left ear and that in its right. The ears are generally at slightly different distances from the source of a sound, so that sound waves reach them at slightly different times. The barn owl is particularly sensitive to these minute differences, exploiting them to determine the azimuth of the sound. In addition the sound is perceived as being somewhat louder by the ear that is closer to the source, and this difference offers further clues to horizontal location. For the barn owl the difference in loudness also helps to specify elevation because of an unusual asymmetry in the owl's ears. The right ear and its opening are directed slightly upward; the left ear and its opening are directed downward. For this reason the right ear is more sensitive to sounds from above and the left ear to sounds from below.

The differences in timing and loudness provide enough information for the bird to accurately locate sounds both horizontally and vertically. To be of service to the owl, however, the information must be organized and interpreted. Much of the processing is accomplished in brain centers near the beginning of the auditory pathway. From these centers nerve impulses travel to a network of neurons in the midbrain that are arranged in the form of a map of space. Each neuron in this network is excited only by sounds from one small region of space. From this structure impulses are relayed to the higher brain centers. The selection of sensory cues and their transformation into a map of space is what enables the barn owl to locate its prey in total darkness with deadly accuracy.

The barn owl has a wide range, both as a species and as an individual hunter. Barn owls are found throughout the tropical and temperate areas of the world. Many live close to human settlements, often nesting in barns or in belfries; they also nest in hollow trees and in holes in earth banks or rocks. Like most other owls they remain paired for long periods, sometimes for life, returning to breed in the same place year after year. The birds hunt in open areas, and they cover more ground than any other nocturnal bird. Studies of the bird's pellets (small objects coughed up by the bird that contain the indigestible remnants of prey) have shown that more than 95 percent of its prey are small mammals, mainly field mice; the rest are amphibians and other birds.

The nine species of barn owls are different enough from other owls to form their own family: the Tytonidae. The common barn owl, *Tyto alba*, is the most numerous species. It stands between 12 and 18 inches high and has a white face, a buff-colored back and a buff-on-white breast; its lower parts are mostly white with dark flecks. Each of the bird's middle toes has a small comb with which it dresses its feathers.

The most striking anatomical feature of the barn owl, and the one that plays the most important role in its location of prey, is the face. The skull is relatively narrow and small and the face is large and round, made up primarily of layers of stiff, dense feathers arrayed in tightly packed rows. The feathered structure, called the facial ruff, forms a surface that is a very efficient reflector of high-frequency sounds.

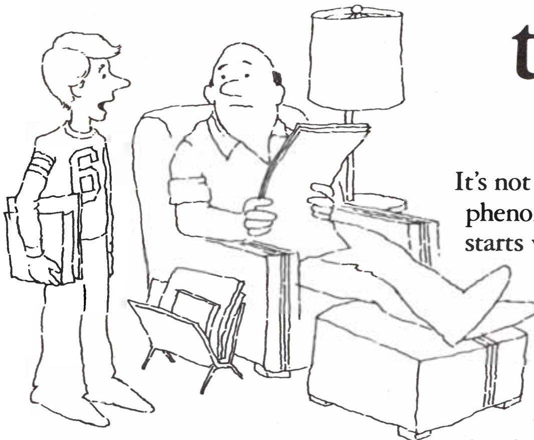
Two troughs run through the ruff from the forehead to the lower jaw, each about two centimeters wide and nine centimeters long. The troughs are similar in shape to the fleshy external pinna of the human ear, and they serve the same purpose: to collect high-frequency sounds from a large volume of space and funnel them into the ear canals. The troughs join below the beak but are separated above it by a thick ridge of feathers. The ear openings themselves are hidden under the preaural flaps: two flaps of skin that project to the side next to the eyes. The entire elaborate facial structure is hidden under a layer of particularly fine feathers that are acoustically transparent. The acoustic properties of the facial ruff are closely associated with the bird's method of locating the source of the sound.

In order to survive the barn owl must be able to locate prey with sound alone. Field mice are difficult to see even in broad daylight because their coloring blends with that of their surroundings; in addition they tend to travel through tunnels in grass or snow. By night, when the mice forage, they are essentially invisible even to the keen eyes of the owl. Hunting from the air makes the task even more difficult, since the owl must determine the angle of elevation above the prey. A determination of azimuth alone would leave an entire line of possi-

STRIKE OF THE BARN OWL in total darkness is shown in this sequence of exposures made in the laboratory with infrared radiation, to which the eyes of the owl are not sensitive. Unlike ground-living predators, the bird must determine its elevation above the prey as well as the direction in the horizontal plane. The owl can locate mice solely by sound. Moreover, just before striking it aligns its talons with the long axis of the mouse's body, as is shown in the final exposure. This action shows that the bird can infer the direction of the prey's motion from sound.

© 1981 SCIENTIFIC AMERICAN, INC

"Dad, can I use the IBM computer tonight?"



It's not an unusual phenomenon. It starts when your son asks to borrow a tie. Or when your daughter wants to use your metal racquet. Sometimes you let them. Often you don't. But when they start asking to use your IBM Personal Computer, it's better to say yes.

Because learning about computers is a subject your kids can study and enjoy at home.

It's also a fact that the IBM Personal Computer can be as useful in your home as it is in your office. To help plan the family budget, for instance. Or to compute anything from interest paid to calories consumed. You can even tap directly into the Dow Jones data bank with your telephone and an inexpensive adapter.

But as surely as an IBM Personal Computer can help you, it can also help your children. Because just by playing games or drawing colorful graphics, your son or daughter will discover what makes a computer tick—and what it can do. They can take the same word processing program you use to create business reports to write and edit book reports (and learn how to type in the process). Your kids might even get so "computer smart," they'll start writing their own programs in BASIC or Pascal.

Ultimately, an IBM Personal Computer can be one of the best investments you make in your family's future. And one of the least expensive. Starting at less than $1,600† there's a system that, with the addition of one simple device, hooks up to your home TV and uses your audio cassette recorder.

To introduce your family to the IBM Personal Computer, visit any ComputerLand® store or Sears Business Systems Center. Or see it all at one of our IBM Product Centers. (The IBM Data Processing Division will serve business customers who want to purchase in quantity.)

And remember. When your kids ask to use your IBM Personal Computer, let them. But just make sure you can get it back. After all, your son's still wearing that tie. IBM®

The IBM Personal Computer and me.

†This price applies to IBM Product Centers. Prices may vary at other stores.

For the IBM Personal Computer dealer nearest you, call (800) 447-4700. In Illinois, (800) 322-4400. In Alaska or Hawaii, (800) 447-0890.

© 1981 SCIENTIFIC AMERICAN, INC

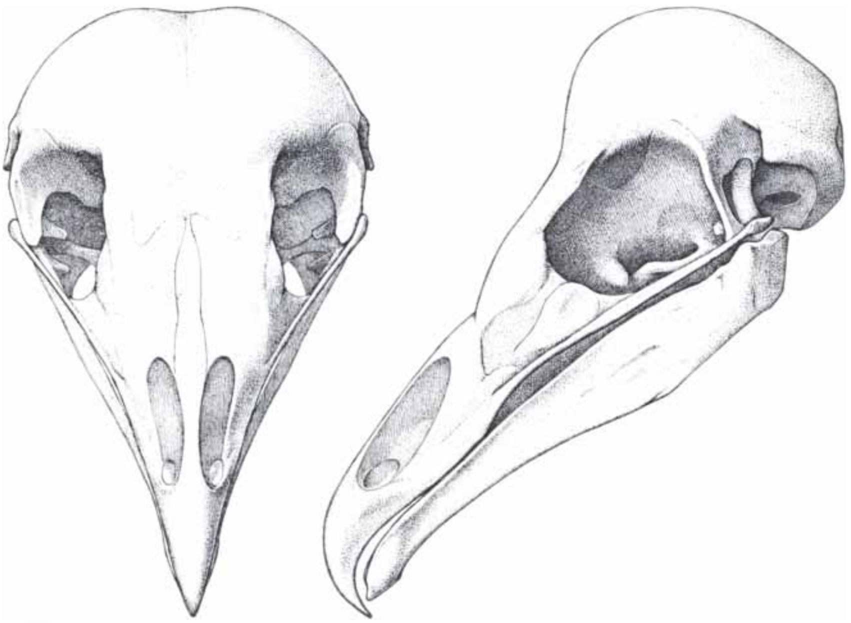
ble target sites along the ground below.

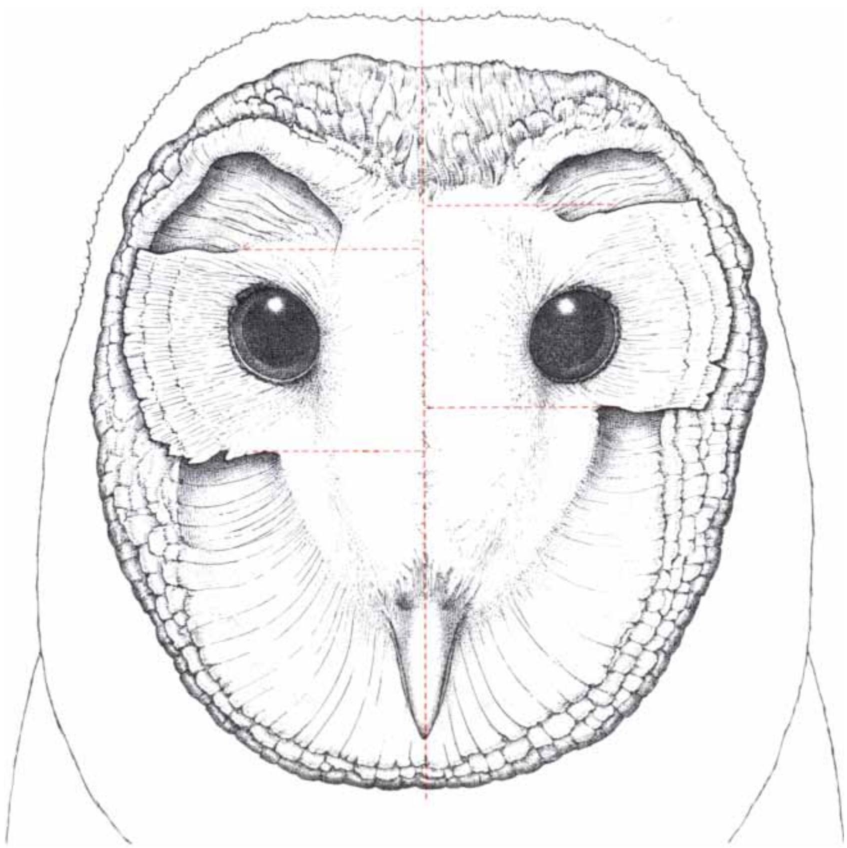
The barn owl locates sounds in two spatial dimensions with great accuracy. Roger S. Payne, and later Masakazu Konishi and I, demonstrated that the bird is capable of locating the source of a sound within a range of one to two degrees in both azimuth and elevation; one degree is about the width of a little finger at arm's length. Surprisingly, until the barn owl was tested, man was the species with the greatest known ability to locate the source of a sound; human beings are about as accurate as the owl in azimuth but are three times worse in elevation. Monkeys and cats, other species with excellent hearing, are about four times worse than owls in locating sounds in the horizontal dimension, the only one in which they have been tested.

The sensitivity of the barn owl's hearing is shown both by its capacity to locate distant sounds and by its ability to orient its talons for the final strike. When the owl swoops down on a mouse, even in a completely dark experimental chamber, it quickly aligns its talons with the body axis of the mouse. It was Payne who first suggested that this behavior is not accidental. When the mouse turns and runs in a different direction, the owl realigns its talons accordingly. This behavior clearly increases the probability of a successful strike; it also implies that the owl not only identifies the location of the sound source with extreme accuracy but also detects subtle changes in the origin of the sound from which it infers the direction of movement of the prey.

Several kinds of experiments have helped to elucidate how the barn owl accomplishes these difficult tasks. Experiments with birds in free flight have measured how accurately the owl flies toward and strikes at an invisible sound source. Head-orientation experiments, where the bird was perched on a testing stand, have helped to measure the precision with which it aligns its head with an incoming sound. Experiments where the brain of an anesthetized owl was probed with a microelectrode while the bird was exposed to various sounds have shown how the sensory information is organized and interpreted by the central nervous system.

Konishi and I have done a series of head-orientation experiments. This experimental system has several advantages over tests conducted with birds in free flight. In free-flight tests flight errors may be confused with sound-location errors. In addition the angle of the sound source in relation to the bird's head at the moment the bird decides to strike cannot be determined. Free-flight trials are also complicated and time-consuming to conduct. In contrast, head-orientation experiments are relatively simple to conduct, and they allow the rela-





FACIAL STRUCTURE of the barn owl is responsible for much of the bird's precision in hearing. The face is formed by rows of tightly packed feathers called the facial ruff extending from the relatively narrow skull. The external ears are troughs formed by the ruff that run down the length of the face to join below the beak. They collect sounds and funnel them into ear-canal openings hidden under the preaural flaps (flaps of skin projecting outward from next to the eyes). The left ear is more sensitive to low-frequency sounds from the left and the right ear is more sensitive to those from the right. At high frequencies, however, the right ear is more sensitive upward, because the preaural flap and opening are lower on the right and the trough is tilted up. The opening and the flap are higher on the left side and the trough is tilted down. The left ear is more sensitive to sounds coming from below. Differences in perceived loudness can therefore yield clues to the elevation of a source of sound as well as to its horizontal direction.

© 1981 SCIENTIFIC AMERICAN, INC

tion between the head and the sound source to be measured.

These experiments take advantage of a natural response of the owl when it is hunting. On hearing a noise the bird turns its head in a rapid flick that brings the source of the sound directly in front of it. This movement brings the sounds into the region where the bird's hearing is keenest. The eyes of the barn owl are immobile, and so the movement also enables the bird to see a target with maximum acuity. Konishi and I monitored this behavior by mounting a lightweight "search" coil on top of the owl's head. Magnetic fields generated by other coils were centered so that when the bird perched normally, the search coil was at the intersection of the horizontal field and the vertical one. The electric current induced in the search coil varied with its orientation to these fields. By evaluating the magnitude of two distinguishable signals one could measure the horizontal and vertical components of the orientation of the owl's head.

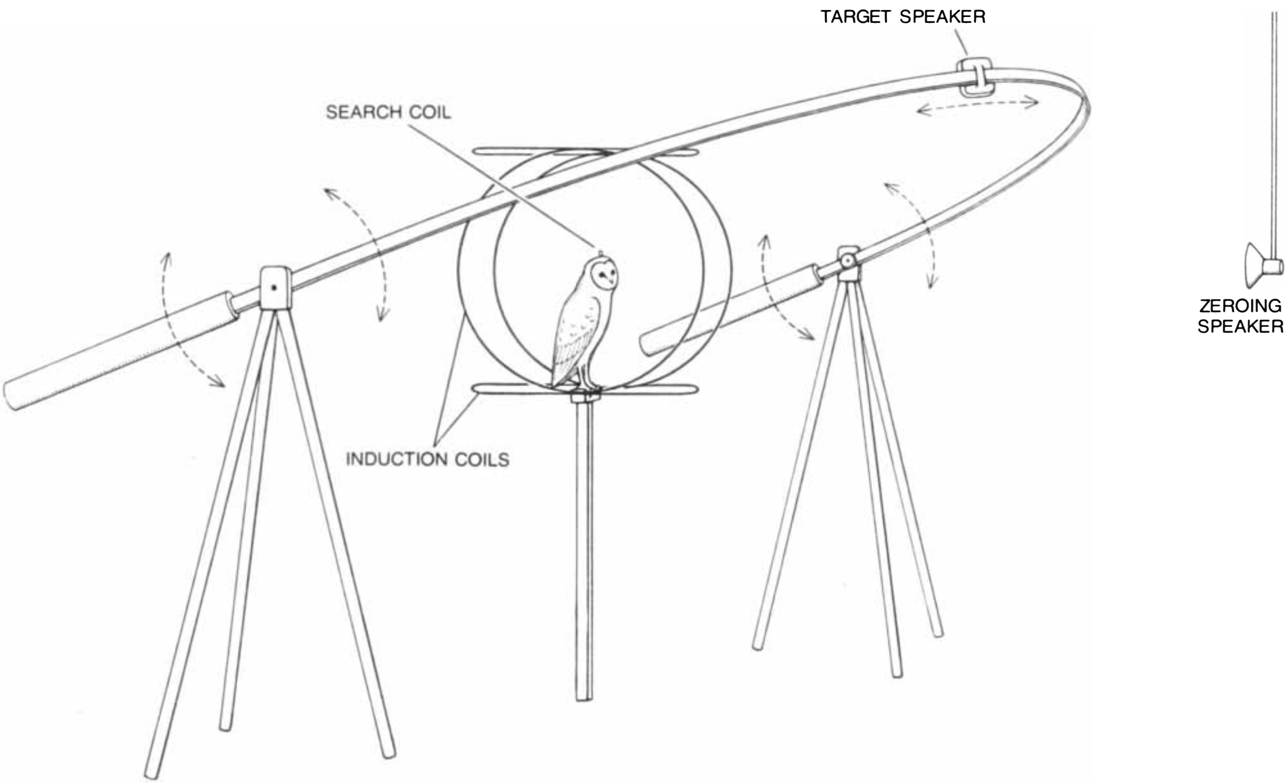
The tests were done in a totally dark chamber lined with materials that eliminate echoes. Sounds were generated by a stationary speaker (the "zeroing" speaker) and a movable speaker (the "target" speaker). The owl first turned to face a sound from the zeroing speaker, placed in front of its perch; a sound delivered by the target speaker then caused the bird to turn its head in the characteristic flicking movement. A computer controlled the location of the target speaker and recorded its location and the alignment of the owl's head.

The head-orientation trials have yielded much information about how the owl determines the origin of a sound. One of the important features of the process is that it can achieve maximum accuracy even with sounds that end before the head movement begins. This indicates that the owl's auditory system determines the azimuth and elevation of a sound without head movement and then utilizes the information to direct the head-orientation response. The head-movement tests also show that the owl's accuracy deteriorates with increases in the angle between the source of the sound and the orientation of the bird's head.

Our experiments and those of others have shown that the barn owl's ability to locate the origin of a sound is dependent on the presence of high frequencies in the sound. Although the owl's hearing is sensitive to a broad range of frequencies, from 100 hertz (cycles per second) to 12,000 hertz, it can locate accurately only sounds with frequencies between 3,000 and 9,000 hertz. In addition experiments in which one of the bird's ears is plugged show that both ears are necessary for the accurate locating of targets. If one ear is plugged, the owl makes large errors in the direction of that ear.

With these characteristics in mind we proceeded to investigate the exact information the barn owl selects from natural sounds. To locate the source of a sound the owl must determine the direction of propagation of the sound waves based on information from detectors at two points, namely its ears. The most useful spatial information is gained by comparing information from these two sources, since the differences between them depend not on the absolute sound level but only on the orientation of the ears in the sound field.

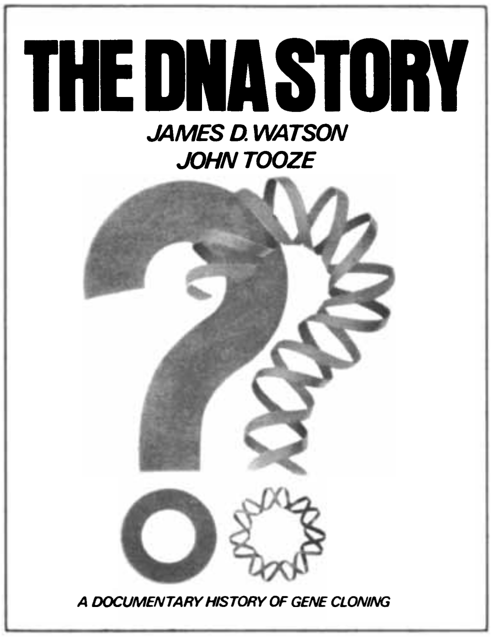
One valuable cue of this kind is the difference in the time of arrival of the sound in the two ears. When the sound comes directly from the side, the difference is at its maximum; when the sound is directly in front of the bird, there is no difference in the arrival time at the two ears. Between these limits the time difference varies with the angle of the



HEAD-ORIENTATION TESTS measured the accuracy of the owl's hearing. These experiments take advantage of a natural response made by the hunting owl: on hearing a noise the bird turns its head to face the source of sound. In the experimental situation the bird remained perched on a stand. A "search" coil mounted on its head was placed at the intersection of horizontal and vertical magnetic fields induced by stationary coils. Any head movement caused a measurable change in the current in the search coil. The owl's attention was first directed to a sound coming from a fixed "zeroing" speaker. A sound from a movable "target" speaker then caused the bird to turn its head in a rapid movement. A computer controlled the location of the target speaker and recorded movements of the bird's head. It was thereby possible to measure the accuracy with which the owl responded to sounds coming from various positions in space.

© 1981 SCIENTIFIC AMERICAN, INC

An Insider's Perspective on the Gene-Cloning Controversy



In *The DNA Story,* James D. Watson, author of the best-selling *The Double Helix,* and John Tooze offer an absorbing record of a social and scientific subject of incalculable consequence.

The DNA Story is a three-part documentary that provides a visual, historical, and scientific perspective:

- An eight-page color insert features reproductions of paintings by George Kelvin that capture the essence of the DNA story. The paintings beautifully depict the double helix, replication, steps in gene expression, and industrial applications of DNA.
- Documents collected from the last decade give you a first-hand look at the concerns of the scientists who pioneered DNA research; at the public reaction to an area of science that evokes both hope and fear; at accounts in the press, ranging from articles in *New Scientist, New England Journal of Medicine,* and *Science* to pieces in the *New York Times, Rolling Stone,* and *Business Week;* at the national and international contention that has continued over the past decade.
- The scientific background outlines the techniques for recombining DNA and identifying cloned genes and describes what we have already learned by using the techniques.

James D. Watson, co-winner of the 1962 Nobel Prize in Medicine and recipient of the 1977 Presidential Medal of Freedom, is Director of the Cold Spring Harbor Laboratory in New York.

John Tooze is Executive Secretary of the European Molecular Biology Organization and has also worked at the Imperial Cancer Research Institute in England and at Harvard University.

Please send me _____ copies of *The DNA Story* at $19.95 each. I enclose payment or credit card information with order.

____ I enclose check or money order for full amount plus $1.50 postage and handling charge. (California residents add appropriate sales tax.)

____ Please charge my ☐ Master Charge ☐ VISA.

Account # ________________ Expiration Date ________

Signature ______________________________

(All credit card orders must be signed.)

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

The DNA Story
A Documentary History of Gene Cloning
James D. Watson and John Tooze
September 1981, 600 pages (approx.), 100 illustrations (approx.)

Name ______________________________

Address ______________________________

City ______________________________

State ____________________ Zip __________

Guarantee: Examine *The DNA Story* for fourteen days. If for any reason you are not satisfied, you may return it for a full and prompt refund or credit.

© 1981 SCIENTIFIC AMERICAN, INC

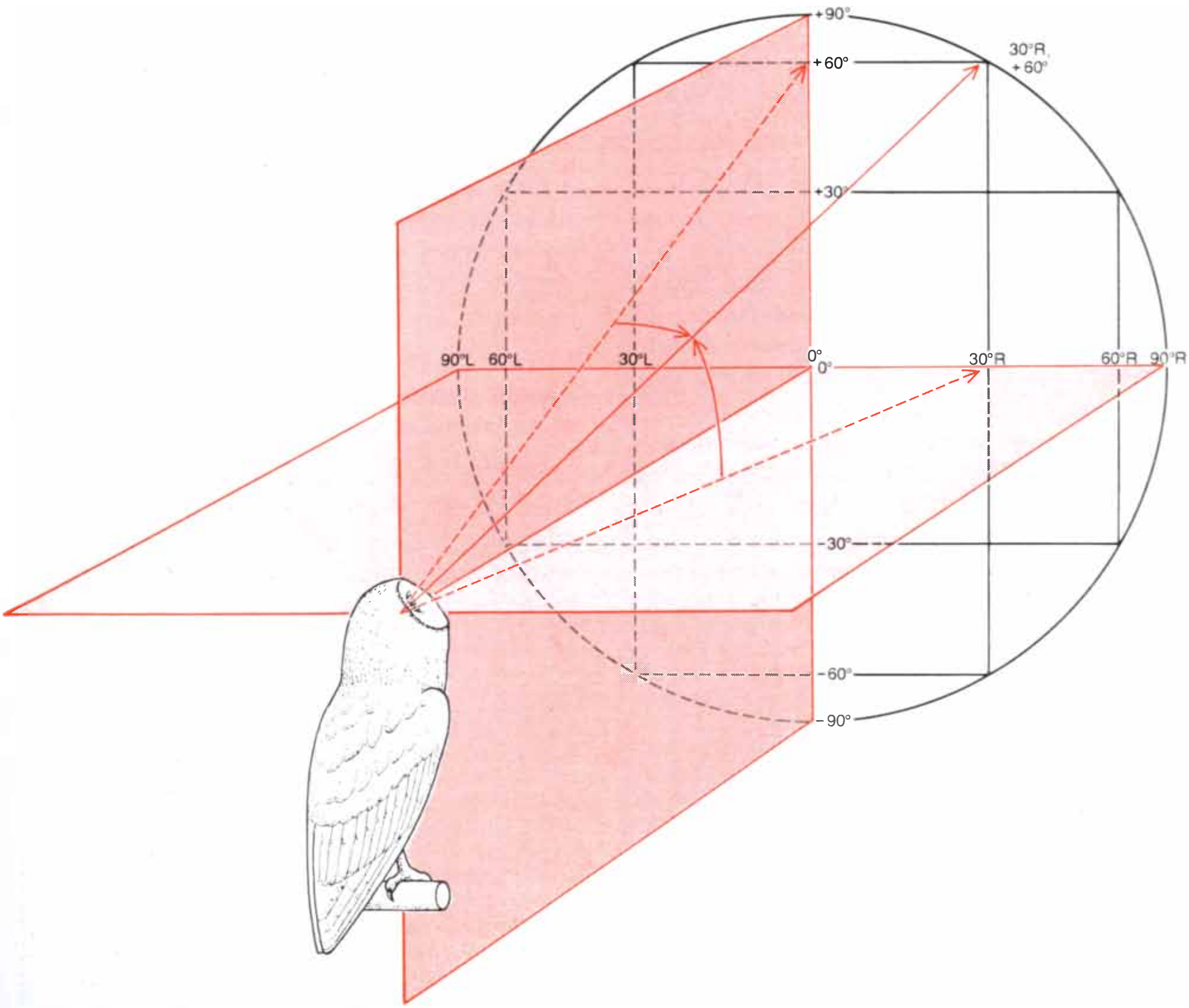
sound in the horizontal plane. The time delay can therefore yield information about the azimuth of the sound. This is not sufficient for the bird to locate the sound exactly, because sounds from several directions can give rise to the same difference in time. In three-dimensional space these directions form a cone around the axis between the owl's ears.

This is an example of the inadequacy of any one cue to provide information about both the horizontal and the vertical angle of a source of sound. To specify a location in both dimensions two independent cues are needed. In the owl's case the additional information is provided by differences in the directional sensitivity of the ears.

Directional sensitivity is provided by the facial ruff. Like a hand cupped behind the ear, the troughs of the ruff amplify the sound and make the ear more sensitive to sounds from certain directions. The amount of amplification and directional sensitivity imparted by the feathers of the facial ruff varies dramatically with the frequency of the sound. This is owing to one of the properties of the sound waves themselves. When sound waves encounter an object, they can bend around it or be reflected back from it. Which of these happens depends on the wavelength of the sound and the size of the object. If the wavelength is long compared with the object, the waves tend to propagate around the object; if the wavelength is short, the waves tend to be reflected back in the direction from which they came.

As a result of this phenomenon frequencies of less than 3,000 hertz are not efficiently reflected by the ruff. Because the funneling action of the ear depends on its capacity to reflect sound its directional sensitivity at low frequencies is relatively poor. At 3,000 hertz, for example, the left ear is only slightly more sensitive to sounds coming from an area between 20 and 40 degrees to the left than it is to sounds coming from other directions. The right ear has a similar degree of sensitivity to the right. Since the sensitivity of each ear at low frequencies changes only gradually with direction, the comparison of sound intensities at low frequencies can provide only a coarse spatial cue. Moreover, this difference yields no clue to the elevation of the sound.

With higher-frequency sound waves the situation is quite different. Each ear is much more sensitive to the direction of the sound; a small change in sound direction gives rise to a large change in perceived intensity. In addition, instead of being more sensitive to the right or to the left, the right ear is more sensitive above the horizontal plane and the left



DOUBLE-POLE COORDINATE SYSTEM serves to map the positions of the owl's head in head-orientation tests. Each direction is specified by two measurements: the angle from the horizontal and that from the vertical through which the owl must turn its head to face that way. Facing forward, as the bird normally perches, the orientation is 0 degrees (horizontal) and 0 degrees (vertical). The map represents the 180 degrees of space in front of the bird. The other maps accompanying this article have the same coordinate system.

© 1981 SCIENTIFIC AMERICAN, INC

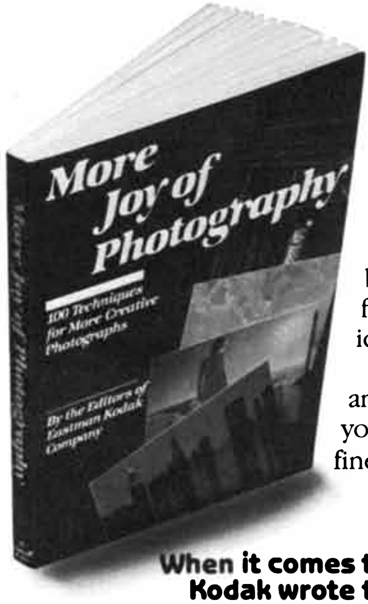
ear is more sensitive below it. This sensitivity is the result of an unusual anatomical asymmetry. The ruff on the left is directed slightly downward, and the ear opening and the preaural flap are higher in the ruff on the left side. On the right side the reverse is the case. Accordingly as the source of the sound moves up the high-frequency components of a natural sound become louder in the right ear and softer in the left. As the source of the sound moves down the sounds become louder in the left ear. Since at high frequencies the perceived loudness changes rapidly with elevation, this cue offers information that is very precise.

Although that information is valuable to the barn owl, it is also complex. The magnitude of the difference in intensity varies according to the frequency of the sound, because of the greater capacity of the ruff to reflect sounds at higher frequencies. The direction indicated also varies with frequency, since horizontal location is given by low frequencies and vertical location by high ones. The owl's auditory system must therefore compare the intensities detected at each ear for each frequency. A comparison of intensities made frequency by frequency is called an interaural spectrum.

Since low-frequency sounds yield clues to azimuth and those of high frequency yield clues to elevation, the interaural spectrum could by itself provide enough information for the owl to locate prey. Much evidence supports the hypothesis that owls use this spectrum. The strike accuracy of the bird increases sharply as the bandwidth (the number of frequencies contained in a sound) is increased. From differences in the intensity of a single tone (a sound of only a single frequency) the owl can determine direction in only one dimension; as the spectrum broadens more intensity differences are available, and their values indicate the angle of the source in more than one plane. Experiments in which one of the owl's ears is plugged show more directly that the owl compares intensities. A trained owl with its right ear plugged strikes to the left and short of the target; one with its left ear plugged strikes to the right and beyond the target. That the errors have components of both elevation and azimuth implies that the owl gains both types of information from comparisons of intensity.

Further confirmation has been obtained by removing the owl's facial ruff. When the ruff is removed, the owl is able to locate the azimuth of a sound quite well but cannot identify its vertical location: the bird consistently orients to a point on the horizontal, regardless of the elevation of the target. This accords with our hypothesis: the sound-reflecting properties of the ruff underlie directional sensitivity at high frequencies, which enables the owl to identify the

GET MORE JOY.



Take more pride in your pictures. Develop your photographic style. Nearly 500 photos, mostly in color, show you how.

Ideal for the 35 mm photographer, this sequel to the best-selling *Joy of Photography* features 298 pages of creative ideas, tips, and techniques.

Find *More Joy of Photography* and other Kodak photo books at your camera store or wherever fine photography books are sold.

When it comes to photography, Kodak wrote the book.

Kodak

© Eastman Kodak Company, 1981

Celestron® Multipurpose **Telephotos**

Let You Reach Out...

A long focal length telephoto lens is irreplaceable for many aspects of sports, nature and action photography—there are many times when only a "long" lens can achieve the right framing, isolate a subject against a complex background or provide the image scale you want for dramatic, artistic photographs.

Only Celestron offers a complete range of compact, mirror-lens telephoto lenses of 300 to 3910mm focal lengths that can also be used as visual spotting scopes and high quality, large aperture astronomical telescopes.

You are invited to see the multipurpose Celestrons at your local camera dealer and to learn about the full potential of a Celestron by sending for our beautiful, full-color, 52-page catalog describing our complete telephoto, astronomical telescope and binocular lines.

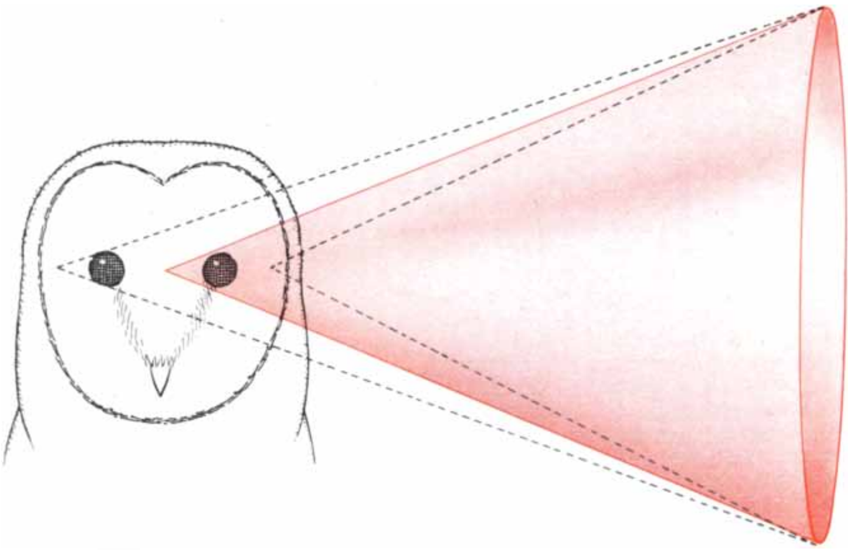
You'll be surprised at how little a Celestron costs—far, far below equivalent, bulky conventional telephoto lenses that have none of the versatility of a Celestron.

To capture the unusual
Celestron 750mm f/6 Photograph

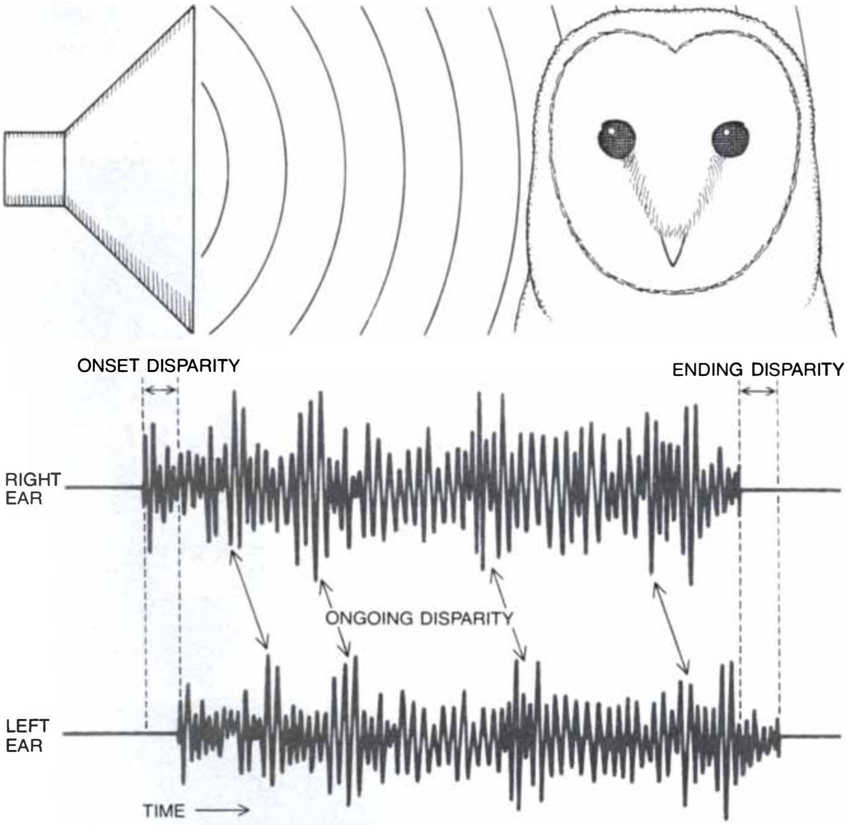
Free 8-page brochure or send $3.00 for 52-page full-color catalog on how to select and use a Celestron telescope/telephoto lens.

Celestron® International
2835 Columbia St., (Box 3578-SA2)
Torrance, Calif. 90503, U.S.A.
Telephone: (213) 328-9560
Dealer inquiries invited.

© 1981 SCIENTIFIC AMERICAN, INC



CONE OF CONFUSION (*color*) **is formed by the directions among which the barn owl cannot distinguish on the basis of time delay alone. Time delay can provide information about the horizontal angle of a sound source. Since the left and right ears are generally at slightly different distances from the source of a sound, sound waves reach them at slightly different times. The greater the angle of a sound source from the bird's frontal plane, the greater the time delay. There are many directions, however, that give rise to the same path lengths (*broken lines*) and hence to the same time delay; other cues are required for the bird to tell them apart. In three-dimensional space these directions form a cone whose peak is between the two ears.**



SOUND TRACE shows two kinds of differences in the timing of the sound between the barn owl's left and right ears. In this schematization the height of the trace indicates the pressure caused by the sound waves in each ear. When a sound comes from the right, the waves begin and end earlier in the right ear; major changes in intensity also occur slightly earlier there. These differences are collectively known as transient disparity. In addition, throughout the duration of the sound the waveforms are slightly advanced in the right ear; this is called ongoing disparity. Man relies on both differences to find the source of a sound. The barn owl relies heavily on ongoing disparity, but there is no evidence that the bird exploits the transient difference.

vertical angle of the source. Removal of the ruff eliminates the ability to discriminate among elevations. Some disparity in intensities is retained because the ear openings and preaural flaps are placed asymmetrically in the fold of skin supporting the feathers of the ruff, but this is not enough to make it possible to identify the elevation of the sound.

That barn owls rely on the interaural spectrum to locate sounds in both azimuth and elevation has thus been amply confirmed by the results gathered from the head-orientation tests. It is clear from other findings, however, that the bird also makes some use of timing differences in locating its invisible prey. The timing delay is manifested in two aspects of the binaural signal. First, the sound begins and ends sooner in the ear closer to the source; the timing of major discontinuities in intensity in the sound is also slightly different in each ear. These differences are known collectively as transient disparity. Second, throughout the duration of the sound the sound waves reaching the far ear will be slightly delayed. With a single frequency this difference in the timing of the waveforms is known as phase delay; with more complex natural sounds, made up of many frequencies, it is called ongoing time disparity.

In nature the ongoing and the transient disparities are of about equal magnitude; they vary with changes in the azimuth of the source of sound. They do, however, have different advantages for locating sounds. The ongoing time disparity can be measured repeatedly while the sound lasts. Transient disparity, on the other hand, can be monitored only intermittently, but it is less likely than the ongoing disparity to be confused by echoes.

Human beings rely on both transient and ongoing disparity to determine the source of a sound. Owls appear to rely on only the ongoing difference. Like other kinds of spatial information, the ongoing disparity has a major ambiguity. It may be best understood in the case of a tone coming directly from the side. The signals detected by the owl's ears are sinusoidal (regular) waves; because of the different distances to the ears the waves will be slightly out of phase with each other. The magnitude of the phase delay so created will depend both on the frequency of the tone and on the distance between the ears. As the frequency of the wave or the distance between the ears increases, the wave passes through more of its cycle as it travels around the head to reach the far ear; hence the phase delay is greater.

When the frequency of the tone is so high that the wave passes through exactly half of its cycle before it reaches the far ear, the phase delay corresponds to half of the wavelength. Such a delay could be caused by a sound coming di-

© 1981 SCIENTIFIC AMERICAN, INC

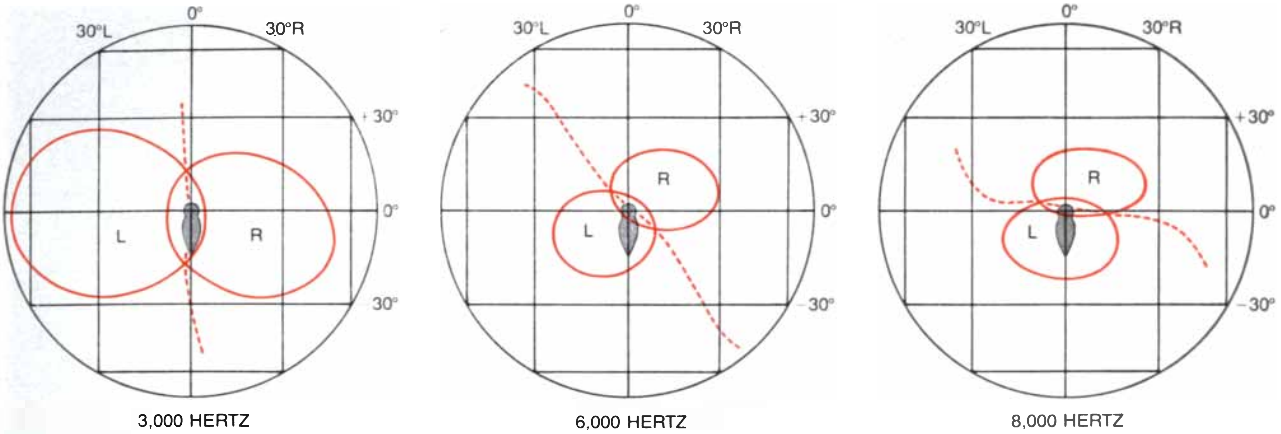
rectly from the owl's left or directly from its right, since the difference in path lengths is the same for these two directions. It is therefore impossible for the bird's auditory system to determine the direction of the sound on the basis of ongoing disparity alone. At higher frequencies the situation is worse still. When the wavelength is equal to the distance between the ears, for example, there is no phase delay, since the wave travels through its entire cycle while passing around the head. This relation could correspond to a sound coming from the right, from the left or from directly ahead; on the basis of phase delay alone the bird has no way of determining which is the case.

The wavelengths at which such ambiguities arise depend on the distance between the ears. The barn owl's ears are about five centimeters apart; phase ambiguity will therefore arise at a wavelength of 10 centimeters or less, which corresponds to frequencies of 3,000 hertz or more. Since the barn owl has no difficulty determining the azimuth of even high-frequency tones, Konishi and I assumed that at high frequencies the bird must rely on some source of information other than the ongoing time disparity. A likely candidate for the additional cue was transient disparity, because it is not affected by changes in frequency and because other species, including man, are known to depend on it at high frequencies.

