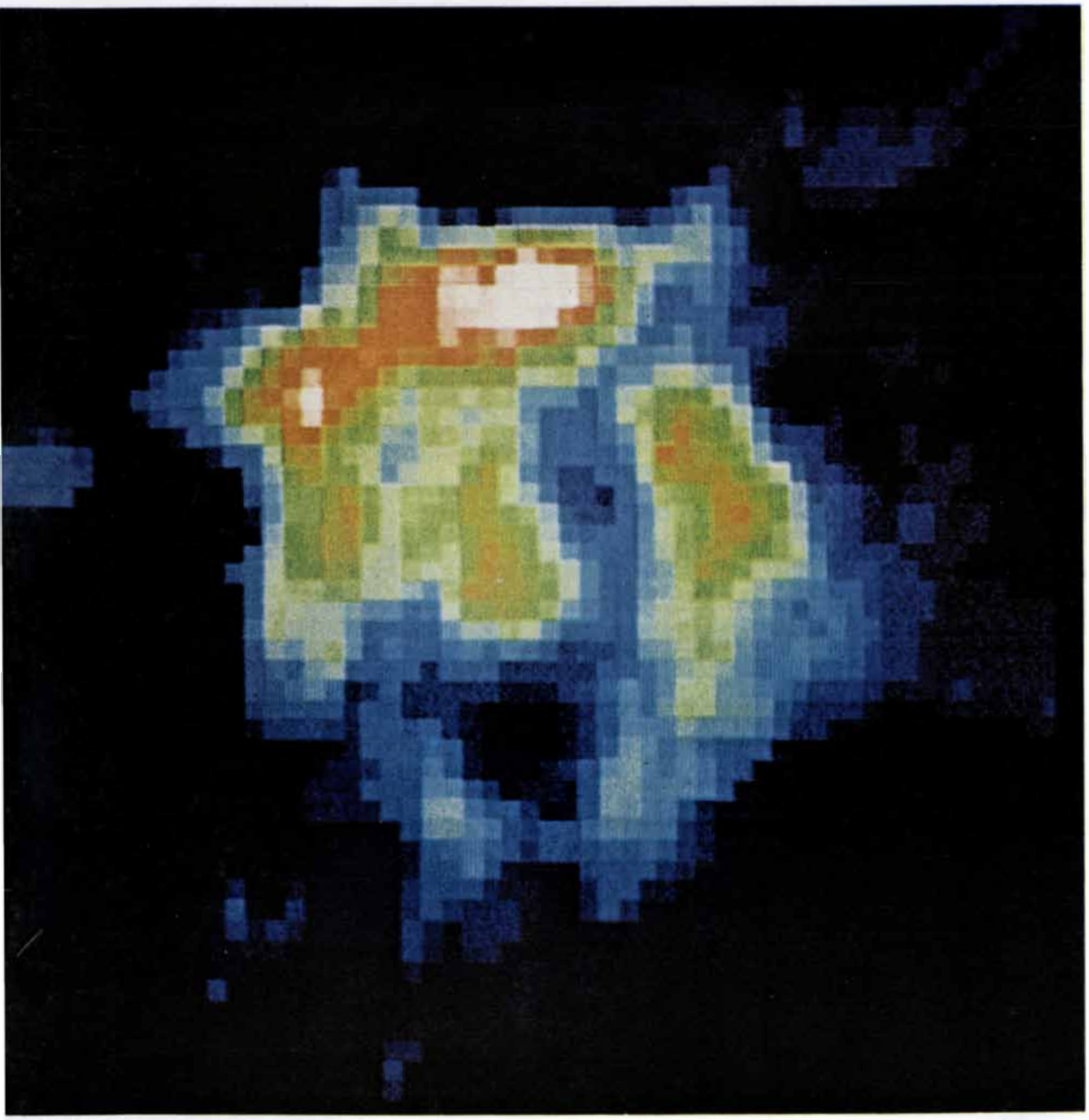
SCIENTIFIC AMERICAN



X RAYS FROM A SUPERNOVA REMNANT

$1.25

December 1975

Money this kind of

Esquire

THE MAGAZINE FOR MEN AUGUST 1975

VW's new Rabbit is significant because it is a complete departure for Volkswagen, and also because it is the specific type of car that Detroit will be building in the 1980's.

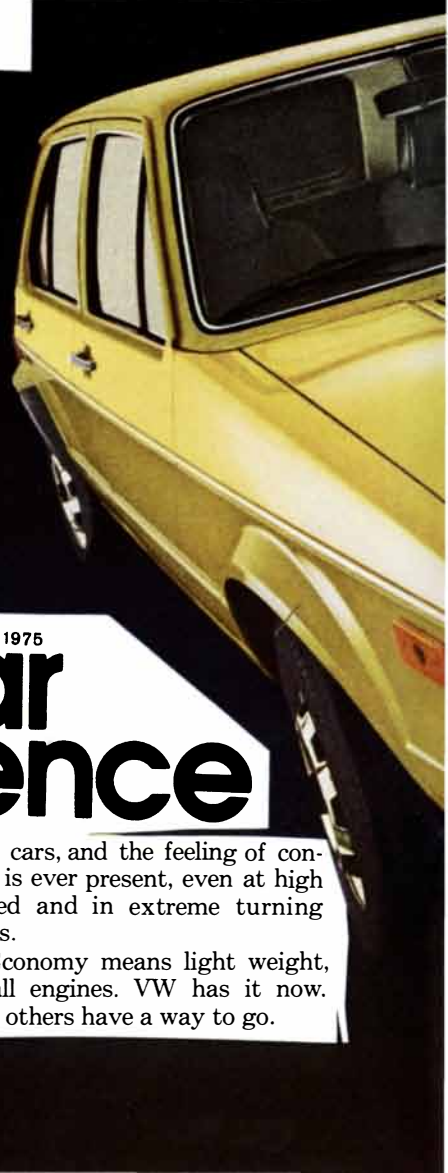
The statistics speak for themselves: accommodation for four, a seventy-horsepower engine, fuel consumption of thirty-eight mpg and a weight of under two thousand pounds.

What they came up with was "a car that doesn't have an ounce of fat, one which provides excellent operating economy, as well as performance and value."

Volkswagen is evidently confident in its new model, because it is covered by the VW Owner's Security Blanket, which is as good as you can get.

Personally, I think that VW's Rabbit is one very good idea ahead of its time.

VW's note: The 1976 EPA estimates for the standard shift model are 39 mpg on the highway, 25 mpg in the city. Your actual mileage may vary, depending on the type of driving you do, your driving habits, your car's condition and optional equipment.



APRIL 1975

Popular Mechanics

The most important new import for 1975 is the VW Rabbit.

The 1800-pound Rabbit is a mechanical masterpiece. It gets up to 60 mph in about 12 seconds—giving it the edge on some V8 subcompacts. Its hatchback design provides 24.7 cubic feet of luggage capacity with the rear seat folded.

VW got the greatest possible amount of usable interior space into the smallest possible outer shell—and an exterior with some style.

JUNE 1975

Popular Science

A totally new kind of small car, Volkswagen's Rabbit, may make things difficult for U.S. small-car makers in the coming months.

Its speed through the maneuvering courses matched or exceeded the best times of the other test cars, and the feeling of control is ever present, even at high speed and in extreme turning tests.

Economy means light weight, small engines. VW has it now. The others have a way to go.

can't buy advertising:

ROAD & TRACK

MAY 1975

The winner, and not by a hare (sorry, couldn't resist). This car does it all: it's small, light, roomy and fast, with nimble and responsive steering, ride and handling. A modern and sophisticated car with a handsome Guigiaro-designed hatchback body, the Rabbit offers one of the most space-saving mechanical layouts we've seen yet: front-wheel drive, transverse engine and a unique, independent rear suspension featuring an integral anti-roll bar and using so little space it's remarkable.

Seats are firm in the German manner and you sit high, viewing the world through an expansive greenhouse.

The Rabbit has a solid feel and an ultramodern look to it. Best of all it is almost sinfully enjoyable to drive.

ROAD TEST

JULY 1975

The Volkswagen Rabbit should be recognized as a true worldcar; it would be as at home commuting in Los Angeles, on a ski trip in the Alps, or chasing kangaroos across Australia. It is the finest example to date of a totally integrated passenger car, useful anywhere in the world and is qualified as no other imported car of 1975 for the Road Test Engineering Award.

CAR and DRIVER

APRIL 1975

Whole populations of drivers will live for years with this car, strongly impressed by its generally nimble disposition and its sensitive feel of the road through the steering wheel and brake pedal. It slips through city traffic like a bicycle and thrives on the parking-space remnants most cars pass by. You can stuff enough groceries for a football team through the rear hatch while the back seat folds and pivots forward out of the way. The only thing you'll need a trailer for is objects too heavy to boost across the high lift-over.

The Chivas Regal of Scotches.

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Established 1845 **SCIENTIFIC AMERICAN** December 1975 Volume 233 Number 6

ARTICLES

DEPARTMENTS

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THE COVER

The picture on the cover is an X-ray map of the Cygnus Loop, the remnant of a supernova that exploded in the constellation Cygnus some 20,000 years ago (see "X Rays from Supernova Remnants," page 38). It was made from data obtained by Saul A. Rappaport and his colleagues at the Massachusetts Institute of Technology, who sent an X-ray detector above the earth's atmosphere aboard a rocket. The detector scanned the nebula and recorded the intensity of the X-ray emission with respect to position in the sky. The data were then displayed on a color-television tube by Richard J. Borken of the University of Wisconsin. The colors represent the distribution of the X-ray intensity across the source: white areas have the greatest intensity and blue areas the least. Bright area toward top of picture corresponds to the location of the well-known Veil Nebula as it is seen in visible light.