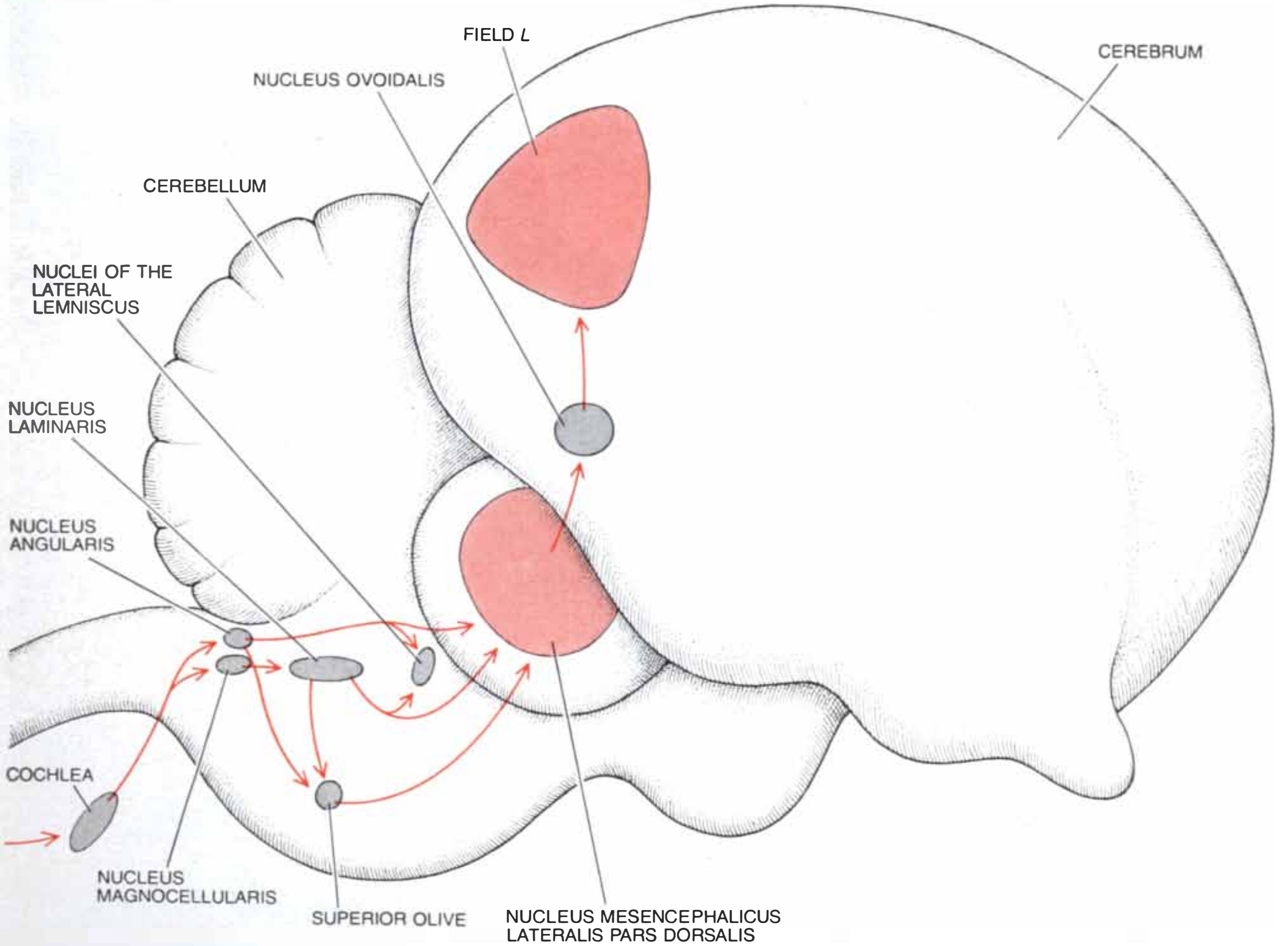
How wrong this conclusion was has been demonstrated conclusively by Andrew Moiseff and Konishi in a further head-orientation experiment with the barn owl. They presented sound directly and independently to both ears by means of small speakers implanted in the owl's ear canals. This technique enabled them to eliminate transient disparities and differences in intensity between the ears as they varied the ongoing time disparity. The delay between the waveforms of the sound in the two ears could be adjusted in steps as small as one microsecond. In response to ongoing disparities of as little as 10 microseconds or as much as 80 microseconds the owl made quick horizontal turns of the head that corresponded approximately to the angle implied in the ongoing difference. This response suggests, in the absence of other interaural cues, that the owl continues to make use of the phase delay, or ongoing disparity, even at high frequencies.

The finding was startling because it implied that the barn owl has some means of overcoming the phase ambiguity. Furthermore, for the owl's auditory system to sense such small differences in the timing of the waveforms in the two ears it must receive specific information about acoustic signals occurring at 7,000 hertz, or once every 143 microseconds. This is remarkable, because the nerve impulses that convey this infor-

© 1981 SCIENTIFIC AMERICAN, INC



DIRECTIONAL SENSITIVITY of the ears of the barn owl changes with the frequency of sound waves. The funneling action of the troughs in the facial ruff makes the ears more sensitive to sounds from some directions than to sounds from others. At low frequency the area of maximum sensitivity of the left ear is to the left and that of the right ear is to the right. Waves with higher frequencies are more efficiently reflected by the ruff. Since the left trough is tilted down and the right trough up, as the frequency increases the areas of greatest sensitivity move toward vertical alignment: the right ear is more sensitive upward and the left ear downward. At 8,000 hertz (cycles per second) the regions of most sensitive hearing are almost directly above and below the bird. Because natural sound usually has many frequencies, the owl can exploit differences in loudness to identify both the horizontal and the vertical direction of a sound source.



AUDITORY PATHWAY of the central nervous system of the barn owl leads from the cochlea to an area of the forebrain known as Field *L*. Along this route the nerve impulses undergo considerable processing: data about the timing and frequency of sound are converted into information about the location of the sound source. Much processing takes place in various centers of the lower brain. By the time the impulses have reached the nucleus of the midbrain that is called the mesencephalicus lateralis pars dorsalis (MLD) they are directed into a network of neurons that respond to sounds from specific areas; the distribution of those areas forms a two-dimensional map of the space in front of the bird. Information about a sound's location then passes to Field *L*, corresponding to the auditory cortex of mammals.

© 1981 SCIENTIFIC AMERICAN, INC

mation from the cochlea to the brain last for more than 1,000 microseconds.

Ongoing time disparity is very useful to the barn owl; by itself, however, the cue does not have the precision the owl needs in order to hunt. With speakers implanted in the ear canals the owl responded to a given ongoing time disparity with turns that varied in magnitude by up to 15 degrees in either direction. In contrast, the largest standard deviation of error for owls responding to external targets is only 2.5 degrees in either direction, and the error is usually less than 1.5 degrees. Other cues must therefore be combined with the ongoing disparity. It is known that differences in intensity help to specify location, but we also tried to discover whether the bird employs transient disparities.

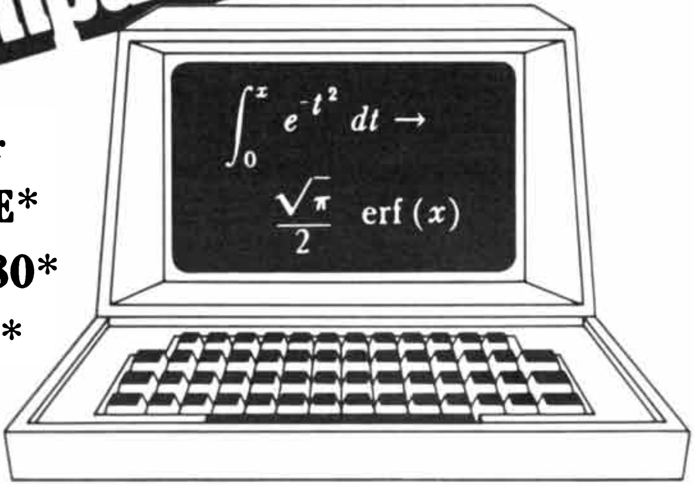
Our original hypothesis, that the owl relies on transient disparity to compensate for phase ambiguity at high frequencies, has clearly been invalidated. The owl's performance in determining the azimuth of a tone suggests that transient disparities are not relied on at all. In head-orientation trials the owl was presented with tones of 7,000 and 8,000 hertz. The speaker was sometimes at 30 degrees to the right and sometimes at 30 degrees to the left. In these situations a curious kind of behavior was observed: with the target at 30 degrees to the right the owl sometimes turned 30 degrees to the left, and vice versa.

This confusion is clearly a manifestation of phase ambiguity. The cycle period of a 7,000-hertz tone is 143 microseconds and that of an 8,000-hertz tone is 125 microseconds. With a source of sound at 30 degrees to the right or the left these tones pass through about half a cycle in traveling over the difference between the path lengths to the ears. Therefore a tone coming from 30 degrees to the right yields the same phase delay as one coming from 30 degrees to the left. The ambiguity is present only in the ongoing disparity; if the owl had been relying on transient disparity, it would immediately have picked out the correct location.

This result confirms that the owl continues to rely on phase-delay information, even at high frequencies, in spite of its ambiguity, and apparently does not rely on transient disparity. Since the wavelength of low-frequency sounds is considerably greater than the distance between the ears, phase ambiguity does not exist at low frequencies. Moreover, the presence of a number of frequencies in natural sounds helps the owl to resolve phase ambiguities. When many different pairs of directions arise from different frequencies, the owl selects the one direction in space that is consistent with one member of each pair.

Head-orientation trials clearly show that the barn owl relies on two kinds of information to determine the origin of

Computer Algebra



for your
APPLE*
TRS-80*
CP/M*
PET*
from
$20 to $250:
muMATH
muLISP
PICOMATH

*manufacturer's trademark

the SOFT WAREHOUSE™
P.O. Box 11174 / Honolulu, Hawaii 96828-0174
Telephone (808) 734-5801

To preserve your copies of SCIENTIFIC AMERICAN

A choice of handsome and durable library files—or binders—for your copies of SCIENTIFIC AMERICAN. Both styles bound in dark green library fabric stamped in gold leaf.

Files Each file holds 12 issues. Price per file $5.95; three for $17.00; six for $30.00, postpaid. *(Add $2.50 each outside U.S.A.)*

Binders Each binder holds 12 issues. Issues open flat. Price per binder $7.50; three for $21.75; six for $42.00, postpaid. *(Add $2.50 each outside U.S.A.)*

To: Jesse Jones Box Corp., P.O. Box 5120, Philadelphia, Pa. 19141

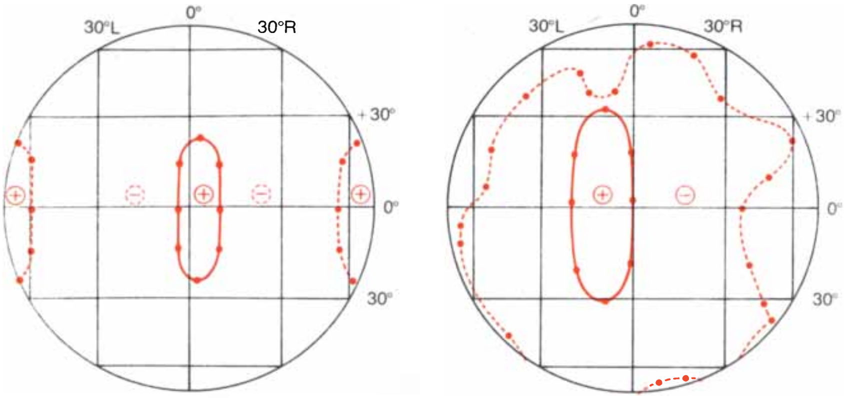
I enclose my check or money order for $_____ (U. S. funds only).
Send me _____ SCIENTIFIC AMERICAN ☐ Files. ☐ Binders.

file binder

Name ____________
(please print)
Address ____________
City ____________
State ________ Zip ________

NOTE: Satisfaction guaranteed or money refunded. Allow four to six weeks for delivery.

© 1981 SCIENTIFIC AMERICAN, INC



TWO TYPES OF NEURONS in the brain of the barn owl are sensitive to sounds from specific directions. Shown here are maps of the receptive fields of the two cell types. Receptive fields are the regions of space within which sounds will produce an excitatory response in the neuron. Complex-field neurons, found in the MLD, have several such areas. A typical complex-field receptive pattern is shown at the left. The receptive areas correspond to the directions that give rise to identical ongoing disparities in the timing of sound waves. Between those regions sounds produce an inhibitory response. Limited-field neurons are found in both the MLD and Field *L*. A typical limited-field receptive pattern is shown at the right. Limited-field cells have a single receptive area. Sounds from outside this area produce a strong inhibitory response. Each limited-field cell responds to a specific difference between the ears in sound timing and intensity.

a sound: the interaural spectrum and the ongoing time difference. The latter yields clues to the azimuth of the sound source. The differences in intensity between the ears yield clues to both the azimuth and the elevation. To learn how the auditory system transforms these cues into a neural image of sound location calls for a different experimental approach.

The technique I resorted to, first with Konishi and later in independent experiments, is that of inserting a microelectrode into the brain of an anesthetized owl and searching for sites of neuronal activity while sounds are presented to the bird's ears. Konishi and I began the experiments with the same apparatus we had used in the head-orientation trials. After the owl was anesthetized its head was held rigidly in a special stereotaxic frame. A microelectrode was lowered into the brain until nerve impulses from a single neuron could be recorded. By moving the target speaker around the owl it was possible to map the regions of space to which the neuron responded.

Since the source of a sound in space is determined only after considerable neural processing, we began our study by exploring structures fairly far along the auditory pathway: in the midbrain and forebrain. The main auditory center in the midbrain of birds is called the nucleus mesencephalicus lateralis pars dorsalis (MLD). (It corresponds to the structure in the brain of mammals called the inferior colliculus.) Nerve impulses reaching this center have already been processed in one or more nuclei farther down the auditory pathway. Farther up the pathway an area designated Field *L* is the primary receiving center in the forebrain for auditory impulses. (This structure corresponds to the auditory cortex in mammals; birds have no exact analogue to the auditory cortex.)

In both the MLD and Field *L* the large majority of neurons do not respond precisely to spatial cues. Some of the neurons show their highest level of activity in response to sounds from a certain region of space, but the borders of the region are not sharp, and they vary greatly with the intensity of a sound. Other neurons are even less specific in their response, being excited by sounds from virtually all directions. These neurons probably contribute not to specifying location but to the detection or identification of sounds.

Two types of neuron found in the MLD and Field *L*, however, are highly sensitive to sound location. The first of them, called the complex-field neuron, is found in large numbers in the MLD, usually in clusters scattered among other kinds of neurons. The activity of complex-field neurons is stimulated by sounds coming from several separate regions of space, called excitatory fields. The neurons are much less excited, or are even inhibited, by sounds arising in the regions of space between the excitatory fields.

When the location of the centers of the excitatory fields in space are calculated for an individual complex-field neuron, an interesting correspondence is observed. The excitatory fields are the same as the regions of space the owl confuses under conditions of phase ambiguity. The multiple excitatory fields represent the regions from which sounds reaching the ears will generate phase delays of equivalent magnitude. Each complex-field neuron therefore seems to be sensitive to a particular phase delay at a particular frequency. The presence of several excitatory fields for each neuron would appear to be the physical correlate of spatial confusion due to phase ambiguity.

The second type of neuron, called the limited-field neuron, which is found in both the MLD and Field *L*, responds in an even more specific way. Limited-field cells are excited only by sounds coming from a single region of space. The regions to which limited-field neurons respond are typically elliptical. Their size varies in azimuth from seven degrees to 42 degrees and in elevation from 23 degrees to an entire band in front of the bird. Unlike other neurons in the auditory pathway, the limited-field neurons are extremely selective, responding only to changes in location; large changes in sound intensity cause little if any alteration in the sharp borders of the receptive region.

Some of the sharpness of the borders of the limited-field-neuron receptive regions is due to the fact that sounds coming from outside the excitatory region inhibit the cell's response. The inhibitory effect becomes stronger as the location of the sound approaches the border of the excitatory region, at which point the inhibiting effect changes to one of excitation. Although the spatial regions that give rise to an excitatory response are fairly large, within them there is a smaller region of the best response. These "best regions" vary in size from 2.5 to 15 degrees in azimuth and from five to 45 degrees in elevation.

Limited-field units are found in both the MLD and Field *L*. Their distribution in the two centers is, however, fundamentally different. In Field *L* limited-field neurons make up only about 15 percent of the total population of nerve cells, and they are often found scattered among other types. In the MLD, on the other hand, these cells are concentrated on the side and front margins of the nucleus, interspersed only with a few neurons of the complex-field type. After we had intensively explored and mapped the MLD it became apparent to us that the arrangement of limited-field neurons in that nucleus constitutes a map of two-dimensional space, with the distribution of the receptive areas of the neurons following the contours of space.

The map is distorted, however: the area in front of the bird, the region of maximum auditory acuity, is represented disproportionately. Sound azimuths are arrayed in the horizontal plane. On the right side of the structure representing the map are neurons that are excited by sounds originating between 15 degrees to the right and 60 degrees to the left. On the opposite side are neurons stimulated by sounds between 15 degrees to the left and 60 degrees to the right. This arrangement means that the 30 degrees of space in front of the bird is

© 1981 SCIENTIFIC AMERICAN, INC

represented on both sides of the map and therefore by two sets of neurons. In addition the map is arranged so that on both sides the population of neurons that represent the 30 degrees in front is disproportionately large. As a result of the double representation and the large number of neurons on each side the 30 degrees in front is analyzed with great precision, a fact that may explain the owl's particular accuracy in locating sounds in this area.

Sound elevations are arrayed transversely on the map. The "best regions" of the limited-field neurons range from 40 degrees upward to 80 degrees downward. The upper fields are at the top of the curved surface of the map and the lower fields are at the bottom.

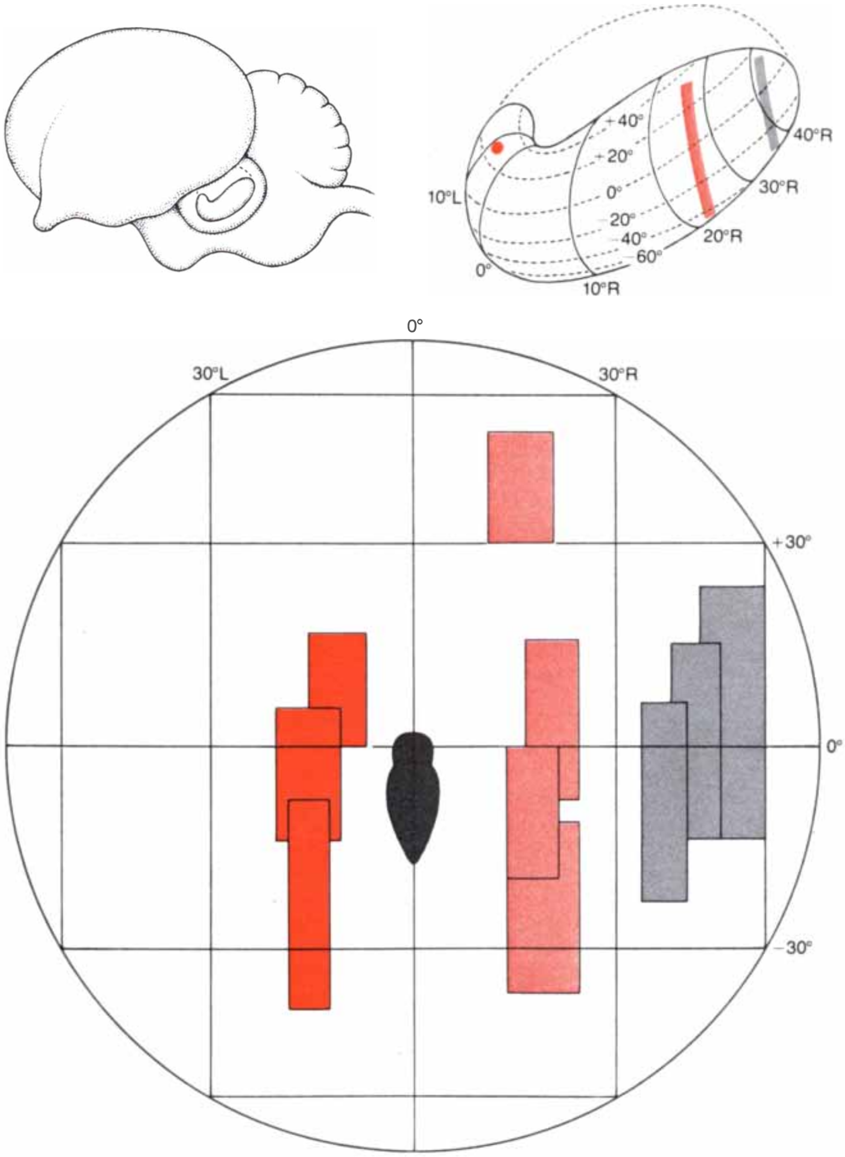
How does the nervous system of the barn owl construct this remarkable map? Substantial understanding of the process has come from experiments by Moiseff and Konishi. In these tests speakers were placed in the ear canals of anesthetized owls. When sound was delivered separately to the two ears, the timing and intensity differences required to elicit a response in each neuron could be observed. These values were then correlated with the areas of space known to excite each set of neurons. The results of the investigations show that the limited-field units in the map are quite sensitive to ongoing differences in timing. This observation corresponds nicely to the bird's dependence on ongoing disparities demonstrated in head-orientation experiments.

Limited-field neurons respond only to an extremely narrow band of ongoing time delays: the size of the band ranges from 40 to 100 microseconds. Even within this minute range one particular delay always elicited the greatest response. Changing the ongoing difference by as little as 10 microseconds could change the strength of the neuron's response by as much as 75 percent. This degree of sensitivity complements (and helps to explain) the owl's precision in aerial hunting.

The ongoing disparity that gives rise to the greatest response also corresponds to the region of space to which the cell responds. Neurons that respond to sounds coming from the front are maximally excited by small ongoing disparities. Neurons that respond to sounds at greater angles require larger disparities. These results confirm at the level of individual cells the conclusion drawn from behavioral tests: that the owl relies heavily on the ongoing difference in timing between the ears to determine location in the horizontal plane.

Such experiments have also helped to confirm and explain the owl's reliance on differences in sound intensity. By varying the relative intensity of sounds presented independently to the ears of an anesthetized owl it was found that for each limited-field neuron there is one difference in intensity that evokes the maximum response. Changing the difference away from this value causes the response to decrease and finally to cease. The pattern is not affected by the changes in the average sound level; it depends only on the difference in intensity between the ears.

The evidence derived from probing the brain of the barn owl shows that the map of space in the MLD is created by the same cues the owl was known to rely on in finding the azimuth and elevation of a sound: ongoing time disparities and the interaural spectrum. By means of an exquisitely precise transformation the auditory system converts these cues into spatial information. The arrangement of the cells of the map implies that neighboring neurons respond to cues that are only very slightly different. Moreover, the order of the excitatory fields in the map follows the continuity of space. How the brain of the owl is able to achieve such precise connections presents an intriguing problem for further investigation.



TWO-DIMENSIONAL MAP of frontal space is found in the MLD of the barn owl. The map is made up of limited-field neurons. Each cell responds to sounds from a specific region of space. The arrangement of the receptive areas of the neurons follows spatial contours. Shown above is the region on the left side of the brain that responds to sounds from the right. Neurons in this region are sensitive to sounds in an area from 15 degrees on the left to 60 degrees on the right, and from 40 degrees upward to 80 degrees downward. Electrode traces through the structure will thus correspond to a set of regions of space aligned vertically; a set of three such traces and the spatial regions they correspond to are shown. A corresponding structure on the right side of the owl's brain consists of the neurons that respond to sounds originating from the left. The region from 15 degrees on the left to 15 degrees on the right is thus represented on both sides of the brain and is mapped on each side by a disproportionately large number of neurons; this is the area of the barn owl's greatest acuity in locating a sound source.

© 1981 SCIENTIFIC AMERICAN, INC

Fibrinogen and Fibrin

The plasma protein fibrinogen is converted into fibrin to form a blood clot. In time the clot breaks down. Both processes can now be understood in terms of the detailed structure of the protein

by Russell F. Doolittle

Prick us and we bleed, but the bleeding stops; the blood clots. The sticky cell fragments called platelets clump at the site of the puncture, partially sealing the leak. The platelets have another important function: their surface serves as an assembly area for the mobilization of an elaborate force of enzymes, the ultimate product of which is the protein-cleaving enzyme thrombin. The target for that protease is fibrinogen, a large molecule that ordinarily circulates, dissolved, in the blood plasma. Under attack by thrombin the fibrinogen undergoes a remarkable transformation. The altered molecules link up, spontaneously aligning themselves into the long threadlike polymer called fibrin, the primary ingredient of a blood clot. The strands of fibrin form a network. The network (which forms only in the direct vicinity of the clumped platelets, because that is where thrombin is generated) pervades the blood plasma locally and changes it from a solution to a gel. The blood clots.

What kind of molecule is fibrinogen that it can be attacked by a protease (thrombin) and thereupon spontaneously polymerize? That question should not be dealt with until another aspect of the clotting phenomenon is considered. A fibrin clot is designed not to last forever. It is a transitory device, quickly formed and soon dismantled in favor of a more permanent repair system. There are even more pressing reasons for dissolving a blood clot. A small piece of a clot (an embolus) dislodged into the circulatory system can occlude a small blood vessel; an embolism in the lung can be fatal. A thrombus—a clot formed at the wrong time and place, not in response to injury but as a consequence of some disease process such as atherosclerosis—can lead to a heart attack or a stroke.

To minimize the danger of embolism and to reduce the likelihood of thrombosis, as well as to clear away a therapeutic clot in the wound-healing process, a proteolytic system complementary to the one that generates thrombin is called on. It gives rise to the enzyme plasmin, which destroys the fibrin network and restores the fluidity of the plasma. Now the question becomes: What kind of molecule is it that can polymerize on being attacked by one protease (thrombin) and then "depolymerize" under attack by another protease (plasmin)? Put another way, how is the functioning of fibrinogen and fibrin explained by their structure? The answer is the subject of this article.

The structure of fibrinogen has been highly controversial for the past 10 or 15 years. Although some skirmishing continues among a few protein chemists, I think there is now overwhelming evidence, from a variety of investigative techniques, to support the structure I shall present.

One source of controversy has been apparently conflicting evidence from electron micrography. In 1959 Cecil E. Hall and Henry S. Slayter, who were working at the Massachusetts Institute of Technology, published exquisite micrographs that showed fibrinogen as a trinodular, or three-globule, structure [see "The Clotting of Fibrinogen," by Koloman Laki; SCIENTIFIC AMERICAN, March, 1962]. Unfortunately structural chemists were a long way behind the electron microscopists at the time, and although the trinodular form was for a while generally accepted, there was little in the way of chemical underpinning for it. As it happened, the methodology of electron microscopy changed rapidly in the early 1960's. Hall and Slayter had made their micrographs with the shadowing technique, and then negative staining came to be the preferred method. Fibrinogen does not take well to most negative stains, and a series of reports over the next decade held that the trinodular structure observed by Hall and Slayter was merely an artifact. Instead, these later workers maintained, fibrinogen was more like a bloated beach ball, which opened up during polymerization to form fibrin. Recently, however, shadowing techniques have made a comeback, enabling a number of laboratories once again to show a trinodular structure for fibrinogen. Moreover, several workers have even been able to visualize a trinodular structure by means of negative staining.

Many other experiments support a trinodular (or at least a polydomainal) structure for fibrinogen, particularly when they are all taken together. These include an early X-ray-diffraction study, a variety of hydrodynamic measurements (such as analytical ultracentrifugation) and other physicochemical determinations, and also studies in which the fibrinogen molecule is fragmented with enzymes. In recent years the entire covalent structure of the human fibrinogen molecule (the full sequence of the amino acid units of its protein chains and the ways the chains are interconnected) has been established. It confirms in detail a particular polydomainal structure.

In the 1930's W. T. Astbury of the University of Leeds undertook an intensive study of the structure of fibrous proteins by the method of X-ray diffraction. In a fibrous material the molecules are presumably aligned lengthwise, so that the repeat distance from one amino acid to another, if it is regular, is revealed by the scattered X rays when the beam is perpendicular to the fiber axis. In the early 1940's Kenneth Bailey collaborated with Astbury in an attempt to establish differences between fibrinogen and fibrin. They found that the two proteins exhibited identical diffraction patterns, which in turn were indistinguishable from those Astbury had found earlier for certain other fibrous proteins such as keratin and myosin.

As a result of these experiments and others fibrinogen and fibrin were classified in a group of proteins characterized by a particular repeat distance. The distance was later shown to be unique to "coiled coils," in which two or more protein chains in the form called an alpha helix are twisted together, or su-

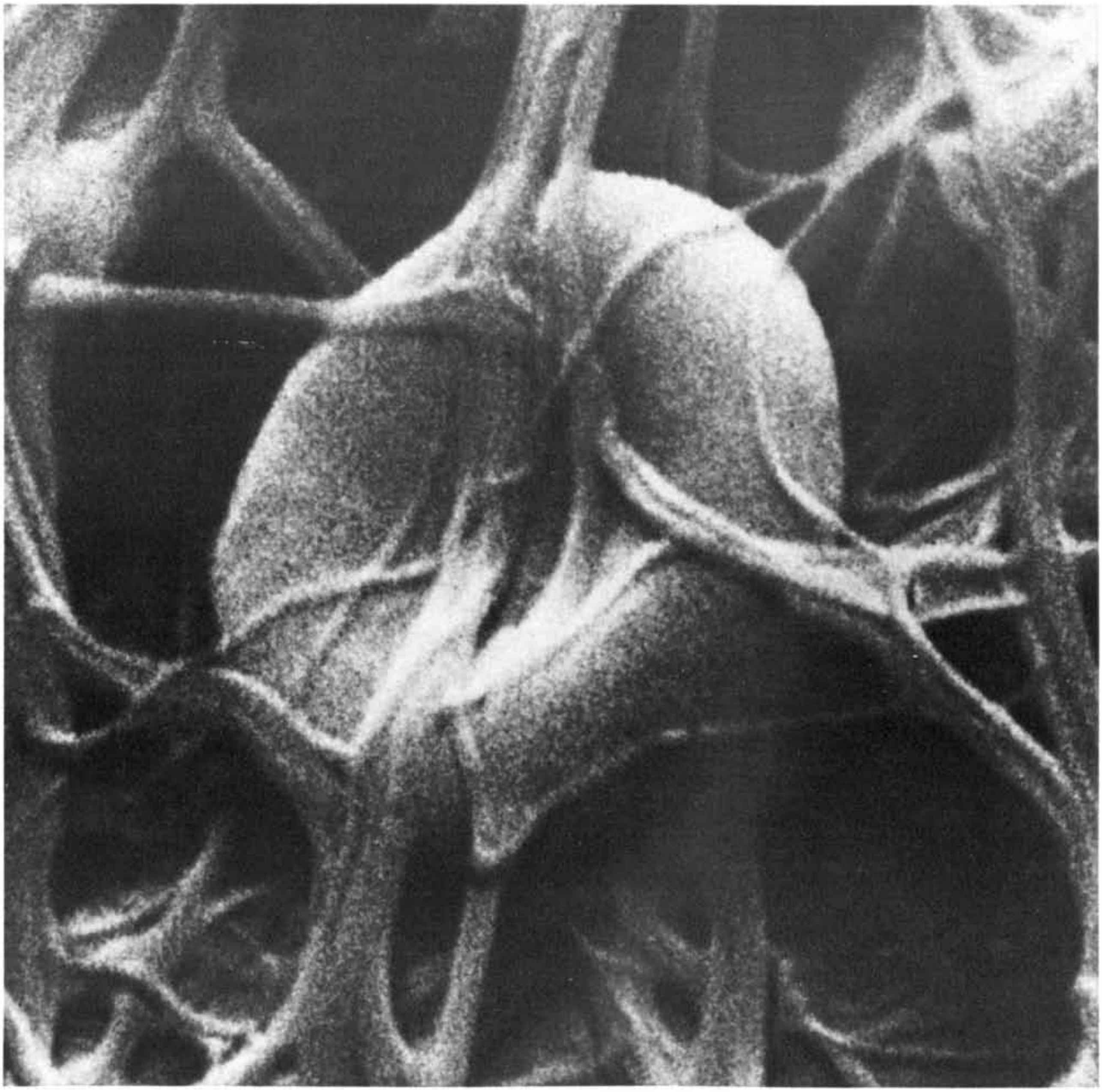
© 1981 SCIENTIFIC AMERICAN, INC

percoiled. The electron micrographs of Hall and Slayter showed a molecule composed of three aligned globules, but the connections between the globules could not be resolved. That indicated they must be less than 15 angstrom units thick; Carolyn Cohen, who is now at Brandeis University, suggested that the connections might be the coiled coils.

In the 1940's and 1950's fibrinogen, as well as many other commonly available proteins, was subjected to an onslaught of physicochemical studies. Its molecular weight was accurately determined to be 340,000 daltons, which corresponds to a total of about 3,000 amino acids. Its shape was another matter. The physicochemical data were as consistent with a long, thin asymmetric structure as with a swollen, highly hydrated symmetrical one. As it turns out, the data are also entirely in harmony with a molecule composed of linked nodules.

More data came from the enzymatic fragmentation studies. As early as 1961 investigators at the Pasteur Institute in Paris decided to break down the large fibrinogen molecule into manageable components by digesting it with plasmin. They ended up with a set of core fragments, the major ones of which, separated on the basis of size by ion-exchange chromatography, were designated fragments *A* through *E*. Fragments *D* and *E* made up the bulk of the recovered mass, and there was about twice as much of *D* as there was of *E*.

These fragments, and another set produced by digestion with the enzyme trypsin, were thoroughly investigated by Elemer Mihalyi of the National Heart,



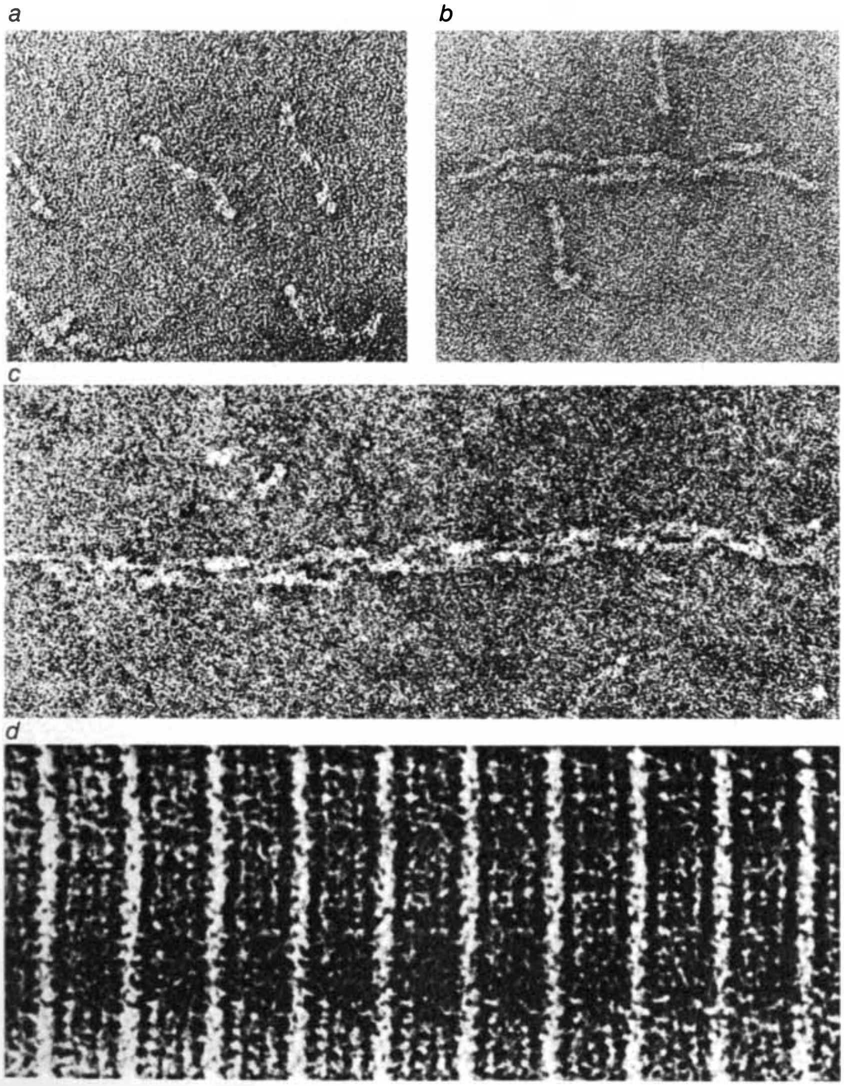
FIBRIN STRANDS, enlarged about 20,000 diameters, enmesh a red blood cell in an electron micrograph made by Emil O. Bernstein and Eila Kairinen of the Gillette Research Institute. Each strand is an aggregate of individual fibrin monomers generated by the action of the enzyme thrombin on fibrinogen molecules. Strands are from a clot formed in intravenous catheter implanted near a patient's heart.

© 1981 SCIENTIFIC AMERICAN, INC

Lung, and Blood Institute and his coworkers. Their studies led to two major conclusions. First, the architecture of fibrinogen makes it susceptible to a kind of attack that is independent of the attacking enzyme: the vulnerability of the substrate rather than the preferential specificity of the enzyme is the directive feature. This is just what would be expected for a structure made up of linked globules. Second, the globules themselves have a certain amount of rotational independence in the intact molecule, that is, in solution they are not rigidly oriented in space with respect to one another. These experiments were followed by the findings of Victor J. Marder of the National Institute of Arthritis and Metabolic Diseases, who studied the time course of the plasmin-directed breakdown of fibrinogen. His characterization of transient intermediate breakdown products was consistent with a situation in which the enzyme was successively cutting links between the domains of a three-globule molecule.

Two other items of structural evidence should be mentioned before I turn to the amino acid sequencing. The polydomainal structure is also supported by a study of the protein's "melting point." If a protein is heated under carefully observed conditions, a temperature is reached at which the protein "melts," or denatures: the amino acid chains, formerly disposed in a precise three-dimensional conformation, collapse. This point can be detected by changes in heat flow alone. John W. Donovan and Ronald A. Beardslee of the Western Regional Research Center of the U.S. Department of Agriculture showed that two proteins in intimate contact melt at a single temperature that is different from the melting point of either of the individual proteins. Donovan went on to show, with Mihalyi, that fibrinogen is unique in this respect. It has two melting points, one for the two fragments *D* and one for fragment *E*, demonstrating convincingly that the two domains are not in intimate contact with each other.

Finally, Nancy M. Tooney and Carolyn Cohen studied the structure of microcrystals, prepared from partially digested fibrinogen, by analyzing optical-diffraction patterns and electron micrographs. Their results demonstrated that the fundamental unit length of fibrinogen must be 450 angstroms; this is in good accord with the 475-angstrom length determined by Hall and Slayter from electron microscopy and is also consistent with much of the hydrodynamic data. Recently Cohen has managed to obtain genuine crystals from variously modified fibrinogens, and although the data are still at a preliminary stage, they seem to be consistent with a molecule occupying a "cylinder of influence" about 450 angstroms long and 90 angstroms in diameter.



FIBRINOGEN AND FIBRIN, negatively stained with uranyl acetate, are enlarged 375,000 diameters (*a, b, c*) and 500,000 diameters (*d*) in electron micrographs made by Robley C. Williams of the University of California at Berkeley. Individual fibrinogen molecules treated with calcium ions display a three-globule structure (*a*). Thrombin converts fibrinogen into fibrin monomers. At an early stage in clot formation (*b*) two chains of three monomers each are seen; the two chains are offset by a half-monomer overlap. At a later stage (*c*) a two-chain strand has developed; the bright regions along the strand represent two terminal domains of two monomers in end-to-end contact. In a segment of a fully developed, thick fibrin strand (*d*) the individual fibrin monomers are oriented horizontally. The prominent vertical striations, 230,000 angstrom units apart (half the length of a monomer), are formed by terminal domains in register throughout the three-dimensional strand. The print was made by exposing a negative 10 times and offsetting it between exposures by the interval between striations. The technique reduces "noise" in the micrograph while preserving (and confirming) the periodic structure.

Establishing the amino acid sequence of a protein as large as fibrinogen is a formidable undertaking. It was clear that many aspects of fibrinogen chemistry could be understood only if sequence information was available, however, and so workers in a number of laboratories began pecking away at the task.

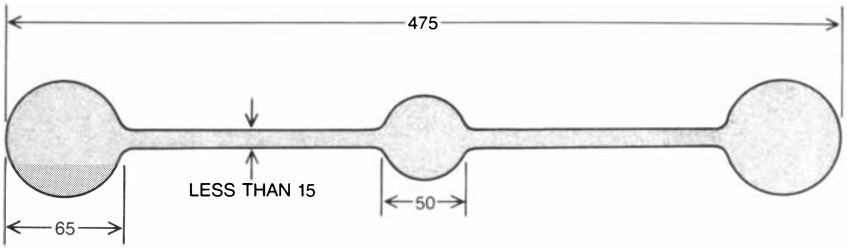
Protein chains have an amino (NH_2) end and a carboxy (COOH) end. When the amino acid units at the amino terminals of chains in fibrinogen were determined, three different "end groups" were identified, two copies of each of which were present in each intact 340,000-dalton molecule. Then three different chains were isolated. The total of their molecular weights came to only half the total weight of the intact molecule. These findings made it clear that the molecule is composed of two sets of three nonidentical chains interconnected by disulfide bonds. (One of the 20 amino acids is cysteine. Two cysteines can be linked by way of their sulfur atoms.) The chains were designated alpha, beta and gamma.

© 1981 SCIENTIFIC AMERICAN, INC

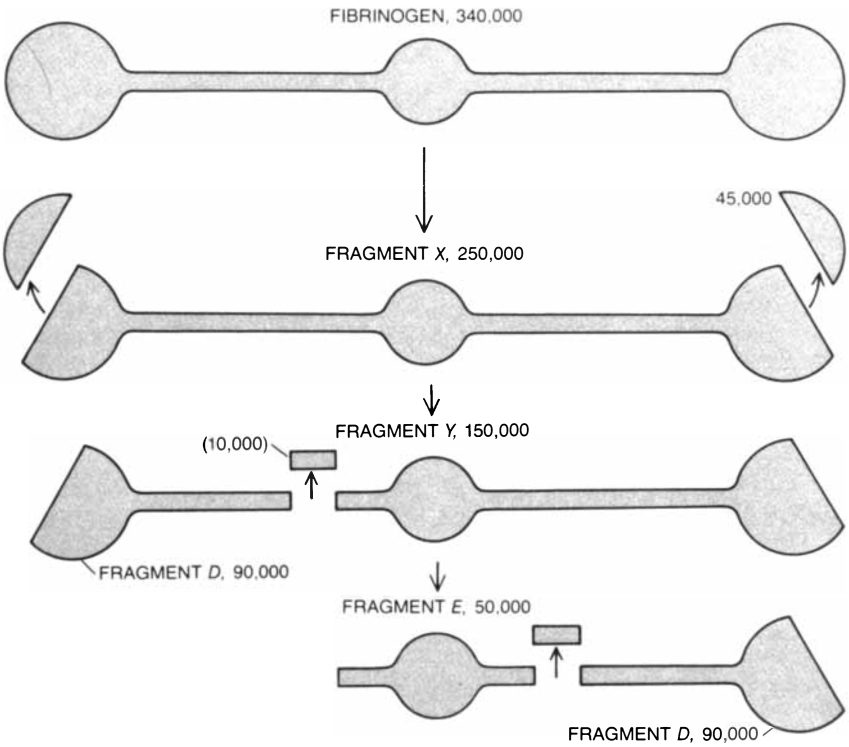
The first major attack on the primary structure of human fibrinogen was made in Birger Blombäck's laboratory at the Karolinska Institute in Stockholm in the late 1960's. Blombäck and his colleagues treated fibrinogen not with a protease but with cyanogen bromide, which cleaves protein at only a few sites. They isolated a fragment that contained all the amino terminals of the three nonidentical chains. The fragment was subsequently found to be a disulfide-linked dimer (a compound with two identical halves), revealing that all six amino terminals of the fibrinogen molecule are clustered near one another in the intact molecule.

The fragment accounted for only about 15 percent of the mass of fibrinogen, but it accounted for almost half of the two-cysteine units (cystines) constituting a disulfide bond, and so it was named the disulfide knot. Virtually the entire sequence of the fragment, which had 247 amino acids in each of its two halves, was determined by the Karolinska group. Subsequent experiments by Marder showed that the disulfide knot is very similar to fragment *E*. Both are dimers, and they cross-react in immunological tests. Moreover, there are two fragments *D* for every fragment *E*. Fragment *E* (or the disulfide knot) is the central domain of fibrinogen; the two fragments *D* are the terminal domains.

After Blombäck's initial assault the sequence offensive stalled for a while, and when the action resumed, it had shifted to two other laboratories: Agnes Henschen's at the Max Planck Institute for Biochemistry in Munich and ours at the University of California at San Diego. After several years of intensive competitive effort the entire covalent structure was established; most of it was determined independently in both laboratories. The alpha chain consists of 610 amino acid units, the beta chain of 461 and the gamma chain of 411, for a total of 1,482 amino acids in each of the dimeric halves. The calculated molecular weight is 329,842. Approximately 10,000 daltons more is added by two different carbohydrate clusters on each half, bringing the total into perfect agreement with the earlier physicochemical measurements.



TRINODULAR (THREE-GLOBULE) MODEL of the fibrinogen molecule was proposed in 1959 by Cecil E. Hall and Henry S. Slayter of the Massachusetts Institute of Technology. The dimensions are given in angstroms. This early model was based largely on the appearance of the molecule in electron micrographs made by a heavy-metal shadowing technique.



DIGESTION OF FIBRINOGEN with the enzyme plasmin was studied by Victor J. Marder in 1968. The enzyme gave rise successively to the intermediate products *X* and *Y* and to the core fragments *D* and *E*, which are shown here (in terms of the Hall-Slayter model) along with their molecular weight. The fragments and the time course of their appearance are consistent with the enzymatic cleavage of links between the domains of a three-globule molecule.

I shall consider a few of the highlights revealed by the sequence studies, particularly those that have a direct bearing on three-dimensional structure. An early notion that the three chains might be homologous (similar enough to have been derived from a common ancestral chain) was increasingly confirmed as sequence data accumulated. As in so many proteins, the homology was best exemplified by the location of the cysteines, all of which, Henschen had long since found, participate in the formation of disulfide bonds.

The most interesting aspect of the disulfides, in my view, was revealed during the sequencing of the alpha chain. Blombäck had found that each of the three nonidentical chains incorporated an unusual set of cysteines in a sequence of five amino acids: cysteine-*X*-*Y*-*Z*-cysteine. We then found a second such sequence in the alpha chain, 111 amino acid units farther along the chain. Would the other two chains have similar second sequences at the same relative locations? Within a few days we had tentatively answered the question with an excited yes, although it took considerably more effort to prove it. All three chains have two cysteine-bounded five-unit sequences separated by 111 amino acids (in the alpha and gamma chains) or by 112 (in the beta chain). Two obvious structural questions arose: How are the disulfide bonds arranged between pairs of these particular cysteines, and what is the three-dimensional arrangement of the 111 (or 112) amino acid units separating the two cysteine-bounded sequences in each chain?

Even before we began our experiments we deduced a solution to the first problem on evolutionary grounds. We reasoned that in some ancestral fibrinogen molecule there had been three identical chains (which had since been varied by mutation of their genes). It is axiomatic that the same sequence in the same environment must have the same

© 1981 SCIENTIFIC AMERICAN, INC

three-dimensional arrangement, and so a structure with a threefold symmetry must be evoked, so that each chain is equivalent. This calls for an assemblage in which disulfide connections link the first cysteine of one chain to the second cysteine of the second chain, the first cysteine of the second chain to the second cysteine of the third chain and finally the first cysteine of the third chain to the second cysteine of the first chain, thereby completing a "disulfide ring." When we constructed a detailed model of such a structure, the cysteine side chains fell into place and the disulfide bonds formed just such a ring. All the biochemical data that have accumulated since then support the proposed interconnection.

The nature of the sequences between the disulfide rings was even more interesting. Examination of the sequences revealed that amino acids that have nonpolar (hydrophobic, or water-repelling) side chains recur rhythmically through much of each sequence, suggesting a helical arrangement. Computer schemes for assessing the likelihood a particular sequence will have a particular conformation revealed that much of each inter-ring segment ought to be in the form of an alpha helix. It seemed clear that these segments must correspond to the coiled coils. By making models we could show that the sequences lend themselves to forming a three-strand rope in which all the polar (hydrophilic) side chains are turned outward into the surrounding water and most of the hydrophobic side chains are turned inward to form a nonpolar core. Finally, we were able to estimate the distance from one disulfide ring to the next. Whereas the "translational" distance for a standard alpha helix is approximately 1.5 angstroms per amino acid unit, supercoiling shortens the distance, so that each amino acid advances about 1.43 angstroms. If this value is multiplied by 111, the distance between disulfide rings comes to 158.7 angstroms. That is in good agreement with the distance between globules in the Hall-Slayter model, which is about 150 angstroms.

The only significant regions of alpha-helical structure in any of the chains appear to be those between the disulfide rings. The carboxy-terminal halves of the beta and gamma chains, which are strongly homologous, appear to be highly folded, compact regions; they make up the bulk of the terminal fragments *D*. The alpha chain's carboxy half, on the other hand, is an unfolded, highly polar protuberance that is readily cleaved away from the parent molecule by a variety of proteases. Fibrinogen lacking these alpha-chain extensions is closely akin to the intermediate Marder called fragment *X*.

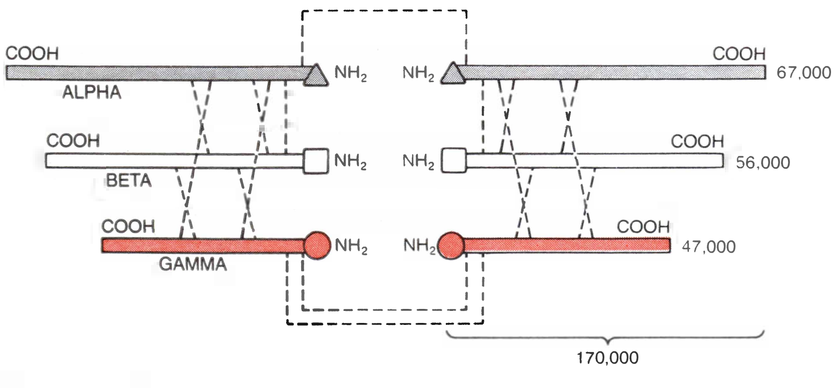
So much for structure as such. How does that structure relate to function: to polymerization and fibrinolysis? It was discovered 30 years ago that the triggering event for the transformation of fibrinogen into fibrin is the thrombin-catalyzed removal of two pairs of small, polar peptides (short protein chains), the fibrinopeptides *A* and *B*, which are at the amino terminals of the alpha and beta chains respectively. Each fibrinogen molecule is thereby converted into a fibrin monomer, and the monomers link up spontaneously to form the fibrin network. Why do fibrin monomers polymerize whereas fibrinogen molecules do not? One early view was that the fibrinopeptides, which ordinarily bear a substantial negative charge, keep the individual fibrinogen molecules apart by simple electrostatic repulsion. In 1952 John D. Ferry of the University of Wisconsin at Madison proposed that the release of the negatively charged fibrinopeptides could allow the monomers to approach one another, whereupon various weak, short-range attractive forces might come into play.

Ferry made another significant observation about polymerization. It was known that fibrin strands exhibit a characteristic banded pattern in electron micrographs, the repeat distance being about 230 angstroms. Since this distance is roughly half the length of a fibrin monomer, Ferry suggested that polymerization must proceed by means of lateral pairing, with "partial overlapping resulting in two parallel and end-to-end chains with staggered junctions." This view was supported by light-scattering studies of the growing polymer.

In another finding bearing on polymerization, Bailey and Astbury had found no difference between the X-ray-diffraction patterns of fibrinogen and of fibrin, leading them to conclude that "fibrin is no other than an insoluble modification of fibrinogen without any fundamental change in molecular plan." In addition the more recent calorimetric study by Donovan and Mihalyi did not reveal any significant difference in the melting points of fibrinogen and fibrin. As well as reinforcing the fundamental similarity of fibrinogen and the fibrin monomer, this showed that the intermolecular contacts in fibrin are not particularly "cooperative." They must be few in number and rather stiff; two fibrin units hold each other like dancers at arm's length rather than nestled cheek to cheek.

It is now possible to reexamine some of the early notions about polymerization in the light of the amino acid sequences, beginning with the electrostatic interactions. The human fibrinogen molecule as a whole has about 26 more negative charges than positive charges, but the excess negative charge is not spread equally over the entire molecule. A disproportionate amount of the excess is on the central domain. Removal of the two fibrinopeptides *A* reduces the excess negative charge on the central domain from minus 8 to minus 1. When the fibrinopeptides *B* are cleaved away, the central domain actually assumes a net positive charge of plus 5. The coiled-coil regions have approximately the same number of positively charged side chains as they do negatively charged ones, in keeping with the idea that these connectors are not involved in intermolecular interactions but instead remain open and accessible to eventual attack by plasmin.

Each of the terminal domains, however, has a net negative charge of minus 4. That is neatly compatible with each terminal domain's having a complementary electrostatic interaction with a positively charged central domain during polymerization, giving rise to the staggered, overlapping aggregation of fibrin monomers proposed by Ferry on the basis of the banding pattern in electron micrographs.



SIX-CHAIN STRUCTURE of fibrinogen was established by the early 1970's. Three different amino acids were found to be linked to amino (NH_2) groups, which define one end of a protein chain, and there were two copies of each "end group." Breakage of the interchain disulfide bonds (*broken lines*) isolated three different chains: alpha, beta and gamma, whose total molecular weight, 170,000, accounted for half of the weight of the molecule; there are two copies of each chain. Many disulfide bonds were found to be in a "disulfide knot" incorporating the amino terminals; it was shown to be largely coincident with fragment *E*, the central domain.

© 1981 SCIENTIFIC AMERICAN, INC

FIBRINOPEPTIDE *A*

1 Ala Asp Ser Gly Glu Gly Asp Phe Leu Ala Glu Gly Gly Gly Val Arg Gly Pro Arg Val Val Glu Arg His Gln
26 Ser Ala Cys Lys Asp Ser Asp Trp Pro Phe Cys Ser Asp Glu Asp Trp Asn Tyr Lys Cys Pro Ser Gly Cys Arg
51 Met Lys Gly Leu Ile Asp Glu Val Asn Gln Asp Phe Thr Asn Arg Ile Asn Lys Leu Lys Asn Ser Leu Phe Glu
76 Tyr Gln Lys Asn Asn Lys Asp Ser His Ser Leu Thr Thr Asn Ile Met Glu Ile Leu Arg Gly Asp Phe Ser Ser
101 Ala Asn Asn Arg Asp Asn Thr Tyr Asn Arg Val Ser Glu Asp Leu Arg Ser Arg Ile Glu Val Leu Lys Arg Lys
126 Val Ile Gln Lys Val Gln His Ile Gln Leu Leu Gln Lys Asn Val Arg Ala Gln Leu Val Asp Met Lys Arg Leu
151 Glu Val Asp Ile Asp Ile Lys Ile Arg Ser Cys Arg Gly Ser Cys Ser Arg Ala Leu Ala Arg Glu Val Asp Leu
176 Lys Asn Tyr Glu Asp Gln Gln Lys Gln Leu Glu Gln Val Ile Ala Lys Asp Leu Leu Pro Ser Arg Asp Arg Gln
201 His Leu Pro Leu Ile Lys Met Lys Pro Val Pro Asn Leu Val Pro Gly Asn Phe Lys Ser Gln Leu Gln Lys Val
226 Pro Pro Glu Trp Lys Ala Leu Thr Asp Met Pro Gln Met Arg Met Glu Leu Glu Arg Pro Gly Gly Asn Glu Ile
251 Thr Arg Gly Gly Ser Thr Ser Tyr Gly Thr Gly Ser Glu Thr Glu Ser Pro Arg Asn Pro Ser Ser Ala Gly Ser
276 Trp Asn Ser Gly Ser Ser Gly Pro Gly Ser Thr Gly Asn Arg Asn Pro Gly Ser Ser Gly Thr Gly Ser Gly Ala
301 Thr Trp Lys Pro Gly Ser Ser Gly Pro Gly Ser Thr Gly Ser Trp Asn Ser Gly Ser Ser Gly Thr Gly Ser Thr
326 Gly Asn Gln Asn Pro Gly Ser Pro Arg Pro Gly Ser Thr Gly Thr Trp Asn Pro Gly Ser Ser Glu Arg Gly Ser
351 Ala Gly His Trp Thr Ser Glu Ser Ser Val Ser Gly Ser Thr Gly Gln Trp His Ser Glu Ser Gly Ser Phe Arg
376 Pro Asp Ser Pro Gly Ser Gly Asn Ala Arg Pro Asn Asp Pro Asn Trp Gly Thr Phe Glu Glu Val Ser Gly Asn
401 Val Ser Pro Gly Thr Arg Arg Glu Tyr His Thr Glu Lys Leu Val Thr Ser Lys Gly Asp Lys Glu Leu Arg Thr
426 Gly Lys Glu Lys Val Thr Ser Gly Ser Thr Thr Thr Thr Arg Arg Ser Cys Ser Lys Thr Val Thr Lys Thr Val
451 Ile Gly Pro Asp Gly His Lys Glu Val Thr Lys Glu Val Val Thr Ser Glu Asp Gly Ser Asp Cys Pro Glu Ala
476 Met Asp Leu Gly Thr Leu Ser Gly Ile Gly Thr Leu Asp Gly Phe Arg His Arg His Pro Asp Glu Ala Ala Phe
501 Phe Asp Thr Ala Ser Thr Gly Lys Thr Phe Pro Gly Phe Phe Ser Pro Met Leu Gly Glu Phe Val Ser Glu Thr
526 Glu Ser Arg Gly Ser Glu Ser Gly Ile Phe Thr Asn Thr Lys Glu Ser Ser Ser His His Pro Gly Ile Ala Glu
551 Phe Pro Ser Arg Gly Lys Ser Ser Ser Tyr Ser Lys Gln Phe Thr Ser Ser Thr Ser Tyr Asn Arg Gly Asp Ser
576 Thr Phe Glu Ser Lys Ser Tyr Lys Met Ala Asp Glu Ala Gly Ser Glu Ala Asp His Glu Gly Thr His Ser Thr
601 Lys Arg Gly His Ala Lys Ser Arg Pro Val

Ala Alanine
Arg Arginine
Asn Asparagine
Asp Aspartate
Cys Cysteine
Gln Glutamine
Glu Glutamate
Gly Glycine
His Histidine
Ile Isoleucine
Leu Leucine
Lys Lysine
Met Methionine
Phe Phenylalanine
Pro Proline
Ser Serine
Thr Threonine
Trp Tryptophan
Tyr Tyrosine
Val Valine

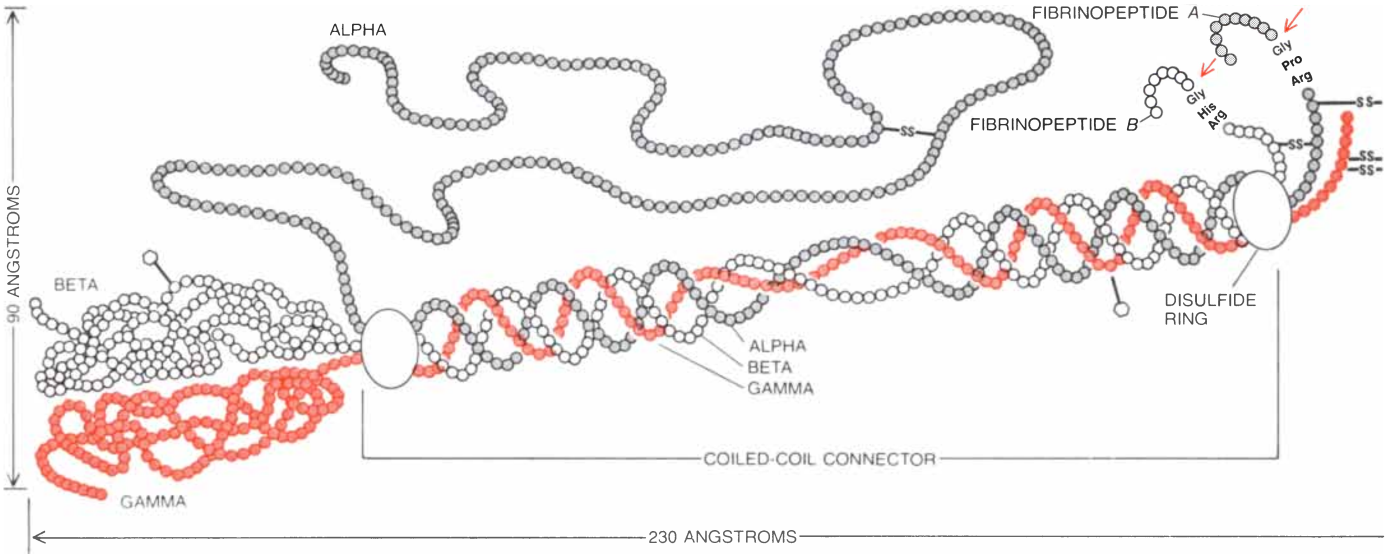
AMINO ACID SEQUENCE OF ALPHA CHAIN, established largely in the author's laboratory, is given in full; the abbreviations of the 20 amino acids are shown at the left. The colored arrow shows where thrombin cleaves the chain, releasing the short fibrinopeptide *A* from the amino end of the chain. The darker shade of gray indicates extent of the "coiled coil" connector. The eight cysteines, the amino acids that take part in disulfide bonding, are shown in color.

What is the mechanism of the interaction? A simple postulate would be that there are specific polymerization sites on the monomers, which are shielded, in fibrinogen, by the fibrinopeptides. The notion of specific polymerization sites suggests complementary structures, which is to say donor sites and acceptor sites, or "knobs" and "holes." For both efficiency and economy only the knobs or the holes would have to be shielded by the fibrinopeptides. Assume that the holes are always available. In that case the release of the fibrinopeptides from a central domain could expose a set of knobs, which could then interact with holes on the terminal domains of neighboring molecules. Since the starting monomer is double-ended, the initial two-monomer assembly can grow in either direction. The growing polymer is two molecules thick and accommodates the half-molecule staggered overlap.

Given the general notion of interacting knobs and holes, with the knobs on the central domain guarded by fibrinopeptides and the holes always available on the terminal domains, how many are there of each, and are all the sets the same? After all, there are two kinds of fibrinopeptides, *A* and *B*, and they are known to be released at different rates. Torvard C. Laurent and Blombäck long ago suggested that the removal of the fibrinopeptides *A*, which in mammalian systems happens first, allows the formation of polymers that are primarily derived from end-to-end interactions, whereas the subsequent release of the fibrinopeptides *B* could allow a lateral interaction leading to thick fibers. Their idea was based on early suggestions about fiber polymerization and constitution advanced by Ferry and Peter R. Morrison, who were both then at Harvard University. Noting the difference in the opacity of fibrin gels formed under various conditions, they distinguished between "fine clots," in which the strands seemed to be protofibrils only one or two molecules thick, and "coarse clots," with thick fibers made up of bundles of the protofibrils associated laterally. There ought, then, to be two distinct sets of knobs, one set guarded by the fibrinopeptides *A* and one by the fibrinopeptides *B*, and two sets of complementary holes.

From the start it had seemed likely that the amino terminals exposed by the thrombin-catalyzed removal of the fibrinopeptides were themselves the contact sites for polymerization, and so

© 1981 SCIENTIFIC AMERICAN, INC

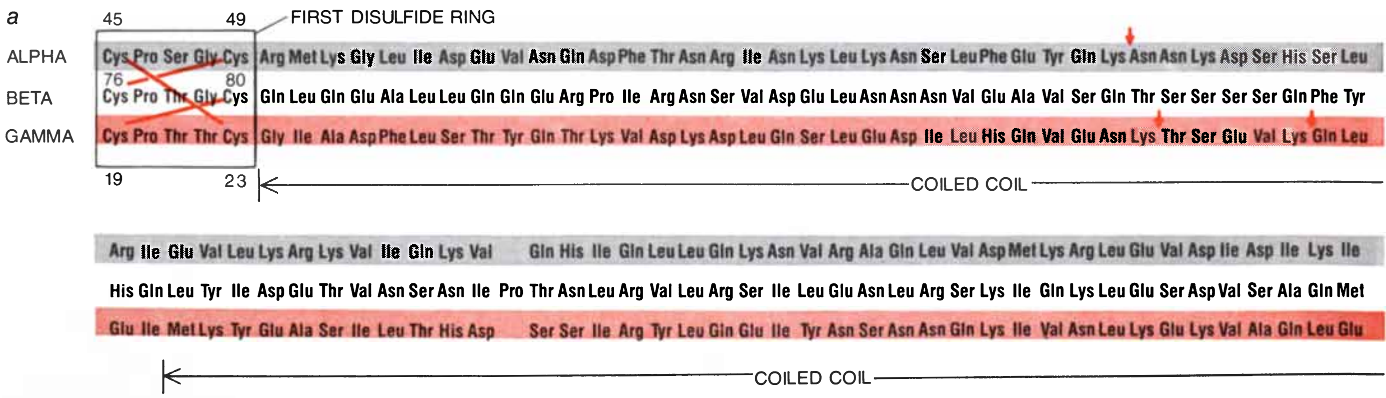


DETAILED MODEL OF FIBRINOGEN was devised by the author and his colleagues to take account of the complete amino acid sequence. The molecule is a dimer; the vertical broken line shows its axis of rotational symmetry. It is composed of two sets of three chains: alpha (*gray*), beta (*white*) and gamma (*color*). The chains are linked by 29 disulfide bonds (*S–S*), 13 within each half of the dimer and three connecting the two halves; each "disulfide ring" incorporates three such bonds, as is shown in detail in the illustration at the

my graduate student Andrew P. Laudano and I decided to synthesize what should be synthetic knobs: peptides corresponding to the amino-terminal segments newly exposed by the release of fibrinopeptides. Synthetic glycine-proline-arginine tripeptides (or longer peptides beginning with that sequence), which correspond to the alpha-chain amino-terminal sequence, were found to bind to fibrinogen and certain preparations of fragment *D*. They also inhibited the polymerization of fibrin monomers; the synthetic knobs filled the naturally occurring holes and prevented interaction with the natural knobs on the monomers' central domain. On the other hand, although peptides corresponding to the beta-chain sequence (glycine-histidine-arginine) exposed by the removal of fibrinopeptide *B* also bound to fibrinogen and to fragment *D*, they did not prevent the polymerization of fibrin monomers in the human system. Competition studies showed that two kinds of sites are involved. Evidently the initial polymerization depends exclusively on the alpha-chain knobs.

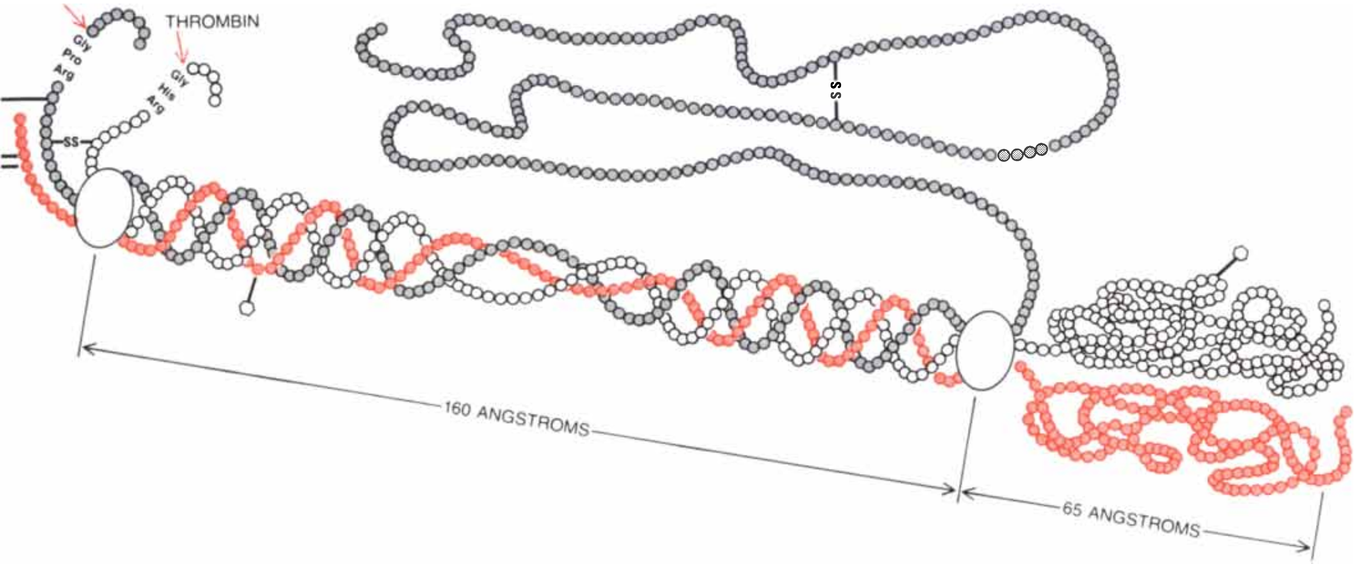
The location of the holes on the terminal domains has recently been defined more precisely. Frits Haverkate of the University of Leiden showed that the nature of the fragment *D* generated by plasmin is influenced by calcium ions. In their absence digestion proceeds much further, generating small fragments *D* in which the gamma chain is significantly shortened at the carboxy end. When we examined the binding of the synthetic knobs to these two kinds of *D*, we found that the alpha knob bound only to the larger *D*; all binding was abolished when the gamma chain was shortened. In contrast, the beta knob bound equally well to both kinds of fragment *D*. Evidently the carboxy-terminal segment of the gamma chain contributes to forming the hole for the alpha knob. Recently Stephanie Olexa and Andrei Z. Budzynski of the Temple University Medical School and Hospital have isolated a peptide from the gamma chain's carboxy end that binds to the central domain; it appears to be a major part of the fabric of the alpha knob's hole.

The knob-and-hole links formed under the influence of thrombin alone involve attractive forces (including electrostatic interactions and perhaps also hydrogen bonding) that can be rather easily disrupted. Under physiological (as opposed to experimental) conditions fibrin strands are strengthened, and the fibrin gel is stabilized, by the introduction of covalent bonds between adjacent monomers. This is accomplished by an enzyme called factor XIII, which is activated (by the thrombin-catalyzed re-



AMINO ACID SEQUENCE OF ALL THREE CHAINS is given (*a*) for a region incorporating the two disulfide rings. (There is one such region in each half of the fibrinogen dimer, of course.) Over much of the region the chains appear to be coiled coils. This would account for a particular X-ray-diffraction pattern discerned in early studies. The coiled coils also account for the rodlike parts of the early

© 1981 SCIENTIFIC AMERICAN, INC



bottom of these two pages. The connector region between disulfide rings is largely composed of supercoiled alpha helixes (coiled coils), with a relatively unstructured stretch in the center of each connector. In the terminal domains the beta and gamma chains are compactly folded; the alpha chain is hydrophilic and "floats" loosely in the aqueous environment. Two carbohydrate chains (*hexagons*) are attached to each half. Specific amino acids are named at the sites where release of the fibrinopeptides forms alpha and beta "knobs."

moval of a peptide) from a precursor in the plasma and in platelets. The active enzyme stitches together neighboring monomers in the fibrin polymer by forming a peptide bond (the same bond that links successive amino acids of a protein chain) between the side chains of suitably disposed lysines (donors) and glutamines (acceptors) and so cross-linking two chains. Covalently stabilized fibrin is mechanically stronger than non-cross-linked fibrin and is also more resistant to enzymatic dissolution. It is not, however, morphologically different from the non-cross-linked type when viewed in electron micrographs; cross-linking does not seem to introduce gross structural rearrangement.

My graduate student Renné Chen and I found that the first cross-links introduced in fibrin during the stabilization process are between the gamma chains of two adjacent molecules. Subsequently Patrick A. McKee of the Duke University Medical Center showed that multiple cross-links are also established, more slowly, between alpha chains.

The complete structure of the gamma-gamma cross-link was quickly determined. Both the donor (lysine) and the acceptor (glutamine) units are near the carboxy end of the gamma chain. The joined molecules are oriented in an antiparallel manner and are bonded by two reciprocal cross-links eight amino acid units apart. The fact that virtually all gamma chains become paired in this highly restrictive geometry indicates that each of the units in the fibrin polymer has an equivalent orientation. Because the carboxy-terminal regions of gamma chains are in the terminal domains of fibrinogen, plasmin digestion of gamma-linked fibrin gives rise to a fragment-*D* dimer, as was first noted in McKee's laboratory.

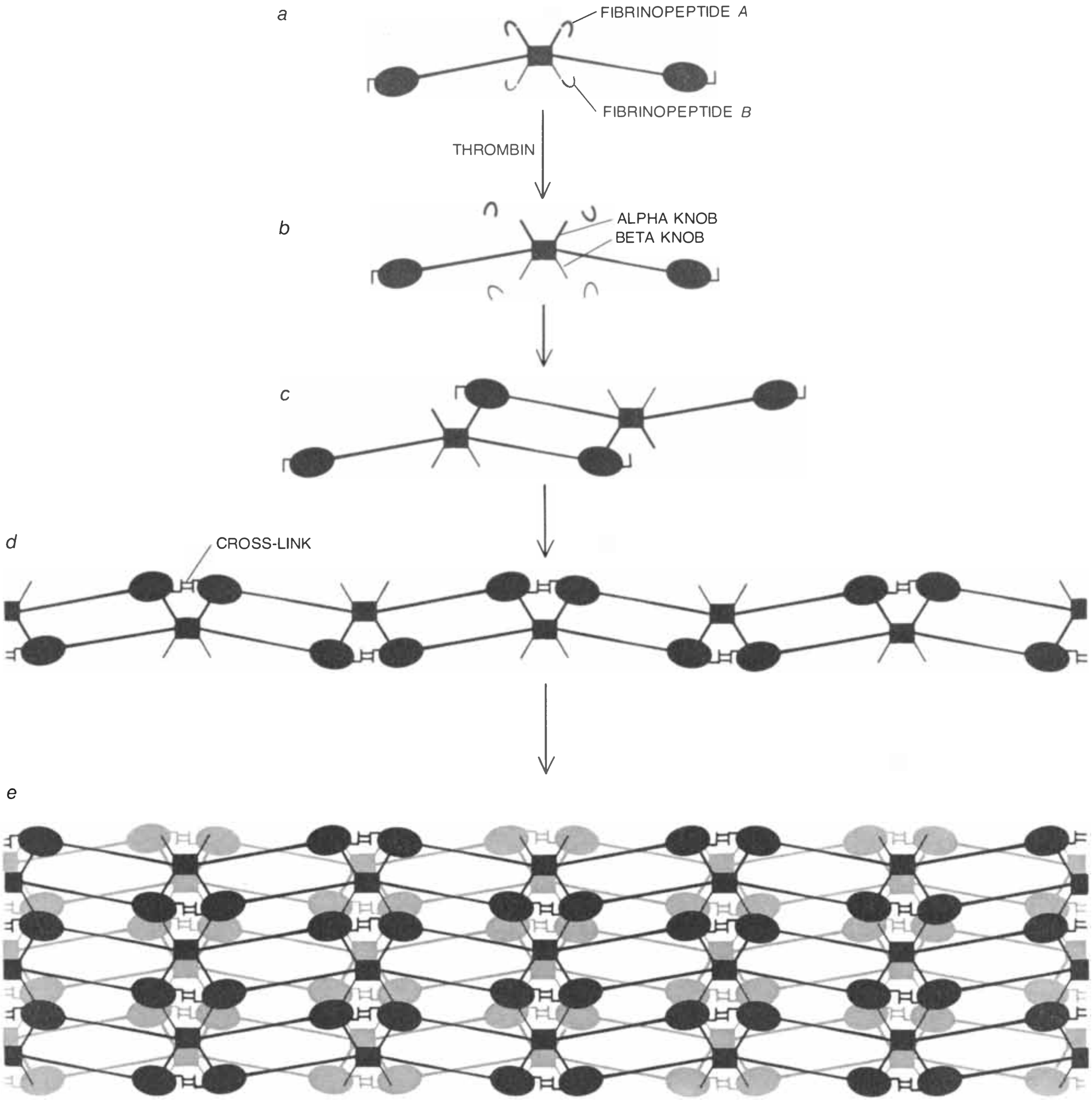
A gamma-chain cross-link connects two monomers to form a dimer, but alpha chains can be cross-linked into extended polymeric arrays. This means each alpha chain is linked to at least two other alpha chains, so that there must be at least two different glutamine acceptors and two potential lysine donors on every alpha chain. The glutamines were precisely located during the course of our sequence studies. In human fibrinogen they are 38 amino acids apart in about the middle of the alpha chain. The lysines that participate in alpha-chain cross-linking appear to be in a cluster 200 amino acid units nearer the carboxy end of the chain.

As I noted at the beginning of this article, there has to be a mechanism for dissolving clots that are no longer needed, that become dislodged into the general circulation or that form at the

Hall-Slayter model: the connectors between the globular central and terminal domains of the molecule. Colored arrows indicate where plasmin is known to cleave the chains. The three bonds within each disulfide ring are shown in color. A molecular model of one disulfide ring (*b*), seen from the amino end of the molecule, shows conformation of cysteine-*X*-*Y*-*Z*-cysteine sequences on the three chains.

© 1981 SCIENTIFIC AMERICAN, INC

wrong time and place. The architecture of the fibrin array is as suited to the breakdown of fibrin as it is to polymerization, if not more so. The structural basis is clear: the accessibility and vulnerability of vital connections. The limiting of intermolecular contacts to the nodular bodies of the fibrin monomers leaves open channels to the interdomainal connectors through which proteolytic agents (including plasmin, its precursor plasminogen and the activators that convert the precursor into the active enzyme) can diffuse. Furthermore, instead of having to cut all the way through a solid rodlike molecule, plasmin has only to cleave the slender three-strand connectors. As a result dissolution requires the breakage of a relatively small number of bonds. It can be supposed that a section of a fiber is solubilized by the cleavage of any two connectors that are within, say, 10 to 20 fibrin monomers of each other. The system is thereby reduced to the "intermediate polymer" stage, reversing the process whereby intermediate polymers form in advance of



POLYMERIZATION SCHEME proposed here is consistent with electron-micrographic and structural data. The fibrinogen molecule (*a*) is converted into a fibrin monomer (*b*) by the release of fibrinopeptides *A* and *B* from the amino terminals of the alpha and beta chains respectively. The newly exposed ends of the alpha chains serve as "knobs" that interact with "holes" in the terminal domain, linking fibrin monomers with the observed half-monomer overlap (*c*). The assembly can be extended into a long "intermediate polymer" two molecules thick (*d*), which is stabilized by the formation of covalent cross-links between adjacent terminal domains. Intermediate polymers are then interwoven laterally to form a fully developed fibrin strand (*e*), the thick cablelike structure of which can only be suggested in this drawing. The initial polymerization seems to depend specifically on the alpha knobs. The end-to-end covalent cross-linking is between two gamma chains. Lateral growth may be mediated by the beta knobs and then strengthened by alpha-chain cross-linking.

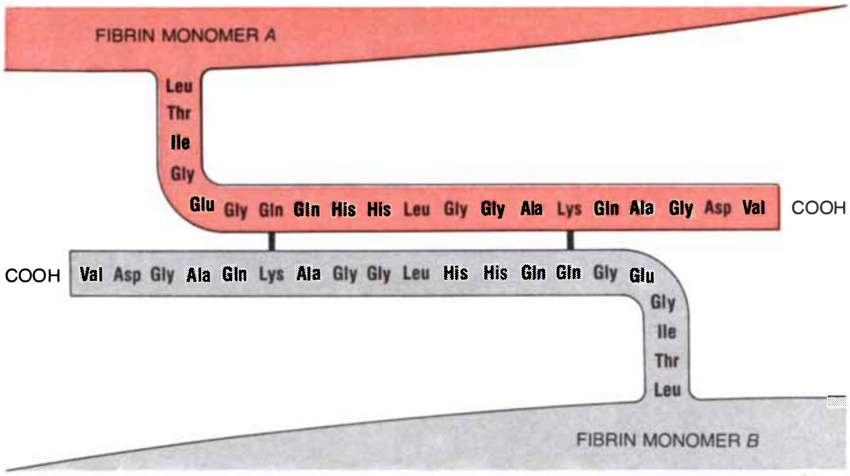
© 1981 SCIENTIFIC AMERICAN, INC

the fibrin network on the way to the formation of the gel. Proteolytic digestion then continues until these intermediate polymers are reduced to core fragments.

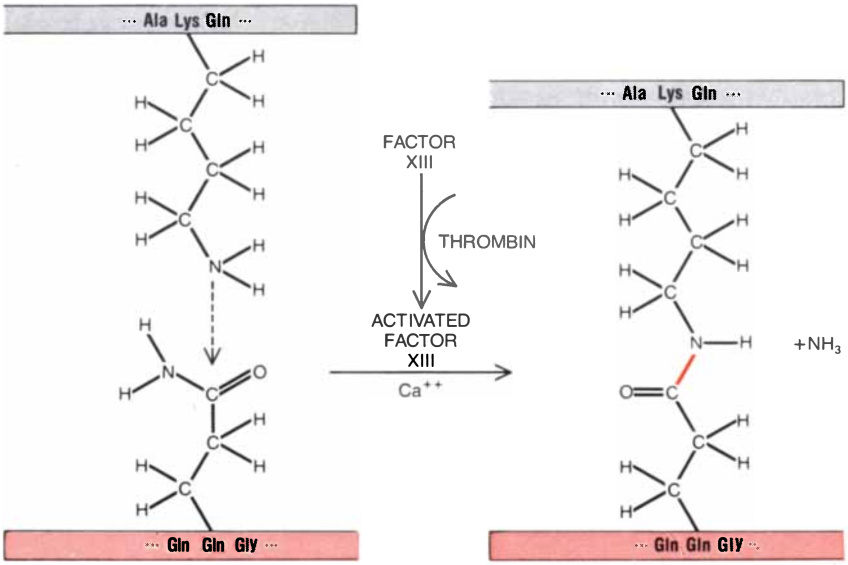
The dissolution scheme underscores both the open nature of fibrin clots and the extended polydomainal structure of fibrinogen and the fibrin monomer. The plasmin-generated products of fibrin degradation are remarkably similar to the products of experimental fibrinogen degradation. Obviously the intermolecular associations holding the fibrin units together do not shield the units from proteolytic attack. That is in contrast to many other biological systems where the interaction of two large molecules affords one or both of them a degree of protection against enzyme-engendered degradation. The similarity of the digestion products also implies that there is no gross rearrangement of the basic molecule during polymerization.

Fibrin stabilized by covalent bonding is lysed at a distinctly lower rate than unstabilized fibrin, as Johannes Gormsen of the University of Copenhagen has shown. Nevertheless, after complete digestion by plasmin the only observed difference in the final products is the presence of the dimerized "double *D*" in cross-linked preparations. Under less drastic conditions, however, Gilbert Hudry-Clergeon, working in Michel Suscillon's laboratory at the University of Grenoble, isolated an entity he called "D_2E" from partial plasmin digests of cross-linked fibrin. The complex, which was later also identified and characterized by others and whose existence is generally accepted, is composed of a "double *D*" and a fragment *E*, presumably from another monomer with which the two *D*'s were linked prior to digestion. The complex "D_2E" is exactly what ought to result given a scheme of interaction involving knobs on one domain and holes on the other.

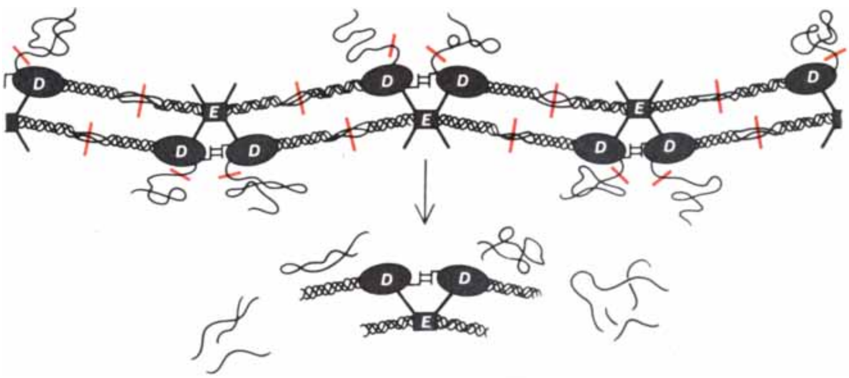
I have tried to show how knowledge of the amino acid sequence of fibrinogen bolsters some long-standing notions about the protein's three-dimensional structure and general behavior. The sequence data flesh out a model in which two large terminal domains are connected to a central region by sets of three-strand ropes, giving rise to a trinodular structure similar to the one electron microscopists proposed some 20 years ago. This extended polydomainal structure is exquisitely suited to a series of consecutive operations—polymerization, stabilization and fibrinolysis—that first stop bleeding and then clear away the clot to prevent blood-vessel blockage. Now that the molecular details of these phenomena are understood it may be possible to design reasonable ways of keeping the system in balance in people whose blood tends to clot under the wrong circumstances.



FIBRIN CLOT is stabilized by the cross-linking of two antiparallel gamma-chain regions. Reciprocal covalent bonds are formed between two lysine-glutamine pairs near the carboxy ends.



COVALENT BOND (C–N) of the cross-link is formed by the condensation of lysine and glutamine side chains, with the removal of an ammonia (NH_3) group. The reaction is catalyzed by the calcium-dependent enzyme called factor XIII, which is activated by thrombin.



CLOT IS DISSOLVED by the action of plasmin, some of whose principal points of attack are shown (*colored lines*). The enzyme has easy access to the coiled-coil connectors, which it cleaves first in the relatively unstructured middle region. Plasmin digestion of cross-linked fibrin gives rise to "D_2E" fragments stabilized by covalent bonding and knob-to-hole links.

© 1981 SCIENTIFIC AMERICAN, INC

Computer Algebra

Symbols as well as numbers can be manipulated by a computer. New, general-purpose algorithms can undertake a wide variety of routine mathematical work and solve intractable problems

by Richard Pavelle, Michael Rothstein and John Fitch

Of all the tasks to which the computer can be applied none is more daunting than the manipulation of complex mathematical expressions. For numerical calculations the digital computer is now thoroughly established as a device that can greatly ease the human burden of work. It is less generally appreciated that there are computer programs equally well adapted to the manipulation of algebraic expressions. In other words, the computer can work not only with numbers themselves but also with more abstract symbols that represent numerical quantities.

Perhaps one reason the algebraic capabilities of the computer have not been fully exploited is that computer programming itself is much like algebra in character. It might therefore seem there is a natural division of labor: the programmer manipulates algebraic symbols, whereas the computer is confined to arithmetic calculations, or "number crunching." Yet the dichotomy between the programmer and the computer was recognized to be a false one as early as 1844 by Augusta Ada Byron, Countess of Lovelace, the daughter of Lord Byron and possibly the first computer programmer. Lady Lovelace was a benefactor of Charles Babbage's and devised some of the programs for the early mechanical computer that Babbage called the difference engine. She pointed out that the computer could "arrange and combine its numerical quantities exactly as if they were letters or any other general symbols; and in fact it might bring out its results in algebraic notation, were provisions made accordingly." Similarly, the modern digital computer is a general-purpose machine that can carry out any algorithm, or precisely specified procedure. The algorithms of algebra can be executed by a computer as readily as those of arithmetic.

In 1973 one of us (Pavelle) undertook an algebraic calculation pertaining to the general theory of relativity; the calculation required three months of work with pencil and paper. The following year a more formidable problem arose in an attempt to define the mathematical properties that might distinguish general relativity from various other theories of gravitation. Instead of attempting another calculation by hand, Pavelle decided to construct a computer program for manipulating mathematical expressions of the kind that commonly appear in gravitational theories. The program was then written in the computer language of a powerful system of algebraic programs called MACSYMA, then under development at the Massachusetts Institute of Technology. Once Pavelle's program was installed in MACSYMA, the 1973 problem was solved as a test; the computer confirmed the results of the three-month calculation in two minutes. The experience is not unusual among users of computer-algebra systems.