THE ILLUSTRATIONS

Cover photograph by Richard J. Borken, University of Wisconsin

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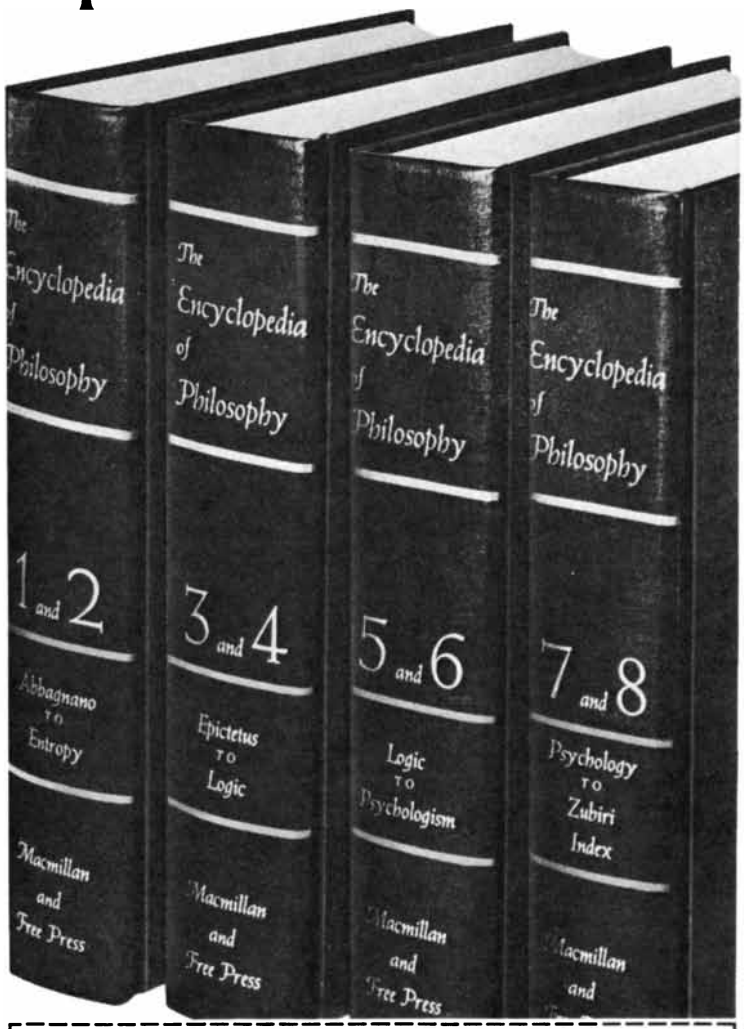

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4.
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7.
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8.
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Halogen fog lights. Standard equipment.

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13.
Cockpit. Control panel has full instrumentation. Tachometer, quartz crystal clock, cruise control, AM/FM stereo radio, electrically operated windows are all standard equipment.

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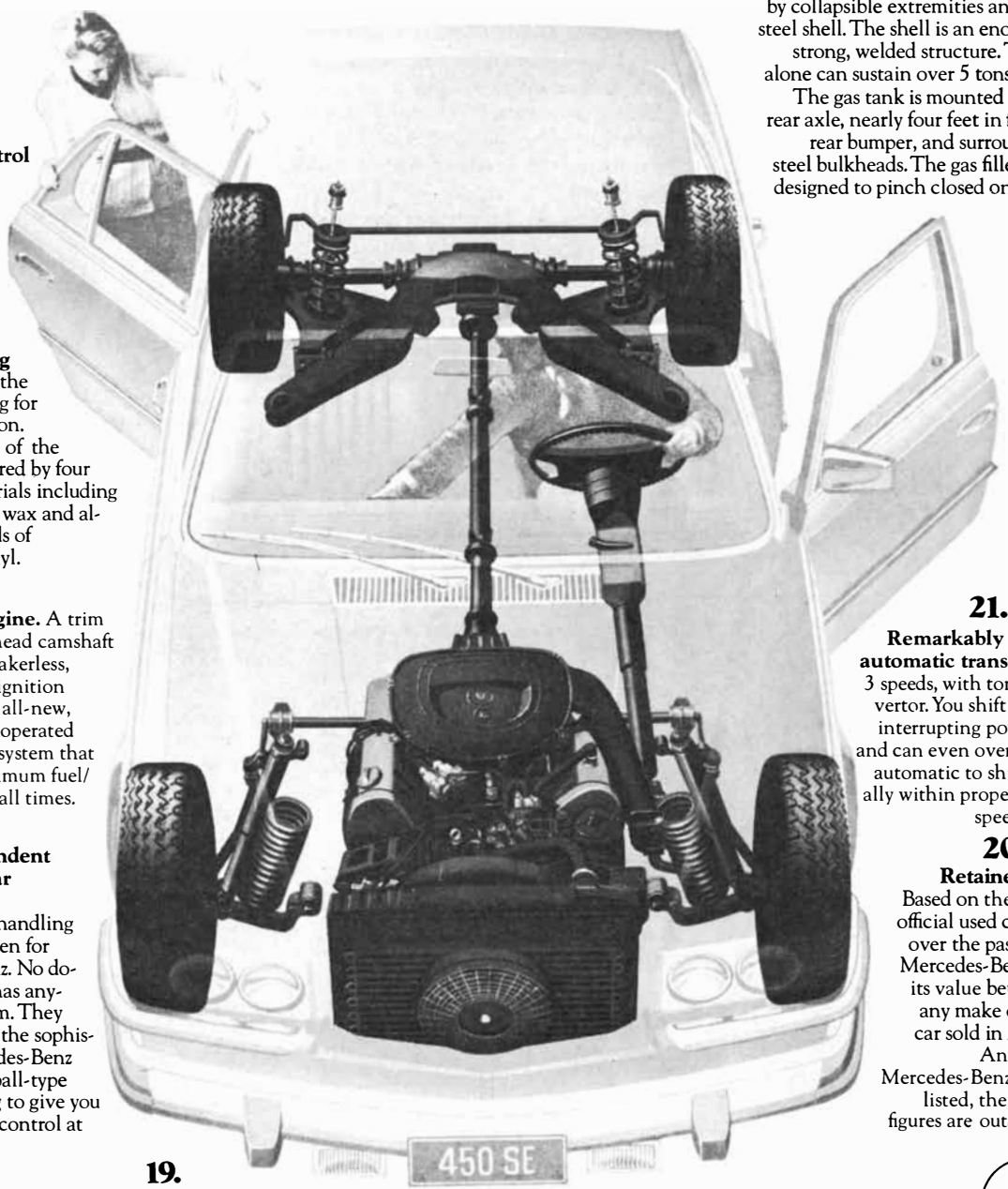

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LETTERS

Sirs:

By coincidence the October issue of *Scientific American* contained an exchange of letters between William C. Yengst of Science Applications, Inc., and Kosta Tsipis of the Massachusetts Institute of Technology (dealing with Tsipis' article on the accuracy of strategic missiles) and the article by Herbert F. York on the debate over the hydrogen bomb. Without taking up in detail the merits of Tsipis' and Yengst's arguments or York's perceptions of what history might have been like if the Oppenheimer committee's recommendation against the high-priority development of the hydrogen bomb had been followed, I should like to comment on a salient feature of all this material.

In his argument in favor of proceeding with the speedy development of highly accurate ICBM's Yengst writes: "To paraphrase Murphy's law: 'If it has been shown that a technology is feasible, eventually someone will demonstrate or use it.' If the U.S. does not continue to develop its ICBM quality, the Soviets (or Chinese) may, and they could ultimately put the U.S. at a technological disadvantage." This is Yengst's ultimate answer to the criticism put forward by Tsipis that the development of high-accuracy missiles is of minimal military value to the U.S. and is in fact likely to be destabilizing in regard to the strategic future of both countries. Similarly, York makes it clear that President Truman's decision to proceed with the high-priority development of the hydrogen bomb could have been based on his conclusion that otherwise the U.S. would run a small risk of being second best, and that this would be too undesirable a *political* alternative. Yet York maintains that if President Truman had taken the advice of the Oppenheimer committee, the U.S., even under the "worst case" assumption of subsequent Soviet bomb developments, would have been no less secure.

In arguing that if we don't do it, the Soviets might do it first, Yengst ignores how little either the U.S. or the U.S.S.R. would gain technically by expediting the development of high-accuracy weapons. In short, Yengst's formulation of Murphy's law is tantamount to the conclusion that if any technology, however ineffective or harmful, is feasible, then it must be pursued. If that view is accepted, then man has indeed lost control of his own destiny.

WOLFGANG K. H. PANOFSKY

Director
Stanford Linear Accelerator
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NAME

NEW ADDRESS

OLD ADDRESS

Sirs:

I am a constant reader of your column "Mathematical Games." However, I have become increasingly disturbed by certain attitudes you express and which apparently you feel are so "natural" that they require no justification.

Consider your reference in the September column to Rev. 7:9, where the number saved was "a great multitude, which no man could number." From this Dr. Matrix concludes that the set of saved souls must be infinite and uncountable.

If Dr. Matrix were not so obtuse, he would realize that God in her infinite wisdom meant the words in her book to be taken literally. "No man could number" means just that: men could not number but women could.

In fact, throughout the Bible we find

There are times when only the very best will do.

A birthday.
Happy homecoming.
Welcome to fatherhood.
The Holiday season.
Bon voyage.
Welcome to the neighborhood.
Thank you.
Father's Day.
An anniversary.

...these are just some of the times you instinctively feel the gift should be equal in every way to the thought. You wish the best; you give the best.

What is best?

We'd like to give you an easy answer. We'd like to say that Maker's Mark is the finest whisky to come out of Kentucky.

But Bill Samuels, our president, won't let us say it.

He says there's no such thing as a universal "best" in whisky — that it's always a matter of personal taste.

We do know this, Bill set out to make the very best whisky he knew how — and as a fourth generation Kentucky distiller, he knew how.

And in his own eyes, he succeeded. In other words, he believes Maker's Mark is the best Kentucky whisky to be had at any price. And we can say that there's a large and steadily growing number of people who agree with him.

There is no way our little distillery can put up enough Maker's Mark to go around everywhere. So you may not be able to find it the first place you try — but that's another reason why those who receive a bottle will value it all the more.

Maker's Mark Distillery, Loretto, Ky., Ninety Proof - Fully Matured.

Just for giving?

So far, we haven't touched on those times when you yourself might feel especially deserving. All we can say is this: Try a bottle of Maker's Mark. There's a good chance you will consider it the best you've ever tasted. And if so, you'll be all set for those times when only the very best will do.

You're invited...

...to visit our little restored distillery on Star Hill Farm. It's the only one in Kentucky to be entered in the National Register of Historic Places. We think you might enjoy "discovering" it in the rolling Bluegrass countryside near Loretto. Meanwhile, our full-color folder offers you an armchair tour. Write for your free copy.

evidence that women were the account keepers and mathematicians. While men were busy with such pursuits as virgin-raping, horn-blowing and yawning, women were inventing number systems.

To return to Rev. 7:9, we can assume that men knew about fingers and toes. We have evidence that it was rare for more than nine men to assemble peacefully. (If as few as 10 men congregated without a fight, the event was considered miraculous and the ground on which they met was deemed blessed. This is the origin of the Hebrew minyan.) Therefore "no man could number" means simply an amount greater than 180.