In order to understand the need for automatic systems of algebraic manipulation it must be appreciated that many concepts in science are embodied in mathematical statements where there is little point to numerical evaluation. Consider the simple expression $3\pi^2/\pi$. As any student of algebra knows, the fraction can be reduced by canceling π from both the numerator and the denominator to obtain the simplified form 3π. The numerical value of 3π may be of interest, but it may also be sufficient, and perhaps of greater utility, to leave the expression in the symbolic, nonnumerical form. With a computer programmed to do only arithmetic, the expression $3\pi^2/\pi$ must be evaluated; when the calculation is done with a precision of 10 significant figures, the value obtained is 9.424777958. The number, besides being a rather uninformative string of digits, is not the same as the number obtained from the numerical evaluation (to 10 significant figures) of 3π. The latter number is 9.424777962; the discrepancy in the last two decimal places results from round-off errors introduced by the computer. The equivalence of $3\pi^2/\pi$ and 3π would probably not be recognized by a computer programmed in this way.

The example illustrates three advantages that algebraic programs have over purely numerical ones. First, it is frequently more economical of computer time to simplify an expression algebraically before evaluating it numerically. Although in this example the saving in computer time is trivial, there are many complicated problems in which the economy that results from algebraic simplification is significant. Second, unlike the numerical approximations generated by a computer, algebraic answers are exact. Approximations necessarily introduce errors; if there are many successive numerical operations, the errors can accumulate and make nonsense of the final result. Only if a careful error analysis is undertaken can the final answer be stated with confidence, and such error analysis is one of the most complex problems faced in many fields.

The third and perhaps the most important advantage is that the goals of scientific investigation are often better served by a result in algebraic form. As Richard W. Hamming of Bell Laboratories has written, "the purpose of computing is insight, not numbers." Insight is sometimes obtained by evaluating a mathematical expression, but in many cases the relations of the quantities are made clearer by algebraic means.

In the study of a chemical process, for example, it is possible to express algebraically the relation between the stability of the process and the relative quantities of the substances present. From such a relation one can predict quite accurately whether a small change in one quantity will cause a violent reaction or a controlled one. Similarly, in the theory of stellar evolution one can examine algebraically how a number of variables determine whether a star will become a neutron star or a black hole, or how the variables interact to predict the existence of a new object.

There is a fourth advantage of the automatic systems we shall call computer-algebra systems, which is brought out by considering some pragmatic aspects of the accumulation of scientific knowledge. A scientific theory is often stated in a concise and quite general mathematical expression that suggests the

© 1981 SCIENTIFIC AMERICAN, INC

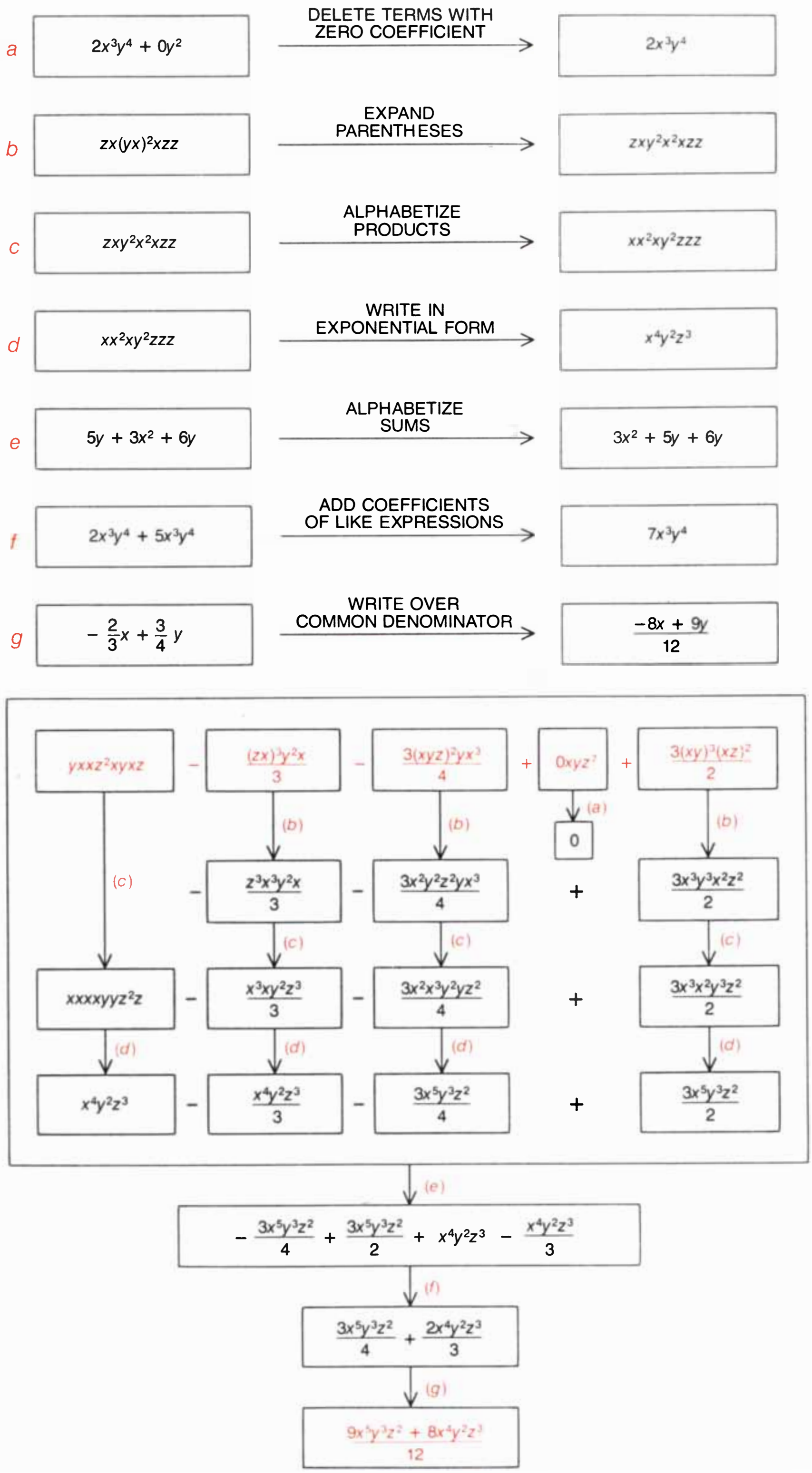
form the theory will take under certain assumptions. For example, a portion of the general theory of relativity, known as the Einstein field equations, can be written down in one line, given certain widely accepted notational conventions. To explore the physical implications of the theory is to explore the mathematical implications of the field equations, but with some exceptions the exploration requires algebraic operations that are intractable if they are done by hand. Even under assumptions that simplify the problem enormously, the algebra is so taxing that few investigators will risk their health, happiness and professional well-being attempting a solution.

The results of such work, even if they are admitted to the main body of scientific knowledge, stand as isolated intellectual outposts, untested by other workers and accepted primarily on the reputation of the investigator rather than on any promise of future critical examination. Such a regrettable state of affairs can prevail in any scientific field at what might be called the frontiers of intractability. For many fields computer algebra has now significantly expanded the frontiers.

In celestial mechanics there is a distinguished tradition of long algebraic calculations. In 1847 the French astronomer Charles Delaunay began to calculate the position of the moon as a function of time. In a sense the calculation is a straightforward application of Newton's theory of universal gravitation. In Newton's theory the orbit of a point mass around a spherical mass of uniform density is an ellipse, but the characteristics of the earth-moon system make the moon's orbit a curve considerably more complex than an ellipse. The plane of the moon's orbit around the earth is inclined at a small angle to the plane of the earth's orbit around the sun, and the angle varies under the perturbing influence of the sun's gravitational field. The sun also causes the lunar perigee (the point in the moon's orbit where it is closest to the earth) to precess slowly with respect to the stars.

Because of such complications the position of the moon has often been determined not from some function of time, as Delaunay set out to do, but by numerical extrapolation from a previous lunar position. Over short periods the errors accumulated in the extrapolation are small, and a correction can be made by again determining the position of the moon by observation. Calculating fast enough to keep up with the progress of the moon is fairly difficult even for the fastest computers, and the required observations are both time-consuming and costly. Delaunay's calculation avoided these difficulties, but it had one serious shortcoming: it demanded 20 years of his life to carry out and check.

The results of Delaunay's work were



COMPUTER ALGORITHM for simplifying an algebraic expression by combining like terms closely resembles the standard manual method of simplification. For the computer each step of the procedure must be precisely specified. In the upper diagram the effect of each step on a simple algebraic expression is illustrated. In the lower diagram the application of the algorithm to the more complicated expression shown in color is illustrated by a flow chart. The colored letters that label the arrows in the flow chart correspond to the elementary operations in the upper diagram. The simplified form of the expression generated by the algorithm is given in color at the bottom. Simplification is one of the tasks that must be done by any set of computer programs intended to solve mathematical problems expressed in symbols rather than numerical quantities. Although the simplification algorithm usually yields a useful and manageable algebraic expression, no single algorithm can reduce every expression to its simplest form.

© 1981 SCIENTIFIC AMERICAN, INC

```
(C1) F(J):=FACTOR(NUSUM(K^J,K,O,N));

(D1) F(J) := FACTOR(NUSUM(K^J, K, O, N)

(C2) FOR J:1 THRU 2 DO DISPLAY (SUM(K↑J ,K,O,N) = F(J));

(D2)  N
     ====
     \              N (N + 1)
      >       K  =  ---------
     /                  2
     ====
     K = O

      N
     ====
     \              N (N + 1) (2 N + 1)
      >       K^2 = -------------------
     /                       6
     ====
     K = O

(C1) (X+7)^10;

(D1) (X + 7)^10

(C2) EXPAND(D1);

(D2)          X^10 +       70 X^9 +      2205 X^8 +      41160 X^7 + 504210 X^6 + 4235364 X^5

     + 24706290 X^4  + 98825160 X^3 + 259416045 X^2 + 403536070 X  + 282475249

(C1) X^3+B*X^2+A^2*X^2-9*A*X^2+A^2*B*X-2*A*B*X-9*A↑3*X+14*A↑2*X-2*A^3*B+14*A^4=0;

(D1) X^3 + B X^2 + A^2 X^2 - 9 A X^2 + A^2 B X - 2 A B X

     - 9 A^3 X + 14 A^2 X - 2 A^3 B + 14 A^4 = 0

(C2) SOLVE(D1,X);

(D2) [X = 7 A - B, X = - A^2, X = 2 A]

(D1)            1125899906842624 Y^40 +          9007199254740992 Y^39 +          43523068273885184 Y^38

            + 96686654500110336 Y^37 +         71892942171668480 Y^36 -         203545990580404224 Y^35

              - 3231739551940608 Y^34 +       2967153761027358720 Y^33 +        3933037175129505792 Y^32

         - 10392801849559220224 Y^31 -       26535490294760079360 Y^30 +       60970867840763559936 Y^29

         + 124971270109665427456 Y^28 -     294061554052926275584 Y^27 -      377892103185282105344 Y^26

       + 1043007763435371888640 Y^25 +    1247934126027765186560 Y^24 -     4589204662544561602560 Y^23

         - 5344792849977751570432 Y^22 + 13715332431765689073664 Y^21 - 13302644475428239835136 Y^20

      - 11542363148164431609856 Y^19 + 30184905793343524306944 Y^18 - 11553929011986625003520 Y^17

      - 20761961484788844621824 Y^16 + 23716893785532021784576 Y^15 -   1470688776981600935936 Y^14

      - 11829726550983847370752 Y^13 +   7047410412446462752768 Y^12 +   5906483242725501333760 Y^11

        - 2234695017099712874496 Y^10 +     836560570027035444224 Y^9  +      38308661311225029504 Y^8

           - 113171442907550345472 Y^7  +      29418059499453088640 Y^6  +          666807807062928864 Y^5

              - 14344056936110925 12 Y^4  +        283861281845610304 Y^3  -          20855579198349088 Y^2

                  + 370175331659648 Y    - 1886186974063


(C2) FACTOR(D1);

Time= 130855 msec.


(D2)    (4096 Y^10 +     8192 Y^9 -     3008 Y^8 -    30848 Y^7 +  21056 Y^6 + 146496 Y^5

      - 221360 Y^4  +     1232 Y^3 +  144464 Y^2 -    78488 Y  + 11993)

        *(4096 Y^10 +     8192 Y^9 +     1600 Y^8 -    20608 Y^7 +  20032 Y^6 + 87360 Y^5

      - 105904 Y^4  +    18544 Y^3 +   11888 Y^2 -     3416 Y  + 41)

        *(8192 Y^10 +    12288 Y^9 +    66560 Y^8 -    22528 Y^7 - 138240 Y^6 + 572928 Y^5

       - 90496 Y^4  -   356032 Y^3 +  113032 Y^2 +    23420 Y  - 8179)

        *(8192 Y^10 +    20480 Y^9 +    58368 Y^8 -   161792 Y^7 + 198656 Y^6 + 199680 Y^5

      - 414848 Y^4  -     4160 Y^3 +  171816 Y^2 -    48556 Y  + 469)
```

COMPUTER-ALGEBRA SYSTEM called MACSYMA, developed at the Massachusetts Institute of Technology, is a general-purpose set of programs that can solve problems in algebra far beyond the abilities of most mathematicians. The system communicates with the user in a conversational style. After logging in to the system the user types the algebraic expression to be manipulated on the *C* line, or command line, in a computer language that resembles ALGOL or FORTRAN. The system responds on the *D* line with a rewritten version of the expression that is closer to the way it would appear on a printed page. The user then types a second command, and the computer carries out the indicated operation. In the first two examples the computer finds an expression for the sum of the first *n* terms of a series, where each term has the form of the expression next to the letter Σ. (Σk^2 is a way of writing $1^2 + 2^2 + 3^2 + \ldots + n^2$.) In the next two examples the computer expands a binomial expression and solves a nonnumerical cubic equation exactly. The upward-pointing arrows indicate exponentiation and the asterisks indicate multiplication. The final example illustrates some of the computational power of the system. The maximum area of a hexagon inscribed in a circle with a diameter of 1 is one of the roots of the enormous 40th-degree polynomial shown. Manual methods of finding roots are unable to cope with a polynomial of this size; it is easier to factor the polynomial and find the roots of the factors. The computer-algebra system gives the most complete factorization whose terms have integral coefficients. A computer can solve the problem in about two minutes.

published in two volumes in 1867, and they remained unchallenged for more than 100 years. During World War II there was interest in expressing the coordinates of fixed stars as a function of time in order to help in determining the positions of German U-boats, but there was no further work on the orbit of the moon or of other bodies in the solar system. With the advent of artificial earth satellites, however, Delaunay's method for determining orbits became economically attractive.

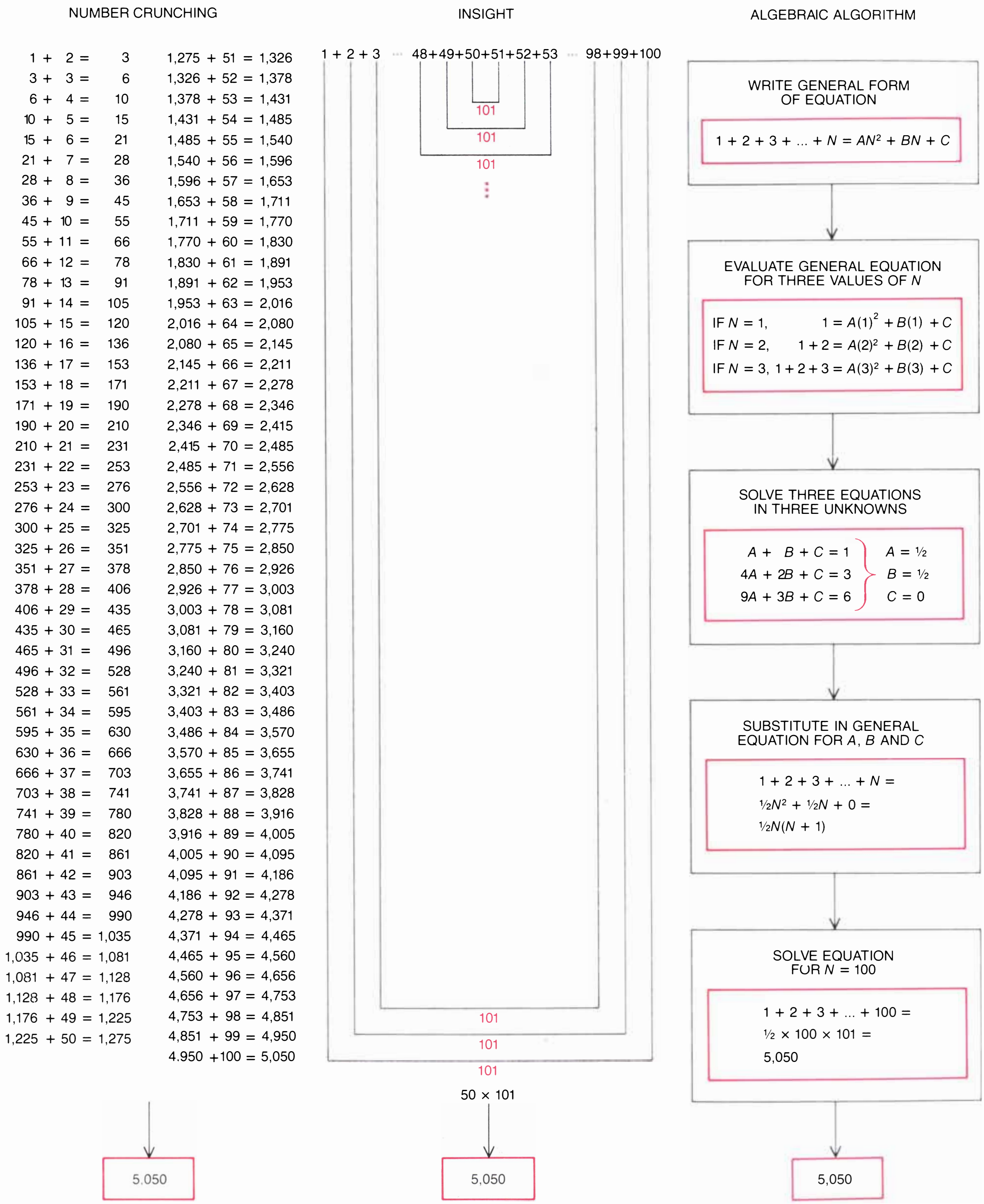
In order to devise algebraic expressions for satellite orbits, André Deprit, Jacques Henrard and Arnold Rom, who were then at the Boeing Scientific Research Laboratories in Seattle, began to investigate algorithms for doing the Delaunay calculation with a computer. In 1970 they made the calculation in about 20 hours of computer time. Remarkably, they found only three errors in Delaunay's work, all in terms of small value; moreover, two of the errors were mere consequences of the third one. Computer-algebra systems have since been developed that extend Delaunay's method by taking into account the effects of atmospheric drag and the nonspherical shape of the earth on a satellite in a low-altitude orbit. The algorithms are now sometimes employed in satellite tracking.

Considering the human life span, a reduction in the time needed for an operation from 20 years to 20 hours is a qualitative gain. Problems as complex as Delaunay's problem can become the focus of research for an investigator who has far less patience than Delaunay had. Moreover, the investigator can spend a much greater proportion of his time weighing the significance of his algebraic results. He can experiment with elaborate calculations without betting his career on the correctness and the utility of the answer. Perhaps the most telling indication that computer algebra has shifted the frontier of intractability in celestial mechanics is that Delaunay's huge calculation has been undertaken as a test of new computer-algebra systems.

How can a computer be programmed to carry out algebraic manipulations? Many of the algorithms employed in computer algebra began as the basic procedures devised by earlier generations of mathematicians that are now taught to algebra students in high school and college. For example, the methods for solving equations in which a single unknown quantity is raised to the first or the second power have been known since the time of Hammurabi, about 1750 B.C. Unlike the student who may develop an intuitive but vague sense of how to proceed through such a solution, however, the computer must follow a rigorous procedure that specifies at every point what the computer is to do.

Consider how a student with a mod-

© 1981 SCIENTIFIC AMERICAN, INC



APPLICATION OF COMPUTER ALGEBRA to a numerical calculation can save computer-processing time by simplifying an algebraic expression before it is evaluated numerically. To find the sum of the first 100 integers a numerical calculation requires 99 separate additions. A simpler algorithm employed by the computer-algebra program solves the problem by taking advantage of a general mathematical result showing that the sum of the first n integers is a quadratic, or second-degree, polynomial function of n. Similarly, the algorithm would find the sum of the squares of the first n integers by constructing a third-degree polynomial function of n. Although the algorithm is effective, it is not necessarily the fastest way to solve the problem or the one that leads to the clearest understanding of it. According to legend, the German mathematician Carl Friedrich Gauss noticed at the age of seven that the integers from 1 to 100 can be grouped in pairs so that all the pairs add to the same number, namely 101. The sum of the first 100 integers is therefore equal to 101 multiplied by 50, which is the number of pairs. Computer-algebra systems usually cannot recognize such patterns; on the other hand, Gauss's method cannot be applied to finding the sums of squares, cubes or higher powers of integers, as the computer-algebra algorithm can.

© 1981 SCIENTIFIC AMERICAN, INC

A CAR FOR THE LEFT SIDE OF YOUR BRAIN.

The left side of your brain, recent investigations tell us, is the logical side.

It figures out that $1+1=2$. And, in a few cases, that $E=mc^2$.

On a more mundane level, it chooses the socks you wear, the cereal you eat, and the car you drive. All by means of rigorous Aristotelian logic.

However, and a big however it is, for real satisfaction, you must achieve harmony with the other side of your brain.

The right side, the poetic side, that says, "Yeah, Car X has a reputation for lasting a long time but it's so dull, who'd want to drive it that long anyway?"

The Saab Turbo looked at from all sides.

To the left side of your brain, Saab turbocharging is a technological feat that retains good gas mileage while also increasing performance.

To the right side of your brain, Saab turbocharging is what makes a Saab go like a bat out of hell.

The left side sees the safety in high performance. (Passing on a two-lane highway. Entering a freeway in the midst of high-speed traffic.)

The right side lives only for the thrills.

The left side considers that *Road & Track* magazine just named Saab "The Sports Sedan for the Eighties." By unanimous choice of its editors.

The right side eschews informed endorsements by editors who have spent a lifetime comparing cars. The right side doesn't know much about cars, but knows what it likes.

The left side scans this chart.

Wheelbase	*99.1 inches*
Length	*187.6 inches*
Width	*66.5 inches*
Height	*55.9 inches*
Fuel-tank capacity	*16.6 gallons*
EPA City	*19 mpg**
EPA Highway	*31 mpg**

The right side looks at the picture on the opposite page.

The left side compares a Saab's comfort with that of a Mercedes. Its performance with that of a BMW. Its braking with that of an Audi.

The right side looks at the picture.

The left side looks ahead to the winter when a Saab's front-wheel drive will keep a Saab in front of traffic.

The right side looks at the picture.

The left side also considers the other seasons of the year when a Saab's front-wheel drive gives it the cornering ability of a sports car.

The right side looks again at the picture.

Getting what you need vs. getting what you want.

Needs are boring; desires are what make life worth living.

The left side of your brain is your mother telling you that a Saab is good for you. "Eat your vegetables." (In today's world, you need a car engineered like a Saab.) "Put on your raincoat." (The Saab is economical. Look at the price-value relationship.) "Do your homework." (The passive safety of the construction. The active safety of the handling.)

*1982 SAAB PRICE** LIST*

900 3-Door	*5-Speed*	*$10,400*
	Automatic	*10,750*
900 4-Door	*5-Speed*	*$10,700*
	Automatic	*11,050*
900S 3-Door	*5-Speed*	*$12,100*
	Automatic	*12,450*
900S 4-Door	*5-Speed*	*$12,700*
	Automatic	*13,050*
900 Turbo 3-Door	*5-Speed*	*$15,600*
	Automatic	*15,950*
900 Turbo 4-Door	*5-Speed*	*$16,260*
	Automatic	*16,610*

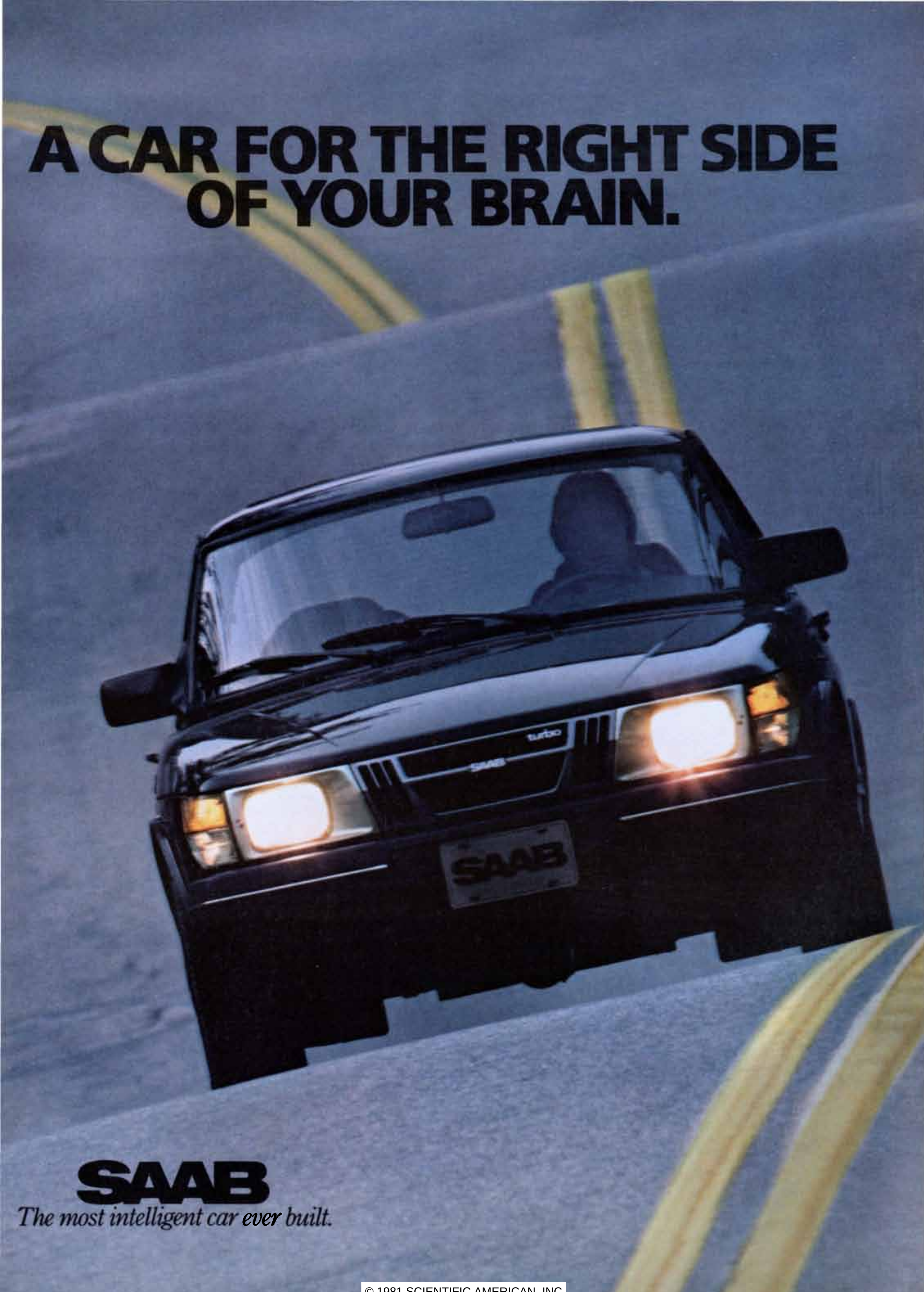
All turbo models include a Sony XR70, 4-Speaker Stereo Sound System as standard equipment. The stereo can be, of course, perfectly balanced: left and right.

The right side of your brain guides your foot to the clutch, your hand to the gears, and listens for the "zzzooommm."

Together, they see the 1982 Saab Turbo as the responsible car the times demand you get. And the performance car you've always, deep down, wanted with half your mind.

**Saab 900 Turbo. Remember, use estimated mpg for comparison only. Mileage varies with speed, trip length, and weather. Actual highway mileage will probably be less. **Manufacturer's suggested retail price. Not including taxes, license, freight, dealer charges or options desired by either side of your brain.*

© 1981 SCIENTIFIC AMERICAN, INC



© 1981 SCIENTIFIC AMERICAN, INC

She can't wear a Ming vase to La Bohème.

Born out of fire and ice more than a hundred
million years ago. Every diamond is unique.
But a diamond this large is even more precious.
A gift so rare, it can never be measured.
Until you see the look in her eyes.
THE DIAMOND SOLITAIRE.
A RARE GIFT.

The one and a quarter carat diamond bracelet shown is enlarged for detail.

A diamond is forever. De Beers

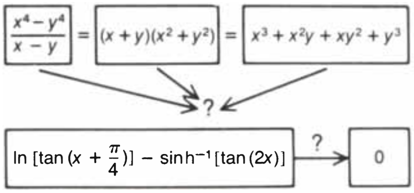
© 1981 SCIENTIFIC AMERICAN, INC

erate facility for simple algebra might solve the equation $3x - 1 = 2(x + 5)$. First he would "clear parentheses" by multiplying both terms within the parentheses, x and 5, by 2, obtaining $3x - 1 = 2x + 10$. He would then transfer the term $2x$ to the left side of the equation and the term -1 to the right, changing signs as he goes and adding or subtracting terms as necessary. Thus in a single additional step he would obtain the answer $x = 11$.

In a computer-algebra program the steps to the solution of the problem have to be specified in somewhat tedious detail, and the shortcuts that might be recognized by a student during work on a particular problem must be spelled out. The first step in solving the equation in our example would probably not differ in the program from the student's method: the program would clear parentheses and obtain the expression $3x - 1 = 2x + 10$. In order to reach the last line, however, the program would have to transfer the terms of the equation one by one to a convenient side of the equal sign. One way to do this would be to program the computer to add an expression called the additive inverse to all the numerical constants appearing on the left side of the equal sign and to all terms that include variables appearing on the right side of the equal sign. Since -1 is the only constant to appear on the left of the equal sign, the computer would add its additive inverse, $+1$, to both sides of the equation, obtaining $3x - 1 + 1 = 2x + 10 + 1$. The program would then rearrange the terms, if necessary, and add or subtract where possible, obtaining $3x = 2x + 11$.

Next, the program would search the expressions on the right of the equal sign for terms including variables and find the additive inverse of the first such term it encountered. In the example the computer would construct the additive inverse of $2x$ (namely $-2x$) and add it to both sides of the equation, thereby obtaining $3x - 2x = 2x + 11 - 2x$. Once again the terms would be rearranged so that like terms could be combined: $3x - 2x = 2x - 2x + 11$. Finally, the program would combine the terms having the same variable names and stop when a single variable appeared on the left side of the equation and a numerical constant appeared on the right: $x = 11$. Such an algorithm is neither the simplest nor the most efficient method one can devise for programming a computer to solve equations that have one unknown quantity, but it is not sufficiently complex either. There are many possibilities, such as the appearance of the expression $2x = 22$ at some step in the solution of the problem, that the algorithm as we have described it is not equipped to deal with.

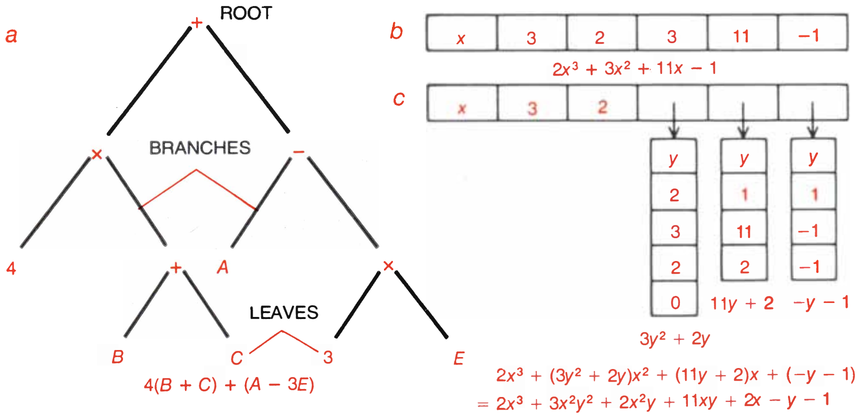
In developing an algorithm for computer algebra it is not necessary to follow the procedure that is most efficient in manual calculation. Delaunay proved several theorems that he then employed to simplify intermediate calculations. Although the theorems could be incorporated into a program, the effort necessary to express them in algorithmic form encouraged Deprit and his colleagues to search for a method more compatible with mechanized execution. The one they invented requires transformations that would have exceeded the abilities even of Delaunay, but the algorithm is easy to program and can be executed quickly with a computer. The development of new algorithms is one of the most active areas of investigation in computer algebra; it is largely because of such work that computer-algebra systems have been improved significantly in the past few years.



SIMPLIFICATION of an expression presents a problem of choice for a computer-algebra system: given several equivalent forms of an expression, such as those in the upper part of the illustration, which is to be considered the simplest? Many systems now being designed leave the choice partly to the person working with the system. The complex expression in the lower part of the illustration is equal to zero for all values of x for which the tangents are positive real numbers. The expression does not vanish for all values of x, however. If a computer-algebra system were to substitute zero for the expression, the relation of the final answer to the original problem could become quite obscure. The expressions *ln*, *tan* and *sinh*$^{-1}$ are the standard notations respectively for the natural logarithm, the tangent and the inverse hyperbolic sine.

In order to represent an algebraic expression in a computer program, most systems store the minimum information needed to specify the expression uniquely. Current representational schemes employ one of two basic approaches or a combination of the two. In one approach an expression is represented as an inverted treelike structure in which the leaves are the operands. For example, suppose one wished to represent the expression $2(x + 4)$ in a computer. The leaves of the tree would be the terms 2, x and 4, although they would appear at different levels. Both the x and the 4 would be connected by upward-moving branches to a plus sign. The symbol 2, however, would not be linked to the plus sign. Instead branches from the 2 and from the plus sign would meet at the top, or root, of the tree, which would be labeled with a multiplication sign. The representation makes more efficient the search for subordinate expressions of predetermined form.

In the second scheme "slots" are assigned in some definite order to represent the information carried by an expression. To represent a polynomial in one variable, for instance, one slot is assigned to the name of the variable, the next slot to the degree of the polynomial (the largest power of the variable that appears in the polynomial) and the fol-



REPRESENTING AN ALGEBRAIC FUNCTION in a computer may require several strategies. The inverted tree diagram (*a*) is a simple and convenient means of representing the sequence of operations that apply to the variables and constants in an expression. A polynomial function of one variable can be represented by a sequence (*b*) that consists of the name of the variable, the degree of the polynomial (equal to the largest power of the variable that appears in the polynomial) and the numerical values of the coefficients of descending powers of the variable. To represent a polynomial function of two variables (*c*) a generalization of the polynomial representation for one variable can be employed. Here the horizontal group of slots represents a third-degree polynomial function of the variable x, whereas the vertical groups of slots represent polynomial functions of the variable y. The three polynomials in y are understood to be coefficients, or multipliers, of the terms of the polynomial in x that correspond to the three slots left blank. Hence the coefficient of the term x^2 is $3y^2 + 2y$, the coefficient of the term x is $11y + 2$ and the coefficient of the constant term of the polynomial in x is $-y - 1$.

© 1981 SCIENTIFIC AMERICAN, INC

QUESTAR® 12 on the QUESTAR® MOUNT

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

The Questar 12 is a superb instrument for the serious astronomer, for the university astronomy department or the engineer seeking sophisticated tracking and surveillance equipment for which Questar Corporation has a noted reputation.

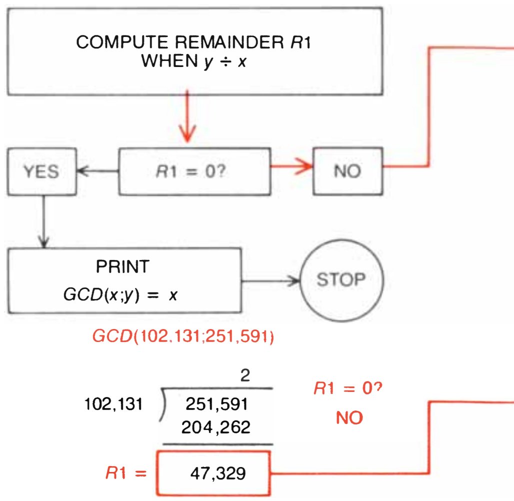
Questar Corporation Box C, Dept. 20, New Hope, Pa. 18938 (215) 862-5277

© Questar Corporation 1981

lowing slots to the coefficients of descending powers of the variable. The set of information slots can be made a part of a tree-structure representation when more complicated expressions must be stored.

Although every representation in a computer must be unambiguous, any given algebraic expression can be represented in a variety of equivalent ways. One might want to construct an algorithm that would always represent an expression in the simplest form possible; in such an algorithm, for instance, $x + x + x$ might always be represented as $3x$. People disagree, however, over what constitutes the simplest form of an expression. Stylistic preferences differ in much the same way as political ideologies do: programs designed by conservatives make no transformations on an expression unless they are specifically instructed by the user to do so, whereas programs designed by radicals always change the user's expression to their own preferred form. Many people like to retain some control over the simplification of an expression because the utility of a particular form may depend on the circumstances in which it is encountered. In any event, even if people could agree on what is the simplest form of every expression, it is known that the construction of a general algorithm for simplification is impossible.

Computer-algebra systems can simplify expressions that are exceedingly large and complex. Such expressions may incorporate not only the elementary polynomial, trigonometric and logarithmic functions but also the more complex functions that can arise in scientific work. The user of a computer-algebra system can also define his own functions, specify their properties and



FLOW CHART diagrams the operation of the Euclidean algorithm, a rigorous procedure for determining the greatest common divisor (GCD) of two integers. (The greatest

© 1981 SCIENTIFIC AMERICAN, INC

supply the rules of simplification appropriate to them; indeed, the computer can sometimes be employed to find such rules. In most cases little is known in advance about how an expression will simplify. The most practical method is to retrieve from the computer's memory all the kinds of algebraic expression the program can already simplify, supply whatever additional algebraic identities the programmer can think of and allow the computer to proceed on its own. The method works surprisingly well: it can often simplify as effectively as an expert mathematician.

Because of the need in algebraic calculations for exact rather than approximate answers, a computer-algebra system must be able to manipulate huge numbers with unlimited precision. In most computers numbers are ordinarily represented with a fixed number of significant digits, although the precision of the arithmetic operations can sometimes be doubled or even increased severalfold. For the purposes of computer algebra, however, no limits on precision can be set in advance.

Consider one algorithm that can be employed to simplify a rational polynomial expression (one in which one polynomial is divided by another). The algorithm is a generalization and modification of a method called the Euclidean algorithm for determining the greatest common divisor (GCD) of two numbers, which has been known for 2,200 years. The GCD of two numbers, such as 6 and 8, is found by a fixed sequence of repeated divisions; once the GCD is found, a fraction can be reduced to its lowest terms by dividing both the numerator and the denominator by the GCD. For the fraction 6/8 the GCD is 2 and the reduced form is 3/4.

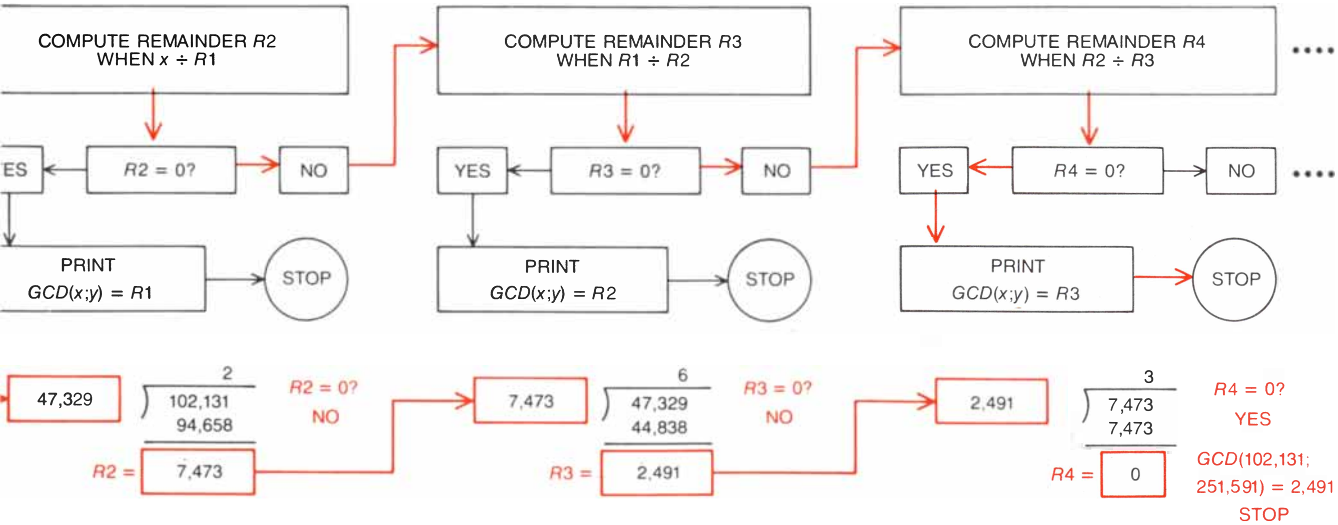
When the Euclidean algorithm is applied to a polynomial, however, the quotients and remainders in the repeated divisions can rapidly develop terms in which the fractional coefficients are ratios of enormous numbers. To avoid computing with enormous numbers, certain techniques have been devised for reducing the size of the numbers carried along in the computation. For example, a constant numerical factor can be eliminated from a polynomial in the Euclidean algorithm. Rounding any of the coefficients before the calculation is complete, however, would make nonsense of the final answer.

One of the most important algorithms developed in the past 15 years for computer-algebra systems is an algorithm that can solve problems in indefinite integration. Integration is a basic method of calculus, first invented independently by Newton and Leibniz, whereby an unlimited number of arbitrarily small quantities can be combined to yield some specific quantity. In what is called indefinite integration, the method is generalized: the outcome of the integration is expressed as a function of at least one variable instead of as some definite quantity. Such problems are encountered often in the physical and biological sciences, but their difficulty has bedeviled mathematicians for hundreds of years. It was once thought that no general algorithm for the solution of such problems could be constructed; the standard approach to their solution calls both for guesswork and for consulting published tables of integrals.

The algorithm that was successfully constructed for indefinite integration is similar to an algorithm subsequently developed to determine an algebraic expression for a finite sum of expressions that all have the same form [*see illustration on page 139*]. If an integral can be solved at all in closed form (rather than as the sum of an infinite series of terms), it is possible to predict the general algebraic form of the solution and then work backward by differentiation (the reverse of integration) to determine the exact formula. The algorithm has been incorporated into several computer-algebra systems. A numerical computer study of eight widely employed tables of indefinite integrals discovered that about 10 percent of the formulas are in error; one of the tables was found to have an error rate of 25 percent.

The funds spent on the development of computer-algebra systems probably do not exceed $3 million per year in the U.S. Nevertheless, the systems already exhibit great sophistication and diversity of design. There are about 60 such systems today, and they can be classified into three main groups that reflect their historical development. The systems in the first group are the descendants of the earliest attempts to write programs in computer algebra; they were designed to solve specific problems in fields such as mathematical physics and theoretical chemistry. Because a special-purpose program can be finely tuned for the kind of input expected, it can operate at great speed. Currently such programs exist for solving problems in quantum electrodynamics (ASHMEDAI), lunar theory and general relativity (CAMAL), high-energy physics (SCHOONSCHIP), indicial tensor manipulation (SHEEP) and celestial mechanics (TRIGMAN) and for solving equations limited to polynomials and rational functions (ALTRAN). There is even a special-purpose program called ALDES-SAC/2 that can assist in developing new computer-algebra programs.

The systems in the second major

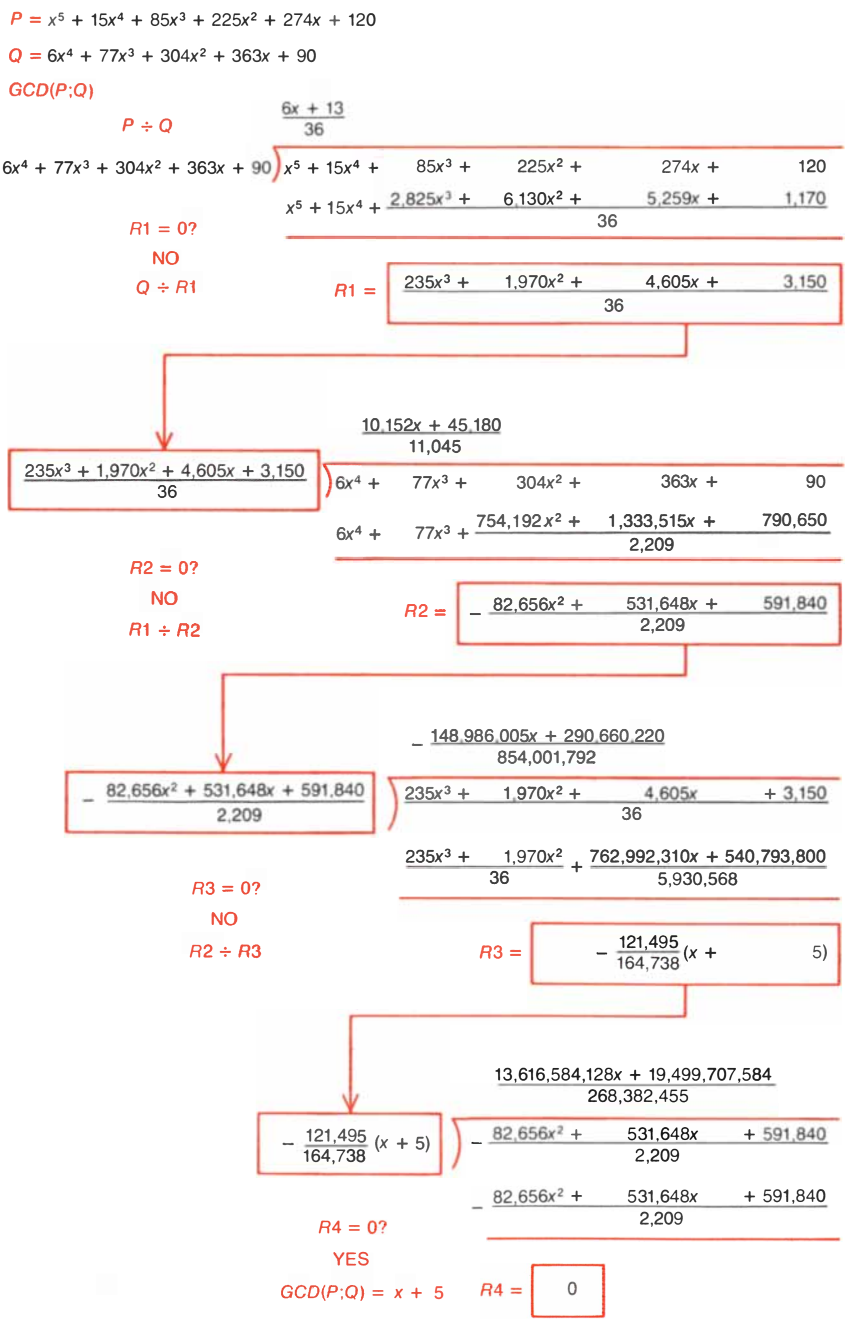


common divisor is the largest integer that will divide both given integers without leaving a remainder.) The algorithm was discovered at least 2,200 years ago; except for the four elementary operations of arithmetic it is the oldest algorithm known. Colored arrows in the flow chart indicate the transitional states of the algorithm for the numerical example in the lower part of the diagram. The Euclidean algorithm is not limited to integers; a slightly modified procedure can determine the greatest common divisor of two polynomials.

© 1981 SCIENTIFIC AMERICAN, INC

group are the general-purpose ones, which provide the investigator with as many mathematical capabilities as possible. Such systems can carry out the four basic arithmetic operations, perform definite and indefinite integration and solve equations, including ordinary differential equations that express algebraically how the change in one variable depends on changes in other variables. The programs can also solve systems of linear or nonlinear algebraic equations, differentiate, simplify, factor, compute with finite or infinite sums of expressions called Taylor series and perform all the functions of the special-purpose systems, although not with as much speed and power. The four best-known general-purpose systems are MACSYMA; REDUCE, a system developed at Stanford University, the University of Utah and the Rand Corporation; SCRATCHPAD, developed by the International Business Machines Corporation, and SMP, developed at the California Institute of Technology. They represent the most advanced achievements in computer algebra so far.

Computer-algebra systems designed to operate with microcomputers have now begun to appear. They are slower and less comprehensive than the general systems designed for large computers, but they can still perform far more complex calculations more accurately than many mathematicians can. The most sophisticated and widely available such system is called muMATH; it was developed at the Soft Warehouse in Honolulu. MuMATH provides some of the capabilities of the general systems, although the size, memory and speed of the microcomputer do not allow muMATH to attack very complex problems. Nevertheless, such systems (or their more powerful descendants) may find their way into personal microcomputers and perhaps even notebook-size calculators before the end of the decade.



EUCLIDEAN ALGORITHM applied to polynomials determines their greatest common divisor by repeated divisions, in the same way as it determines the greatest common divisor of two integers. The algorithm can give rise to huge intermediate numerical results that cannot be rounded off. For this reason the arithmetic operations in a computer-algebra system must have unlimited precision. Ordinarily a number stored in a computer is allotted a fixed amount of space in the computer memory, but in a computer-algebra system no fixed allocation can be made. Mathematicians who study the properties of large numbers have been attracted to this feature of computer-algebra systems. Colored arrows and the statements printed in color correspond to the steps of the algorithm diagrammed in the illustration on pages 144 and 145.

Computer-algebra systems tend increasingly to be written in simple, high-level programming languages that resemble ordinary mathematical expressions. The systems are also generally designed to interact with the programmer in a conversational manner. The beginner can often learn in a few minutes to solve many kinds of nontrivial problem beyond his power to solve by hand. With most general systems the user types in a command in a language similar to the computer languages ALGOL or FORTRAN. If the command includes fractions, exponents or other symbols that do not normally appear on the same line in print, the computer replies with a rewritten version of the expression that displays it in more natural form. The user can then specify certain operations to be carried out on the expression, such as adding it to itself, raising it to a power, differentiating it or integrating it. The computer executes the operation, simplifies the resulting expression and prints it or displays it on a video terminal. If the operation depends on, say, whether the positive or the negative square root of an expression is to be extracted, the computer queries the user before the calculation is finished.

Computer algebra has been applied in a variety of disciplines, including acoustics, algebraic geometry, economics, fluid mechanics, structural mechanics and number theory, and in the design of propellers, ship hulls, helicopter blades, electron microscopes and large-scale integrated circuits. We shall describe three additional applications in which com-

© 1981 SCIENTIFIC AMERICAN, INC

Olympus OM-1. Every inch a classic. Inside and out.

You are looking at the most revolutionary SLR of all time. The camera more than a *million* photographers have made into a modern classic. The *original* SLR compact, proven and perfected like no other. Elegant. Smooth. Precise. Enduring. That's the Olympus OM-1. A classic.

A classic in control. Its ultra-precise manual meter lets *you* control exposures with fingertip ease, always. Its finder is free of the clutter so common in conventional cameras–and far larger and brighter as well, thanks to its precious silver coating, multi-coated mirror, and superb Olympus optics.

A classic in ruggedness. Not for OM-1 are the plastic panels of ordinary SLR's. Here, you'll find a solid, all-metal body. Metal gears born of aerospace technology. Chromed-steel lensmount that defies wobble and wear. And more than a score of vibration-taming shock absorbers. So OM-1 works flawlessly under temperatures and conditions so extreme, others won't work.

A classic in capabilities. The world's first compact 5 shots-per-second motor drive, and the world's most ingenious automatic flash units. Dozens of matchless Olympus lenses, more than 300 matched accessories in all. All fully compatible with every OM-1 ever made. From the largest compact system anywhere.

See OM-1 at your Olympus dealer. Alone in its class, because it's a classic. For information, write Olympus, Woodbury, NY 11797. In Canada: W. Carsen Co. Ltd., Toronto.

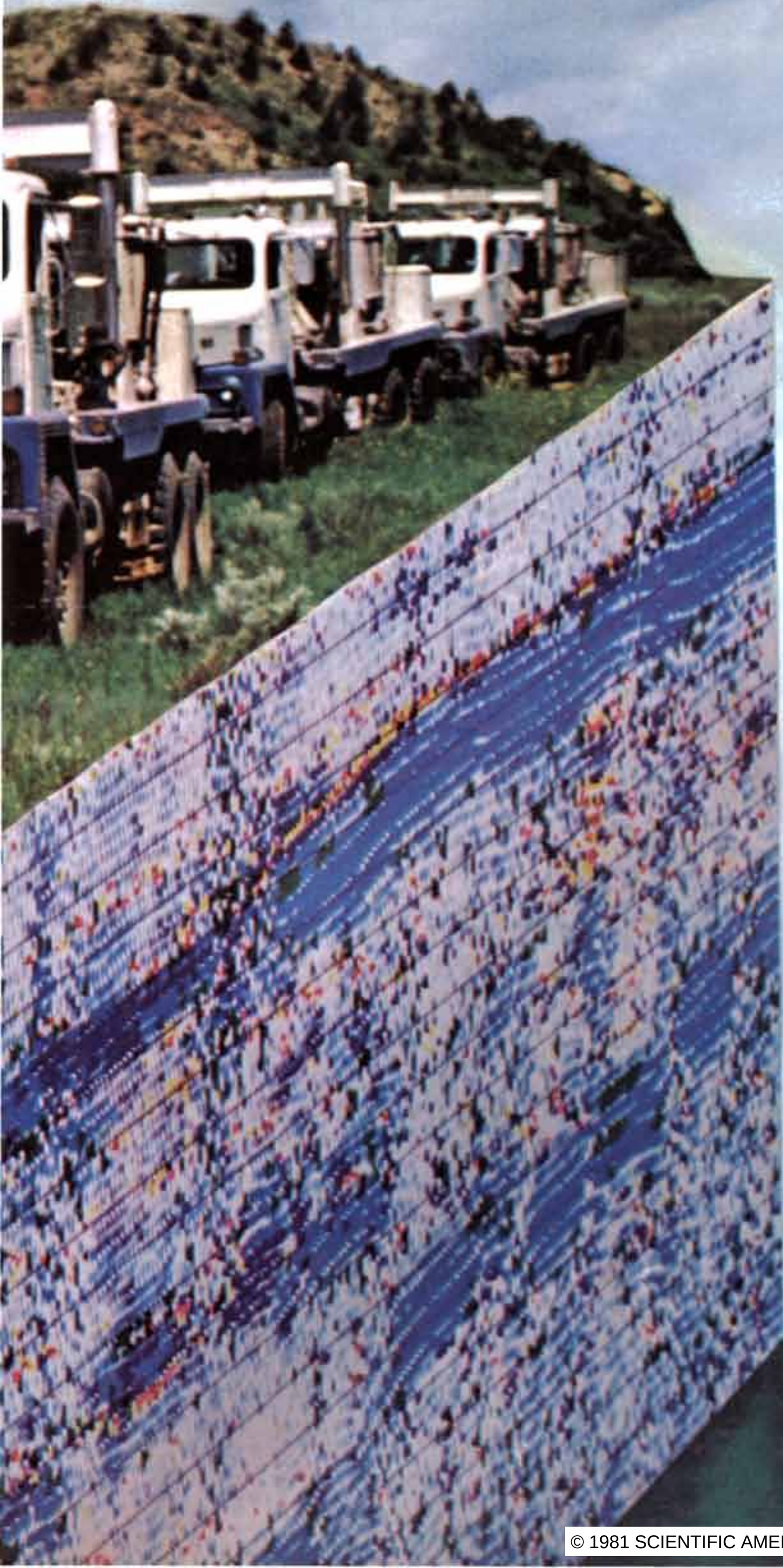
OLYMPUS® OM-1

© 1981 SCIENTIFIC AMERICAN, INC

© 1981 SCIENTIFIC AMERICAN, INC

"We're taking great color photos of Oklahoma–16,000 feet down."

C.J. Waidelich, President and Chief Executive Officer, Cities Service Company, Tulsa, Oklahoma



A major breakthrough in seismology is increasing our success ratio in finding new energy reserves.

Mapping underground terrain—like we're doing here in Oklahoma—is nothing new. But Cities Service geophysicists are taking basic seismic data and adding a significant twist—the ability to isolate and recognize geophysical findings and attributes through a unique color process.

We call this development Cit-Chrome.* Now when we look at seismic sections, we're able to see things we might have missed before.

Color seismic is helping us do a better job of finding new deposits—before a wildcat is even drilled. So when we *do* drill, our ratio of successful wells goes up.

This is just one of many advanced technological tools Cities Service is using. We're also using computers that process seismic data so that the subsurface can be visualized in three dimension, and satellite telemetry photos to help pinpoint untapped energy resources.

Cities Service geophysical information from all over the world is fed into our Technology Center in Tulsa for in-depth analysis. It's the newest, and one of the most advanced centers of its kind. This multimillion dollar complex symbolizes the commitment we've made to change America's energy future for the better.

CITIES SERVICE COMPANY

On top of the problem, part of the solution.

*Registered Trademark Cities Service Company

© 1981 SCIENTIFIC AMERICAN, INC

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."

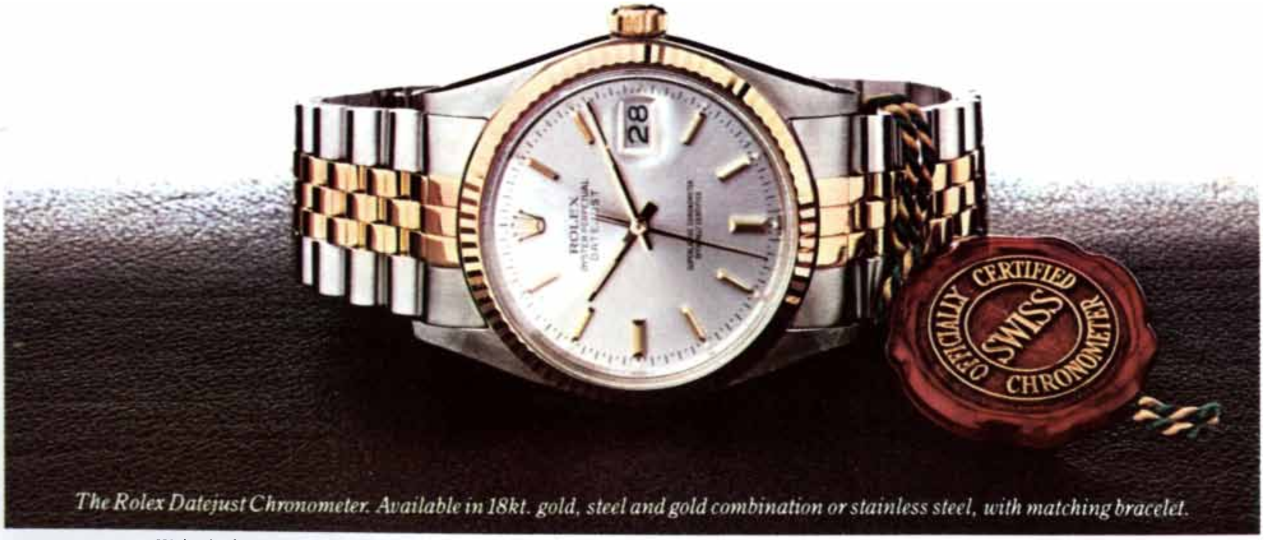
David Plastow recognizes the similar philosophy behind the watch he wears.

"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 has 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



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

Write for brochure. Rolex Watch, U.S.A., Inc., Dept. 298, Rolex Building, 665 Fifth Avenue, New York, N.Y. 10022.
World headquarters in Geneva. Other offices in Canada and major countries around the world.

© 1981 SCIENTIFIC AMERICAN, INC

puter algebra is making contributions.

For investigations in plasma physics and the development of fusion-energy sources some calculations require numerical and algebraic computer techniques to be combined. The algebraic formulas that describe the properties of a plasma in a magnetic field can become quite complex, and they tend to impede physical understanding. What has been lacking is a means for obtaining approximate rather than exact analytic expressions for such phenomena. To solve the problem the Plasma Theory Group at M.I.T. has devised a computer-algebra technique capable of partitioning the terms in the computation according to the physical processes that generate them. By numerical methods one can then eliminate from the series of terms describing each process those that are relatively small. The result is an algebraic expression that describes the dominant properties and remains sufficiently simple for the physical significance of each term to be perceived.

In order to derive testable predictions from theories of the interactions of ele-

234 THÉORIE DU MOUVEMENT DE LA LUNE.

la fonction R ne contient plus aucun terme périodique; elle se trouve donc réduite à son terme non périodique seul, terme qui, en tenant compte des parties fournies par les opérations 129, 260, 349 et 415, a pour valeur

$$R = \frac{\mu}{2a}$$

$$+ m'\frac{a^2}{a'^3}\Big\{\frac{1}{4} - \frac{3}{2}\gamma^2 + \frac{3}{8}e^2 + \frac{3}{8}e'^2 + \frac{3}{2}\gamma^4 - \frac{9}{4}\gamma^2e^2 - \frac{9}{4}\gamma^2e'^2 + \frac{9}{16}e^2e'^2 + \frac{15}{32}e'^4 - \frac{33}{2}\gamma^4e^2$$

$$+ \frac{9}{4}\gamma^4e'^2 + \frac{75}{16}\gamma^2e^4 - \frac{27}{8}\gamma^2e^2e'^2 - \frac{45}{16}\gamma^2e'^4 + \frac{45}{64}e^2e'^4$$

$$+ \Big(\frac{9}{16}\gamma^2 + \frac{225}{64}e^2 - \frac{27}{16}\gamma^4 - \frac{387}{32}\gamma^2e^2 + \boxed{\frac{23}{16}\gamma^2e'^2} - \frac{225}{128}e^4 + \frac{825}{64}e^2e'^2 + \frac{9}{8}\gamma^6$$

$$+ \frac{3897}{64}\gamma^4e^2 - \frac{99}{16}\gamma^4e'^2 - \frac{1431}{256}\gamma^2e^4 - \frac{1419}{32}\gamma^2e^2e'^2 - \frac{225}{512}e^6 - \frac{825}{128}e^4e'^2\Big)\frac{n'}{n}$$

$$- \Big(\frac{31}{32} - \frac{33}{8}\gamma^2 - \frac{971}{32}e^2 + \frac{465}{64}e'^2 + \frac{273}{64}\gamma^4 + \frac{5709}{64}\gamma^2e^2 - \frac{117}{4}\gamma^2e'^2 + \frac{4989}{256}e^4$$

$$- \frac{1905}{8}e^2e'^2 + \frac{3255}{128}e'^4\Big)\frac{n'^2}{n^2}$$

$$- \Big(\frac{255}{32} - \frac{31515}{1024}\gamma^2 - \frac{551115}{4096}e^2 + \frac{6885}{64}e'^2 + \frac{20511}{512}\gamma^4 + \frac{927831}{2048}\gamma^2e^2$$

$$- \frac{218115}{512}\gamma^2e'^2 + \frac{1622985}{16384}e^4 - \frac{4069635}{2048}e^2e'^2\Big)\frac{n'^3}{n^3}$$

$$- \Big(\frac{5515}{192} - \frac{296779}{3072}\gamma^2 - \frac{6380965}{12288}e^2 + \frac{16285}{24}e'^2\Big)\frac{n'^4}{n^4}$$

$$- \Big(\frac{28841}{288} - \frac{1138183307}{294912}\gamma^2 - \frac{1681901051}{1179648}e^2 + \frac{1393609}{384}e'^2\Big)\frac{n'^5}{n^5}$$

$$- \frac{9814775}{36864}\frac{n'^6}{n^6} - \frac{428268199}{663552}\frac{n'^7}{n^7}$$

$$+ \Big[\frac{9}{64} - \frac{45}{16}\gamma^2 + \frac{45}{64}e^2 + \frac{15}{128}e'^2$$

$$+ \Big(\frac{225}{512} - \frac{1935}{256}\gamma^2 + \frac{7425}{1024}e^2 + \frac{225}{64}e'^2\Big)\frac{n'}{n} + \frac{869}{512}\frac{n'^2}{n^2} - \frac{10391}{8192}\frac{n'^3}{n^3}\Big]\frac{a^2}{a'^2}\Big\}.$$

MASSIVE ALGEBRAIC CALCULATION completed by hand in 1867 was recomputed for the first time in 1970 with a computer-algebra system. The original calculation was undertaken by the French astronomer Charles Delaunay and was published in two volumes; a page of the second volume is reproduced here. Delaunay's calculation, which took 10 years to finish and another 10 years to check, gave the position of the moon as a function of time to a precision never before attained. Three errors were detected when the calculation was checked by André Deprit, Jacques Henrard and Arnold Rom of the Boeing Scientific Research Laboratories in Seattle. The major error, which gave rise to the other two errors, is outlined in color; the expression should be 33/16 $\gamma^2 e'^2$. The checking required about 20 hours of running time on a computer. Although computer algebra was responsible for exposing Delaunay's errors, the tables have since been turned: the remarkable precision of the calculation has been employed to test a few new computer-algebra systems for accuracy before they were put into service.

No more cold coffee

with MUG•MATE
Your personal cup heater.

Keep your coffee/tea/soup hot to the last drop on this miniature hot plate. Perfect for office, home or school! Money back guarantee.
Special Christmas Gift Offer!
10% discount on orders of 12 or more. Send us your gift list; we'll ship with gift card in your name. Christmas delivery guaranteed.

RUSH me _____ **MUG•MATE** s @ $12.95 + $1.50 shipping each (in Calif. add 78¢ S.T.). Enclosed is ☐ check/M.O. or charge to ☐ Visa or ☐ MasterCard.
Card # Exp.
Name
Address Apt
City State Zip
HONEX
1485 Bayshore Blvd., San Francisco, CA 94124

Garden Camera CALCULATORS

Hewlett Packard

HP 67	$288.50
HP 97	568.50
HP 31E	34.50
HP 32E	42.50
HP 37E	57.95
HP 33C	68.50
HP 34C	114.50
HP 38C	114.50
HP 41C	188.50
HP 41CV	Call
System I	Call
Accessories	Call

Texas Instruments

TI 58C	79.95
TI 59	188.50
PC 100C	155.00
TI M8A	52.50

Chess Challenger

Level 7	78.50
Level 8	104.95
Level 10	119.50
Voice	229.50
Bridge	229.50

master charge THE INTERBANK CARD
VISA
Prices subject to change without notice
Speed your order
TOLL FREE!

Call for low prices on Nikon, Minolta, Olympus and all Major Brand Cameras

Call 1 (800) 223-0595
Or Send postage and handling to
GARDEN CAMERA
345 Seventh Avenue, N.Y., N.Y. 10001
New York, Alaska & Hawaii Call:
Tel: (212) 868-1420 Open Weekdays 8:30-6:00
OPEN SUNDAYS 10-4 p.m. Closed Saturdays

© 1981 SCIENTIFIC AMERICAN, INC

mentary particles it has been necessary to evaluate expressions that can include thousands of integrals, many of which have unusual and deceptive mathematical properties. The numerical evaluation is open to two of the criticisms of numerical methods we have already mentioned: it is not as useful as an algebraic result for showing how contributions from various physical phenomena affect the interaction, and it introduces errors of approximation. As experimental techniques are refined the uncertainties introduced by approximation can become so large that the predictions of the theories cannot be distinguished. It is likely the application of computer-algebra methods will be of great help in generating theoretical predictions of the required precision.

In the study of theoretical alternatives to general relativity a test called Birkhoff's theorem has recently become popular. The mathematician George David Birkhoff of Harvard University showed in 1923 that the general theory of relativity excludes the propagation through space of gravitational pulses that might conceivably be generated by radial pulsations of matter in a star. Because no such pulses have been detected, and because they are impossible according to both Einstein's and Newton's theories of gravity, the exclusion of the pulses has come to be expected of any potential gravitational theory. The calculation required to determine whether or not a theory of gravity satisfies Birkhoff's theorem is lengthy, but it has now become straightforward with computer-algebra systems. A gravitational theory formulated by C. N. Yang of the State University of New York at Stony Brook was recently shown by the use of a computer-algebra system to violate Birkhoff's theorem. The calculation corrected a hand calculation that had been believed and cited for many years.

It is important to recognize that computer-algebra systems need not be employed solely for large calculations. Relatively simple problems often arise for which algebraic manipulation can contribute to understanding or make numerical calculation more efficient. One can sometimes reduce numerical computer-processing time by a factor of 100 or more by the judicious application of algebraic processing. Moreover, computer-algebra programs can substitute for an entire library of mathematical reference works. "Knowledge-based" programs that include integration methods, methods for solving differential equations and the like may make such reference works as obsolete as a table of logarithms. As inexpensive computers are improved, computer algebra will become available for teaching, study, research and perhaps unthought-of applications to all interested people in their own offices and homes.

computique computique computique

apple computer

BEST PRICES U.S.A.

• APPLE II, II PLUS (16K, 32K, 48K)
• APPLE III
• DOS 3.3
• APPLE PLOT
• APPLE PASCAL (64K)
• APPLE FORTRAN
• VISICALC 16 SEC
• VISIPLOT
• VISITREND
• APPLE WRITER
• GRAPHICS TABLET
• BPI (GL, AR, & PAYROLL)
• MODEM
• DOW JONES NEWS & QUOTES
• DECISION EVALUATOR
• CONTROLLER
• MICRO-COURIER
• EPSON
• CENTRONICS
• QUME
• SILENTYPE
• ANADEX
• SANYO, BW, COLOR GREENSCREEN
• EXTENDED WARRANTY

AUTHORIZED DEALER AND SERVICE CENTER

Your HEWLETT PACKARD Headquarters

THE HP-85!

Complete Enhancements, Peripherals and Accessories

HP-67	289.95	HP-37E BUS	59.95
HP-97	584.95	HP-11C NEW	CALL
HP-33C SCI	79.95	HP-12C NEW	CALL
HP-34C SCI	114.95	HP-43, 41CV	CALL
HP-38C BUS/RE	119.95	HP-85	CALL
HP-32E SCI	49.95	HP-125 NEW	CALL

GET A $20 REBATE ON THE TI-59 PROGRAMMABLE.

Texas Instruments

TI-59 960 PROG	179.95		
PC-100C	169.95		
LCD-PROG NEW	59.95		
TI-30II NEW	18.95		
TI-35SP SCI	22.50		
TI-40 SCI NEW	28.95		
BUS ANAL I	19.95	SPEAK & SPELL, READ	59.95
BUS ANAL II	44.95	SPEAK & MATH	59.95
BUS CARD	39.95	TOUCH & TELL NEW	54.95
MBA	54.95	TI-5100 DISPLAY	39.95
INVEST ANALYST	48.95	TI-5010 HAND/PRINT	49.95
TI-54 SCI NEW	39.95	TI-5120 PRINTER	59.95
TI-55II NEW	44.95	TI-5130 PRINT/DISP	79.95
TI-57 PROG SCI	39.95	TI-5135 PRINT/DISP	79.95
TI-58C PROG CALC	89.95	TI-5142 PRINT/DISP	99.95

TOUCH THE FUTURE

ATARI 400 (16K) 349.95
ATARI VISICALC AVAILABLE .... CALL

CHESS CHALLENGER 7 .... 89.95
SENSORY CHESS 129.95

SHARP
5813 SCI PROGRAMMABLE 34.95
1182A PRINT/DISPLAY 74.95
TALKING CLOCK 79.95
EL-6200 DIG EXEC SEC 89.95

CASIO
AA-81 DIG/ANALOG ALARM .69.95
VL-TONE MUSICAL INSTRUMENT/CALC 69.95
W100 DEPTH TESTED ALARM CHRONO ... 39.95
FX7100 SCI CHRONO ALARM CALC 49.95
FX3500 SCI PROGRAMMABLE CALC 39.95

(714) 549-7373 INFORMATION LINE
(800) 432-7066 TOLL FREE (Within CA)
(800) 854-0523 TOLL FREE (Outside CA)

WE WILL MEET OR BEAT ANY COMPETITOR'S ADVERTISED PRICE ON MOST ITEMS IF HE HAS THE MDSE. ON HAND.
VISA, MASTERCARD, MONEY ORDER, PERS. CK. (14 WRKG. DAYS TO CLR.), COD ACCEPTED; MIN. $4.95 SHIPPING U.S.A.; AIR ON REQST.; CAL. RES. ADD 6% SALES TX.; ALL MDSE. SUBJ. TO AVAIL.; PRICES SUBJ. TO CHANGE; S A-D

MAIL & PHONE ORDERS ONLY
3211 SO. HARBOR BLVD.
SANTA ANA, CA 92704
NEWPORT
(714) 549-7373

WRITE OR CALL FOR FREE CATALOG

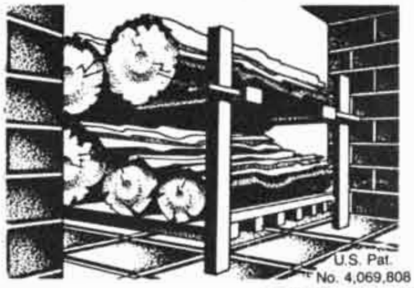
computique

PASADENA (213) 795-3007
MID-WILSHIRE (213) 385-7777
TARZANA (213) 705-7507
LAWNDALE (213) 370-5795
WEST LOS ANGELES (213) 820-0423
BREA (714) 990-6600

PROFESSIONAL DISCOUNTS

"Physicist's Fire"

with the Texas Fireframe® Grate



U.S. Pat. No. 4,069,808

"Amazing amount of heat" *BETTER HOMES AND GARDENS*; "Easy to start" *TIME*; "slow-burning" *NEW YORK TIMES*; "No rotation or stirring of the logs" *SCIENTIFIC AMERICAN*; "2.6 × more efficient" *POPULAR SCIENCE*. "Easy to maintain" D. J. Ticko, New Fairfield, CT. "Does a fantastic job" Frank Stanton NYC.

For full scientific description, see L. Cranberg, Am. Jour. Physics, June '81. Reprints on request.

Grate Model S-25: 25" front width, 21" back width, 13" deep. Model KS-25: same, **heavy-duty, gift-boxed**. Model U-25: 25×21×15. Model U-17: 17×14×13. Model U-33: 33×29×15. Copyrighted instructions.

___S-25 @$44.95 (26#); ___U-25 @ $44.95 (28#)
___U-17 @$36.95 (20#); ___U-33 @ $56.95 (35#)
___KS-25 @$51.95(31#); ___Reprint (s-a envelope)

Add 10% for shipping in U.S.; Enclose check or Visa, MC # ____________ Exp. Date ____

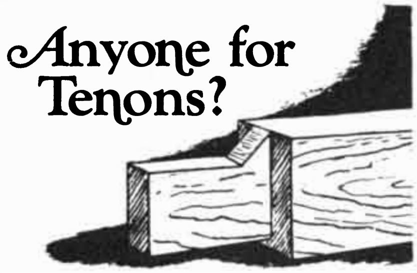
Name ____________

Address ____________

City ____________ State ______ Zip ____________

TEXAS FIREFRAME CO.
P.O. Box 3435 Austin, Texas 78764

Anyone for Tenons?



If your racket is tenons, doubles or singles, and you want a perfect match every time, you can learn from the professionals. They know a classic way to join two pieces of wood together is with a tenon that fits into a mortise.

Fine Woodworking magazine speaks this language to more than 200,000 readers—people seriously interested in making beautiful things out of wood. Whether you are an aspiring novice or an accomplished expert, you'll find it an especially informative magazine, with finely detailed articles about techniques and tools, materials and design. It's written by master craftsmen who share their many years of woodworking experience. And it's printed on heavy paper to withstand years of reference. All back issues are in print and indexed periodically.

If you want to become a better woodworker, send $14.00 for a one-year subscription (6 issues). Or call us toll-free, 1-800-243-7252, to charge your order to Visa or MasterCard (Connecticut residents call 1-426-8171).

Fine WoodWorking®

The Taunton Press
52 Church Hill Rd.
P.O. Box 355KC
Newtown
Connecticut 06470

© 1981 SCIENTIFIC AMERICAN, INC

explore the world below

Oceanus®

Published by
Woods Hole Oceanographic Institution
one of the world's leading centers of ocean research

Marine Scientists talking directly to the serious student of the sea

SUBSCRIPTION DEPT. BOX H
1172 COMMONWEALTH AVENUE
BOSTON, MASSACHUSETTS 02134
Please make checks payable to Woods Hole Oceanographic Institution, Woods Hole, Massachusetts 02543.

Please enter my subscription to OCEANUS for one year at $15.00 (four issues).
☐ payment enclosed ☐ bill me

Name..Address ....

City..State....................................Zip ....

© 1981 SCIENTIFIC AMERICAN, INC

The Anthropic Principle

Certain conditions, such as temperature, were favorable to the emergence of life on the earth. The anthropic principle argues the reverse: the presence of life may "explain" the conditions

by George Gale

The earth is an exceptionally hospitable place for mankind, with abundant water and an average temperature that happens to lie in the narrow range where water is a liquid. In view of the evolutionary origin of life, these facts are hardly surprising; if the earth were cold and dry like Mars, or if it had a steaming, caustic atmosphere like that of Venus, intelligent beings would not have evolved to remark on the hostility of their surroundings. It seems decidedly odd, however, to argue that the presence of life on the earth might "explain" why the planet has a temperature between the freezing point and the boiling point of water. The usual practice has been to argue the opposite proposition, namely that life evolved on the earth because the circumstances were conducive to its existence.

Although the reasoning may at first seem backward, the idea that the mere presence of intelligent life can have some explanatory power has recently been introduced into cosmology, where the task is to understand the history not of a single planet but of the entire universe. It is easy to imagine a universe quite different from the observed one. For example, changing the values of certain physical constants might give rise to a universe where the chemical elements heavier than helium are never formed or where all stars are large, hot and short-lived. In most such imaginary reconstructions of the universe it is unlikely that an intelligent form of life would ever appear. The fact that the real universe does harbor intelligent observers therefore places certain constraints on the diversity of ways the universe could have begun and on the physical laws that could have governed its development. In other words, the universe has the properties we observe today because if its earlier properties had been much different, we would not be here as observers now. The principle underlying this method of cosmological analysis has been named the anthropic principle, from the Greek *anthropos,* man.

The mode of reasoning embodied in the anthropic principle is quite different from the deductive mode that has long been characteristic of much scientific thought. A deductive theory begins by specifying the initial conditions of a physical system and the laws of nature that apply to it; the theory then predicts the subsequent state of the system. For example, one might deduce the present conditions on the earth by specifying the initial size, mass and chemical composition of the nebula from which the solar system condensed, then tracing the evolution of the sun and the planets under the influence of physical laws that describe gravitational forces, nuclear reactions and so on. The anthropic principle has been invoked in cosmology precisely because the deductive method cannot readily be employed there. The initial conditions of the universe are not known, and the physical laws that operated early in its history are also uncertain; the laws may even depend on the initial conditions. Indeed, perhaps the only constraint that can be imposed on a theory reconstructing the initial conditions of the universe and the corresponding laws of nature is the requirement that those conditions and laws give rise to an inhabited universe.

At the least the anthropic principle suggests connections between the existence of man and aspects of physics that one might have thought would have little bearing on biology. In its strongest form the principle might reveal that the universe we live in is the only conceivable universe in which intelligent life could exist. It is fair to say, however, that not all cosmologists and philosophers of science assent to the utility of the anthropic principle, or even to its legitimacy. Here I shall describe some of the ways in which the principle has been applied and let the reader judge its validity.

The concept that underlies much of modern cosmology is called the Copernican principle. Its origins can be traced to the assertion made in 1543 by Nicolaus Copernicus that the earth is not the center of the universe. The modern, extended form of the principle was not stated explicitly, however, until 1948 by Hermann Bondi of the University of Cambridge. It holds that the position of human observers in the universe is not in any way privileged or especially distinguished from other positions; hence observations in cosmology are valid not only for the earth or for the solar system but also for remote regions of the universe. The Copernican principle or some assumption like it is methodologically necessary in cosmology; without it cosmological findings could be dismissed as idiosyncrasies stemming from physical features peculiar to the fraction of the universe inhabited by human observers. Of course, as Bondi himself recognized, the usefulness of the Copernican principle is no guarantee of its truth.

A generalization of the Copernican principle has come to be known as the cosmological principle. It states that not only is the position of the solar system without privileged status but furthermore no position anywhere in the universe is privileged. Implicit in this idea is the assumption that the large-scale structure of the universe is uniform: apart from local irregularities, such as galaxies, all regions of the universe are exactly alike. A homogeneous structure is appealing (in the absence of evidence to the contrary) because it is the simplest possible structure. On this methodological assumption the earth occupies a typical position in space.

Evidence for the cosmological principle comes from the reproducibility of most scientific experiments. Even when an experiment, such as a measurement of the speed of light, is done repeatedly in the same laboratory, it is nonetheless being done both at different times and at different points in space (because the earth has moved in the interim). Insofar as the results are the same, the position of the earth does not affect the experiment. Such evidence is less than convincing, however, because conclusions in cosmology pertain to regions

© 1981 SCIENTIFIC AMERICAN, INC

of space-time much larger than those traversed by the earth.

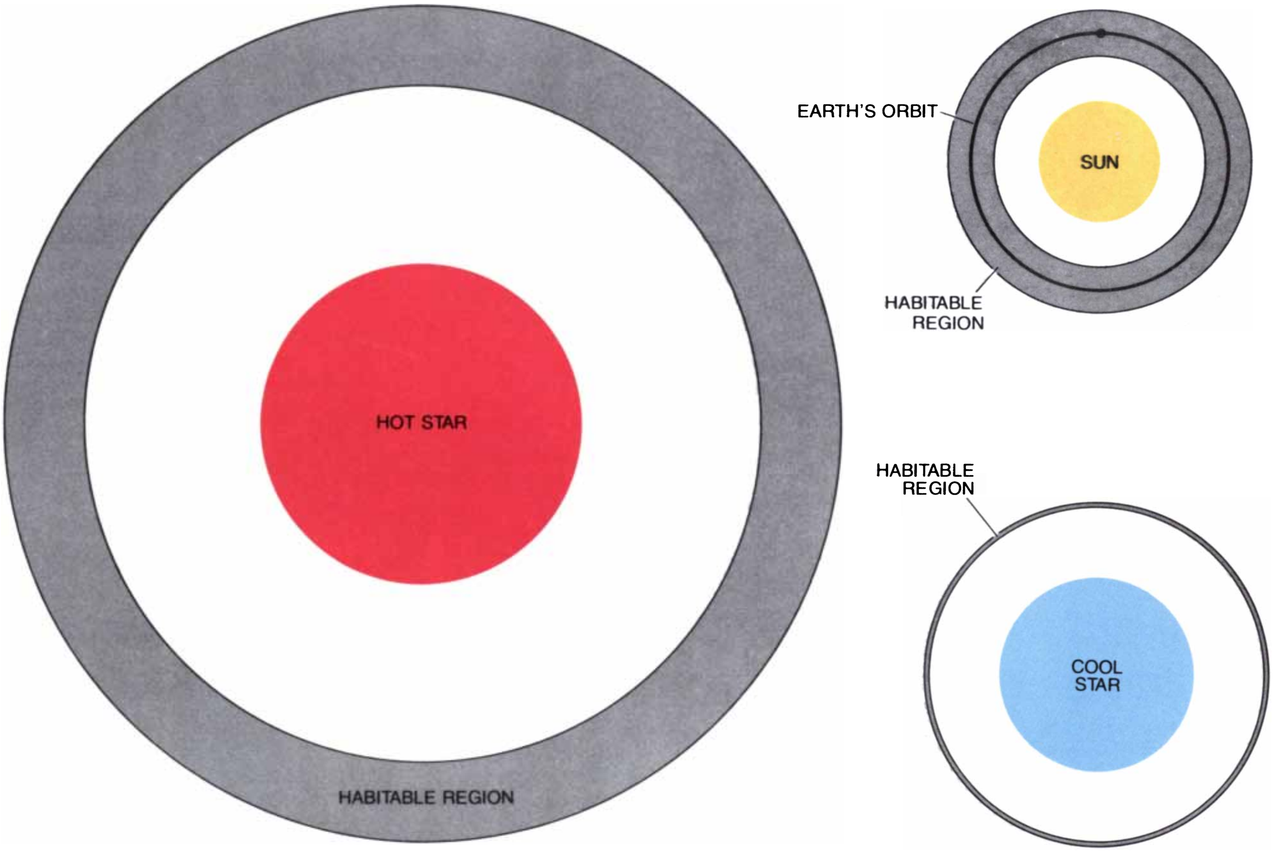
Bondi and Thomas Gold of Cornell University proposed a still more general assumption called the perfect cosmological principle. It states that apart from local irregularities the universe is uniform both in space and in time, so that an observer would see the same large-scale structure from any place and at any epoch. The perfect cosmological principle is the basis of the steady-state model, which in its original formulation posited a universe completely uniform throughout space and time. In order to accommodate evidence that the universe is expanding, the model assumes that matter is being created continuously. The steady-state model has since largely been abandoned and as a result so has the perfect cosmological principle. The cause was the detection in 1965 of the universal background of microwave radiation. The microwave background is interpreted as the remnant of a stage in the early universe when it was much hotter and denser than it is now.

Although the microwave background radiation rules out the temporal uniformity of the universe, it provides the most compelling evidence for large-scale spatial uniformity. The observed radiation is isotropic—that is, it comes from all directions with equal intensity—to an accuracy of better than one part in 1,000. Thus the properties of the background radiation support the cosmological principle but not the perfect cosmological principle.

The observed expansion of the universe is also consistent with the cosmological principle. The expansion has no center: an observer in any galaxy would see all other distant galaxies in all directions receding from him. The farther away a galaxy is, the greater its velocity of recession is. For galaxies at the same distance the recessional velocities are equal within an accuracy of better than one part in 1,000.

The microwave background, the recession of distant galaxies and the cosmological principle are all brought together in the big-bang model, which takes as the origin of the universe a dimensionless point of apparently infinite density. Such an origin is suggested by imagining the current recessional velocities to be reversed; extrapolating backward shows that all the galaxies would meet at a point. Because the universe has been expanding since the moment of the big bang, one can estimate its age from the characteristics of the expansion. If the recessional velocities had not changed over time, the age of the universe would be equal to the distance between any two galaxies divided by the velocity with which they are receding from each other. This hypothetical age is called the Hubble time, after Edwin P. Hubble, who in 1923 discovered the relation between distance and recessional velocity.

Actually it is likely that the recession-

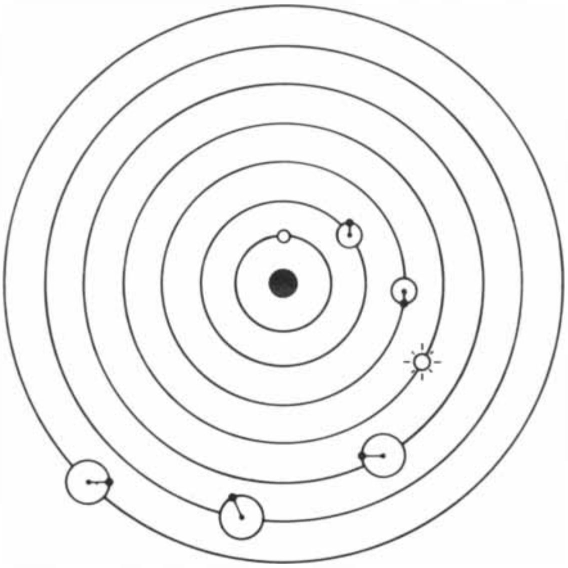


HABITABLE STAR SYSTEMS include only those in which a star heats up a region of space where the temperature falls in the narrow range in which water is a liquid. In the diagram at the left is the warmest star whose planets could support intelligent life; in the diagram at the upper right is the sun; in the diagram at the lower right is the coolest star whose planets could support intelligent life. (In each diagram the star and the planetary system are drawn to a different scale.) The upper and lower limits on the size of a life-supporting star arise from different properties of the stellar systems. A larger and brighter star could provide a habitable region, but the star would remain in a stable stage of its evolution too briefly for life to evolve. A smaller and dimmer star could also provide a habitable region, but the planet would be too close to the star. As a result of tidal interactions the planet would stop rotating and an extreme temperature difference would develop between the light side and the dark side. Ultimately the planet's atmosphere would be boiled away on the light side and frozen on the dark side. Life evolved on the earth because of the circumstance that it happens to occupy a habitable region. The anthropic principle argues the opposite proposition, namely that the presence of life on the earth explains why the planet has a temperature in the narrow range where water is a liquid. It remains to be seen whether the anthropic principle will win general acceptance among cosmologists.