Mother wit was always threatened by male brawn. To preserve the tradition of feminine mathematics every woman in biblical times gave her daughters names that concealed numbers or mathematical terms. These anagrams were so clever that some carry through even in English translation. Eve, of course, is "Vee," meaning five. Naomi is contained in "I am one" (not Dr. Matrix' masochistic "I moan"). Esther is "Threes," Dinah "I hand," denoting both one and five. Rebekah contains baker, indicating baker's dozen.

With this perspective an entirely new numerological analysis of the Bible can be made. Dr. Matrix has shown such male prejudice that he is obviously unfit for the task. I suggest you commission Matrix' daughter Iva (from "a IV") to complete the task.

MAY BERESIN

Department of Mathematics
Adelphi University
Garden City, N.Y.

Sirs:

In "The Effects of Light on the Human Body" [SCIENTIFIC AMERICAN, July] Richard J. Wurtman mentioned that light falling on the retina of rats "presumably" facilitates ovulation. This reminded us of Hamlet's warning to Polonius concerning Ophelia: "Let her not walk i' th' sun. Conception is a blessing, but not as your daughter may conceive. Friend, look to't." (Act II, Scene 2). The connection between ideas expressed centuries apart underscores the point that many a discarded theory holds a concept worthy of further study.

VIRGIL DIODATO

LOUISE WILLIAMS

Muncie, Ind.

One of a series of reports on the first hundred years of the telephone.

The Bell System didn't just happen. It was planned, right from the start.

Thanks to Alexander Graham Bell, all nations have telephones. Thanks to Theodore Newton Vail, the United States has the world's best telephone system.

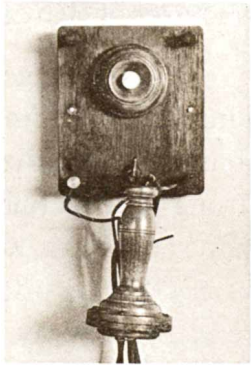
Alexander Graham Bell

Theodore Newton Vail

Theodore Newton Vail was the first General Manager of the Bell Telephone Company. He was hired in 1878, when the telephone was two years old, and 10,755 sets were in service, most of them in the Northeast. His vision of what the new invention could become equaled Bell's own.

Both men saw that the success of the infant telephone industry depended on offering customers an integrated nationwide telephone system. The goal, as Vail later phrased it, was "one policy, one system, universal service." "The strength of the Bell System," he wrote, "lies in this universality."

Vail's economic insight was remarkable for his day. He was managing a new kind of enterprise, one of the first of what we now call technological industries. He saw that technology gave birth to the telephone, and that technology also imposed new requirements on the managers of the business. Manufacturing telephones required a large commitment of capital, for specialized factories. Improving the telephone required coordination of research efforts, plus more capital for laboratories. Marketing the telephone successfully required reasonable assurance that supply and demand would keep pace with each other. Vail realized that the only way those requirements could be met was for management to plan every step of the enterprise, from sources of supply to customer orders.



Vail's ability to plan turned Bell's invention into the best telephone system in the world.

Contrast the case of the manager of a simpler business —a small bakery, for instance. The manager has great freedom. If cake doesn't sell, he can bake bread. If white bread doesn't sell, he can bake rye. There is no need to commit large sums of capital, since the same ovens serve for all three products. No research effort is required, since the recipes are well known. If the price of flour goes up, the manager can raise the price of bread immediately. If demand varies, he can bake more bread or

The predecessor of Bell Telephone Laboratories: the Bell company's Mechanical Department in the 1880's.

less. The technological industry, by its very nature, lacks such flexibility.

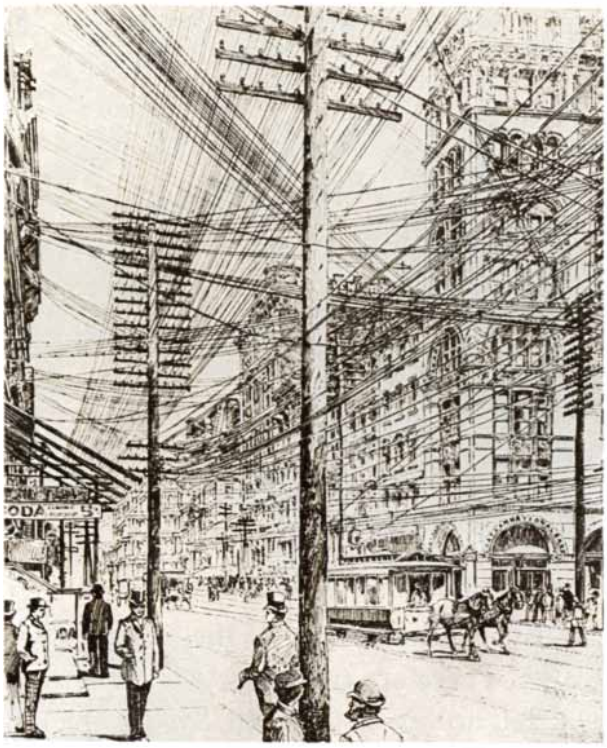
The first telephones were made in a Boston machine shop. Demand soon outstripped capacity, and firms in several cities were licensed to make sets under the Bell patents. Vail wanted closer integration of manufacture, to assure the company's service objectives. In 1881, the Bell company acquired controlling interest in the Western Electric Company of Chicago, and in 1882, made that company the manufacturer of Bell equipment.

This arrangement was desirable for a number of technical reasons: quality, reliability, standardization. Vail also had a strong managerial reason. The Bell company's business was providing telephone *service.* Success depended on having a dependable supply of quality equipment needed for the service, at a reasonable cost. By integrating manufacturing within the Bell company, Vail took a long step toward that goal.

At this point the groundwork was laid for a nationwide network. In 1884 the first Boston to New York line proved that commercial long distance telephony was possible—and profitable. Vail and his associates organized an additional company, whose corporate charter put Vail's dream in black and white. Its business was to be "constructing, buying, owning, leasing or otherwise obtaining, lines...and equipment, using, operating or otherwise maintaining, the same....The lines of this association...will connect one or more points in each and every city, town or place, in...the United States, Canada and Mexico, and also by cable and other appropriate means with the rest of the known world...."

Despite all the progress made, Vail saw a basic threat to the industry. Although it was growing, the quality of the service it provided was deteriorating. Some of the earliest equipment needed to be replaced. Rapid expansion was causing growing pains. Vail knew these service problems must be dealt with. But the Boston financiers who determined company policy felt their primary duty was to maximize profit for investors. The financiers represented the thinking of the day; once again Vail's ideas were decades ahead of his time. In 1887, Vail felt compelled to resign. For the next twenty years, he followed telephone developments as an interested outsider.

In 1893 and 1894, the Bell telephone patents expired. New telephone companies sprang up almost overnight, many of them in cities already served by Bell companies. Since the wires of the new companies did not connect with Bell wires, their subscribers could not talk with Bell subscribers. In order to be in touch with all the telephones in town, stores and offices had to have two telephones. That meant two directories, two sets of wires—and two bills. Nevertheless, demand for all telephones was soaring.



Broadway and John Street, New York City, 1890. Vail succeeded in getting the city's wires put underground.

The new companies grew, the Bell affiliated companies grew, the confusion grew.

Growth brought financial problems. Earnings, handsome as they were, were insufficient to finance such rapid expansion. (The telephone industry is a capital intensive industry.) Bell management borrowed more and more money from big banks. By 1907, lenders were getting hard to find. Then came the Panic of 1907. To protect their interests, the bankers demanded that telephone management invite Vail back to run things. Vail accepted the invitation. That year there were 3,132,000 Bell telephones in service.

Vail's return to command restored the financial community's confidence in the Bell company, so towering was the reputation he had built. Improving the quality of the service was his first concern. He made sure that concern was understood by Bell people throughout the land. Thanks to their efforts, and investment in needed equipment, service improved.

Further improvement depended on improving telephone technology. Research was going on in various parts of the company, in various cities. To encourage better planning and coordination, Vail unified the research effort. And he directed the researchers to examine at once a new device, the audion tube invented by Dr. Lee De Forest. Working with De Forest, telephone researchers developed the vacuum tube electronic amplifier, which greatly extended the range of long distance service, and led in time to commercial radio and television.

Duplicate telephone companies in various towns were incompatible with good service. Waterworks and electric companies were recognized as "public utilities," granted exclusive franchises for geographical areas. Vail believed that same reasoning applied to the telephone industry. He set out to eliminate the duplication by buying out the rival companies where that was possible, or selling out to them in some towns if that was the only way. In 1913, as a step toward universal service, he agreed to allow the independent (non-Bell) companies to use the Bell long distance lines.

Now Vail could speak confidently of a *telephone system* rather than a large number of isolated, unconnected telephone companies. He was the first to use the phrase "Bell System." He could look to the day when telephone service would be well within the means of the average American. And that gave him the final element in his planning: he could make long-range estimates of the needs of his customers.

The chain was complete: research and development, an efficient source of supply in the Western Electric Company and total responsibility for installation, maintenance and repair in the local companies.

Because Vail could plan in this way, the company could invest the necessary millions in equipment for current needs, and in research for predictable future growth.

The Bell System continues today in the pattern Vail set. Not as a matter of tradition, but because the concept works. We are planning today American telephone service for the 21st Century. Western Electric and the associated Bell Companies are installing new electronic switching systems nationwide, which make possible many additional telephone services. Scientists and engineers at Bell Laboratories, birthplace of the first electrical digital computer and the transistor, are working now on new technology to transmit telephone calls on a beam of light, to handle calling volumes expected by the year 2000.

Research, manufacturing, operations —one Bell System, a planned approach that works. Efficiency and productivity are well ahead of the average for all other

Electronic switching systems, a thousand times faster than the equipment they replace, are now being installed across the nation.

industries, the system is the best in the world. There are two tests you can make yourself to see if the Bell System really works: Compare telephone prices to the price of almost anything else over the past twenty-five years. Long distance service is one of the few things that have hardly gone up at all. Other telephone services have gone up far less than the price of almost anything else you buy. The economics of a planned telephone system have surely been to the customer's benefit. What about the service? Well, just pick up your telephone. Call any number in the United States.

The best telephone system in the world didn't just happen. It was planned that way.

One Bell System. It works.