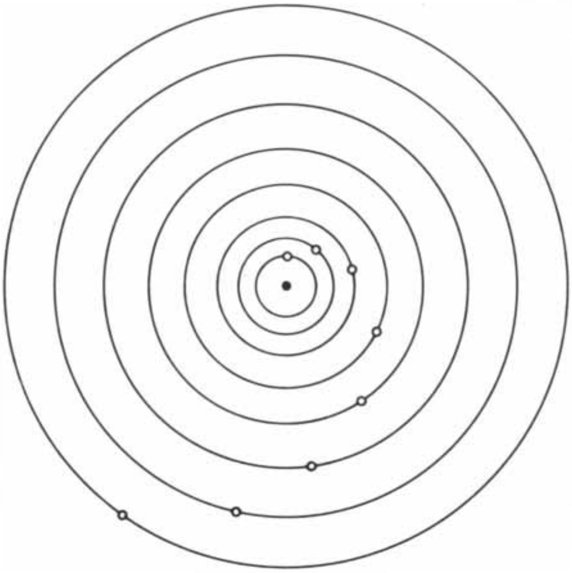
© 1981 SCIENTIFIC AMERICAN, INC

© 1981 SCIENTIFIC AMERICAN, INC

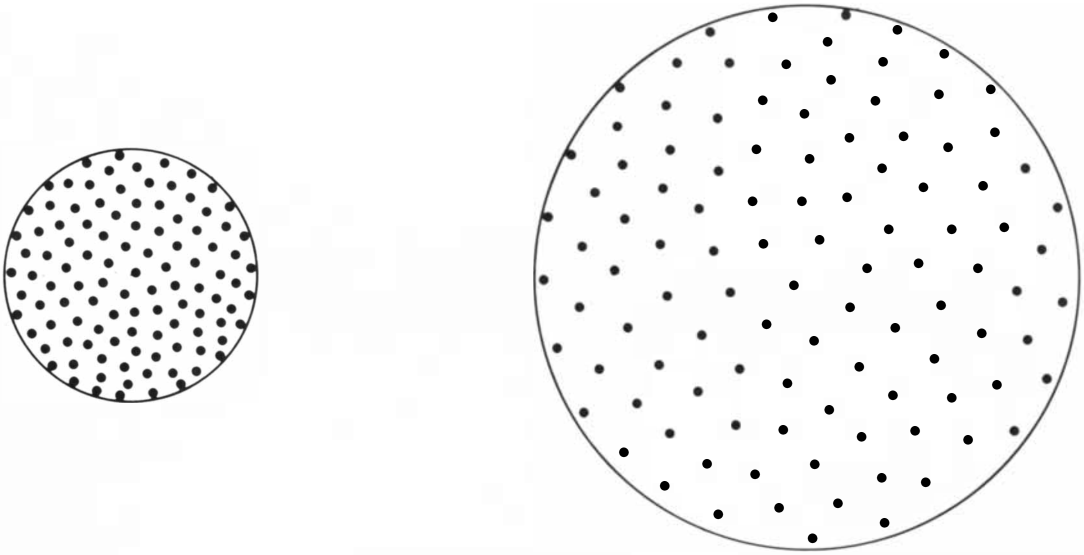
© 1981 SCIENTIFIC AMERICAN, INC



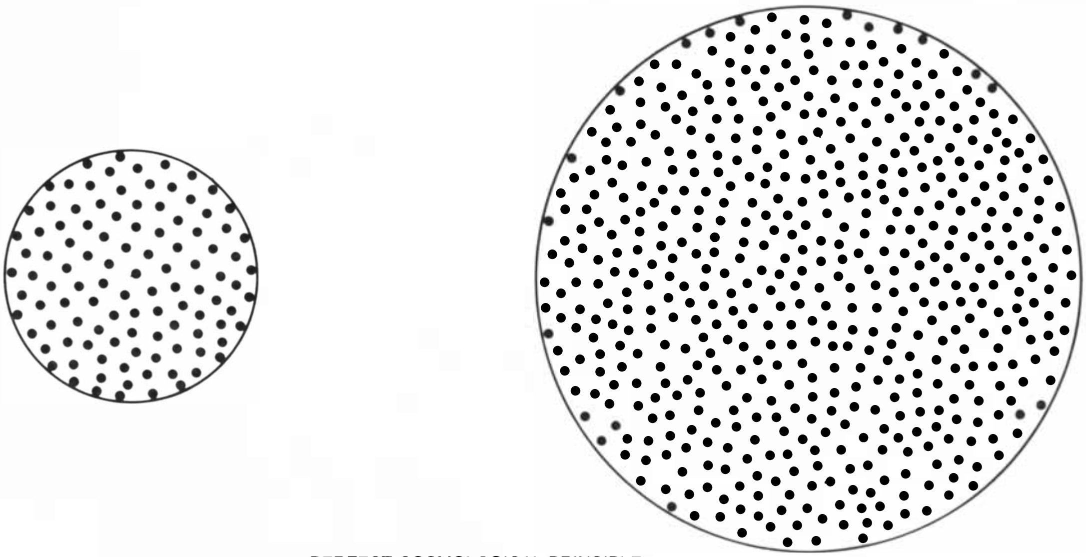
PTOLEMAIC SYSTEM



COPERNICAN SYSTEM



COSMOLOGICAL PRINCIPLE



PERFECT COSMOLOGICAL PRINCIPLE

© 1981 SCIENTIFIC AMERICAN, INC

al velocities have changed, although it is not clear by how much. One cause of such change is the mutual gravitational attraction of all the galaxies, which tends to slow the expansion of the universe. The change in the rate of expansion in the period since the big bang determines whether the universe is "open" or "closed." An open universe will expand forever. A closed universe will eventually stop expanding, start contracting and ultimately collapse in a "big stop." If the universe is open, the current expansion rate suggests its age is roughly 20 billion years. If the universe is closed, the rate of expansion suggests it is about 13 billion years old.

The anthropic principle was introduced by Robert H. Dicke of Princeton University in 1961; he proposed it in the course of analyzing work done by P. A. M. Dirac some 30 years before. Dirac had called attention to certain curious numerical relations among dimensionless numbers that have an important role in physics and astrophysics. A dimensionless number is one that has no units of measurement associated with it, so that its value is the same in any system of measurement. Dirac did not consider the exact value of the numbers but only their order of magnitude: the power of 10 that most nearly expresses the value. He found several instances where the order of magnitude is an integral power of the large number 10^{40}.

Three numbers that figured prominently in Dirac's work are measures of force, time and mass. The first quantity is a dimensionless form of the gravitational coupling constant, which is a measure of the strength of the gravitational force; it has a value of roughly 10^{-40}. The second dimensionless number is the age of the universe expressed in atomic units: Dirac defined it as the ratio of the Hubble age to the time required for light to traverse a distance equal to the radius of a proton. The ratio has a value of roughly 10^{40}. (Because Dirac was concerned only with the order of magnitude, the Hubble age and the other age estimates yield much the same result.) The third dimensionless quantity is the number of massive particles (such as protons and neutrons) in the visible region of the universe; the number is estimated to be about 10^{80}.

Dirac noted three order-of-magnitude relations among these quantities. First, the gravitational coupling constant is the reciprocal of the age of the universe in atomic units. Second, the number of massive particles is the square of the age of the universe in atomic units. Third, the gravitational coupling constant is the reciprocal of the square root of the number of massive particles. Dirac thought the numerical relations were too striking to be dismissed as coincidences. He proposed that they result from some unknown causal connection.

One possible objection to these ideas is that the age of the universe obviously increases with time. As a result the relations of the numbers should be continuously changing, and it is an extraordinary coincidence that their values should be determined just when they fall into correspondence. Dirac forestalled this criticism by proposing that the gravitational coupling constant and the number of massive particles also change with time in such a way that the order-of-magnitude relations remain valid throughout the history of the universe. For the correspondences to persist gravity must grow weaker in inverse proportion to the time and the number of particles must increase in direct proportion to the square of the time.

Dirac's analysis was generally received with little enthusiasm, but Dicke took it seriously. He proposed that a causal connection between the gravitational coupling constant and the number of massive particles might be founded on a principle first enunciated by Ernst Mach. Mach had proposed that the inertial mass of a particle is determined by its gravitational interaction with distant matter. (The established view was that inertial mass is a property of the particle quite independent of its surroundings.) According to Mach's principle,

MODELS OF THE UNIVERSE prevalent at various times in the past 2,000 years are diagrammed in order of increasing symmetry. In the Ptolemaic system, codified in the second century A.D., the earth has a fixed position at the center of the universe and all other celestial bodies circle the earth. In 1543 Nicolaus Copernicus suggested that the center of the universe is not the earth but the sun. In the 20th century the universe was discovered to be expanding uniformly in all directions, and so the idea that the universe has a center was abandoned. The cosmological principle holds that the large-scale features of the universe would appear the same to an observer in any galaxy looking in any direction. The schematic diagram of the cosmological principle shows the expanding universe at two times; each dot represents a galaxy. No matter which galaxy is singled out, all other galaxies recede from it; as the universe expands, the distance between galaxies changes but their geometric distribution does not. The perfect cosmological principle presents a universe that is even more symmetrical: the large-scale features are the same not only from every point in space but also from every point in time. In the version of the perfect cosmological principle diagrammed here the universe expands but new galaxies form just fast enough to maintain a constant density. The perfect cosmological principle has now largely been abandoned. The anthropic principle, which is not diagrammed, asserts that the earth is a privileged position because intelligent life is present on the planet.

Better Than Jogging

NordicTrack

Jarless Total Body Cardiovascular Exerciser Duplicates X-C Skiing for the Best Motion in Fitness

This revolutionary new exerciser duplicates the smooth, rhythmic, total body motion of X-C skiing for the most effective cardiovascular exercise obtainable. Uniformly exercises more muscles than any other exercise device. Makes high heart rates easy to obtain and keeps more muscles in tone. Also highly effective for weight reduction. Used by both men and women.

Completely jarless natural motion does not cause joint and back problems as in jogging or running. Arm and leg resistances are separately adjustable for maximum effectiveness. The NordicTrack uses no motors and folds compactly for convenience. Used in homes, businesses, and institutions. Our customers include Xerox Corporation, US Army, Penn State U and the YMCA.

PSI 124 F Columbia ct. Chaska, Minn. 55318
1-800-328-5888, MN 612-448-6987, **8-5 Mon-Fri**

How to Argue and Win!

Here is a clear simply written basic guide to logical thinking, showing how to spot the fallacies, the prejudices and emotionalism, the inappropriate analogies, etc., in the other fellow's argument and how to watch for and avoid the irrational in your own judgments. The author makes plain not only **how** but also **why** people resist facing the truth.

A tool for **clear thinking** as well as **convincing others.**

$8.95 plus $1.25 handling

THE ART OF ARGUMENT by Giles St. Aubyn

GEM TESTING

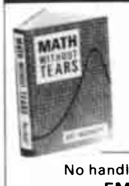
FOR FUN AND PROFIT

This exciting pursuit combines the challenge of detective work . . . the thrill of spotting sensational "buys" . . . the satisfaction of knowing when someone else's big flashy "diamond isn't . . . and the opportunity for highly paid, spare-time earnings. GEM TESTING, bible of amateur and professional alike, is a remarkably simple, lavishly illustrated book by B. W. Anderson, director of London's world famed Precious Stone Laboratory. Anderson has examined more gems than any man in history.

Now he shows you step-by-step the high speed methods by which he unerringly identifies precious stones. Emphasis throughout the book is on rapid examination with the naked eye. This FIRST AMERICAN EDITION of GEM TESTING tells, shows and explains everything you need to know. **Copiously illustrated.**

only $11.95 plus $1.25 handling

Math Without Tears



Using non-technical language and a light touch Roy Hartkopf gives you a basic understanding of many everyday applications of mathematics. He takes the reader from simple counting to trigonometry and calculus, emphasizing the practical aspects of math. Humorously written.

Learn math in the comfort of your own home at minimum cost.

$10.95 plus $1.25 handling

No handling charge on 3 books or more!
EMERSON BOOKS, INC.
Dept. 164-G Verplanck, N.Y. 10596
10-Day Money-Back Guarantee

© 1981 SCIENTIFIC AMERICAN, INC

TYPEWRITERS

SAVE UPTO 60%

FACTORY DIRECT

BRAND NAMES

We sell only well-known quality name-brands. All merchandise carries full manufacturer's warranty, packed in factory-sealed cartons. Most orders are shipped within 48 hours—directly to your home.

HERE ARE SOME EXAMPLES.

	Retail	Ours
Smith Corona Electric Portable	$410	$289
Olivetti Electric Portable	$300	$199
Brother Electric Portable	$280	$179
Royal Electric Portable	$280	$179

FREE CATALOG

Write for fully illustrated 16 page 2 color catalog. You won't believe the prices.

FOR FASTER SERVICE CALL

(609) 452-7500

WE GLADLY ACCEPT—

American International TYPEWRITER COMPANY

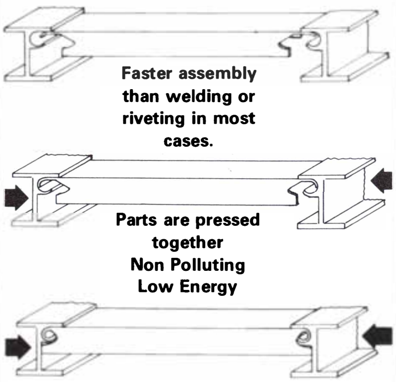
(Dept. E)

745 Alexander Rd., Princeton, N.J. 08540

ECONOMICAL AUTOMATION

WITH PATENTED

CLENCH CURL™



If you have an assembly of side rails and cross-members Clench Curl could supply the simple automation you want. Over 150,000,000 have been formed.

For Use Under License

Patented in 25 Countries

DAYMOND

Division of Redpath Industries Limited

2441 Royal Windsor Dr.

Mississauga, Ont. Can. L5J 4C7

Telex 06-982312 Tel: (416) 823-4423

the weakness of gravitation is related to the enormous amount of distant matter in the universe. If the principle is accepted, it is not surprising that there should be some numerical relation between the gravitational coupling constant and the number of massive particles, which is a measure of the amount of matter in the universe.

It is not apparent, however, why the coupling constant and the number of particles should be related to the Hubble age. On the contrary, if Mach's principle is valid at all, it should remain valid in all eras in the history of the universe, whereas the order-of-magnitude relations would be observed only in the present era. Again, it seems man has appeared at a privileged and therefore unlikely moment.

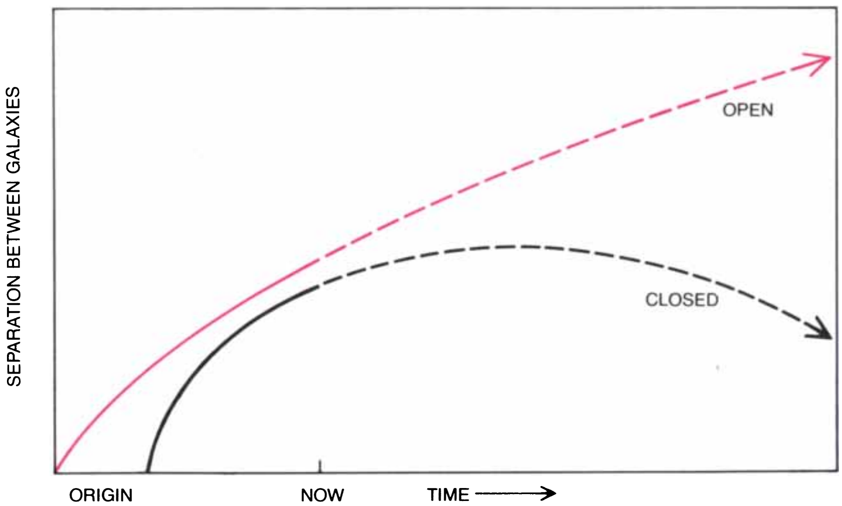
Dicke's answer to this objection was that the value of the Hubble age is strongly constrained by the conditions necessary for the existence of man. One essential condition is that the universe should have aged enough to allow time for the creation of elements heavier than hydrogen, because "it is well known that carbon is required to make physicists." Heavy elements are made in the interior of stars and are released when a star explodes as a supernova. Consequently the Hubble age of an inhabited universe cannot be shorter than the age of the shortest-lived star. On the other hand, if the Hubble age were much greater than the age of a typical star, most stars whose planets could support life would have died by now. Therefore, Dicke concluded, the Hubble age is roughly equal to the life span of a typical star.

The novelty of Dicke's argument deserves close analysis. Given the existence of man, he argued, the Hubble age could not have a value much different from the one it actually has. Hence Dirac's numerical relations apply not to any possible evolutionary universe (where the Hubble age could presumably take on any one of many values) but only to the universe that is observed by physicists today.

One of the most appealing features of Dicke's analysis is its apparent demonstration that the value of the Hubble age is not arbitrary. Reducing the arbitrariness of explanations is a long-standing aim of the sciences, and so in this respect Dicke's work is not unusual; what distinguishes it is the method or the logic of the argument. In general arbitrariness has been eliminated by showing that a phenomenon can be predicted or that a theory can be deduced from some more fundamental premise. Dicke's technique is quite different.

Deductive or predictive logic proceeds from a fundamental assumption to a derived result: the future is deduced from the past. The temporal flow of Dicke's argument is in the opposite direction. He cites a present condition (man's existence) as the explanation of a phenomenon grounded in the past (the age of the universe). Clearly his result cannot be interpreted as a prediction, since it would be a prediction of the past on the basis of that past's own future.

Cosmologists have turned to the an-



AGE OF THE UNIVERSE can be estimated from the characteristics of the current expansion. The diagram shows the separation between galaxies as a function of time. The point labeled "Now" corresponds to the current rate of expansion. From the present rate alone, however, the age of the universe cannot be deduced. The rate has probably diminished since the big bang because of the gravitational attraction of the expanding matter. It is not known whether the expansion will continue forever (*colored curve*) or whether eventually the universe will stop expanding and then collapse under its own gravitation (*black curve*). Either possibility is consistent with the available evidence and with the big-bang model. Continued expansion suggests an age of some 20 billion years; expansion followed by collapse gives an age of about 13 billion years. The age estimated by assuming a constant rate of expansion is the Hubble time.

© 1981 SCIENTIFIC AMERICAN, INC

© 1981 SCIENTIFIC AMERICAN, INC

An easier way to use computers...from a pioneer in computing technology.

The computer printout in the picture above contains the instructions and input needed for the *UNIX* system to format and produce the text on the opposite page.

© 1981 SCIENTIFIC AMERICAN, INC

Our widely accepted *UNIX*™ operating system is simplifying the use of computers. Designed to handle a variety of applications, it is being used to manage and maintain the telecommunications network, control experiments, develop software, process text, prepare documents, and teach computer science.

The *UNIX* system allows users to take small programs and assemble them like building blocks to perform complex tasks. In text processing, for example, the command "Spell Bell Labs Ad" tells a computer to proofread this ad against a dictionary filed in its memory. The program that performs the task was created by simply combining several smaller *UNIX* programs.

Another useful feature of our *UNIX* operating system is its ease in typesetting mathematical expressions. To typeset an equation like

$$\sum_{i=1}^{\infty} \frac{1}{x_i} = \pi$$

someone need only type: "Sum from i = 1 to infinity 1 over x sub i = pi." The computer does everything else.

Since 1969 the Bell System has installed more than 1100 *UNIX* systems. Along with other Bell Labs innovations in computing technology, these systems are enhancing the way the nation's telecommunications network is planned, designed, built, and operated. Through licensing agreements with Western Electric, universities have installed over 800 *UNIX* systems, and government and industrial facilities are using over 400.

The *UNIX* operating system can be used with computers of different manufacturers because it is small, cleanly designed, and written in a general-purpose programming language. Such portability in a computer operating system saves time and money.

Building on the past

The *UNIX* system is just one of many Bell Labs advances in computing science and technology over the years. Among our innovations:

- Application of telephone switching concepts and technology to early computers
- First demonstration of remote computer terminal and data link
- Conception of electronic analog computer
- First design of AND and OR gates for diode circuitry
- Formulation of Information Theory
- Invention of error-detecting and error-correcting codes
- Demonstration of first general-purpose transistorized digital computer
- Development of computer operating systems
- Design of computer languages, including ALTRAN, SNOBOL, L6, and C
- Creation of computer graphics techniques for storing, manipulating, and presenting information
- Development of Fast Fourier Transform
- Design of central processors for switching systems having virtually no downtime

Looking ahead

Computing technology is having a major impact on the telecommunications business. It's increasing the Bell System's ability to provide new services and handle existing ones more efficiently. Today, for example, the nationwide telecommunications network links thousands of software-controlled electronic systems, making it by far the world's largest distributed processing network. We and our partners—Western Electric and the telephone companies of the Bell System—are putting technology to work so that the network will continue to evolve and expand its information-handling capabilities. The object, of course, is to meet the fast-growing and changing needs of Bell System customers.

For information about employment, write:

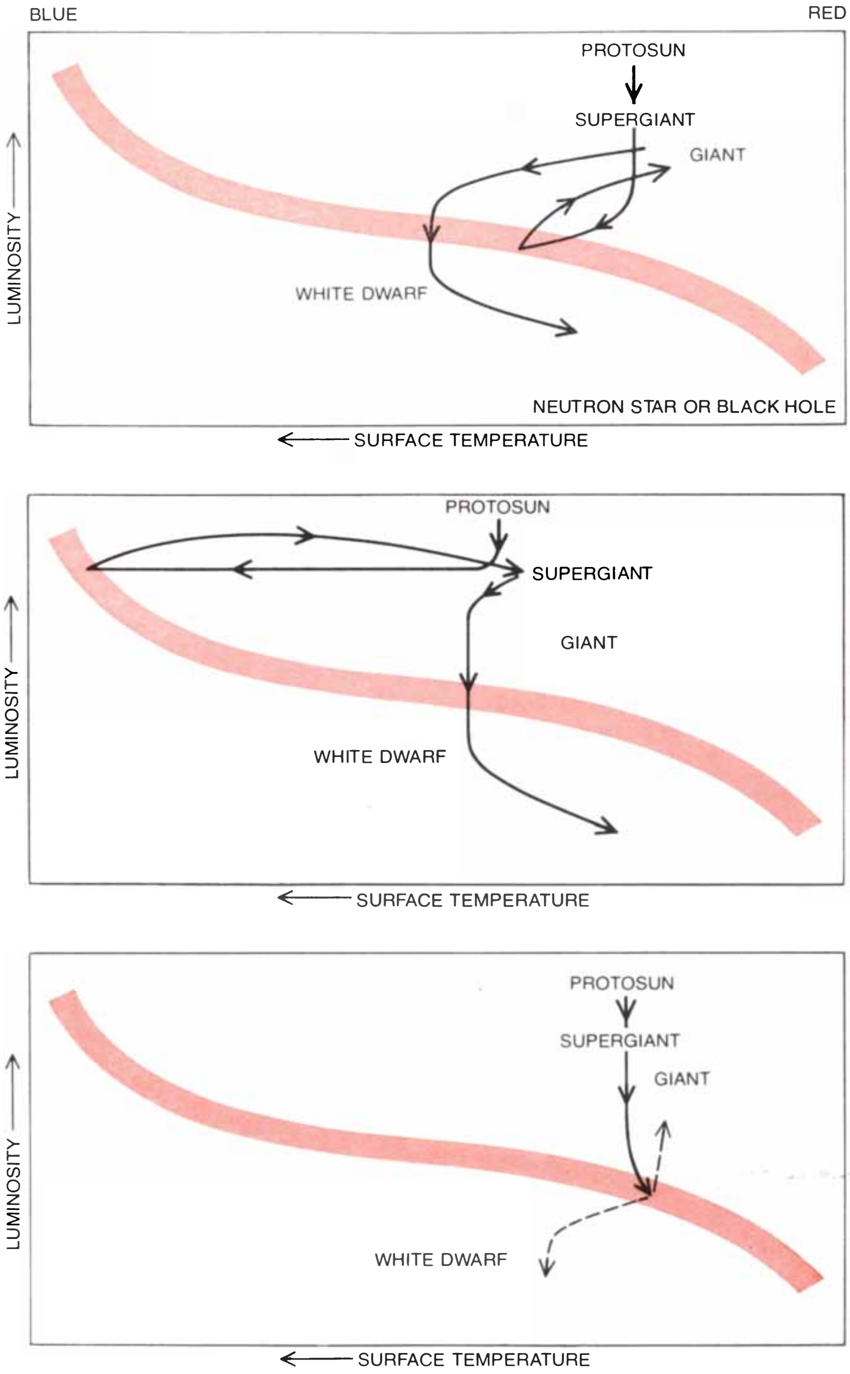
Bell Laboratories, Room HL-3J-238,
600 Mountain Avenue,
Murray Hill, N.J. 07974

Please include a resume.

An equal opportunity employer.

Bell Laboratories

© 1981 SCIENTIFIC AMERICAN, INC



EVOLUTION OF A HABITABLE STAR SYSTEM depends sensitively on the value of the gravitational coupling constant. In these Hertzsprung-Russell diagrams the diagonal band is the main sequence, where stars in a stable stage of evolution are arranged in sequence. The top diagram shows the evolution of the sun in the actual universe. The gas and dust of the protosolar cloud collapsed under the influence of their own gravitation to form the sun, a star on the main sequence. The collapse took roughly 10 million years. After 10 or 15 billion years on the main sequence the sun will explode and become a red giant. Shortly thereafter it will evolve into a white dwarf and then slowly burn out. The middle diagram shows the evolution of the sun in a universe where the gravitational coupling constant is an order of magnitude larger. The sun spends little time on the main sequence but quickly evolves into a blue giant. The right half of the main sequence includes virtually no stars. The bottom diagram shows the evolution of the sun in a universe where the gravitational coupling constant is an order of magnitude smaller. The protosun enters the main sequence as a red dwarf, which remains on the main sequence for an extremely long time but radiates little energy. The left half of the main sequence includes few stars. Neither a blue giant nor a red dwarf could sustain life; the blue giant dies too soon and the red dwarf radiates too weakly. The anthropic principle asserts that the presence of life on the earth explains why the sun is at the division between the blue giants and the red dwarfs and hence why the gravitational constant has the value it is observed to have.

thropic principle because it is difficult to apply predictive logic to the early universe. A deductive explanation in cosmology would presumably show how observed features of the universe, such as the distribution of matter or the value of the gravitational coupling constant, are not arbitrary but instead follow from some underlying principle. Such an explanation is difficult to provide because it requires knowledge of the initial conditions of the universe.

One observed feature of the universe that stands in need of explanation is its isotropy. C. B. Collins and Steven W. Hawking of the University of Cambridge have found that in current models of the universe only a few sets of initial conditions out of the many conditions possible could give rise to the observed isotropy. Any theory in which the isotropy is deduced or predicted must begin by postulating such highly arbitrary initial conditions. Collins and Hawking find this result unsatisfying, because it offers no compelling reason for the universe's having turned out the way it has and not otherwise. What is needed is some prior constraint that would explain why the initial conditions had to be among those few that lead to isotropy; a prior constraint on the initial conditions of the universe, however, is almost inconceivable. Investigators have therefore resorted to the anthropic principle, which limits the class of possible initial conditions not by a prior constraint but by a subsequent one.

One of the most influential applications of the anthropic principle and of nonpredictive logic has been made by Brandon Carter of Cambridge. Carter began exploring the anthropic line of investigation in "reaction against exaggerated subservience to the Copernican principle." Carter argues that although Copernicus demonstrated we must not "assume gratuitously that we occupy a central position in the universe," it does not follow that the situation of human observers cannot be privileged in any way. The position of the observer is necessarily special at least to the extent that certain conditions (of temperature, chemical environment and so on) are prerequisites of his existence. "What we can expect to observe," Carter notes, "must be restricted by the conditions necessary for our presence as observers," and so "although our situation is not necessarily central, it is inevitably privileged to some extent."

Carter's discussion of the anthropic principle represents an interesting conjunction of the physics of the very large and the very small; to illuminate cosmology he relies on an unusual explication of quantum mechanics called the many-worlds interpretation. The many-worlds interpretation was proposed by Hugh Everett III of Princeton and was

© 1981 SCIENTIFIC AMERICAN, INC

How Amoco uses an evolving science to help search for new oil and natural gas.

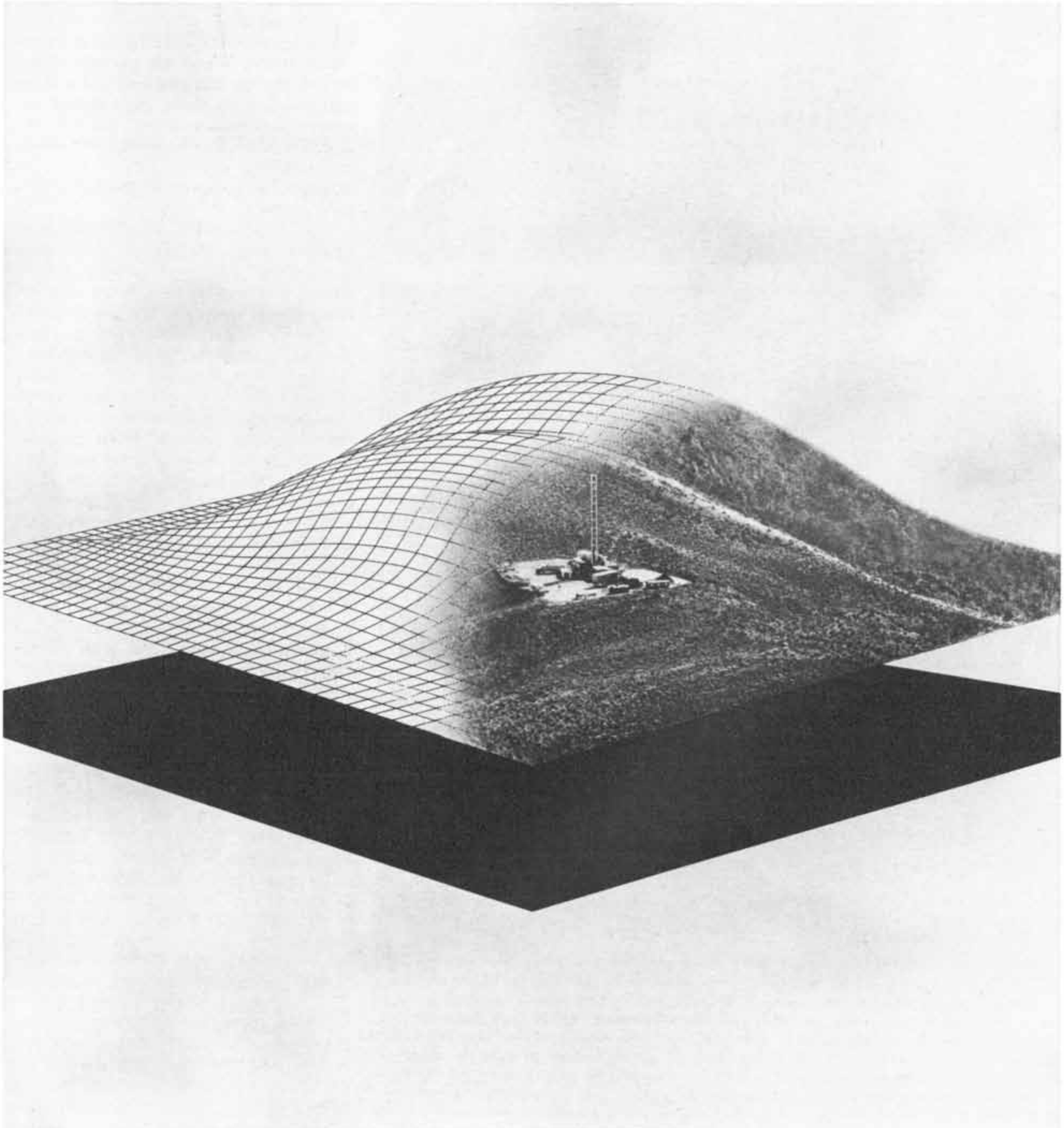
The earth science known as geochemistry is helping Amoco scientists determine the thermal maturity of organic matter in the earth's crust. Oil and natural gas can be present and discovered only in those regions where source beds have been properly matured with the correct ratios of heat and time.

Geochemists use a variety of techniques on rock samples, including pyrolysis and solvent extraction to determine where and when the source beds have expelled their oil.

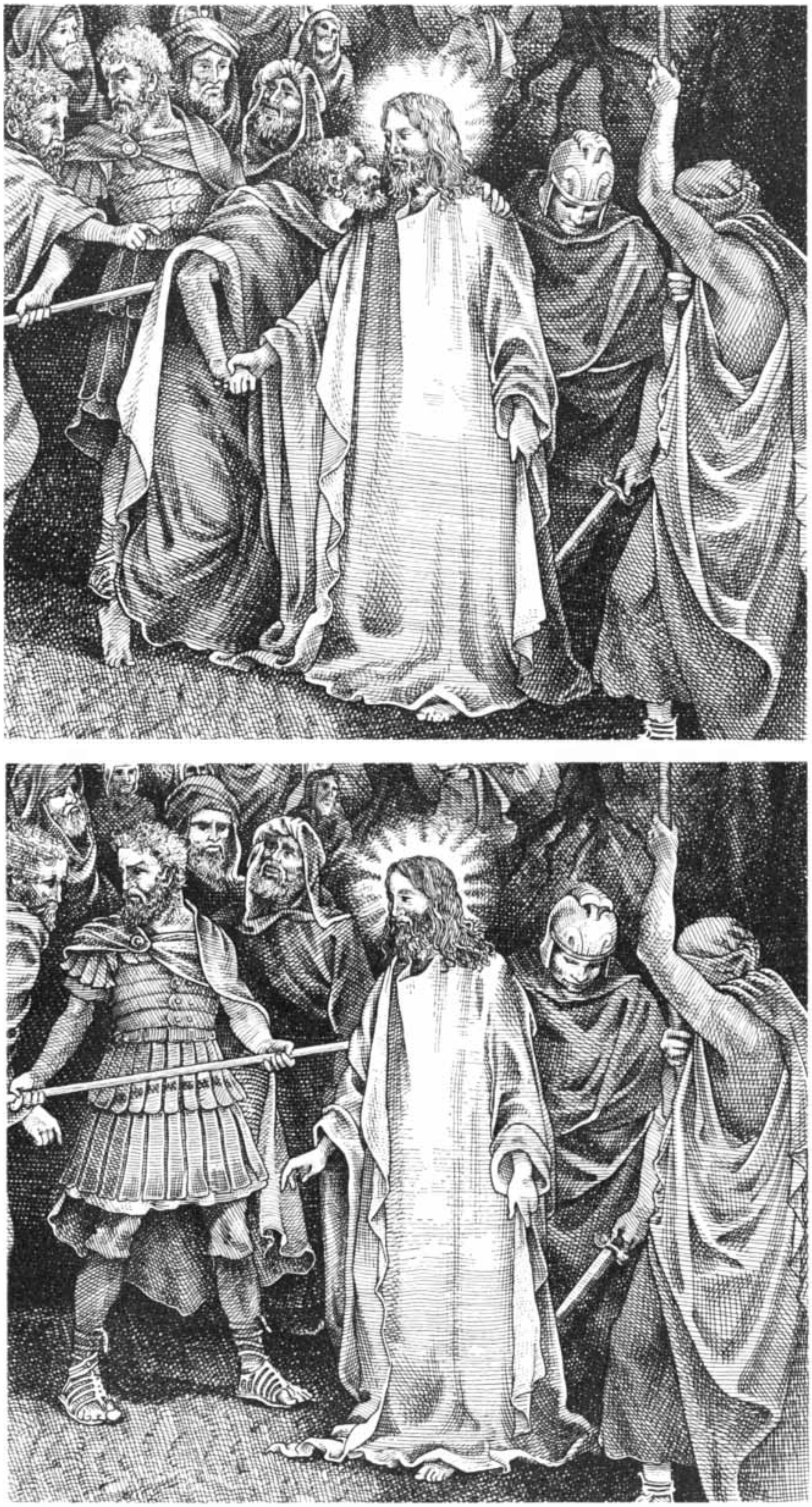
These techniques and others have aided Amoco in understanding the potential of discoveries such as those in the Overthrust Belt in Utah and Wyoming. Amoco is working in this science and others to provide the energy to keep America growing in the year 2000 and beyond.

AMOCO

You expect more from a leader.



© 1981 SCIENTIFIC AMERICAN, INC



ALTERNATIVE WORLDS are suggested by two drawings based on an engraving by Gustave Doré. In one world Judas betrays Christ with a kiss; in the other world Christ is not betrayed. This example was cited by Gottfried Wilhelm von Leibniz some three centuries ago when he proposed that there are an infinite number of possible worlds, each one internally consistent. Some of the worlds would have laws of physics, fundamental constants and initial conditions vastly different from those in the observed world. Leibniz thought the observed world is distinguished from other possible worlds by its having the richest variety of phenomena possible under the physical laws that describe the phenomena. The anthropic principle is often linked to a version of the idea of alternative worlds. For a world to be observable it must satisfy a biological requirement: it must include features congenial to the emergence of life.

developed further by Bryce S. DeWitt and John Archibald Wheeler of the University of Texas at Austin. In the quantum theory predictions give only the probability of an event and not a deterministic statement of whether or not the event will take place. For example, the trajectory of an elementary particle is described by a wave function, a mathematical expression whose amplitude varies in both space and time. The probability of finding the particle at a given point is the square of the amplitude of the wave function at that point. If an observation is actually made at the point, however, the particle is either found there or not found there. A central philosophical concern in quantum mechanics is reconciling the probabilistic interpretation of the wave function with the deterministic outcome of observations. When the particle is observed at a certain position, did it have that position all along, even before the observation was made? If the position is deterministic, it is not clear how to interpret the other points in space to which the wave function assigned a nonzero probability.

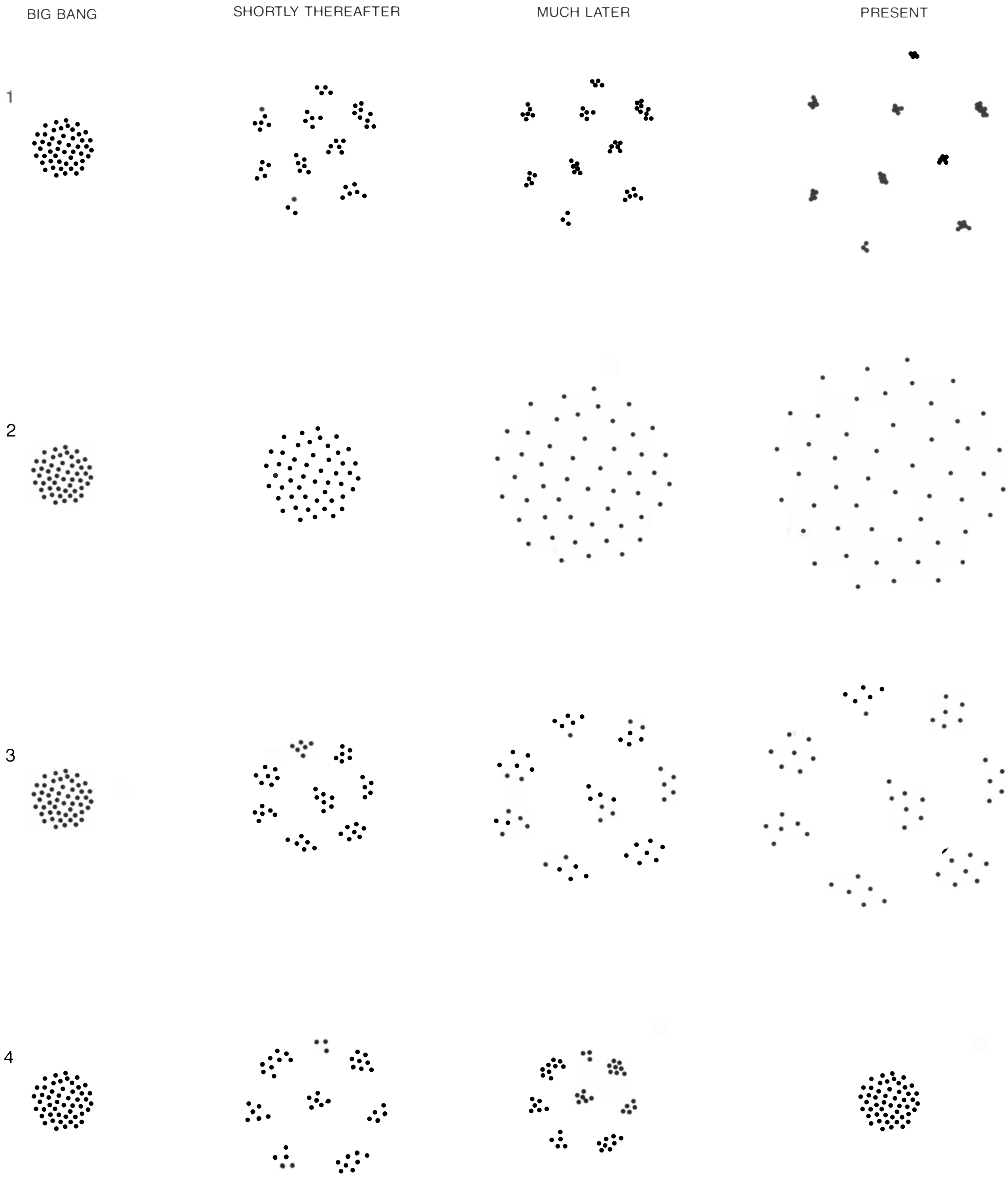
The many-worlds interpretation of quantum mechanics asserts there is no fundamental difference between the observed position of the particle and the other points to which the wave function assigned a nonzero probability. The particle exists at all the points. In order for this to be true, however, it is necessary to suppose there are infinitely many worlds, in each one of which the particle has a definite position. What happens during a measurement is that one world is selected from among the infinite range of possibilities. The wave function is still important because it continues to describe the totality of the worlds.

Although the many-worlds interpretation may seem bizarre, it cannot be ruled out on the basis of the physical evidence; it is compatible with the results of all experiments. The interpretation has the virtue of reconciling the continuity of the quantum-mechanical wave function with the discontinuity of the process of measurement.

The concept of other worlds did not originate with Everett. Some three centuries ago Gottfried Wilhelm von Leibniz proposed that there are infinitely many possible worlds, each one internally consistent and having its own character. Some of the worlds would be vastly different from the actual world, with unfamiliar initial conditions, fundamental constants and laws of physics; other worlds would differ from the known one only in subtleties. For example, there would be a world identical with our own except that its Julius Caesar did not cross the Rubicon. In another world the difference would be that Judas did not betray Christ. The one constraint on a possible world is that it cannot violate

© 1981 SCIENTIFIC AMERICAN, INC

© 1981 SCIENTIFIC AMERICAN, INC



MODELS OF COSMIC EVOLUTION indicate that the present universe, characterized both by large-scale isotropy and by smaller-scale inhomogeneities such as galaxies, would not have arisen if the recessional velocity of the matter formed in the big bang were not equal to the escape velocity of the matter (the speed it needs to counteract its gravitational attraction). The first row of drawings shows the actual evolution of the universe. The big bang had arbitrary, small-scale perturbations, which developed into inhomogeneities that condensed into galaxies. The second row shows the evolution of a universe in which the recessional velocity is greater than the escape velocity and the big bang is homogeneous. The present universe would be completely homogeneous and thus would have no galaxies. The situation would be no better in such a universe if the big bang had arbitrary, small-scale perturbations, as the third row indicates. Such perturbations would result in large-scale inhomogeneities that would not condense into galaxies. The fourth row presents the evolution of a universe where the recessional velocity is less than the escape velocity and the big bang has small-scale perturbations. The perturbations grow into inhomogeneities that eventually start to condense. Before galaxies can form, however, the universe collapses. It appears that the observed combination of large-scale isotropy and small-scale clustering could arise only from highly specific initial conditions. C. B. Collins and Steven W. Hawking have proposed that the singularity of the observed universe can be understood by combining the anthropic principle with the idea of alternative worlds. From an ensemble of infinitely many universes having all possible ratios of recessional velocity to escape velocity, the only universe in which life could emerge is the actual universe, where the velocities are equal.