Bell System

50 AND 100 YEARS AGO

SCIENTIFIC AMERICAN

DECEMBER, 1925: "During the past few months the leading scientific journals have contained several interesting articles concerning the remarkable similarity in effect on the human organism between natural light and ultra-violet light, as well as certain foods containing large amounts of vitamins. The evidence so far indicates that we are probably on the eve of the conquest of the deficiency disease known as rickets. Rickets seems to be primarily due not so much to a deficiency of the bone-forming calcium and phosphorus in the diet as to the inability of the body to make use of what is provided. It is now known that ultra-violet light has the effect of enabling the body to make use of the available bone-forming elements. What actually takes place when the radiation strikes our bodies is not wholly known as yet. Some scientists believe the light activates substances at the surface by a photochemical effect, like that which enables us to take photographs. By means of the blood those substances are later carried inward to the bones, enabling the bones to accumulate the necessary stiffening substances. Much valuable work has been done by Dr. Alfred F. Hess of Columbia University and Dr. H. Steenbock of the University of Wisconsin."

"What has science to say of the future, if by that word we signify a time so remote that even the life of a star is small in comparison? The physicist can tell us that the universe is 'running down,' for heat tends always to flow from the hotter to the colder body, and to escape by radiation from the surfaces of the stars, planets and all other bodies. Slowly, then, all things must cool down. However great their internal stores of energy, these must ultimately be depleted to the point of exhaustion, so that the final scene of the play shows only cold, dark bodies, frozen, rigid and lifeless, moving in their orbits in impenetrable darkness. Irreversibility is written wide and deep upon the face of nature. Most completely irreversible would appear to be the newly discovered process by which matter is turned into free energy. Thus not only is the stage in darkness and silence but also before the last gleams of light disappear the principal actors—the stars—have dwindled away to mere shrunken remnants of their old selves."

"In 1902 Sir Oliver Heaviside, an Englishman, and Professor Kennelly of Harvard suggested that an ionized region in the upper levels of the atmosphere might have an effect in wireless wave propagation. This section of the atmosphere has been referred to since that time as the 'Heaviside surface.' The Naval Research Laboratory, cooperating with the Carnegie Institution of Washington, recently confirmed the Heaviside-Kennelly theory. There are undoubtedly numerous strata rather than a single surface in the upper altitudes, and differing conditions of the ionized region affect various wavelengths differently. Secretary of the Navy Wilbur, in announcing the experiment, spoke of the region as 'a ceiling in the sky, at a varying distance above the surface of the earth, rising and falling as atmospheric conditions vary.' "

"Soon you may pick up your telephone and talk with a man in London as easily as if he were in the next street. What is more, you can do this at a cost of five dollars for three minutes."

SCIENTIFIC AMERICAN

DECEMBER, 1875: "The Brayton gas engine, a motor driven by the combustion of ordinary street gas mingled with air, and now quite well known to engineers, has been made the basis of another invention of somewhat similar nature, in which the motive power is furnished by burning a mixture of crude petroleum vapor and air. The oil engine bids fair to be a successful machine, and one of considerable utility to those who require light power but who wish to avoid the inconveniences of steam. An air pump compresses air into a small reservoir at the lower part of the machine. The air current passes to the cylinder and in suitable proportion mingles with the oil, which is introduced in the form of a spray. The mixture, by a small flame that is constantly maintained, becomes ignited, expands and so acts upon the piston."

"The world's military powers are contesting the question whether the vic-

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When you start your high fidelity system, start with the best. That's Pioneer. Experts agree that your initial choice should be the best model you can afford from a quality manufacturer —rather than a so-called "stereo" component with flashy but meaningless cosmetic touches.

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The Pioneer SX-434

*The value shown is for informational purposes only and includes a cabinet with walnut grained vinyl top and side panels. The actual resale price will be set by the individual Pioneer dealer at his option.

tories in future naval conflicts will be gained by the thickest armor or the heaviest guns. The result of this competition is a constant transition in the prevalent system of warfare. The naval engineers construct vessels with solid iron walls, some 24 inches thick, but hardly are the ships launched before a gun is produced by the artillerists capable of penetrating the armor at long range. Then follows a new vessel, succeeded by a yet more powerful gun, and so the duel continues, each side gaining the advantage in turn. The majority of the experiments, and very costly ones they are, are carried on in England. New ironclads are almost entirely of English construction. In the making of heavy guns, however, England is not alone, as Germany, through the great steel works of Krupp, enters the field as a rival. Krupp has recently announced the undertaking of a 124-tun cannon capable of piercing 23.8-inch armor at a range of seven and a half miles. The caliber of the gun is 14 inches, the weight of shot 1,212 pounds, the charge of powder from 110 to 130 pounds."

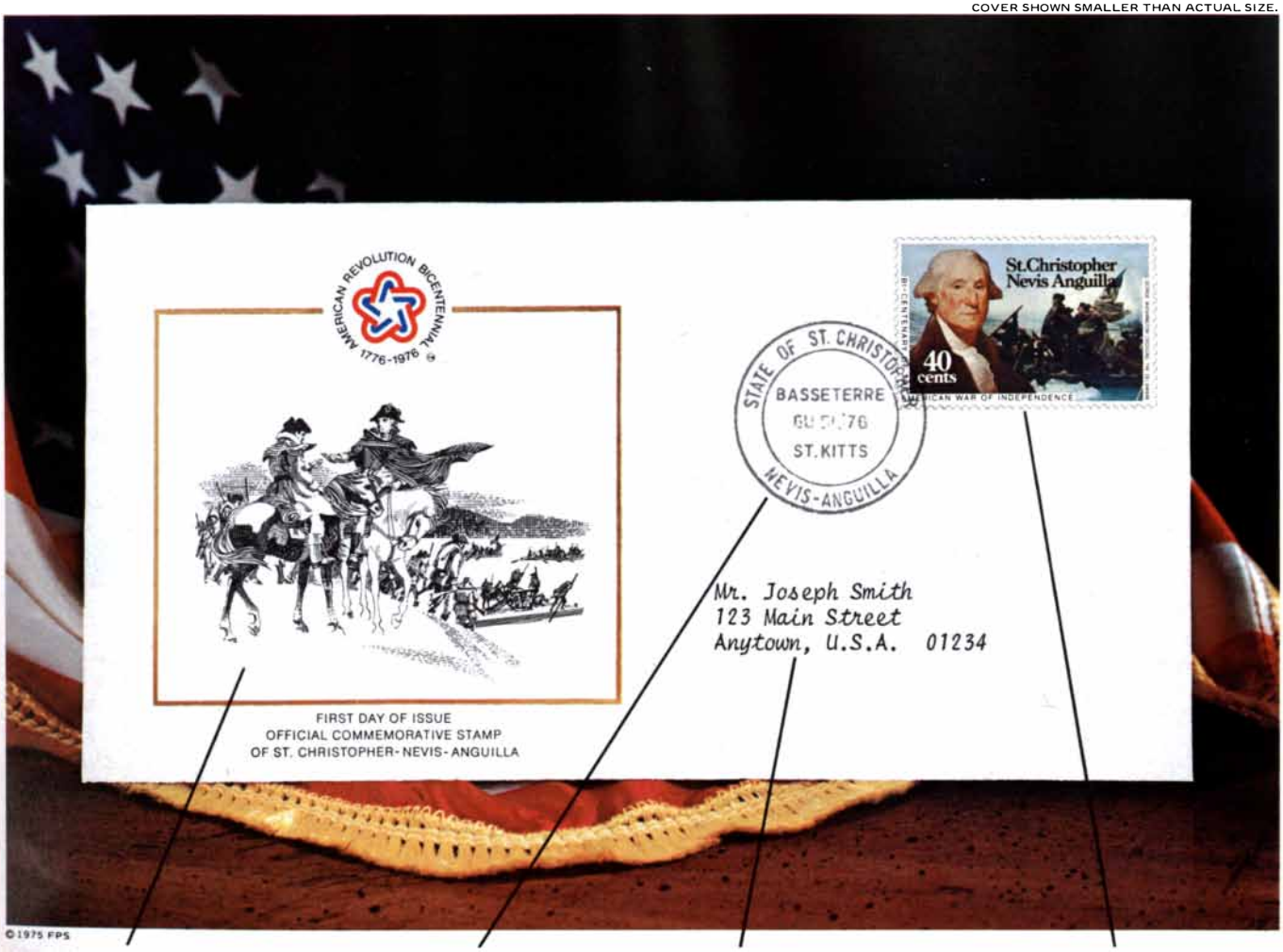
"Those who hold to the dogma of 'no life without antecedent life' are compelled to assume, at some point in the history of the Universe, the occurrence of nothing less than a miracle—that is to say, a phenomenon unknown to Science, and logically unsupposable from a truly scientific point of view. Life must have begun somewhere, once at least. If it was not a natural product of material conditions, its beginning must have marked a breach in that causal connection of events without which Science would be impossible. The weight of all experience is against the assumption of such a breach of continuity: in other words, against a miraculous origin of life. On the other hand, the weight of experience is equally against the assumption of a material condition absolutely unique in character. If life arose once in consequence of material conditions, Science affords no justification for the assertion that such conditions may not be repeated, possibly in our laboratories. This is substantially the position taken by Professor Tyndall in his latest discussion of matter and life. He states that the conclusion of Science, which recognizes an unbroken causal connection between the past and the present, must be that the phenomena of life evolved in the natural course of events, not by the miraculous addition of a new force but by means of the forces already in play."

The American Revolution Bicentennial Administration
established under the laws of the United States
announces the issuance of

The American Revolution Bicentennial First Day Cover Collection

AN INTERNATIONAL COLLECTION OF OFFICIAL BICENTENNIAL
COMMEMORATIVE STAMPS ISSUED ON LIMITED EDITION FIRST DAY COVERS
BY THE FRANKLIN PHILATELIC SOCIETY

COVER SHOWN SMALLER THAN ACTUAL SIZE.



INDIVIDUALLY-DESIGNED CACHET. An original engraved design that complements and enhances the theme of the accompanying stamp.

FIRST DAY OF ISSUE CANCELLATION. Establishes that the cover has been officially postmarked *First Day of Issue* in the nation issuing the Bicentennial stamp.

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OFFICIAL BICENTENNIAL STAMP. The most significant stamp or stamps issued by each nation during 1976 to honor America's Bicentennial.

A strictly limited edition.
Available by advance subscription only.
Subscription deadline: December 31, 1975.

IN 1976, nations in every part of the world will honor the United States of America by issuing *official commemorative stamps* to mark the Bicentennial of American Independence.

This is an unprecedented tribute. A tribute not only to the people of the United States, but to the inspiration which our heritage of freedom has provided to those in other lands.

To bring these historic international stamp issues to all Americans, *an extraordinary world-wide collection of First Day Covers* will be issued—each cover bearing an official Bicentennial commemorative stamp. The collection will be an officially recognized commemorative of the American Revolution Bicentennial Administration—and the *only* international collection of First Day Covers which has been so recognized.

Postmarked throughout the world

The collection will contain individual covers representing *every* nation that issues commemorative stamps to honor our Bicentennial during 1976. There are approximately 40 nations which are planning to issue such stamps. They include Great Britain, France, Mexico, West Germany, Ireland, Denmark, India, Western Samoa, Israel, Monaco, Canada and Italy.

The stamps themselves will be both interesting and educational—and each will be *the most significant Bicentennial stamp issue* of the nation it represents. Each cover will bear the official *First Day of Issue* cancellation for the stamp—and will be *postmarked in the country of issue,* at the *official post office of first issue.* As astute collectors know, this First Day of Issue cancellation is extremely important, since it officially establishes the philatelic significance of the First Day Cover.

Moreover, each cover will include an *original engraved design* that complements and enhances the specific theme of the stamp it carries. And every cover will be *individually personalized* with the name and address of the subscriber, if desired.

In addition, each First Day Cover will bear the *Official Symbol of the United States of America's 200th Anniversary*—and a Certificate of Authenticity from the Administrator of the American Revolution Bicentennial Administration, attesting to its official status.

A single limited edition

These historic First Day Covers will be available as a *complete collection only* —exclusively for advance subscribers. There is a limit of one collection per subscriber, and the total edition of *each* cover will be permanently limited to the *exact* number of valid subscriptions entered by the deadline date of December 31, 1975.

Custom designed collector's album

Each First Day Cover will be accompanied by a handsomely illustrated *display page,* which will provide important information about the featured Bicentennial stamp and the issuing nation.

To protect and display the complete set of First Day Covers, each subscriber will receive a custom designed album as part of his collection.

No advance payment required

Subscribers will receive their First Day Covers at the rate of four per month, beginning in early 1976. The price of each cover will be just $2.75—and this includes the Bicentennial stamp, the complete international first day cover service, individual display pages and personalization. *No advance payment is required;* subscribers will be billed with shipment. The custom designed album will be provided to each subscriber *at no additional charge.*

Subscription deadline: December 31, 1975

As an historic international tribute to our nation's 200th anniversary—and as an officially recognized commemorative of the American Revolution Bicentennial Administration—this collection will be a prized family heirloom to pass along to future generations.

But this is *the only time* that The American Revolution Bicentennial First Day Cover Collection will ever be offered. All subscriptions must be postmarked by December 31, 1975, to be accepted. The Franklin Philatelic Society, the international stamp division of The Franklin Mint, will handle the processing of all subscriptions and shipment of the First Day Covers. Your application should, therefore, be mailed directly to The Franklin Philatelic Society, Franklin Center, Pennsylvania 19091, *by December 31, 1975.*

Custom designed album provided with each collection.

OFFICIAL SYMBOL
OF THE UNITED STATES OF AMERICA'S
200TH ANNIVERSARY

This official symbol will appear on each First Day Cover. *The American Revolution Bicentennial First Day Cover Collection* is an officially recognized commemorative of the American Revolution Bicentennial Administration, #76-19-0574, authorized by Public Law 93-179 of the Congress of the United States, to facilitate and coordinate the events and activities of national and international significance in commemoration of the 200th anniversary of the United States.

OFFICIAL APPLICATION

The American Revolution Bicentennial First Day Cover Collection

Valid only if postmarked by December 31, 1975
Limit: One subscription per person

The Franklin Philatelic Society
Franklin Center, Pennsylvania 19091

Please accept my subscription for the complete collection of the American Revolution Bicentennial First Day Covers, to be sent to me at the rate of 4 per month beginning in early 1976. I understand that the price is $2.75* per cover and that a custom-designed album to hold the complete collection will be sent to me separately at no additional charge.

I need send no money now. I will be billed for my covers as they are issued.

**Plus my state sales tax*

Mr.
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All orders are subject to acceptance.

Your covers will be personalized exactly as indicated above. If you wish a different personalization, print the name and address you wish in block letters on a separate piece of paper and enclose it with this form.

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'76 Monza Towne Coupe by Chevrolet. Our newest model. Our lowest price ever.

Monza Towne Coupe

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When a small car is as nice as a Monza, it isn't easy to make it even nicer.

But we did.

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$3358.85. (Manufacturer's Suggested Retail Price, including dealer new vehicle preparation charge. Destination charge, available equipment like the $32 white stripe tires on the Towne Coupe above, state and local taxes are additional.)

And what a *lot* of small car this newest Monza is for the price!

Its Monza-long list of standard equipment includes a torque-arm rear suspension, body-contoured bucket seats, sill-to-sill cut-pile carpeting, sporty cloth upholstery, full wheel covers, an interior-quieting package and a new Delco Freedom battery under its hood—called that because it's filled for life at the factory.

Plus, check your Chevy dealer about our Dura-Built 2.3 Litre 4-cylinder engine guarantee. (While you're also checking Monza's EPA mileage figures.)

If you're thinking about a new small car this year, why not get a lot of small car? It's easy.

A Chevy Monza.

Chevrolet

THE AUTHORS

GENEVIEVE ATWOOD ("The Strip-mining of Western Coal") is a geologist on the staff of Ford, Bacon and Davis Utah Inc., an engineering firm based in Salt Lake City. She is also a member of the Utah House of Representatives. A 1968 graduate of Bryn Mawr College, where she majored in the history of science, she went on to study geology at Wesleyan University, acquiring her M.A. in 1973. After working for a time as a consultant to the Environment Committee of the Connecticut General Assembly, she joined the staff of the National Academy of Sciences / National Academy of Engineering, where she directed a number of studies pertaining to energy, materials and the environment. She left this post in 1974 to return to her former home state of Utah and run for the legislature; since being elected last fall she has been the chief sponsor of Utah's first strip-mining legislation, which was passed last session. Her outside interests include tennis: she was Utah Junior Champion in 1962 and was nationally ranked from 1961 to 1965.

SALVADOR E. LURIA ("Colicins and the Energetics of Cell Membranes") is Institute Professor and director of the Center for Cancer Research at the Massachusetts Institute of Technology. Born in Italy, Luria was originally trained in medicine, receiving his M.D. from the University of Turin in 1935. After coming to this country in 1940 as a war refugee he taught and did research for a number of years at several American universities, including Indiana University and the University of Illinois, before joining the faculty at M.I.T. in 1959. In 1969 he shared the Nobel prize for physiology or medicine with Max Delbrück and Alfred D. Hershey for "their discoveries concerning the replication mechanism and genetic structure of viruses."

PHILIP A. CHARLES and J. LEONARD CULHANE ("X Rays from Supernova Remnants") are at the Mullard Space Science Laboratory of University College London, where Charles is a graduate student and Culhane is lecturer in physics. Charles obtained his B.S. in astronomy at University College London in 1972. In addition to his work in X-ray astronomy, he reports, he is "particularly keen on soccer, cricket (an English summer sport), gliding, squash and the violin." Culhane holds a B.Sc. and an M.Sc., both in physics, from University College Dublin and a Ph.D. in X-ray astronomy from University College London. He is currently project scientist for the Science Research Council's UK-6 High Energy Astrophysics Satellite and was recently appointed deputy director of the Mullard Space Science Laboratory.

DAVID LAYZER ("The Arrow of Time") is professor of astronomy at Harvard University, where he received his A.B. in mathematics in 1947 and his Ph.D. in theoretical astrophysics in 1950. He writes: "As a graduate student and for several years thereafter I specialized in theoretical atomic physics. Cosmogony started as a side interest but has gradually become my major professional preoccupation. I have also published a number of theoretical papers on the physics of the earth's upper atmosphere. At the moment I am working on solar magnetism and related questions, as well as on problems connected with the origin of astronomical systems. I am also interested in the philosophy of nature, and I have developed a general education course at Harvard, called 'Space, Time and Motion,' that seeks to give a unified account of the logical, mathematical, physical, astronomical, biological and psychological aspects of its subject matter."

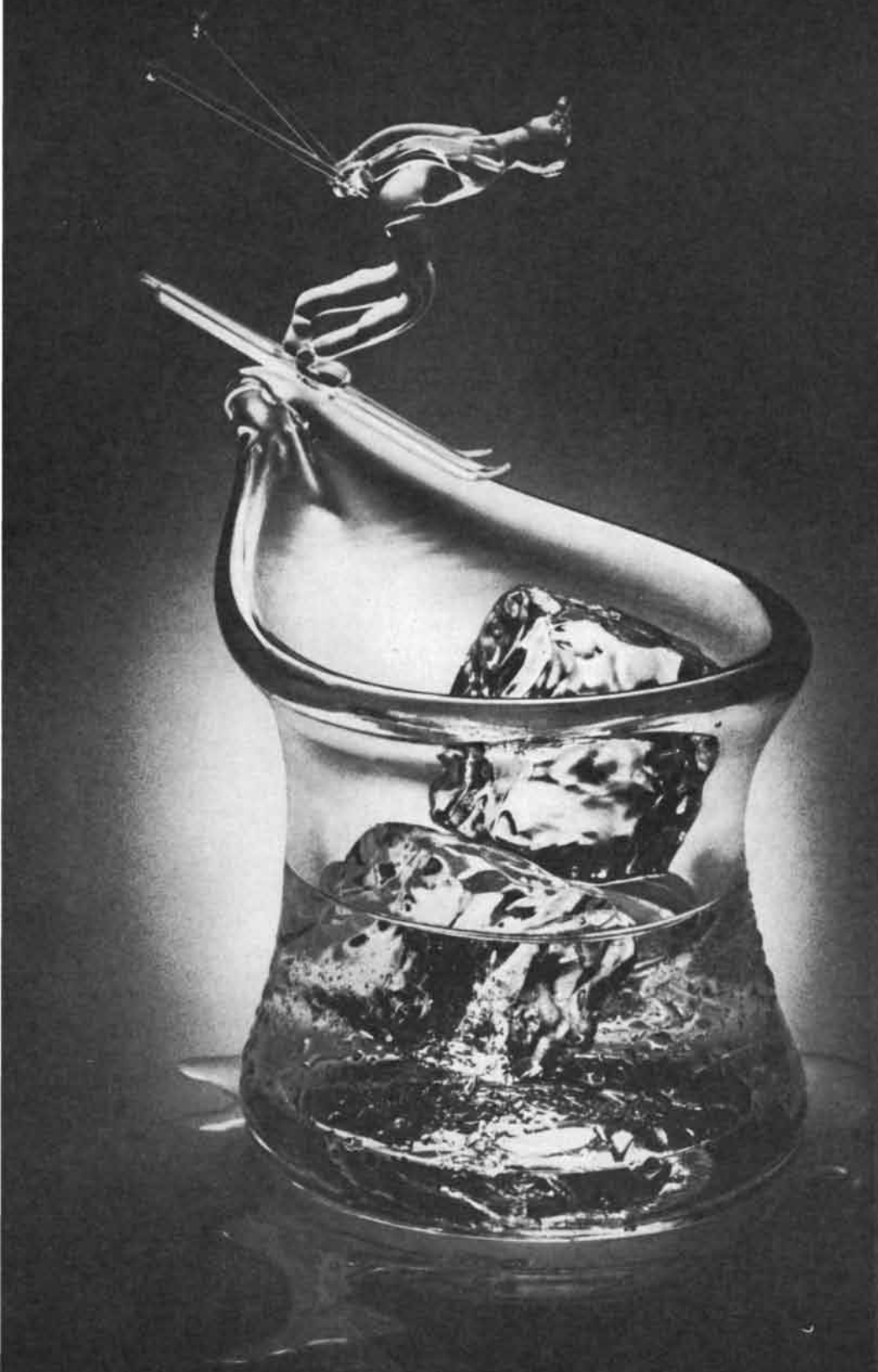
RUTH VAN HEYNINGEN ("What Happens to the Human Lens in Cataract") is a researcher in the Nuffield Laboratory of Ophthalmology at the University of Oxford, where she is a founding fellow of St. Cross College, a new graduate college. A native of South Wales (her surname before marriage was Treverton), she studied biochemistry at the University of Cambridge, conducting her first research work there during World War II on the effect of poison gases on enzyme systems. She has worked at the Nuffield Laboratory for 25 years—"almost always on some aspect of cataract." She is married to W. E. van Heyningen, who wrote the article titled "Tetanus" for the April 1968 issue of SCIENTIFIC AMERICAN.