© 1981 SCIENTIFIC AMERICAN, INC

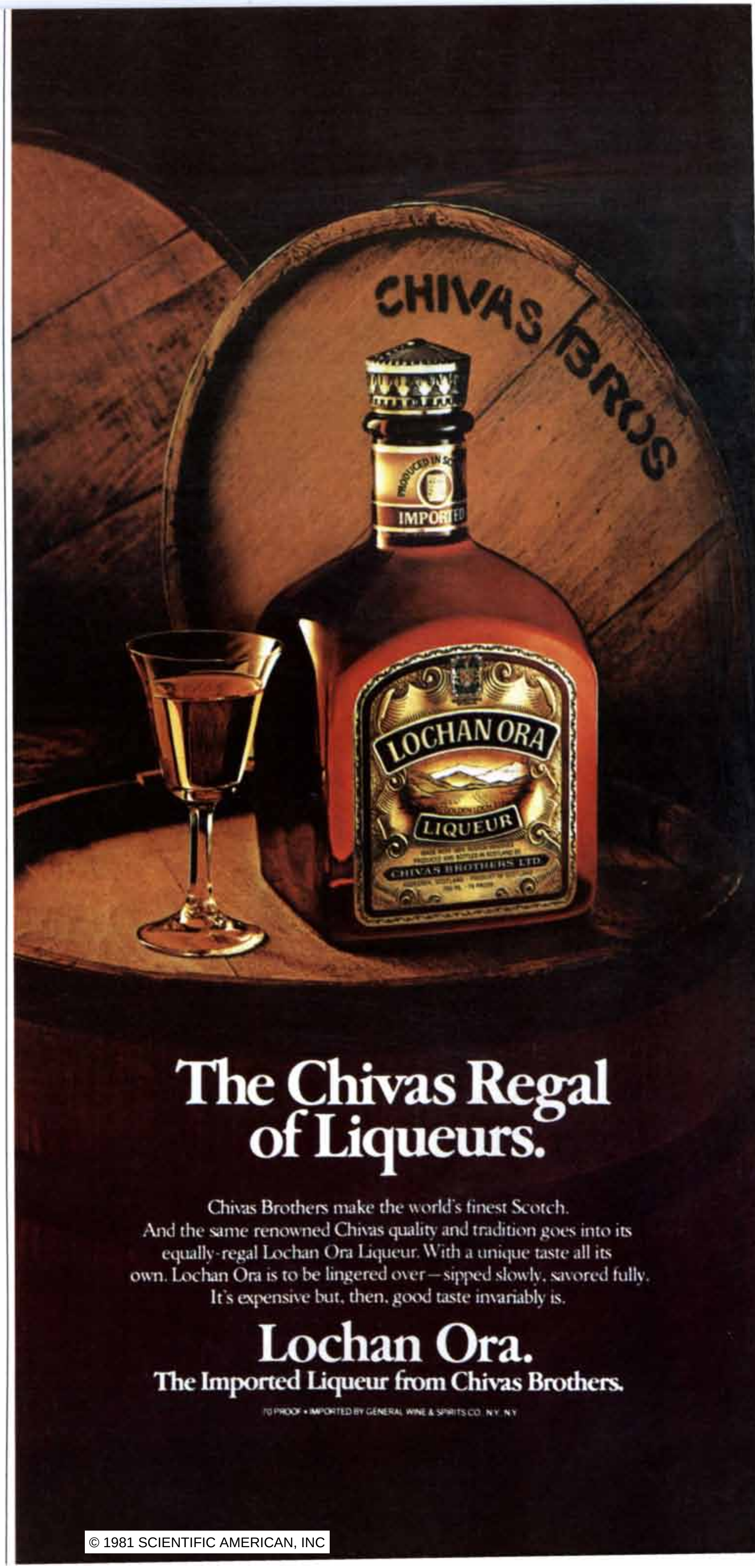
the law of noncontradiction: there is no world in which Caesar both crossed the Rubicon and did not cross it.

In Everett's many-worlds interpretation of the quantum theory all the worlds are equally real. In Leibniz' view, on the other hand, there is a reality principle that singles out a real world among all the possible ones. Leibniz thought scientific investigation would reveal that the observed world maximizes a property he called at various times "economy," "perfection" and "optimality." The last term is the most revealing. Leibniz explained that the optimal world exhibits the richest variety of phenomena possible under the physical laws that describe the phenomena. He employed the concept of optimality to explain the laws of reflection and refraction in optics, and the concept inspired him to develop the principle of the conservation of energy.

In combining the anthropic principle with the many-worlds interpretation of quantum mechanics, Carter also introduces a reality principle. The complex property that distinguishes the real world is not Leibniz' idea of optimality but a property I shall call life-supportiveness. From Everett's infinite ensemble of worlds Carter considers as real only those worlds satisfying a biological requirement: they must include features that make possible "the existence of any organism describable as an observer."

Carter relies on this idea to explain the weakness of gravitation. According to the many-worlds interpretation, worlds might exist in which the coupling constant takes on all possible values from very weak to very strong. The anthropic principle can then explain why we live in a world where the constant has the observed value. Carter demonstrates that if the coupling constant were much different, planets either would not have formed or would not have survived long enough for intelligent life to evolve. Because an observer presumably requires a planet to inhabit, the existence of an observer is strongly linked to the value of the constant.

Carter's demonstration is based on an interesting property of the stars called main-sequence stars, which include the sun. Such stars are at a stable stage of evolution in which the energy liberated by thermonuclear fusion balances the force of gravitational attraction. They are designated main-sequence stars because in a Hertzsprung-Russell diagram (a graph of luminosity v. surface temperature) they fall in evolutionary sequence in a narrow band. Most properties of stars do not depend sensitively on the value of the gravitational coupling constant. An exception is the sharp division of the main-sequence stars into blue giants (hot, bright, massive stars) and red dwarfs (cool, faint, compact stars). The luminosity of a star is proportional



© 1981 SCIENTIFIC AMERICAN, INC

Teaching new tricks

Lockheed knows how.

For many years, aircraft and aluminum were almost synonymous. But new metals and materials have been invading aluminum's domain. Engineers have been turning to titanium and composites (materials made of boron, graphite or carbon fibers) when advanced technology is involved. Lockheed, however, has been turning the technological tables, using new approaches to bring about a renaissance in aluminum as an advanced-technology material.

Powdering aluminum to save millions.

Today, aluminum can withstand maximum temperatures of about 250°F for limited periods. But future supersonic aircraft must endure temperatures of 300°F for long periods.

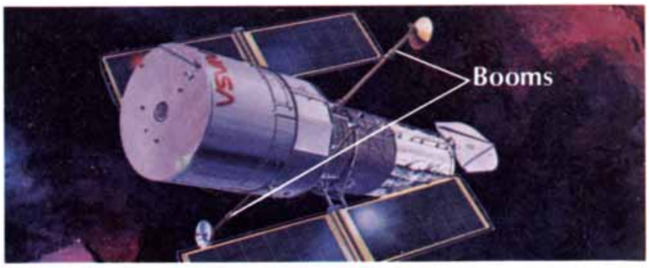
Yet aluminum offers many advantages. It's 36% lighter than titanium. It costs much less than titanium or composites. And it's far easier to fabricate.

To retain these advantages, Lockheed is working with microscopic-sized aluminum particles, 1 to 2/1000ths of an inch in diameter. When alloyed with lithium, cobalt or iron, the results are dramatic. For example, an alloy of 3% lithium and 97% powdered aluminum equals or exceeds the strength of conventional alloys—but is 10% lighter, a weight saving that could mean millions of gallons in fuel savings. And the alloy can withstand prolonged temperatures of 300°F.

The supersonic transport shown above could become practical in the 1990's, thanks in part to the light weight and superior strength of powdered aluminum alloys.

Stiffer than steel, lighter than aluminum.

When launched in the mid-eighties, the NASA/Lockheed Space Telescope will detect objects 50 times fainter than those ever seen before.



Graphite/Aluminum booms. They have extraordinary strength-to-weight ratios.

This wonder of advanced technology will be made, in part, of a remarkable new material based on aluminum metal matrix composite technology. Two slender, rectangular, hollow structures—13 feet by 3.4 inches by 1.7 inches—will do double-duty as structural booms and antenna waveguides.

Made of 60% aluminum and 40% graphite fibers, they will be as stiff as any known structural material—30% stiffer than steel but 13% lighter than conventional aluminum. Weighing only 8 pounds apiece, they will have one of the highest stiffness-to-weight ratios of any structure ever built.

This use of graphite/aluminum in space points the way to Earth applications where great stiffness and extremely light weight are needed.

© 1981 SCIENTIFIC AMERICAN, INC

to an old metal.

Powdered aluminum would be used in 40% of this advanced jetliner in the 1990's.

"Fill 'er up...with 37 lbs. of aluminum."

The electric car has long been a dream, but approaches with traditional lead acid or nickel iron batteries present a problem. They must be recharged every 80 to 100 miles.

Lockheed, however, is working on a possible solution: an aluminum-air battery that provides much greater range.

Basically, the battery uses 37 pounds of aluminum plates and 6½ gallons of tap water, with caustic soda as an active, circulating electrolyte that reacts with air. It would power a small car about 250 miles. Then the driver would make a 9-minute stop at a service station, adding 6½ gallons of water and removing 107 pounds of residue—aluminum hydroxide that can be recycled back into aluminum.

Every 900 miles, the driver would spend 15 minutes at the service station to "recharge" with 60 aluminum plates weighing 37 pounds.

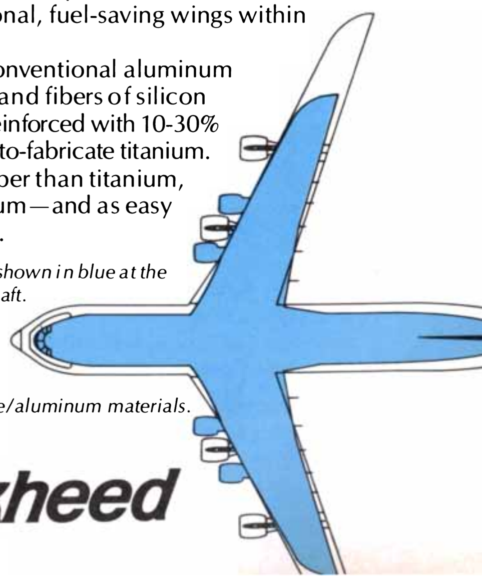
A fanciful vision? Not when the industry on which the battery is based—aluminum—is already in place.

Bewhiskered aluminum.

To save fuel, the ideal wing of a large aircraft would be long or narrow—or both. The wider the wing relative to its length, the more fuel the aircraft burns. However, long aluminum wings tend to flutter and vibrate due to their lack of stiffness. Solving those problems thus far has required extra structural weight that largely reduces the fuel savings.

The solution: new structural materials stiffer and lighter than conventional aluminum alloys. Working in that direction, Lockheed has developed new materials that could be used in operational, fuel-saving wings within 10 years.

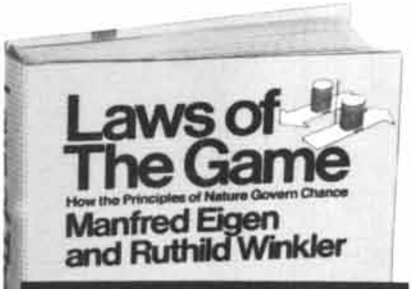
Lockheed reinforces conventional aluminum alloys with tiny whiskers and fibers of silicon carbide. One such alloy reinforced with 10-30% whiskers is as stiff as hard-to-fabricate titanium. It also is lighter and cheaper than titanium, lighter even than aluminum—and as easy to fabricate as aluminum.



Today the Lockheed-built C-5 (shown in blue at the right) is the world's largest aircraft. The drawing shows an even larger, more economical transport that would be possible through extensive use of these new silicon carbide/aluminum materials.

Lockheed

© 1981 SCIENTIFIC AMERICAN, INC



WITH 14 NEW GAMES
devised especially for this book

A challenging and startlingly imaginative extension of von Neumann's theory of games.

Hailed by Jeremy Bernstein:

"Remarkable, fascinating, and very profound...It has that odd, special quality of brilliant scientists at play with ideas...A sort of intellectual garden salad to be savored slowly and digested carefully." —N.Y. Times Book Review

Profusely illustrated with drawings, photographs, and tables, many in color • $19.95 • Knopf

Aha...

GAMES FOR THINKERS

An exciting, new way to learn creative problem solving! Games designed by university professors improve thinking skills using fun, strategy and challenging competition. Like chess, each game can be played at many levels from young children to intelligent adults. Fascinating for everyone!

Write for free catalog and studies that show how WFF 'N PROOF Games can:
- double math achievement
- cut school absenteeism by ⅔ and
- raise I.Q. scores by 20 points

ORDER YOUR GAMES FOR THINKERS TODAY!

WFF'N PROOF (logic)	$16.00
QUERIES 'N THEORIES (sci. method)	13.00
EQUATIONS (creative mathematics)	13.00
ON-SETS (set theory)	13.00
ON-WORDS (word structures)	13.00
PROPAGANDA (social studies)	13.00
CONFIGURATIONS (geometry)	7.75
Complete 7-game Special	**79.95**

All prices include postage and handling.
Satisfaction Guaranteed

Order from: **WFF 'N PROOF**
1490-EE South Blvd., Ann Arbor, MI 48104

to the fourth power of its mass, and so a blue giant rapidly converts its substance into energy; it has a short lifetime. A red dwarf gives off comparatively little energy and lives much longer.

The emergence of life demands two things of a star. First, it must live long enough for living organisms to evolve. Second, it must radiate enough energy to warm a habitable region of space, that is, a region where a planet could have a stable orbit. Neither a blue giant nor a red dwarf satisfies both conditions; the blue giant burns out too quickly and the red dwarf radiates too feebly. What is needed is a star such as the sun, whose position on the main sequence is at the sharp division between the blue giants and the red dwarfs; only a star of this kind has a suitable combination of lifetime and radiant power. If the gravitational coupling constant were an order of magnitude larger, the main sequence would consist entirely of blue giants. If the constant were an order of magnitude smaller, the main sequence would consist only of red dwarfs. In either case life-supporting stars would not exist.

As Carter acknowledged, his argument is rather speculative. The formation of planets is not yet understood well enough to rule out completely the possibility that habitable planets would form in a universe with a different gravitational coupling constant. It must be noted, however, that this uncertainty is related not to the logic of the argument but to its empirical premises.

Carter has relied on the anthropic principle in other contexts, which are based on sounder empirical premises. For example, he has observed that the coupling constant associated with the strong, or nuclear, force "is only marginally strong enough to bind [protons and neutrons] into nuclei; if it were rather weaker, hydrogen would be the only element, and this too would presumably be incompatible with the existence of life."

Collins and Hawking were also led to invoke the anthropic principle. Their investigation set out to account for two observations: the large-scale isotropy of the universe, and particularly of the microwave background radiation, and the presence of smaller-scale inhomogeneities, such as galaxies. They found that the crucial factors are the initial recessional velocity of the matter created in the big bang and the escape velocity of the matter (the speed it would need to overcome its gravitational attraction). If the recessional velocity is less than the escape velocity, the universe collapses before isotropy can develop. If the recessional velocity is greater than the escape velocity, galaxies and other clusterings of matter cannot develop unless there are small-scale inhomogeneities in the initial distribution of matter at the time of the big bang. Such inhomogeneities, however, would have resulted in large-scale anisotropy in the present universe. Collins and Hawking reluctantly concluded that the observed combination of large-scale isotropy and small-scale clustering can result only if the recessional velocity is exactly equal to the escape velocity. Hence the observed universe is a highly privileged one indeed, where the recessional velocity has one arbitrary value out of an infinite range of possibilities.

Collins and Hawking suggested that the discomforting singularity of the observed universe could be understood through the anthropic principle. They began by postulating an ensemble of infinitely many universes having all possible initial conditions, including all values of the recessional velocity. In almost all these universes matter could not condense into galaxies. The only universe in which matter could both form galaxies and exhibit large-scale isotropy is a universe whose recessional velocity is equal to the escape velocity. Collins and Hawking conclude that since "the existence of galaxies would seem to be a necessary precondition for the development of any form of intelligent life,... the fact that we have observed the universe to be isotropic is therefore only a consequence of our existence."

What does the anthropic principle suggest about the overall structure of the world? Suppose in the years to come the anthropic line of investigation reveals that even the smallest change in any initial condition of the universe or in the value of any fundamental quantity would not have allowed life to evolve. This would suggest that of all possible worlds the actual world is the only one congenial to life. Much more evidence would be needed, however, before such a conclusion could be advanced with any confidence.

Wheeler has addressed a still grander question: "How did the universe come into being?" Most philosophers of science deny that the question is scientifically meaningful; any answer would seem to call for a frame of reference beyond science because the very fabric of science (namely space-time) and the laws of physics that describe space-time emerged when the universe was created in the big bang. Wheeler nonetheless argues that as long as one lacks firm evidence of the meaninglessness or undecidability of the question, one cannot be content "to let a major question remain forever in the air, the football of endless indecisive games."

Wheeler approaches the question by analyzing the logic of explanations adopted in physical theories since the Scientific Revolution of the 18th century. He maintains that the logic consists in reducing a phenomenon to a more fundamental one. Thus the concept of

© 1981 SCIENTIFIC AMERICAN, INC

Small computer friendliness vs. big computer power.

HP's new computer systems end the compromise.

Whether it's sophisticated experimentation or data reduction and analysis, Hewlett-Packard's newest technical computer systems put high-powered scientific performance into easy-to-configure, easy-to-use workstations. So you can solve your applications problems just the way *you* want to. And a lot sooner than you might have thought possible.

The HP 9826 for complex experiment control.

Designed specifically for I/O-intensive instrument and control applications, the 9826 uses the powerful new MC 68000 chip for ultra-fast data transfer and number crunching. It also has a variety of I/O ports and built-in drivers, so you're free to concentrate on testing, not on system configuration. Which means you can get your solutions up and running in days, instead of weeks or months.

But the 9826 makes it even easier still. Because you can develop your programs in any of three languages: HP-enhanced BASIC, HPL, or PASCAL. And with a CRT display and advanced graphics built right into the system, you can see and interpret your data almost as soon as you get it.

The HP 9826. System prices start at $8950.

The HP 9845 for high-performance computation.

With a broad range of advanced capabilities (including new options offering three times the computational speed of the basic system), the HP 9845 can be configured to meet your precise needs—from finite element analysis to simulations and modeling. And almost anything in between.

You can also add hard discs, printers, plotters and other peripherals to further tailor the system to your application. And with the 9845's advanced datacomm capabilities, you can even share technical information with other computers in a distributed processing environment.

The HP 9845. System prices start at under $20,000.

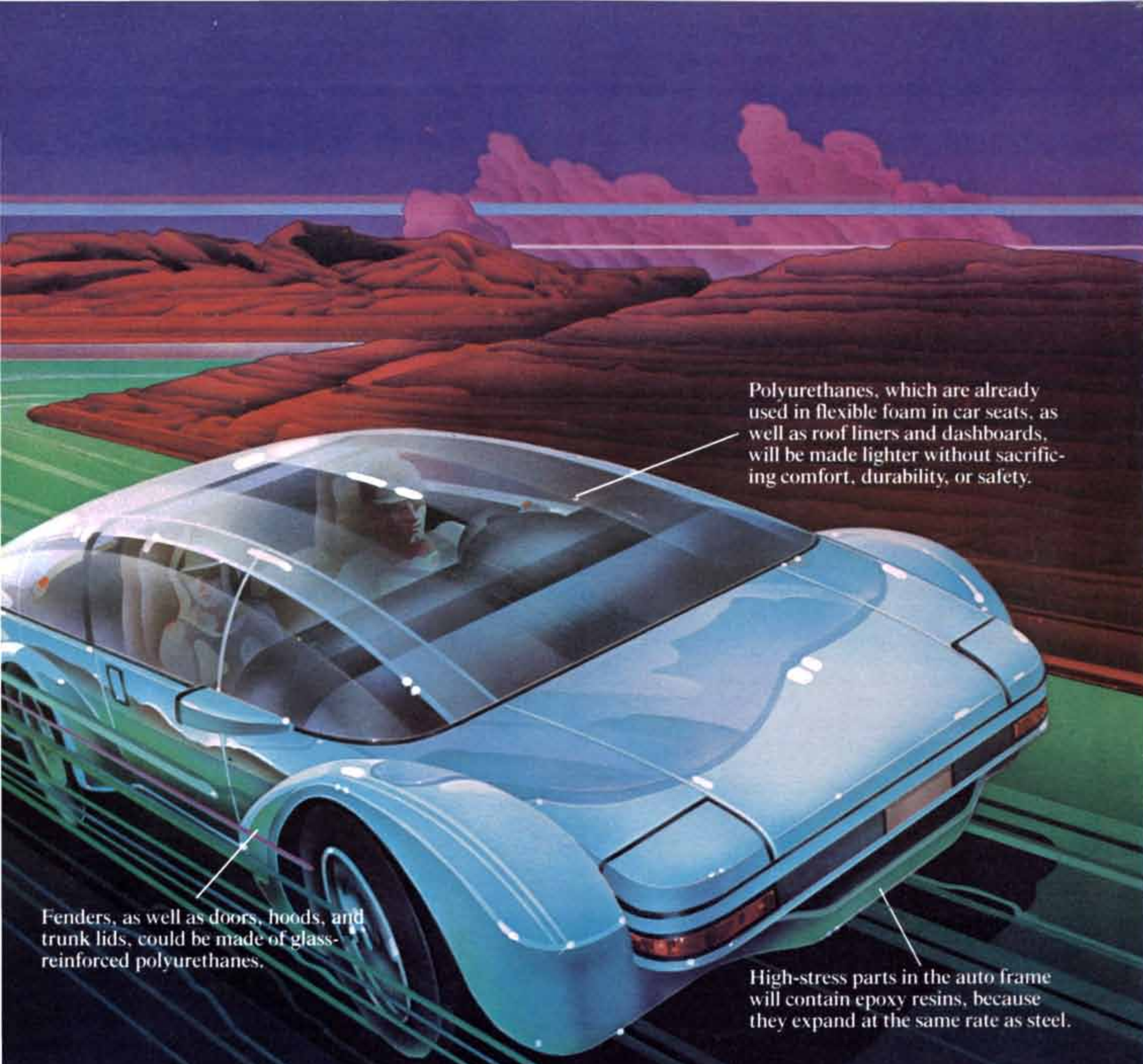
All of our computers are backed by HP's worldwide service organization. For more information, call your local HP sales office listed in the White Pages. Or write to Hewlett-Packard, Attn: Pat Welch, Dept. 56109, 3404 E. Harmony Rd., Ft. Collins, CO 80525.

Prices U.S.A. list: subject to change without notice. 40107

When performance must be measured by results.

HEWLETT PACKARD

© 1981 SCIENTIFIC AMERICAN, INC



We're putting more petroleum in the body of your car so you can put less in your tank.

Oil. In its most familiar form, it runs and lubricates your car.

In a less familiar form, it can be made into petrochemicals which can be turned into plastics. And those plastics could replace the metal in your car.

Research being done with Texaco's petrochemicals is aimed at producing car parts that are 50% lighter and yet as strong and efficient as any used today.

We're also reexamining parts now made with plastics, such as dashboards and seats, to see if they can be made even lighter without sacrificing strength or efficiency.

And we're doing work on glass-reinforced polyurethanes for fenders, doors, and trunk lids. Every pound that we can help auto manufacturers take off their cars could mean less gasoline you'll have to use.

TEXACO

You can trust the Star at home and in your car.

© 1981 SCIENTIFIC AMERICAN, INC

valence in chemistry was reduced to the electrical properties of atoms and the temperature of a gas was reduced to the movement of atoms and molecules. It seems the logic of reduction can have only two possible outcomes, both of which Wheeler finds untenable. Physical theory could terminate in some fundamental, indivisible object or field; alternatively reduction could reveal layer on layer of structure ad infinitum.

Wheeler's way of escaping this quandary is to propose that the reductive mode of logic may itself come to an end. "One finds himself in desperation asking if the structure, rather than terminating in some smallest object or in some most basic field, or going on and on, does not lead in the end to the observer himself in some kind of closed circuit of interdependences." His argument draws on the connection established in quantum mechanics between the observer and the quantum phenomenon he observes. The many-worlds interpretation of quantum mechanics minimizes the role of the observer because the world he observes is considered to be no more real than any other world. Commoner interpretations of quantum mechanics, however, define reality as that which is observed; the observer contributes to reality by the very act of observation. Wheeler adopts an extreme version of this idea by proposing that for a universe to be real it must evolve in such a way that observers come into existence.

In support of this position Wheeler cites the anthropic principle. He contends that "no reason has ever offered itself why certain of the constants and initial conditions have the values they do, except that otherwise anything like observership as we know it would be impossible." He wonders whether one could not "envisage as Carter does 'an ensemble of universes' in only a very small fraction of which life and consciousness are possible? Or ask as we do now if no universe at all could come into being unless it were guaranteed to produce life, consciousness and observership somewhere and for some little length of time in its history-to-be?" Wheeler rejects the common view that life and observership are only accidents in a universe independent of observers and argues instead that "quantum mechanics has led us to take seriously and explore the directly opposite view that the observer is as essential to the creation of the universe as the universe is to the creation of the observer."

With this hypothesis Wheeler has carried the anthropic principle far beyond the domain of the logic of explanation; he has crossed the threshold of metaphysics. Few scientists or philosophers of science would be comfortable with his vision. It remains to be seen whether the less grandiose applications of the anthropic principle will win acceptance.

Amateur Telescope Making

Edited by Albert G. Ingalls
Foreword by Harlow Shapley

This three-book set, published by SCIENTIFIC AMERICAN, has served many thousands of hobbyists as the authoritative reference library of the enthralling art of amateur telescope making.

BOOK ONE the basics of glass grinding and how to complete your first telescope. (510 pages, 300 illustrations)

BOOK TWO how to make finer and larger telescopes; and on to advanced optical work, including micrometers, synchronous clock, steller and solar eclipse photography. (650 pages, 361 illustrations)

BOOK THREE further fields of enterprise, including binoculars, camera lenses, spectrographs, Schmidt optics, eyepiece design, ray tracing. (646 pages, 320 illustrations)

SCIENTIFIC AMERICAN
ATM Dept., 415 Madison Ave., New York, N. Y. 10017

Please send me postpaid the following AMATEUR TELESCOPE MAKING books. My remittance of $______ is enclosed.

☐ **BOOK ONE** **$10.00**
☐ **BOOK TWO** **$12.50**
☐ **BOOK THREE** **$12.50**

For shipment outside U.S. add $1.00 each.

Name______
Address______
City______
State______Zip______

Residents of New York City please add city sales tax
Other NYS residents please add state sales tax plus local tax

© 1981 SCIENTIFIC AMERICAN, INC

THE AMATEUR SCIENTIST

Reflections on the rising bubbles in a bottle of beer

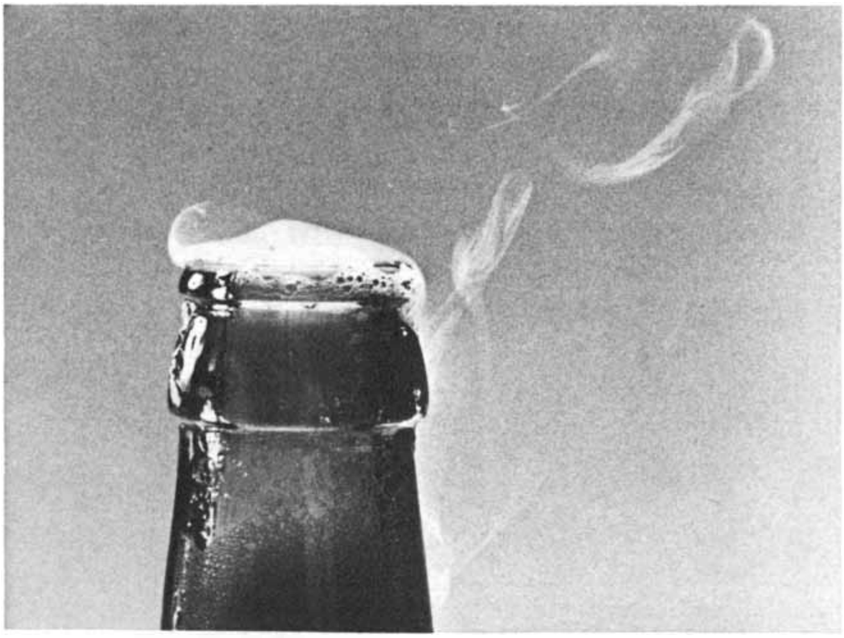
by Jearl Walker

The fizz in beer and carbonated soft drinks arises from carbon dioxide that remains dissolved in the liquid because the drink was bottled or canned under pressure. Without the dissolved carbon dioxide the taste and smell of the beverage would be quite different. When the container is opened, the internal pressure is released and the carbon dioxide comes slowly out of solution as a gas.

When a beer bottle is opened, the sudden change of pressure in the gas just above the beer creates a mild turbulence and cavitation (the formation of partial vacuums) at the surface. As a result bubbles of carbon dioxide form and burst. The pressure change also gives rise to a slight mist just above the open top of the bottle. The mist has two components: large droplets thrown upward by the cavitation and smaller droplets condensing out of the escaping gas (air, water vapor and carbon dioxide).

The condensation is more apparent to me if the beer bottle is only slightly cooled. Then the pressure in the vapor just above the liquid is higher than it would be if the bottle were cold. As I open the bottle this pocket of gas suddenly expands into the atmosphere just above the neck. Such an expansion of gas requires energy because the pocket must push its way into the atmosphere. The gas must do work: it applies a pressure that moves an interface (between the gas and the atmosphere).

Since the expansion is quite fast, there is no time for the energy to be transported from the beer, the bottle or the atmosphere. The gas is driven by the kinetic energy of its own molecules. They have a random motion whose energy is measured indirectly as the temperature of the gas. When the molecules lose energy, they move slower and the temperature of the gas decreases. The decrease in temperature causes the water vapor to condense into droplets, forming the mist that gathers momentarily over the mouth of the freshly opened bottle of beer.



A mist rises from a freshly opened bottle of beer

When beer is poured into a glass, the turbulence and cavitation are much greater. Air is trapped in the liquid, forming bubbles. In the regions where the turbulence lowers the pressure of the beer the dissolved molecules of carbon dioxide collect to form a bubble, which grows as it gathers more carbon dioxide. Since the bubbles are much lighter than the beer, they rise to the surface, where they form the thick raft called the head.

A despicable prank people sometimes play is to surreptitiously shake a closed container of beer or some other carbonated beverage and then hand it to someone else. When the other person opens the container, the contents erupt vigorously and often spray all over him. The shaking generates such severe turbulence in the liquid that small pockets of gas come out of solution in the regions where the turbulence momentarily reduces the local pressure.

When an unshaken bottle of beer is opened, the carbon dioxide has only one major place to come out of solution: the top surface of the beer. A shaken container of beer is different. It develops hundreds or thousands of tiny bubbles, each one providing a surface where additional carbon dioxide can come out of solution. When the container is opened, the transformation from dissolved to undissolved carbon dioxide is so rapid that liquid is expelled.

In a still glass of beer the carbon dioxide comes out of solution far slower. Bubbles of the gas form, break off from the wall of the glass and drift to the surface, where they eventually burst. All the bubbles develop on the walls or the bottom but only at imperfections in the surface of the glass or where a mote of dust has lodged. In the absence of cavitation the bubbles need condensation nuclei. It is not the condensation nucleus itself, however, that gives rise to the bubble but rather the air or carbon dioxide that is adsorbed on the surface of the nucleus.

Imagine a small crevice on the inside of a glass. Air can lodge in the crevice as the glass is filled with beer. The pocket of air provides a surface on which the molecules of carbon dioxide can come out of solution. A bubble of carbon dioxide begins to grow, eventually becoming large enough to break off and float to the surface. Probably enough air and carbon dioxide remain in the crevice to encourage the formation of another bubble.

A mote of dust serves the same purpose if air is adsorbed on its surface. You can promote the formation of bubbles in beer or a soft drink by adding any solid surface onto which air is adsorbed. Perhaps you have noticed that ice

© 1981 SCIENTIFIC AMERICAN, INC

dropped into a soft drink increases the production rate of bubbles and the consequent fizzing. Tiny bubbles of air are trapped in the surface of the ice. When the surface melts, the pockets of air are exposed and can serve as nuclei for bringing the dissolved carbon dioxide out of solution.

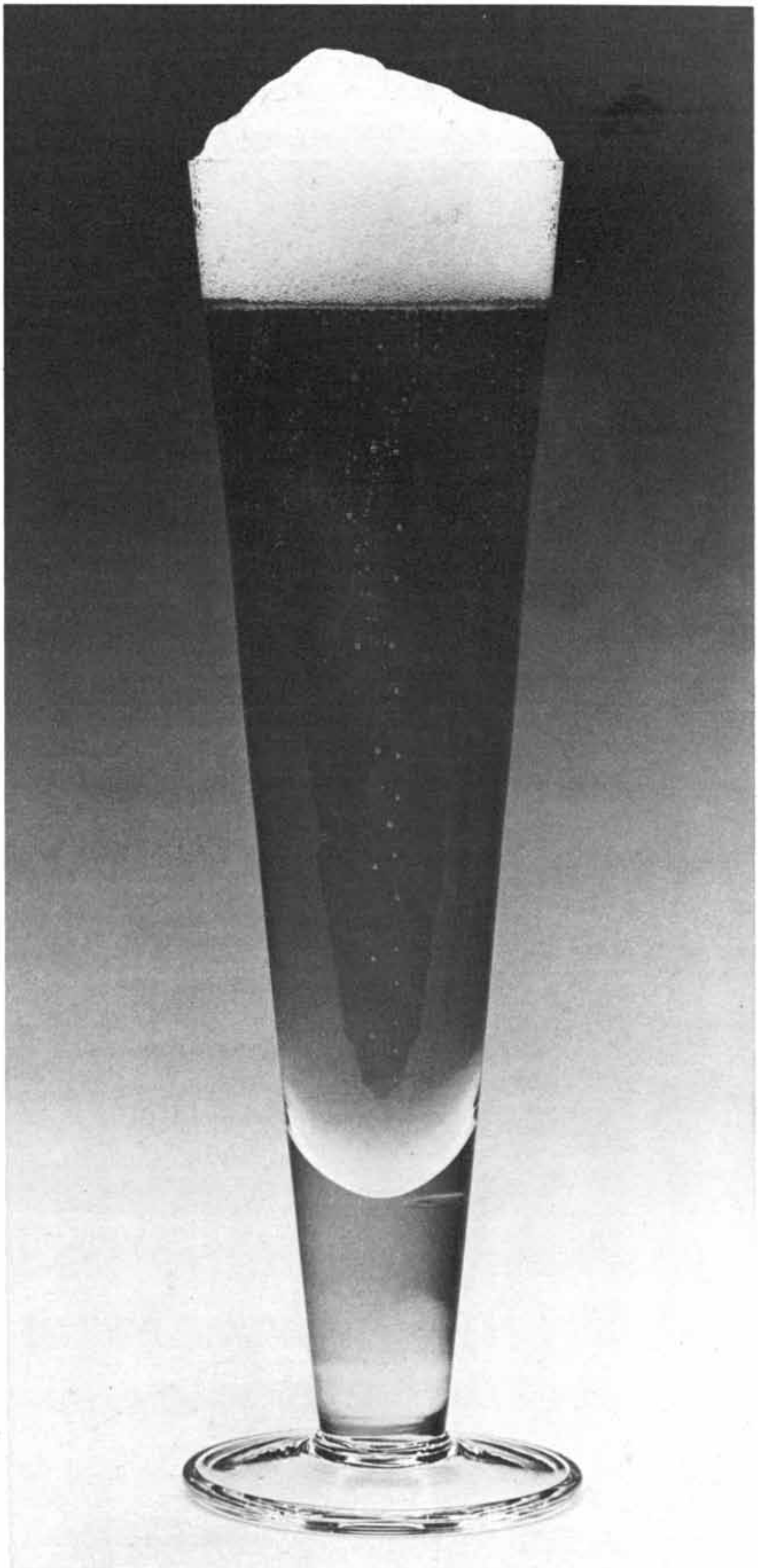
A bubble that forms on the air in a crevice in a glass filled with beer is never spherical. As more carbon dioxide enters the bubble it gets bigger and extends upward. Its shape also changes. As the bubble expands, its top surface remains roughly hemispherical but the lower section narrows into a cylinder. The cylinder is unstable; with further growth of the bubble and narrowing of the cylinder the cylinder collapses, releasing the bubble.

Two forces work on the bubble forming on the air in a crevice. Since the gas is lighter than the beer, buoyancy pulls the growing bubble upward, away from the crevice. The force countering the buoyancy, at least initially, is the surface tension at the boundary between the beer and the gas. This force develops because of the mutual attraction between the molecules in the liquid at the surface, putting the surface effectively in tension. The force of the surface tension at any given point on the curved boundary is perpendicular to the boundary. When the bubble is just forming, these force vectors point toward the central region of the bubble, that is, downward.

As the bubble grows, the buoyancy increases and eventually overwhelms the surface tension. The opposing forces do not engage in a simple tug-of-war in opposite directions. Buoyancy pulls the enlarging bubble farther from the crevice. The bottom section of the bubble then begins to form a cylinder with concave sides. Once the bubble has been pulled sufficiently far upward the cylinder collapses from surface tension, pinching off the upper section of the bubble. Then surface tension shapes the bubble into a somewhat more spherical configuration.

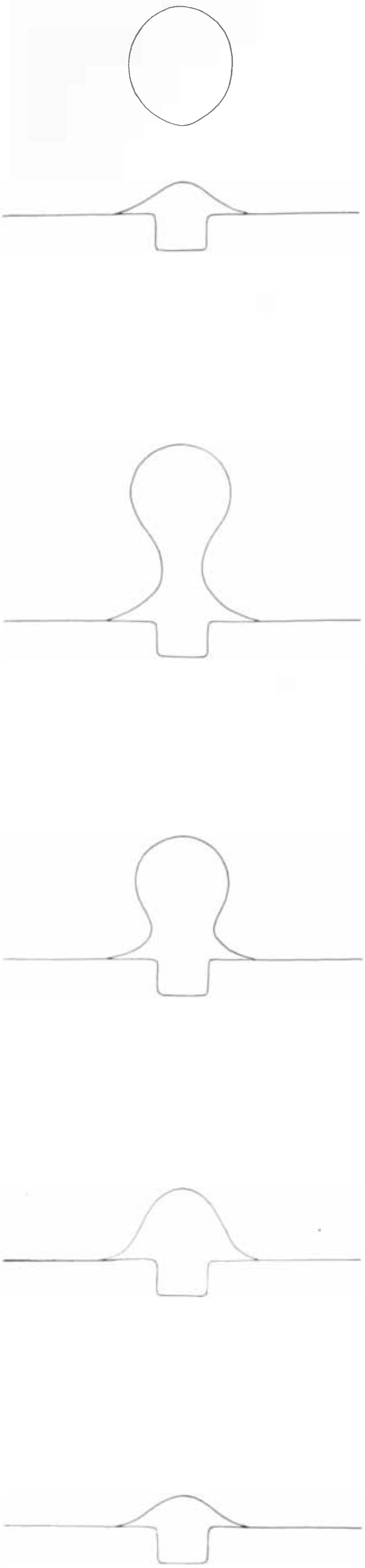
Why do bubbles not form before a container is opened and stop forming in an open container after an hour or so? When the container is closed, the relatively high pressure in the liquid (exerted by the pressure of the gas at the top) creates a high pressure in the gas adsorbed at the nucleating sites. At such a site carbon dioxide molecules are constantly entering and leaving a tiny gas pocket. Since the beer is in equilibrium, as many molecules enter each second as leave. With a high pressure in the gas pocket additional molecules cannot enter to make the bubble expand.

After the container has been opened the pressure in the gas decreases, additional molecules enter and the bubble grows. Although the growth is periodically interrupted as bubbles break away,



Bubbles rise in a tall glass of beer

© 1981 SCIENTIFIC AMERICAN, INC



Bubble formation at a crevice

it continues until the supply of carbon dioxide molecules has been greatly reduced. Once again as many molecules enter the gas pocket as leave it, and the bubbles do not grow.

As a released bubble ascends it increases in size. The main reason is that it moves into areas of progressively less hydrostatic pressure, so that it is able to expand. A diver who has spent some time at depth suffers from this phenomenon if he comes up too fast. Under pressure the nitrogen in air has gone into solution in his blood. When the pressure is released, bubbles form in the body fluids, resulting in the symptoms known as the bends. A slower ascent allows the nitrogen to be reabsorbed into the blood and eliminated in the lungs.

When a bubble in beer reaches the surface, it may linger for several minutes before bursting. The bubble is far from spherical. The hydrostatic pressure just below the bubble (call it point *A*) must equal the pressure at the same level in the beer at a distance from the bubble (point *B*), otherwise beer would flow from one point to the other. At *B* the hydrostatic pressure results from the atmospheric pressure and the weight of the beer above that point. The same atmospheric pressure acts on *A*, but the weight of the liquid above the point is minimal because only a thin film of liquid is there. How can the pressure be equal at *A* and *B*?

The additional pressure at *A* is provided by the surface tension of the arched dome over the bubble. The curvature of the dome contributes a downward force. The surface tension at the concave bottom of the bubble contributes an upward force. The bottom is not as curved as the top, however, and so the upward force is smaller. On the whole the shape of a floating bubble generates a net downward force, which increases the pressure just below the bubble to the equilibrium value.

If a bubble arrives at the surface near a wall of the container, it moves to the wall and adheres to it. If another bubble is nearby, the two bubbles move toward each other. The attraction between two bubbles or a bubble and a wall is due to unequal pressures in the surfaces surrounding a bubble. Between two nearby bubbles the liquid surface is curved, not flat as it is in other directions. The curve is concave, which means that the force of the surface tension pulls upward. As a result the pressure just inside the beer at the curved surface is decreased. On the other sides of the bubbles the pressure is not reduced since the surface is flat. The bubbles are pushed together by the unequal pressures.

When a bubble is near a wall, the surface of the liquid between the bubble and the wall is more curved than that on the opposite side of the bubble. Again the curvature creates a surface tension that reduces the pressure in the liquid surface. The bubble is pushed to the wall.

If two identical bubbles touch, their common wall, which is called a lamella, is flat because of the identical gas pressures on the two sides of the wall. If the bubbles are not the same size, the lamella becomes curved so as to give rise to equal pressures on the two sides. Between two such bubbles the pressure initially differs because of different surface tensions in the bubbles. The larger bubble, with a greater radius of curvature, has a lower internal pressure because the surface tension of its wall is less. When a large bubble touches a small one, their common wall must bulge into the larger bubble. The changes in surface tension resulting from this bulge equalize the pressure in the two bubbles. (Complete equalization is not possible in a foam consisting of bubbles of many different sizes.)