WENDY JAMES ("Sister-Exchange Marriage") teaches social anthropology at the University of Oxford, where she is also a fellow of St. Cross College. On completing her undergraduate studies in geography at St. Hugh's College, Oxford, in 1962, she turned to anthropology, obtaining a second bachelor's degree in 1964 for her thesis on animal symbolism in East Africa. She then took a post as lecturer in social anthropology at the University of Khartoum, a situation that gave her an opportunity to carry out fieldwork among the Uduk people in the Blue Nile province of the Sudan. She returned to Oxford in 1969 as Leverhulme Research Fellow at St. Hugh's College and the following year was awarded a D.Phil. for her thesis on Uduk social organization. Concerning the subject of her article she writes: "I should like to say that the field research would not have been possible without the friendship and help of Shadrach Peyko Dhunya and William Danga in the Sudan and James Owaro and Gali Sambato in Ethiopia."

D. R. UHLMANN and A. G. KOLBECK ("The Microstructure of Polymeric Materials") began their association at the Massachusetts Institute of Technology, where Uhlmann is professor of polymers and ceramics and where Kolbeck did his undergraduate and graduate work in materials science and engineering. Uhlmann was educated at Yale University (B.S., physics, 1958) and Harvard University (Ph.D., applied physics, 1963). In addition to his research on the processing of polymers he reports that he is "actively exploring the conditions under which glasses can be formed, the growth of crystals in glass-forming systems, the conversion of polyacrylonitrile to carbon and the solidification processing of composite materials." Kolbeck, who earned a Ph.D. from M.I.T. for his work on polymeric materials, is currently employed by GTE Laboratories, where he conducts research on high-temperature oxide glasses.

HOWARD E. EVANS and ROBERT W. MATTHEWS ("The Sand Wasps of Australia") are entomologists with a common interest in wasps. Evans, professor of entomology at Colorado State University, was graduated from the University of Connecticut in 1940 and went on to obtain his Ph.D. from Cornell University in 1949. He taught at Cornell for several years before moving to Harvard University's Museum of Comparative Zoology in 1960. Since he arrived in Colorado two years ago, he says, he and his family, "when not otherwise occupied, enjoy backpacking and fishing in Colorado's high country." Matthews is associate professor of entomology at the University of Georgia. A graduate of Michigan State University, he received his Ph.D. from Harvard University in 1969. His current research, he reports, "deals with the social behavior of yellowjackets and the behavior of parasitic Hymenoptera."

You can tell a lot about an individual by what he pours into his glass.



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The "Skier" glass created for the Bushmills Collection by Henry Halem

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Established 1845 SCIENTIFIC AMERICAN December 1975 Volume 233 Number 6

The Strip-mining of Western Coal

If the U.S. is to become self-sufficient in energy terms, it will have to take huge amounts of coal from the thick shallow deposits of the Western states. Can it be done without despoiling the land?

by Genevieve Atwood

The availability of low-cost natural resources within the U.S. has been a major contributing factor to the country's economic and social growth. With oil and gas no longer plentiful, coal has become the mainstay of Project Independence: the effort to make the U.S. self-sufficient in energy terms. The coal industry is hoping to increase production from the 1974 level of 603 million tons to 1.3 billion tons by 1980 and to 2.1 billion tons by 1985. Since a ton of coal has the approximate heating value of four and a half barrels of oil, such an achievement would substitute coal for billions of barrels of oil.

Although people in the coal industry are delighted by the prospect, they are concerned that it may prove to be just another "boom and bust" cycle of the kind that has characterized the industry's history. Prosperity in the coalfields has never been predictable, since it fluctuates according to the availability of other fuels and the development of new energy technologies. There are currently no real alternatives to oil, gas and coal as energy sources; a large-scale role for such sources as oil shale, nuclear energy, geothermal and solar energy is a long way off, and many such sources are subject to attack by environmentalists. Just as steel has had its ups and downs in the market but has never been replaced, so coal may become essential to the U.S. economy.

Thus it seems almost certain that the country will turn increasingly to the vast coal deposits of the Western states, where 150,000 square miles of land are underlain by an estimated 2.9 trillion tons of coal. These deposits constitute 72 percent of the country's identified and hypothetical coal resources. Two distinctive things about minable Western coal reserves (198 billion tons) are that most of the coal has a low sulfur content and that a good deal of it (43 percent, or 86 billion tons, underlying 24,000 square miles) is close enough to the surface for strip-mining, in which the overburden is removed and coal is excavated from an open trench. Strip-mining in the West and in other parts of the country, however, has proved to have catastrophic effects on the land. The questions that arise are: Can the land be restored to its original capacity? If it can be, at what cost? Should the cost be borne by the public that needs the fuel or be covered by the mine operator and incorporated in the cost of the coal? Interested citizens and mine operators in the Western states with large deposits of coal accessible to strip-mining are actively debating these questions.

The amount of coal mined in the Western states (Montana, North Dakota, Wyoming, Utah, Colorado, Arizona and New Mexico) has increased substantially in recent years. The increase, from 75,000 tons per mine in 1961 to an average of a million tons in 1972, was brought about by the escalating market for low-sulfur coal and made possible by advances in mining technology.

Although the production of Western coal has risen sharply, the number of mines operating at any one time has remained fairly constant. Whereas in the past 40 years the number of operating strip mines in the Appalachian region of the East increased from 29 to 2,089, the number of strip mines in the West has remained at about 50 at any given time. Fewer than 35 of those mines account for more than 90 percent of Western coal production. Most Western strip mines are new: three-fourths of the area's tonnage comes from mines that are less than 10 years old.

Each mine has its special characteristics, but most of the mines follow the same six-step mining process. First, scrapers remove the topsoil and other unconsolidated material and put it on spoil piles. Second, the consolidated strata overlying the coal are drilled and blasted. Third, this overburden is removed by a huge dragline or power shovel. Fourth, the coal is drilled and blasted. Fifth, it is loaded into trucks. In the final step the spoil piles are graded by bulldozers.

In the East and the Middle West, where strip mines occupy areas smaller than those of the Western mines, the mining machinery tends to be smaller and more versatile. In the large Western mines the machines are of heroic size. The major workhorse is the dragline, which is employed to remove the overburden and put it in the pit opened

by previous mining. The largest dragline now in operation stands more than 300 feet high and weighs 13,000 tons.

Nonetheless, the dragline is the limiting factor in coal production. In most Western mines these machines work full time, whereas the machines used for loading, hauling and reclamation work part time. Production can be increased only by increasing the rate of removing overburden. Bigger machines are not the answer; some draglines are already so large and heavy that the ground can barely support them as they move on to the next cut.

The trend from underground mining to surface mining has resulted in an enormous increase in productivity. The output per man-hour at a strip mine is approximately eight times the output at a fairly modern underground mine. The same trend has affected the geographic distribution of coal production in the Western states. From 1950 to 1967 Utah was the leading producer of coal west of the Mississippi, with an output of from four to five million tons per year from underground mines. In 1961 Utah International, Inc., opened the first big strip mine, the Navajo Mine in New Mexico. The production capacity of that mine alone is more than seven million tons per year. As a result of the trend toward strip-mining, Utah, where production is from underground mines only, has slipped almost to the bottom of the list of Western coal-producing states. First place has been taken over by Wyoming, where several huge strip mines are in operation.

In Wyoming, Montana and much of the northern Great Plains the conditions for surface mining approach the ideal. Coal seams from 50 to 75 feet thick, with an overburden of a mere 30 to 40 feet, are common. In Eastern and Middle Western mines a 10-foot seam is regarded as being exceptionally thick. There is also more overburden at those mines; at one mine in Oklahoma 95 feet of material must be removed to reach an 18-inch seam of coal.

The level of coal production from Western mines is expected to rise steeply in the near future. In Montana alone it is foreseen that 50 million tons of coal per year will be taken from five large mines by the early 1980's. Burlington Northern, Inc., expects to be hauling 90 million tons of coal per year out of the area by the same time. Plans are under consideration for thousands of miles of slurry pipelines to move millions of tons of coal per year across the country: from Wyoming to Arkansas, Montana to Washington, Wyoming to the Great Lakes and Utah to Nevada.

Although the projections for coal production in the West have virtually no ceiling, the current fraction of the nation's energy supplied by coal has risen only slightly (from 17.6 percent in 1973 to 17.8 percent in 1974). Total coal production rose only 1.4 percent (to about 603 million tons) from 1973 to 1974. Even the present low rate of coal production has subjected Western strip-mining to environmental constraints; sharp increases in production can only result in the multiplication of such constraints. Among the principal environmental concerns, of course, is whether or not Western land disturbed by strip-mining can be restored to something approximating its original condition.

Even though each mine site is different from all the others, a few generalizations can be made about the physical characteristics of Western mines and their potential for reclamation. Part of what can be said about reclamation is based on academic research and part on what the surface-mining industry has done (intermittently for 30 years and quite vigorously for the past five years) toward reclaiming mined land.

Geology and climate have the most significant bearing on a site's potential for reclamation. On the basis of their complex geological history the Western coal lands can be divided into two provinces: the Rocky Mountain province and the northern Great Plains province. The Rocky Mountain province includes the coal lands of the cordillera from Idaho to New Mexico, which lie between forested, granite-cored mountain ranges in broad basins that are comparatively flat but have been dissected by streambeds. The basins are covered by grasses and other dry-environment plants, shrubs and trees. The southwestern section is generally drier than the rest of the province, and the slopes of its mountains are less rugged and less forested than those in Utah, Idaho and Colorado.

The coal laid down in the Rocky Mountain province originated some 100 million years ago in the Cretaceous period. During later epochs of mountain building, forces that compressed the deposits and drove out volatile components upgraded some of the deposits from lignite to bituminous coal. After several million years coal swamps once again formed in the area on the flatlands between emerging highlands. Eventually material eroded from the highlands covered those coal deposits with thick layers of sediment.

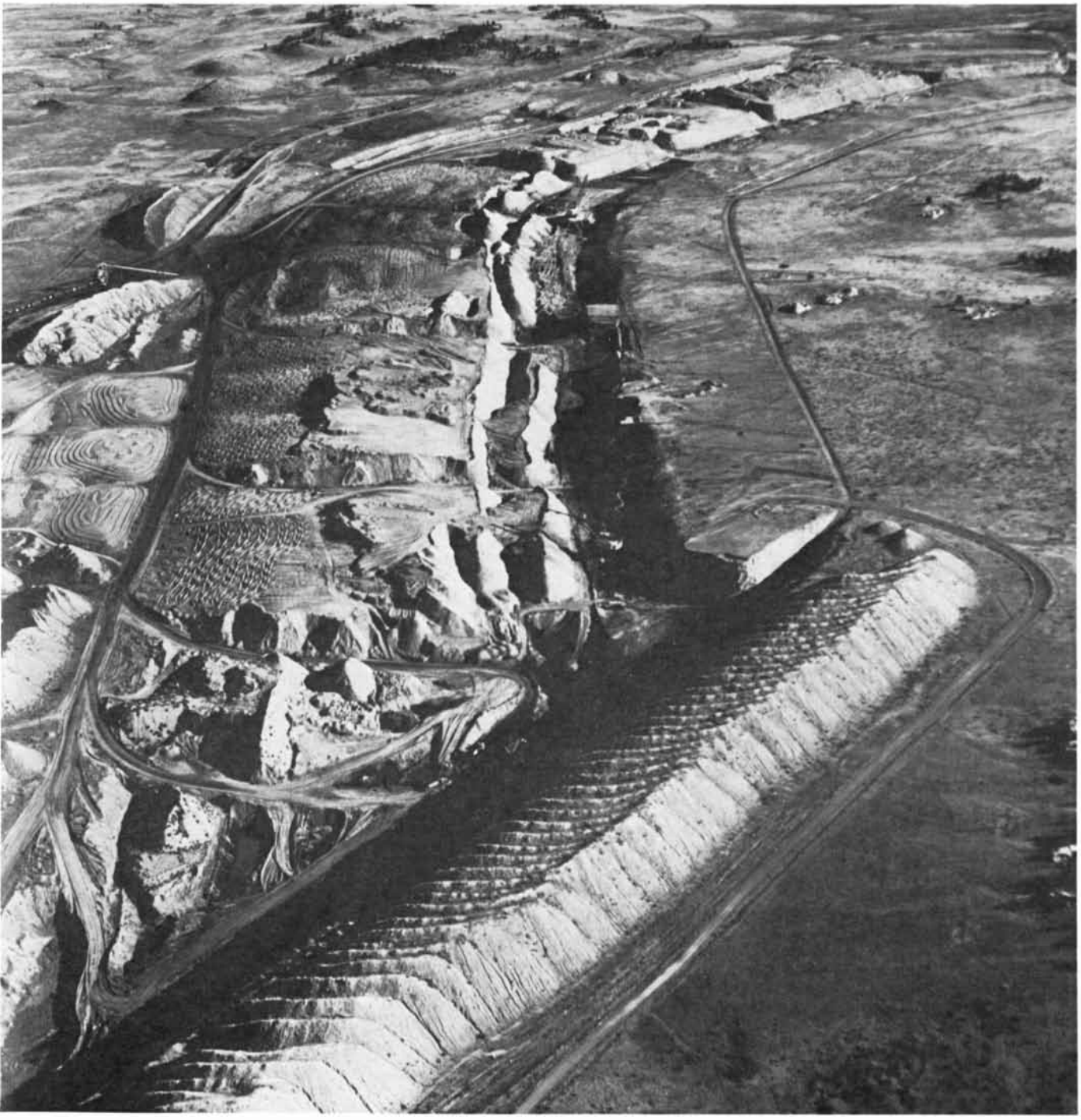
The northern Great Plains province adjoins the Rocky Mountain province. During Paleocene time, some 65 million years ago, extensive beds of lignite were laid down over vast swampy areas. The mountains were low, and moisture-bearing winds from the west reached far into the interior of the continent. As the Rockies continued to be uplifted the winds were gradually cut off and the

STRIP COAL MINE is operated by the Western Energy Co. at Colstrip in southeastern Montana. The prominent ribbed ridge at lower right is a spoil pile made up of ma-

swamps gave way to grasslands. Today coal underlies thousands of square miles of basins covered at lower elevations by mixed-grass prairies and at higher ones by ponderosa pine.

Since Western coals formed under such a variety of geological conditions, they include all grades of coal (the main grades are lignite, subbituminous coal, bituminous coal and anthracite). They are buried under a variety of overburden materials and call for different techniques of both mining and reclamation. Much of the coal underlying several large structural basins is accessible only to underground mining and will not be discussed here. In the current state of the technology the coal has to be within about 225 feet of the surface to be accessible to strip-mining methods.

The present climate of the Western coal lands is arid or semiarid. The annual mean precipitation is low, ranging from four inches or less in the Four Corners area (where the boundaries of Utah, Colorado, Arizona and New Mexico meet) to 20 inches or more in some of

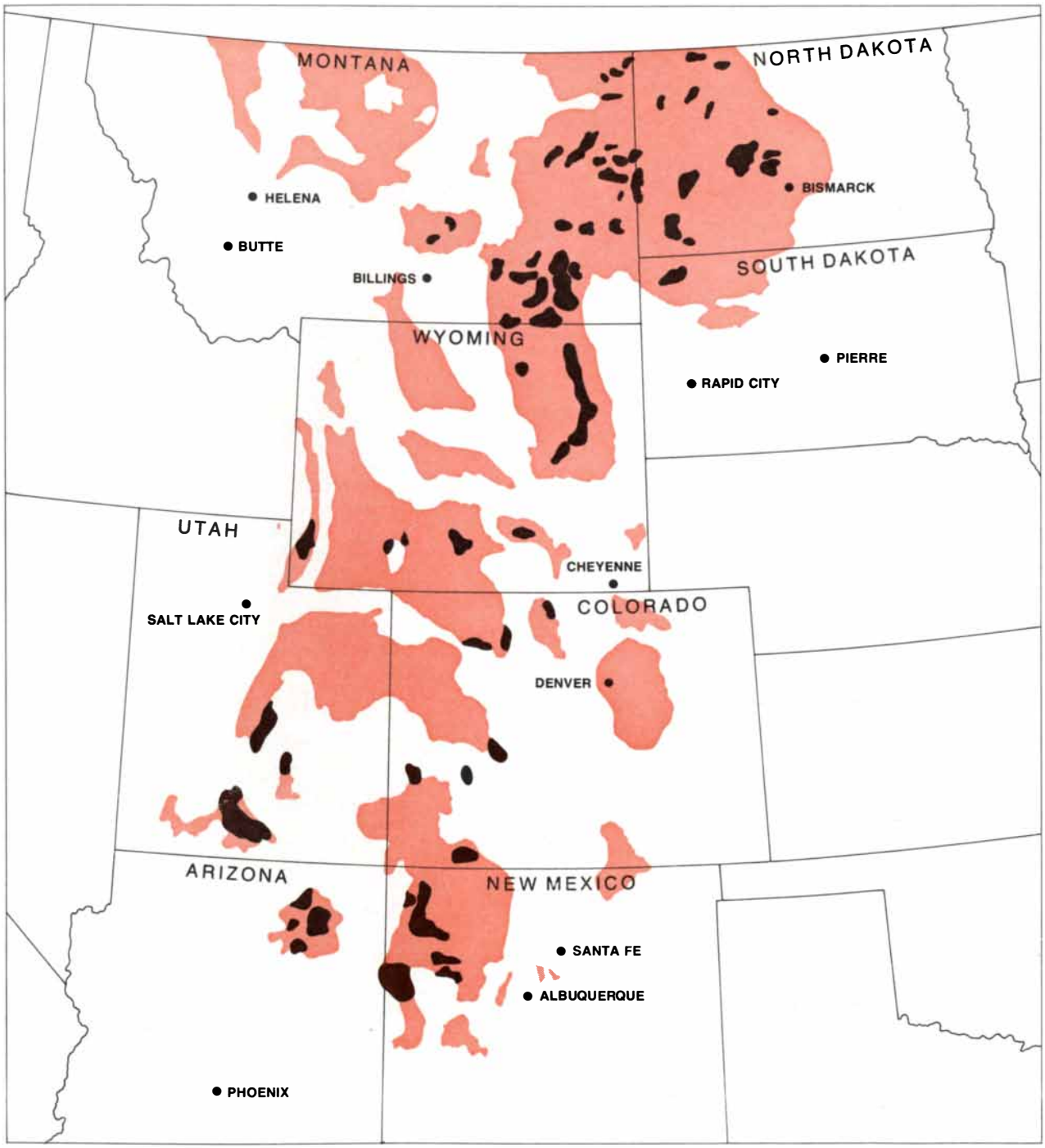


terial that lay over the seam of coal. The conspicuous rills are caused by erosion. Where the trench running toward the top of the photograph bends to the right, a dragline is removing overburden from the coal seam. In the trench a large shovel loads coal into hauling trucks. Running diagonally at left center is a railroad where coal cars are being loaded through a conveyor and a hopper. In the area below the hopper are several old piles of spoil that have been graded as a preliminary step in the reclamation process.

the Colorado coalfields. Droughts are common, and when precipitation does occur, it may come as a cloudburst. The temperature in summer reaches levels that desiccate seedling plants, so that only the hardiest organisms, tolerant to both summer heat and winter cold, survive.