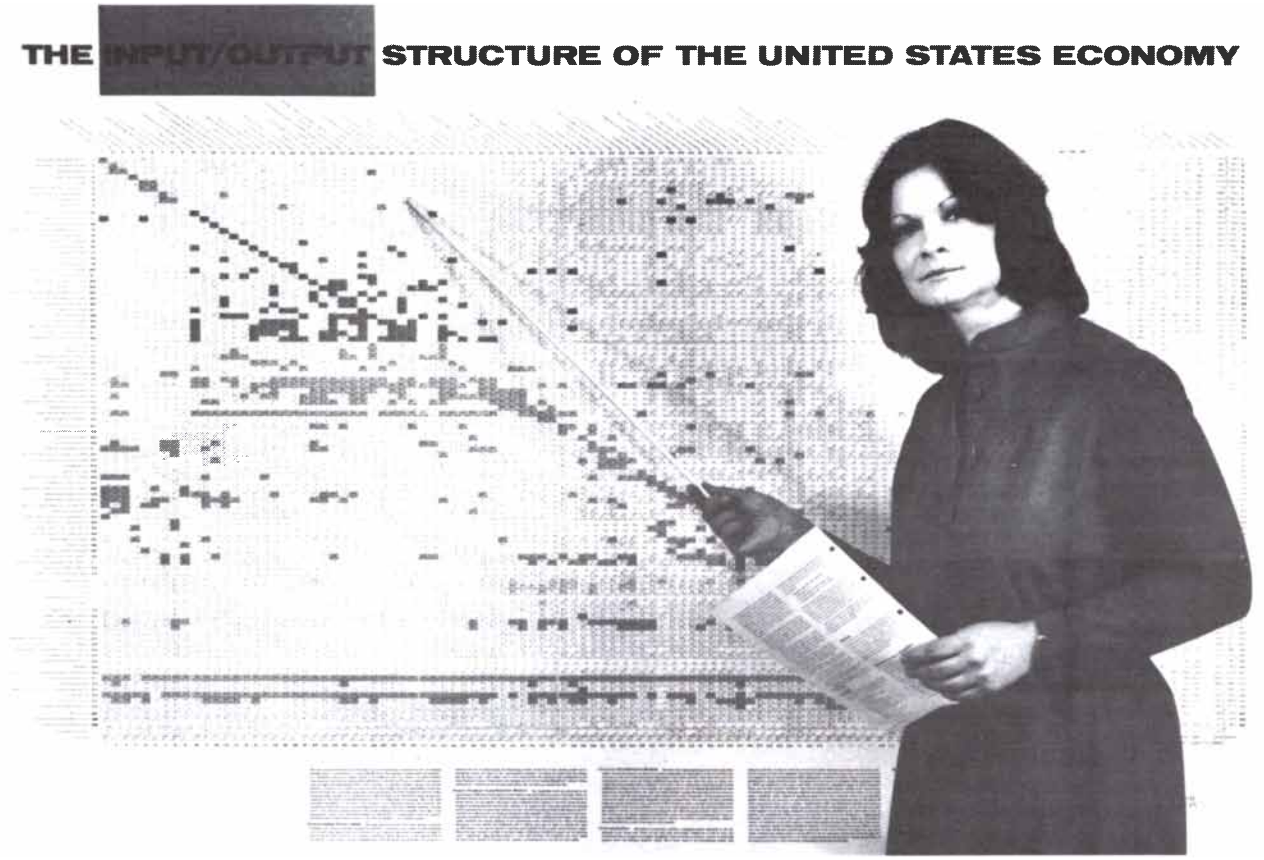
In an idealized foam with bubbles of identical size the bubbles would be organized in groups of three in contact with one another. The lamellae of the bubbles intersect symmetrically at a point called a Plateau border (after Joseph A. F. Plateau, who studied soap bubbles in the 19th century). This organization is the stablest against shocks.

Even if a beer foam had identical bubbles and such a stable organization, it would still collapse within minutes. One reason is that gravity drains liquid from between the lamellae, thinning them until they are only from 20 to 200 nanometers thick. Then they stabilize for a while until a chance shock from the surrounding foam thins them to about five nanometers, at which point they burst.

Drainage is also promoted by a curious interplay of surface tensions within the lamellae. Between two bubbles the surfaces of a lamella are relatively flat and hence low in surface tension. Where three lamellae join in a Plateau border, however, the surfaces are curved, the surface tensions they contribute are larger and the pressure inside the intersection differs from the pressure in the flat region. Since the surfaces facing the intersection are convex, the forces of their surface tensions pull away from the intersection, thereby reducing the pressure there. The pressure inside the lamellae is therefore less at a Plateau border than it is elsewhere. The pressure difference sucks liquid from the relatively flat lamellae into a Plateau border, thinning the lamellae.

A gradual decrease in the number of bubbles in a foam also results from the diffusion of their gas across the thin bubble walls. When a small bubble touches a larger one and the two cannot equalize pressures at their common wall, the higher pressure in the small bubble forces some of its gas to dissolve into the wall. The gas diffuses across the wall

© 1981 SCIENTIFIC AMERICAN, INC



WHAT MAKES THE U.S. ECONOMY TICK?

The editors of SCIENTIFIC AMERICAN have prepared a wall chart displaying for the 1980's the Input/Output Structure of the U.S. Economy based on the latest interindustry study from the U.S. Department of Commerce.

The SCIENTIFIC AMERICAN Input/Output wall chart does for economics what the table of elements does for chemistry. It answers at a glance questions about the linkage between the microeconomics of the firm and the macroeconomics of the system; about the web of technological interdependencies that tie industry to industry; about the industry-by-industry direct and indirect consequences of swings in public and private spending; about the impact of change in technology, and about any other topic you can think of. You are rewarded by surprise as well as by confirmation of your hunches. For teaching and practical and theoretical studies, here is a powerful, graphic tool.

In the familiar format of the SCIENTIFIC AMERICAN Input/Output wall charts for the 1960's and 1970's, the wall chart for the 1980's measures 65″ × 52″ and is printed in eight colors. Each of the nearly 10,000 cells in the 97-sector interindustry matrix shows (1) the interindustry commodity flow, (2) the direct input/output coefficient and (3) the "inverse" coefficient. Where the direct input/output coefficient exceeds .01, the cell is tinted in the color code of the industrial bloc from which the input comes. This device, combined with triangulation of the matrix, brings the structure of interindustry transactions into graphic visibility.

A supplementary table displays, industry by industry, the capital stock employed; the employment of managerial, technical-professional, white-collar and blue-collar personnel; the energy consumption by major categories of fuel, and environmental stress measured by tons of pollutants.

The editors of SCIENTIFIC AMERICAN are happy to acknowledge the collaboration, in the preparation of this wall chart, of Wassily Leontief, originator of input/output analysis—for which contribution to the intellectual apparatus of economics he received the 1973 Nobel prize—and director of the Institute for Economic Analysis at New York University.

Packaged with the chart is an index showing the BEA and SIC code industries aggregated in each of the 97 sectors.

SCIENTIFIC AMERICAN

415 Madison Avenue, Dept. I/O, New York, N.Y. 10017

YES, send me the new SCIENTIFIC AMERICAN 1980's INPUT/OUTPUT wall chart—printed in eight colors on heavy paper measuring 65″ × 52″.

I understand my chart(s) will be shipped prepaid, uncreased*, flat-rolled and in a sturdy mailing tube. (Allow 4-6 weeks for delivery)

I enclose a check for $____ for ____ chart(s) at $35 each, saving me $5 each in handling charges.

Bill me for $____ for ____ chart(s) at $40 each.

Name ________________

Company ________________

Street Address ________________

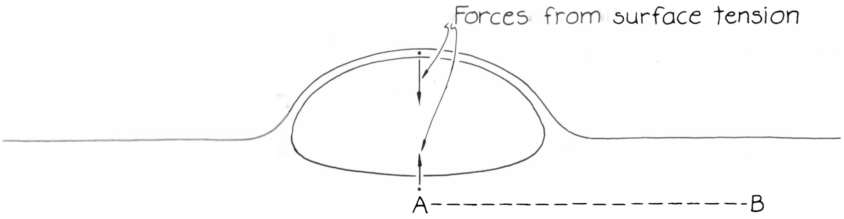
City, State, Zip Code ________________

12/81

*Charts shipped international require one fold.

Make check payable to SCIENTIFIC AMERICAN. Please add sales tax for California, Illinois, Massachusetts, Michigan, Ohio and New York.

© 1981 SCIENTIFIC AMERICAN, INC



The shape of a bubble at the surface of a glass of beer

and enters the larger bubble. In this way larger bubbles consume smaller ones.

Much of the strength of the foam comes from the surface viscosity of the surfaces in the lamellae. Surface viscosity is distinct from bulk viscosity, which is the viscosity of the liquid between the surfaces. The surfaces have such a large viscosity that they may be almost rigid, at least until the stress and shearing on them reach some critical value. Then they yield and the bubble bursts.

In some foams electric forces help to strengthen the bubbles. A layer of charged molecules can lie on each of the two surfaces of the lamella between two adjacent bubbles. As the lamella thins on draining, the layers of charge move closer to each other. Their mutual repulsion prevents or delays the collapse of the lamella.

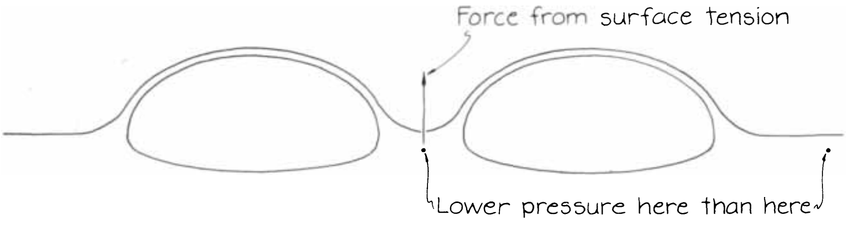
Although such a double layer of electric charge is important for some types of foam, I do not know if it plays a vital role in stabilizing beer foam. The primary stabilizing factors in beer are still not well understood. Proteins apparently help. Aged hops also seem to be important. Other ingredients, such as salts of cobalt, iron, nickel and zinc, are added either to prolong the life of the head on the beer or to enhance the clinging of small bubbles to the glass above the head when the glass is tilted.

I have long been an observer of beer bubbles (for scientific reasons, naturally), but recently Craig Cook, a student at Cleveland State University, showed me a phenomenon that was new to me. It is seen in Pilsner beer glasses, which are prized by beer drinkers more sophisticated than I. A Pilsner glass is fairly wide at the top and tapers to almost a dimple at the bottom. The tapered end is buried in a thick cylinder of glass for ease of holding. A Pilsner glass is unique in that the main output of bubbles is in the narrowly tapered bottom. A steady stream of bubbles, none of them initially more than about .5 millimeter in diameter, rises from the bottom. Fewer bubbles form on the sides of the glass.

The sides of the glass appear to be quite smooth, whereas the bottom seems to be roughened with tiny hills and crevices. If the glass is clean and dry before the beer is added, the crevices hold trapped air pockets that nucleate bubbles of carbon dioxide. The bubbles quickly tear away from the crevices, beginning to ascend while they are still small. The rapid production of the tiny bubbles forms a stream that rises to the center of the top surface of the beer.

When bubbles form on the sides of the glass, they are typically much larger than the ones rising from the bottom. One reason for the difference is that the bubbles at the bottom are under greater hydrostatic pressure and so must be smaller. I believe another reason can be found in the degree of roughness. At the bottom there are many adjacent sites for nucleating bubbles. No one of them can form a base wide enough to generate a large bubble. The size of the bubbles is also limited by the turbulence generated as nearby bubbles break away from their nucleating sites.

I could find no bubbles originating away from the walls, presumably because of a lack of nucleating air pockets. When I dipped a knife into a glass of beer, bubbles immediately began to form on it. After a while the activity lessened. To see whether the decrease was due to a loss of dissolved carbon dioxide in the beer or to a loss of air pockets on the knife, I lowered the knife farther into the beer. Many new bubbles appeared on the freshly submerged part of the blade. The number of nucleating pockets of air on the knife seems to diminish after several minutes of bubble formation.



How pressure is distributed around two bubbles

I observed the same kind of result with the glass. Bubbles were produced at the highest rate in an originally clean, dry glass. The rate decreased with each new container of beer poured into the glass. Pouring still created a foam and many bubbles, but the yield of bubbles several minutes after pouring was less. Apparently the continued use of the glass lessens the number of nucleating air pockets on its walls.

I did several more experiments with a knife dipped in beer. When the knife was tilted, layers of bubbles formed on the underside because they could not escape easily. When I tilted the knife the other way, layers of bubbles began to break away from the knife, clearly demonstrating that the release of one bubble can force the release of others.

The temperature of the knife did not seem to matter, but its cleanliness did. I coated the lower end of a knife with corn oil and then dipped the knife into the beer past the oiled region. The crop of bubbles in the oiled area was much smaller than it was in the unoiled area because the oil covered the air pockets adsorbed onto the metal.

Donald Deneck of New York once showed me how one drinks from a "yard of beer," a container that stands from two to three feet high and has a hemispherical bottom and a long, tapered neck that is narrowest in the middle. When the beer in the neck has been consumed, further drinking from such a container is tricky. To make the beer pour one must tilt the glass so that the hemispherical end is higher than one's mouth, but if the container is tilted too much, a large bubble of air enters the neck, slides to the now-raised bottom and displaces enough beer to douse the drinker.

Deneck's technique is to first tilt the container so that the bottom is only slightly higher than his mouth. Then he gently taps on the side of the neck to send a few small air bubbles or part of the foam up the neck to the hemispherical bottom. These bubbles displace a drinkable amount of beer. By gradually adjusting the tilt of the container and tapping its neck Deneck manages to get his full ration of beer.

I have had many letters about my discussion in May of phosphenes, the luminous figures one can see without benefit of light. Several readers described the phosphene displays that warn of and accompany a migraine headache. Carol McAlpine of Stroudsburg, Pa., wrote that when a migraine is beginning, she sees the network of blood vessels in the retina for an instant after shutting her eyes. Sometimes the network reappears in apparent rhythm with her pulse. After the migraine takes hold she sees "bursts of cloud billows in violet, blue and gray green, which float in all directions, con-

© 1981 SCIENTIFIC AMERICAN, INC

WHEN THERE IS A CAR FROM A COUNTRY THAT DESIGNED THE CONCORDE...

...A car designed by the first people to fly so far into the future...engineered to balance space and utility with true luxury...why drive an ordinary station wagon? When you can drive the remarkable new Renault 18i Sportswagon.

Its uniqueness begins with the design philosophy that has made Renault Europe's leading builder of cars: a fine automobile is a series of interdependent systems based on total system design.

Example: The 18i Sportswagon's carrying capacity is part of a system that includes a special long travel suspension with Variable Rate rear springs, folding rear seat for over 65 cu. ft. of carpeted cargo space and fuel injected, front wheel drive pulling power with rack and pinion steering.

To complete the total system design, no one outdoes the French in their command of interior luxury. From Renault's standard color-keyed carpeting and optional leather seating to the tasteful design of the instrumentation.

38 HWY EST | 25 EST* MPG

*Compare these 1981 EPA estimates with estimated mpg for other cars. Your actual mileage depends on speed, trip length and weather. Actual highway mileage will probably be lower.

And every new Renault 18i sold in the U.S. after September 23, 1981, is covered by American Motors' exclusive Buyer Protection Plan®, the only plan with a full 12-mo./12,000-mi. warranty.

So why drive an ordinary wagon, when you can drive the Renault 18i Sportswagon.

The Renault 18i is available at more than 1300 Renault and American Motors Dealers in sedan and Sportswagon models.

RENAULT

American Motors

© 1981 SCIENTIFIC AMERICAN, INC

YEAR-END SALE ON ALL MEN'S & LADIES' WATERTIGHT SPORT WATCHES

Casio Watersports

Enjoy All Your Favorite Watersports
Whether you're skiing, sailing, swimming or caught in a downpour, these men's and ladies' sport watches are built to endure. **The men's Watersport is watertight to 100 meters (over 300 ft.). And the ladies' Watersport survives to depths of 50 meters (beyond 150 ft.).** Now you active women have a sport watch that you never have to worry about. It's so convenient — just put it on and forget it!

Ladies' Watersport Meets Your Needs
Not only do you get the time in crisp, clear liquid crystal digits, but the ladies' Watersport also includes an auto-calendar with month and date. And for $10.00 more, you get all that plus a 24 hour daily alarm for your hectic schedule. Both have super quartz accuracy to ± 15 seconds per month, 15 month battery life, and stainless steel case with resin band.

Men's Watersport, Watertight and More
Now, with this new Casio Watersport, you receive superior stopwatch capabilities. It times beyond the standard 60 minutes up to an amazing 12 hours with hairsplitting accuracy to 1/10th second. This sophisticated chronograph even records split/lap, time-out, and 1st-2nd place finishes. Plus has a daily alarm & hourly chime, ± 15 second quartz accuracy per month, a calendar, and 5 yr battery. All include Casio's 1 year warranty, and our own 30 day guarantee, return within 30 days if not satisfied for a full refund.

Order Toll-free Today
Charge customers call toll-free 24 hours a day. Order #29 for ladies watersport without alarm, all black resin, only **$24.95.** Or for stainless steel versions with resin band #30 for **$29.95.** without alarm, with alarm, #31, only **$39.95.** Order #725 for men's Watersport in tough black resin case and band, only **$36.95.** Order #88 for men's Watersport with 1 hour chronograph & countdown timer instead of a 12 hour chronograph, in stainless steel case & resin band, only **$49.95.** Order #87 for men's Watersport with 1 hour chronograph & countdown timer instead of a 12 hour chronograph, in stainless steel case & bracelet, only **$54.95.**

(800) 227-1617 To Speed Your Order Ask For EXT. 900
in California (800) 772-3545 - if Lines are Full Call (800) 854-3831/in California (800) 432-7451

DWS marketing international

**350-A Fischer Avenue Dept. SC 12 L
Costa Mesa, California 92626 (714) 540-4444**
Call our toll-free number for quickest service or send your check or money order or credit card info. Please allow time for checks to clear. We accept VISA, M C, A E, D C credit cards. Add $2.50 for insured postage & handling for first product and $1.00 for each additional product. For UPS Blue Label "rush" service add an additional $1.00. Calif. residents add 6% sales tax.
©DWS marketing international 1981

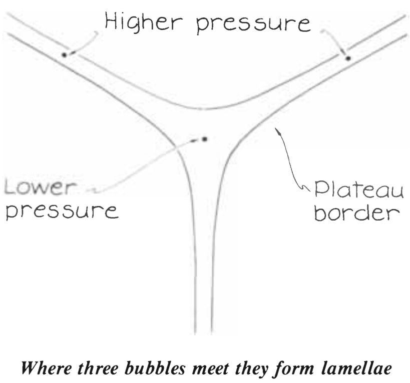
stantly changing shape." As the headache subsides the display changes to an array of dots of the kind I described in connection with the monocular viewing of phosphenes.

Paul Tobias of Los Angeles sent me a report that he and J. P. Meehan have made on phosphene displays instigated by rapid acceleration. Blindfolded volunteers, strapped in a centrifuge, were spun in a circle at an increasing speed. When the effective acceleration reached a certain threshold, the subjects saw an array of blue spots and stars. At an effective acceleration of about 3.6 *g* (3.6 times the acceleration of gravity) the array also developed what they described as golden worms. When the effective acceleration reached 4.5 *g*, the worms formed a brilliant orange gold geometric pattern. Some subjects saw a pulsation in the pattern.

After the centrifuge stopped the subject remained blindfolded for a short time in order to study the afterimage of the phosphenes. The afterimage, which lasted for as long as 90 seconds, was a doughnut or something like a full solar eclipse with a dark background.

These displays appeared only when the effective force on a subject was along the body axis. When the effective force was from the chest to the back, no displays were seen. Tobias and Meehan concluded that the phosphenes depend on the rate at which the acceleration is varied. When the acceleration is along the body axis and is varied fast enough, it probably reduces the blood pressure in the retina and distends the eye. Both effects contribute to the creation of phosphenes.

Astronauts and pilots might see such phosphenes during moments of rapid acceleration if the effective force is along the body axis. I think anyone on a rapidly rotating ride at an amusement park might see the displays. Some rides develop an acceleration of more than 3 *g*. A rider with enough presence of mind during these rapid maneuvers might see phosphenes. I must admit that I am too busy fearing for my life.



Where three bubbles meet they form lamellae

STATEMENT OF OWNERSHIP, MANAGEMENT AND CIRCULATION (required by 39 U.S.C. 3685). *1.* Title of publication: Scientific American. *1A.* Publication number: 00368733. *2.* Date of filing: September 30, 1981. *3.* Frequency of issue: monthly. *3A.* Number of issues published annually: 12. *3B.* Annual subscription price: U.S., possessions and Canada, 1 year $21; all other countries, 1 year $27. *4.* Complete mailing address of known office of publication: 415 Madison Avenue, New York, N.Y. 10017. *5.* Complete mailing address of the headquarters or general business offices of the publishers: 415 Madison Avenue, New York, N.Y. 10017. *6.* Full names and complete mailing address of publisher, editor, and managing editor: Publisher, Gerard Piel, 415 Madison Avenue, New York, N.Y. 10017. Editor, Dennis Flanagan, 415 Madison Avenue, New York, N.Y. 10017. Managing Editor, none. *7.* Owner: Scientific American, Inc., 415 Madison Avenue, New York, N.Y. 10017; Buckley & Co. (for Elinor Mannucci-Glass), c/o Fiduciary Trust Co. of New York, P.O. Box 3199, Church Street Station, New York, N.Y. 10008; George S. Conn, 20 Bittersweet Lane, Mount Kisco, N.Y. 10549; Cudd & Co. for (a) Helen Rosenwald Snellenburg Trust, (b) Robert L. Rosenwald Trust, (c) Estate of Lessing J. Rosenwald, (d) Nathan W. Levin and (e) I. M. Scott, The Chase Manhattan Bank, 1 Chase Manhattan Plaza, New York, N.Y. 10015; Martin M. Davidson, 11 River Lane, Westport, Conn. 06880; Richard E. Deutsch, c/o The Chase Manhattan Bank, P.O. Box 1508, Church Street Station, New York, N.Y. 10008; Dorothy D. Eweson, c/o Brunt & Co., Box 6626, Journal Square, Jersey City, N.J. 07306; Bayard Ewing, c/o Old Stone Bank, Trust Department, 40 Westminster Street, Providence, R.I. 02903; Excelsior Fund, c/o Olwine, Connelley, Chase, O'Donnell & Weyher, 299 Park Avenue, New York, N.Y. 10171; Dennis Flanagan, c/o Scientific American, Inc., 415 Madison Avenue, New York, N.Y. 10017; William T. Golden, Room 4201, 40 Wall Street, New York, N.Y. 10005; C. John Kirby, c/o Scientific American, Inc., 415 Madison Avenue, New York, N.Y. 10017; Frasier W. McCann, Room 726, 10 Rockefeller Plaza, New York, N.Y. 10020; Donald H. Miller, Jr., c/o Scientific American, Inc., 415 Madison Avenue, New York, N.Y. 10017; Eleanor Jackson Piel, Jr., 320 Central Park West, New York, N.Y. 10025; Gerard Piel, 320 Central Park West, New York, N.Y. 10025; Jonathan Bird Piel, 320 Central Park West, New York, N.Y. 10025; The President & Fellows of Harvard College Trust, Attention: Henry J. Ameral, Assistant Treasurer, 70 Federal Street, Boston, Mass. 02110; Barbara K. Rosenwald, P.O. Box 3625, Norfolk, Va. 23514; Julius Rosenwald II, c/o The Chase Manhattan Bank, P.O. Box 1508, Church Street Station, New York, N.Y. 10008; Rowe & Co. (for Rhode Island Charities Trust), c/o Industrial National Bank of Rhode Island, Trust Department, 100 Westminster Street, Providence, R.I. 02903; Stanley Schaefer, 418 Yerba Santa Avenue, Los Altos, Calif. 94022; Joan R. Scott, c/o The Chase Manhattan Bank, P.O. Box 1508, Church Street Station, New York, N.Y. 10008; Richard W. Warrington, 2180 Carmelita Avenue, Hillsborough, Calif. 94010; John Hay Whitney, Room 4600, 110 West 51 Street, New York, N.Y. 10020. *8.* Known bondholders, mortgagees, and other security holders owning or holding 1 percent or more of total amount of bonds, mortgages or other securities: none. *9.* For completion by nonprofit organizations authorized to mail at special rates (Section 411.3, DMM only). The purpose, function, and nonprofit status of this organization and the exempt status for Federal income tax purposes: Not applicable to this organization. *10.* Extent and nature of circulation: *A.* Total number of copies (net press run): average number of copies each issue during preceding 12 months, 855,389; actual number of copies of single issue published nearest to filing date, 850,398. *B.* Paid circulation: *1.* Sales through dealers and carriers, street vendors and counter sales: average number of copies each issue during preceding 12 months, 171,900; actual number of copies of single issue published nearest to filing date, 175,211. *2.* Mail subscription: average number of copies each issue during preceding 12 months, 548,000; actual number of copies of single issue published nearest to filing date, 546,800. *C.* Total paid circulation (sum of *10B1* and *10B2*): average number of copies each issue during preceding 12 months, 719,900; actual number of copies of single issue published nearest to filing date, 722,011. *D.* Free distribution by mail, carrier or other means, samples, complimentary, and other free copies: average number of copies each issue during preceding 12 months, 22,400; actual number of copies of single issue published nearest to filing date, 21,700. *E.* Total distribution (sum of *C* and *D*): average number of copies each issue during preceding 12 months, 742,300; actual number of copies of single issue published nearest to filing date, 743,711. *F.* Copies not distributed: *1.* Office use, leftover, unaccounted, spoiled after printing: average number of copies each issue during preceding 12 months, 8,500; actual number of copies of single issue published nearest to filing date, 4,800. *2.* Return from news agents: average number of copies each issue during preceding 12 months, 104,589; actual number of copies of single issue published nearest to filing date, 101,887. *G.* Total (sum of *E, F1* and *2*—should equal net press run shown in *A*): average number of copies each issue during preceding 12 months, 855,389; actual number of copies of single issue published nearest to filing date, 850,398. *11.* I certify that the statements made by me above are correct and complete. (Signed) George S. Conn, Vice-President and General Manager.

© 1981 SCIENTIFIC AMERICAN, INC

How About Giving a Really Different Gift This Year?

Give Your Family an Entertaining, Educational And *Affordable* TRS-80® Computer!

No "traditional" gift offers your family more than Radio Shack's TRS-80 Model III. It's easy and fun to use, because our huge selection of ready-to-run programs puts your computer to work or play immediately. Start with entertaining, fast-action games for all members of the family like Space Warp and Invasion Force. **Explore the unknown** passages of a pyramid or solve the mysteries of a haunted house, even chart horoscopes. And, games are only the beginning. Balance your checkbook, plan a budget, or **spot stock market trends.** With TRS-80, teaching math skills and learning to write BASIC programs becomes a family affair! The Model III is **expandable** — add more memory, disk drives, a printer, even communications accessories that bring the new "electronic editions" of major newspapers and stock information right into your home! And best of all, our "starter" TRS-80 Model III as shown is only $999.

Give *Yourself* This Time Saver! Our TRS-80 Desktop *Business* Computer

You can accomplish more in less time with our $2495 Two-Disk TRS-80 Model III on your desk. **Ready-to-run** software includes VisiCalc® for financial planning, Profile for record-keeping, and soon, Time Manager,® one of our new management productivity aids. For efficient **word processing** add Scripsit™ and a printer. See both models at your nearest Radio Shack store, dealer or Computer Center — today!

Radio Shack®

The biggest name in little computers™

A DIVISION OF TANDY CORPORATION

Retail prices may vary at individual stores and dealers.
VisiCalc is a trademark of Personal Software, Inc.
Time Manager is a trademark of Image Producers, Inc.

For more unique Christmas ideas, send for a free TRS-80 Computer Catalog.

Radio Shack
Dept. 82-A-111
1300 One Tandy Center
Fort Worth, Texas 76102.

NAME

STREET

CITY STATE

ZIP PHONE

© 1981 SCIENTIFIC AMERICAN, INC

ANNUAL INDEX

The following index lists all the authors and articles that appeared in SCIENTIFIC AMERICAN *during 1981. Also indexed are "Mathematical Games," "Metamagical Themas" and "The Amateur Scientist."*

AUTHORS

© 1981 SCIENTIFIC AMERICAN, INC

IF OTHER MOTORCYCLES WERE BUILT LIKE THIS THEY'D BE EXPENSIVE TOO.

For every motorcycle BMW carefully builds, Suzuki cranks out 45. Yamaha turns out 68. And Honda, a startling 86.

The reason for BMW's strikingly limited production? A passion for extraordinary engineering and hand craftsmanship that high-speed assembly-line techniques simply cannot satisfy.

Each and every BMW frame, for example, is welded entirely by hand instead of machine. It is aligned and scrutinized by a single craftsman and then stamped with his personal seal.

Onto this steady foundation are mounted some of the most precisely tooled components ever to grace a production motorcycle:

A driveshaft, for example, so perfectly formed as to not require a single counterbalancing weight. Cylinders and crankcases that are machined to such infinitesimal tolerances that gaskets are wholly unnecessary.

To insure its durability every critical component on a BMW is actually X-rayed to determine its stress value.

To increase maneuverability these parts are, wherever possible, made of expensive lightweight alloys instead of steel or iron. Culminating in a motorcycle which, model for model, is the lightest in its class.

And not surprisingly, the most expensive in its class. Ranging between $3,600–$7,300, excluding local shipping charges and state taxes.

The rewards? According to Cycle magazine "...high-mileage, years-old BMW's retain their taut, solid feel when lesser motorcycles have long since gotten loose and rattly."

And according to the NADA's motorcycle handbook, BMW's also retain a higher percentage of their original purchase price than any other motorcycle.

Which provides the BMW owner with the singular satisfaction of sitting not only on a superior machine, but on a superior investment as well.

© 1981 BMW of North America, Inc.
The BMW trademark and logo are registered trademarks of Bayerische Motoren Werke, A.G.

THE LEGENDARY MOTORCYCLES OF GERMANY.

BMW

© 1981 SCIENTIFIC AMERICAN, INC

Toshiba freezes without snow.

On an average VCR, you simply can't see a still or slow-motion picture without the usual avalanche of electronic noise.

But thanks to Toshiba's new portable V-9035 Betaformat VCR, the blizzard of interference has been lifted.

The V-9035 has four video heads instead of the usual two. These two extra heads have a single function: to trace the recorded tracks in still and slow motion.

No other VCR has two extra heads designed specifically for this purpose. So it's no surprise the V-9035 gives you totally clear still and slow-motion pictures no other portable can match.

Besides surpassing all others when slowing down or standing still, the V-9035 also lets you make visual searches at either double speed or, with Betascan, at 17 times normal speed. And features the programming capability of handling 8 different programs over 14 days.

And like any Toshiba VCR, it has precise electronic tuning and sensitive solenoid touch controls.

Toshiba also makes everything else that goes into the making of superior home video.

You shoot with the incredible IK-1850-AF autofocus video camera. Its 2/3-inch Univicon/2 vidicon tube functions perfectly in low-light conditions and is housed in a strong, light magnesium body.

You review your work on America's smallest color television: the CA-045. It's small (the screen measures just 4 1/2 inches diagonally), light and has the input/output terminals you need. All of which make it the perfect portable playback monitor.

Toshiba's new portable Betaformat VCR, autofocus video camera and 4 1/2-inch color television. Put them together and you can't beat the system. And that's no snow job.

*Actual TV Pictures.

TOSHIBA
Again, the first.

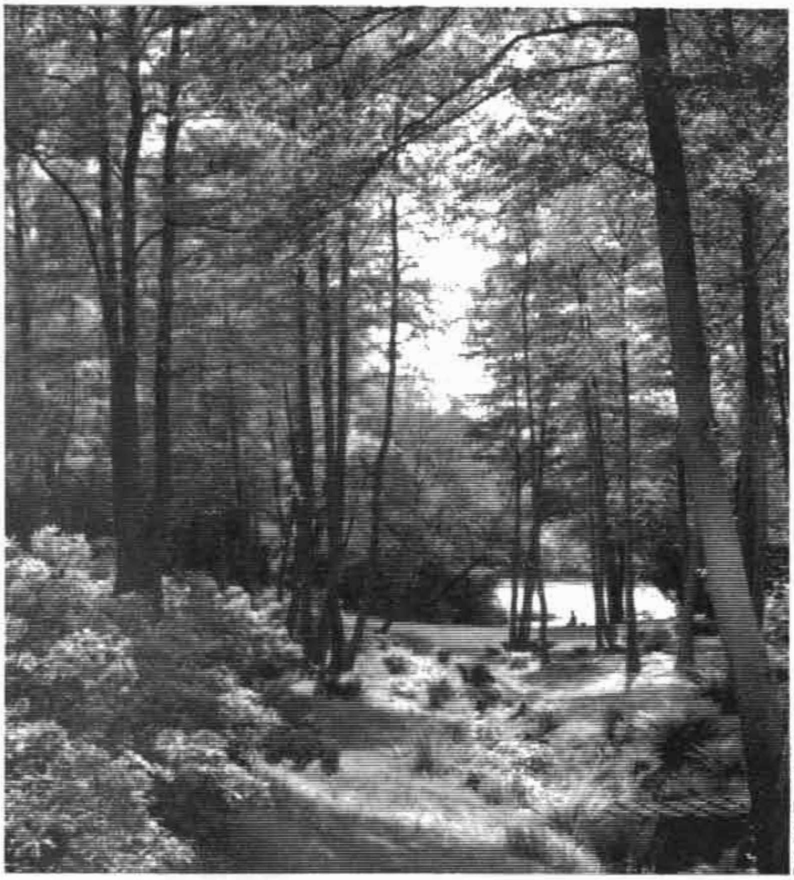
Toshiba America, Inc., 82 Totowa Road, Wayne, NJ 07470

© 1981 SCIENTIFIC AMERICAN, INC

ARTICLES

© 1981 SCIENTIFIC AMERICAN, INC

© 1981 SCIENTIFIC AMERICAN, INC



British Tourist Authority

A Beautifully Illustrated, Authoritative New Sourcebook

Plants in the Landscape

by Philip L. Carpenter, Theodore D. Walker, and
Frederick O. Lanphear, Purdue University

Plants in the Landscape is a unique introduction to the principles and practices of ornamental horticulture in landscape architecture. No other single volume covers such a broad range of topics. Here is a wealth of information on subjects ranging from the landscaping practices of ancient civilizations to no-nonsense, dollars-and-cents descriptions of the present-day landscaping industry. The focus throughout is on landscape plants: how to select and maintain them for healthy growth in a wide range of settings.

Plants in the Landscape is a beautiful book. The text is closely integrated with more than 500 illustrations (including more than 300 photographs). This is a fine sourcebook for the professional and amateur alike, as well as an unparalleled text for courses in ornamental horticulture, landscape architecture, and landscape design.

1975, 481 pp., 534 illus., 32 tables, ISBN 0-7167-0778-0, $24.95

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

© 1981 SCIENTIFIC AMERICAN, INC

BIBLIOGRAPHY

Readers interested in further explanation of the subjects covered by the articles in this issue may find the following lists of publications helpful.

MATHEMATICAL GAMES

WHAT WE KNOW AND DON'T KNOW ABOUT INFLATION. Robert M. Solow in *Technology Review*, Vol. 81, No. 3, pages 30–46; December/January, 1979.

REAGANOMICS: SUPPLY-SIDE ECONOMICS IN ACTION. Bruce R. Bartlett. Arlington House Publishers, 1980.

LASER WEAPONS

RESPONSE OF MATERIALS TO LASER RADIATION: A SHORT COURSE. J. T. Schriempf. Naval Research Laboratories, 1974.

HIGH ENERGY LASER WEAPONS: A TECHNICAL ASSESSMENT. M. Callaham and K. Tsipis. Program in Science and Technology for International Security Report No. 6, Massachusetts Institute of Technology, 1980.

MAGNETIC NAVIGATION IN BACTERIA

MAGNETOTACTIC BACTERIA. Richard Blakemore in *Science*, Vol. 190, No. 4212, pages 377–379; October 24, 1975.

A NOVEL METHOD FOR THE ISOLATION AND STUDY OF A MAGNETOTACTIC BACTERIUM. T. T. Moench and W. A. Konetzka in *Archives of Microbiology*, Vol. 119, pages 203–212; 1978.

MAGNETITE IN FRESHWATER MAGNETOTACTIC BACTERIA. Richard B. Frankel, Richard P. Blakemore and Ralph S. Wolfe in *Science*, Vol. 203, No. 4387, pages 1355–1356; November 30, 1979.

ULTRASTRUCTURE OF A MAGNETOTACTIC SPIRILLUM. D. L. Balkwill, D. Maratea and R. P. Blakemore in *Journal of Bacteriology*, Vol. 141, No. 3. pages 1399–1408; March, 1980.

SOUTH-SEEKING MAGNETOTACTIC BACTERIA IN THE SOUTHERN HEMISPHERE. R. P. Blakemore, R. B. Frankel and Ad. J. Kalmijn in *Nature*, Vol. 286, No. 5771, pages 384–385; July 24, 1980.

MAGNETOTACTIC BACTERIA AT THE GEOMAGNETIC EQUATOR. R. B. Frankel, R. P. Blakemore, F. F. Torres de Araujo, D. M. S. Esquivel and J. Danon in *Science*, Vol. 212, No. 4500, pages 1269–1270; June 12, 1981.

THE RECUMBENT STONE CIRCLES OF SCOTLAND

MEGALITHIC SITES IN BRITAIN. A. Thom. Oxford University Press, 1967.

THE STONE CIRCLES OF THE BRITISH ISLES. Aubrey Burl. Yale University Press, 1976.

JUPITER AND SATURN

NEGATIVE VISCOSITY. Victor P. Starr and Norman E. Gaut in *Scientific American*, Vol. 223, No. 1, pages 72–80; July, 1970.

THE METEOROLOGY OF JUPITER. Andrew P. Ingersoll in *Scientific American*, Vol. 234, No. 3, pages 46–56; March, 1976.

VOYAGER 1 ENCOUNTER WITH JUPITER. *Science*, Vol. 204, No. 4396; June 1, 1979.

VOYAGER 2 ENCOUNTER WITH JUPITER. *Science*, Vol. 206, No. 4421; November 23, 1979.

THE NEW SOLAR SYSTEM. Edited by J. Kelly Beatty, Brian O'Leary and Andrew Chaikin. Cambridge University Press and Sky Publishing Corporation, 1981.

VOYAGER 1 ENCOUNTER WITH SATURN. *Science*, Vol. 212, No. 4491; April 10, 1981.

THE HEARING OF THE BARN OWL

ACOUSTIC LOCATION OF PREY BY BARN OWLS (*TYTO ALBA*). Roger S. Payne in *The Journal of Experimental Biology*, Vol. 54, pages 535–573; 1971.

HOW THE OWL TRACKS ITS PREY. Masakazu Konishi in *American Scientist*, Vol. 61, No. 4, pages 414–424; July–August, 1973.

SOUND LOCALIZATION IN BIRDS. E. I. Knudsen in *Comparative Studies of Hearing in Vertebrates*, edited by Arthur N. Popper and Richard R. Fay. Springer-Verlag, 1980.

FIBRINOGEN AND FIBRIN

CONFORMATION OF FIBRINOGEN: CALORIMETRIC EVIDENCE FOR A THREE-NODULAR STRUCTURE. John W. Donovan and Elemer Mihalyi in *Proceedings of the National Academy of Sciences of the United States of America*, Vol. 71, No. 10, pages 4125–4128; October, 1974.

DESIGNATION OF SEQUENCES INVOLVED IN THE "COILED-COIL" INTERDOMAINAL CONNECTIONS IN FIBRINOGEN: CONSTRUCTION OF AN ATOMIC SCALE MODEL. Russell F. Doolittle, Danielle M. Goldbaum and Larry R. Doolittle in *Journal of Molecular Biology*, Vol. 120, No. 2, pages 311–325; April 5, 1978.

THE AMINO ACID SEQUENCE OF THE α-CHAIN OF HUMAN FIBRINOGEN. R. F. Doolittle, K. W. K. Watt, B. A. Cottrell, D. D. Strong and M. Riley in *Nature*, Vol. 280, No. 5722, pages 464–468; August 9, 1979.

TRINODULAR STRUCTURE OF FIBRINOGEN: CONFIRMATION BY BOTH SHADOWING AND NEGATIVE STAIN ELECTRON MICROSCOPY. Walter E. Fowler and Harold P. Erickson in *Journal of Molecular Biology*, Vol. 134, No. 2, pages 241–249; October 25, 1979.

STUDIES ON SYNTHETIC PEPTIDES THAT BIND TO FIBRINOGEN AND PREVENT FIBRIN POLYMERIZATION: STRUCTURAL REQUIREMENTS, NUMBER OF BINDING SITES, AND SPECIES DIFFERENCES. Andrew P. Laudano and Russell F. Doolittle in *Biochemistry*, Vol. 19, No. 5, pages 1013–1019; March 4, 1980.

COMPUTER ALGEBRA

SYMBOLIC AND ALGEBRAIC COMPUTATION: EUROSAM '79, AN INTERNATIONAL SYMPOSIUM ON SYMBOLIC AND ALGEBRAIC MANIPULATION. Springer-Verlag Lecture Notes in Computer Science No. 72. Springer-Verlag, 1979.

SYMBOLIC MATHEMATICAL COMPUTATION. David R. Stoutemyer and David Y. Y. Yun in *Encyclopedia of Computer Science and Technology, Vol. 15: Supplement*, edited by Jack Belzer, Albert G. Holzman and Allen Kent. Marcel Dekker, 1980.

PROCEEDINGS OF THE 1981 ACM SYMPOSIUM ON SYMBOLIC AND ALGEBRAIC COMPUTATION. Edited by Paul S. Wang. Association for Computer Machinery, 1981.

THE ANTHROPIC PRINCIPLE

QUANTUM MECHANICS AND REALITY. Bryce S. DeWitt in *Physics Today*, Vol. 23, No. 9, pages 30–35; September, 1970.

LARGE NUMBER COINCIDENCES AND THE ANTHROPIC PRINCIPLE IN COSMOLOGY. Brandon Carter in *Confrontation of Cosmological Theories with Observational Data: Proceedings of the Second Copernicus Symposium*, edited by M. A. Longair. D. Reidel Publishing Co., 1974.

ON WHAT GOD CHOSE: PERFECTION AND GOD'S FREEDOM. George Gale in *Studia Leibnitiana*, Band 8, No. 1, pages 69–87; January, 1976.

THE AMATEUR SCIENTIST

GAS IN LIQUIDS. J. T. Davies and E. K. Rideal in *Interfacial Phenomena*. Academic Press, 1963.

FOAMS. J. J. Bikerman. Springer-Verlag, 1973.

SO WHAT'S A BUBBLE? Jeffrey C. May in *SciQuest*, Vol. 52, No. 8, pages 16–20; October, 1979.

CLOUD PHYSICS IN A GLASS OF BEER. Craig F. Bohren and Gail M. Brown in *Weatherwise*, Vol. 34, No. 5, pages 221–223; October, 1981.

© 1981 SCIENTIFIC AMERICAN, INC

Model 7-4885

THE GE COMPUTER RADIO. AT 6 A.M. IT'S SMARTER THAN YOU ARE.

TIME. For starters, The Great Awakening from General Electric is smart enough to let you set the time directly... there's no flipping around the clock.

6:00

WAKE-UP 1. You can program it to change stations for you. So it will rock you to sleep with Strauss, switch to your news station, and wake you at 6:15.

6: 15

WAKE-UP 2. Then it comes back on to wake up your better half to a Beethoven symphony at 7:53. And on the Great Awakening it's all done with push-button ease.

7:53

SNOOZ-ALARM.® For a little extra sleep, press the Snooz-Alarm. It lets you sleep an extra minute or an extra hour. You tell the memory how long.

15

RADIO FM. You can also program up to six of your favorite stations into the Computer Radio's memory. And recall any one of them with the touch of a finger.

102.7

RADIO AM. You can scan all the AM or FM stations by pressing a button or, to tune in one station, just punch in the frequency of your choice on the keyboard.

1410

ERROR. The Great Awakening Computer Radio is so smart it even tells you when you've made an error. But it's no problem to correct... just press a button.

E

ALARM OFF. When you forget to set the alarm... The Great Awakening remembers to remind you.

OFF

WE BRING GOOD THINGS TO LIFE.

GENERAL ELECTRIC

For more information, write to: General Electric Co., E.P., Bldg. 5, Rm. 139, Syracuse, NY 13221.

© 1981 SCIENTIFIC AMERICAN, INC

© 1981 SCIENTIFIC AMERICAN, INC