The soils at arid and semiarid Western sites are poorly developed. Rocks weather slowly, and what sparse vegetation there is adds little organic matter to the soil. Only terrain where glaciers have deposited material has a supply of soil that is more than barely adequate for reclamation. Wind, unimpeded by vegetation, dries the soil and drives sand and soil before it, killing tender plants. The rates of erosion are among the highest in North America.

Under such conditions natural processes are slow. It might take decades or centuries for a disturbed site in a desert to be restored without assistance. Indeed, no successful reclamation after stripping has yet been achieved at any of the more arid sites, although considerable success has been achieved in parts of Colorado and in the more favorable conditions of the semiarid northern Great Plains. Fortunately glaciated and semiarid conditions are more typical of areas where the largest increases in the sur-

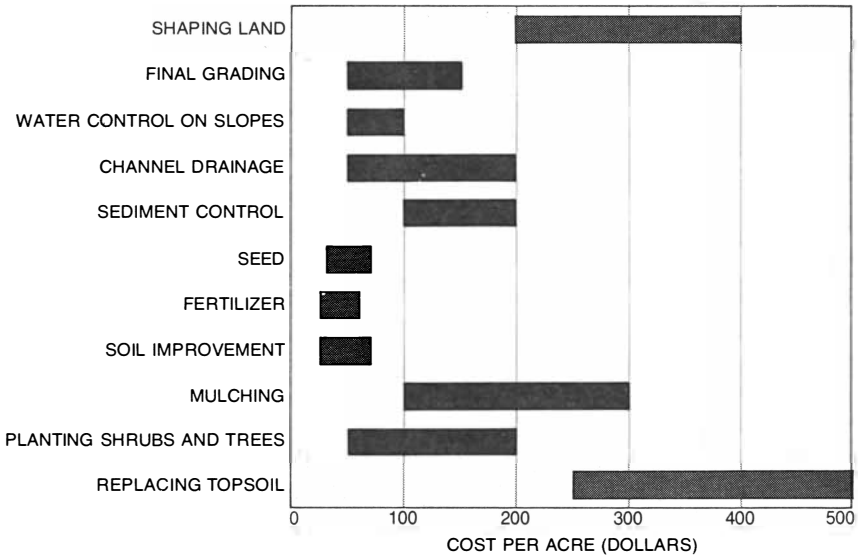


LOCATION OF RESERVES of Western coal is indicated. The parts of the map in color indicate the areas in the region that have major reserves of coal. The areas where the coal is close enough to the surface to be accessible by strip-mining are indicated in black.

face production of coal can be expected.

On the northern Great Plains rainfall ranges between 12 and 16 inches per year; the terrain is gently rolling; the overburden consists of alkaline shales and sandstones, and most of the land is grazed. Reclamation can be successful at most of these sites if enough planning, management, money and time are put into it. The prerequisites to successful reclamation include stability of the site, a nontoxic soil medium capable of holding moisture, proper plant-seeding techniques (which generally require slopes that can be traversed by farm machinery), occasional supplementary water and adequate management of grazing animals.

In the Appalachian region much of the damage has been done by water; the land has been scarred by acid drainage, instability of slopes, erosion and sedimentation. Water is scarce in most of the West, where the most difficult reclamation problems are revegetation and the maintenance of the hydrologic conditions in and around the mine site. Let us examine more closely how strip-mining can give rise to such problems.



COST OF RECLAMATION of Western land where coal has been removed by strip-mining is given as a range of estimates. The figures cover the direct cost of reclamation and are based on data in a report prepared by the National Academy of Sciences for the Ford Foundation. Cost estimates made by mining companies range from $500 to $5,000 per acre.

Nearly all the Western lands underlain by coal can be classified according to some productive purpose and are capable of serving a range of uses: grazing, farming, recreation, watershed management or wildlife management. Surface mining without reclamation removes the land forever from productive use; such land can best be classified as a national sacrifice area. With successful reclamation, however, surface mining can become just one of a series of land uses that merely interrupt a current use and then return the land to an equivalent potential productivity or an even higher one.

Before 1950 most surface mines in the West (for all minerals, not just coal) operated according to the unwritten principle that the mined land would be treated as a sacrifice area. Today some states have strict regulations requiring reclamation. The regulations are not uniform, and they are not uniformly enforced. Moreover, none of them has been in effect for more than five years. Accordingly it cannot yet be determined whether the reclamation efforts made so far have either succeeded or failed.

Mining an area for coal must always disturb the land to some extent, but detrimental changes in topography brought about by mining can be remedied in most areas by employing earth-moving machines to grade and reshape the spoil. The Four Corners region may prove to be an unfortunate exception. The mesa topography of the area has largely been created by flash floods that have cut gullies through layers that are otherwise resistant to erosion. Mining operations involving blasting and the overturning of strata leave a fairly homogeneous nonresistant material. This material is subject to rapid erosion, and if the erosion is widespread, badlands will be formed. In any event the material cannot give rise to the mesa topography that was displaced.

Strip-mining usually buries topsoil under subsurface unconsolidated material. Natural processes will not soon regenerate such soils. Although certain soil characteristics can be artificially created, some mine operators have found it cheaper simply to segregate the topsoil during strip-mining operations. Then when the coal has been removed and the other overburden has been put back, the original topsoil can be spread over it. In a semiarid area reclamation is virtually impossible unless the ground is covered with a nontoxic material capable of holding water.

The changes in surface material brought about by strip-mining may result in changes in vegetation that are in themselves detrimental to the productive capacity of the land. Even in relatively nonproductive regions the impact can be heavy. For example, halogeton, a toxic weed, is among the first and most tenacious plants to revegetate disturbed desert land, to the dismay of ranchers. In more productive areas much can be done to restore or even to enhance the productivity of mined areas by irrigating them. That, however, calls for a long-term commitment to land management that many mining companies are unwilling or unable to make.

Water, in fact, is the key to reclamation in the West. Mined areas, unlike those in the Appalachians, cannot be regarded as having been reclaimed when they have simply been reshaped and revegetated. Their hydrologic function must also be restored. In areas where productive activities, such as ranching, depend on a barely adequate supply of water, any disturbance of that supply can be critical.

The hydrologic measures normally taken after mining can usually reduce such surface-water problems as erosion, sedimentation, silting, ponding and changes in the quality of the water. A variety of techniques for handling material, impounding water and treating water (developed at Appalachian and Middle Western mines and at a strip mine in Washington) can be applied in Western mines. After mining, surface water usually infiltrates the spoil material rapidly, which tends to promote revegetation and the recharge of aquifers. If a soil material has not been successfully established over the spoil, however, a layer of hardpan can form. Then the surface runoff increases, quite likely giving rise to undercutting and the erosion of gullies downstream. Such effects are almost always irreversible. They are similar to the widespread damage to streambeds caused at the turn

STRIP-MINING OPERATION is shown at the Peabody Coal Company's Black Mesa Mine in Arizona. At top a dragline removes overburden from the coal seam. The seam is visible in the trench below the dragline, as are two large trucks that haul the coal out of the trench. At bottom center is a drilling machine employed to prepare the overburden for blasting.

REMOVAL OF COAL proceeds at the Black Mesa Mine. At left a large power shovel digs coal from the seam and stands by to load it into a haulage truck. The rock wall with the drilling machine at its lip (*far right*) is the overburden that must be removed from coal.

of the century by the excessive runoff brought on by overgrazing.

Changes in the quality of the surface water caused by the mining operation can be controlled by treatment at the site. Subtler and more serious are the consequences of leaching and the mechanical erosion of the highly alkaline overburden. An excess of dissolved salts, a high content of trace metals and an increased load of sediment are the commonest symptoms. Although such effects may not be detected at first, they can eventually cause the groundwater to become contaminated.

Groundwater can also be contaminated by the percolation of water through the spoil, the residue of chemicals used in the mining process, the mixing of groundwater layers during the mining cycle and the seepage of low-quality groundwater from one stratum to another. Effects of this kind, which are difficult to prevent and almost impossible to reverse, may not be detected for decades. The groundwater at Colstrip, Mont., is only now being found to have been contaminated by mining operations of 50 years ago.

Pumping water out of a mine so that the mining itself can proceed often gives rise to another set of problems. The water table in the vicinity of the mine is drawn down and thereby lowers the water level in nearby wells. In Gilette, Wyo., for example, it is estimated that intensive mining could result in the lowering or dewatering of some 200 wells used for livestock.

Mining may also change the characteristics of aquifers. It is almost axiomatic that mining alters the porosity and permeability of the overburden. On the northern Great Plains the most valuable aquifer may be the coal seam itself, and the overburden may also be an aquifer. In addition water of poor quality may be contained in pockets in the overburden and in the strata just below the coal. By disturbing these components of the aquifer and by introducing their contents into the rest of the aquifer, mining can lower the quality of the water in it.

The problem of maintaining the aquifer is even more difficult when mining is done on an alluvial valley floor, which is by definition an area of unconsolidated overburden and a high water table. In the West such areas act as buffers to the seasonal fluctuations of surface water and provide the naturally irrigated land where winter hay is grown for cattle. Where surface mining interrupts the alluvial aquifer and reduces the amount of water in it, the surface-water table downstream is lowered and vegetation

with short roots is desiccated. Without its protective cover of vegetation the unconsolidated material of the valley rapidly erodes, downstream areas are undercut and gouged and the productivity of the area can be lost for decades.

If the essential hydrologic functions of alluvial areas could be maintained during mining and restored after mining, there would be no reason not to mine them, particularly since the handling of overburden tends to be cheaper in such areas than it is in the hillier country around them. It is by no means certain, however, that the hydrologic functions can be maintained during mining. Until reliable methods of doing so are devised, surface mining will inevitably endanger the long-term productivity of an area for a cash crop of coal that can be harvested only once.

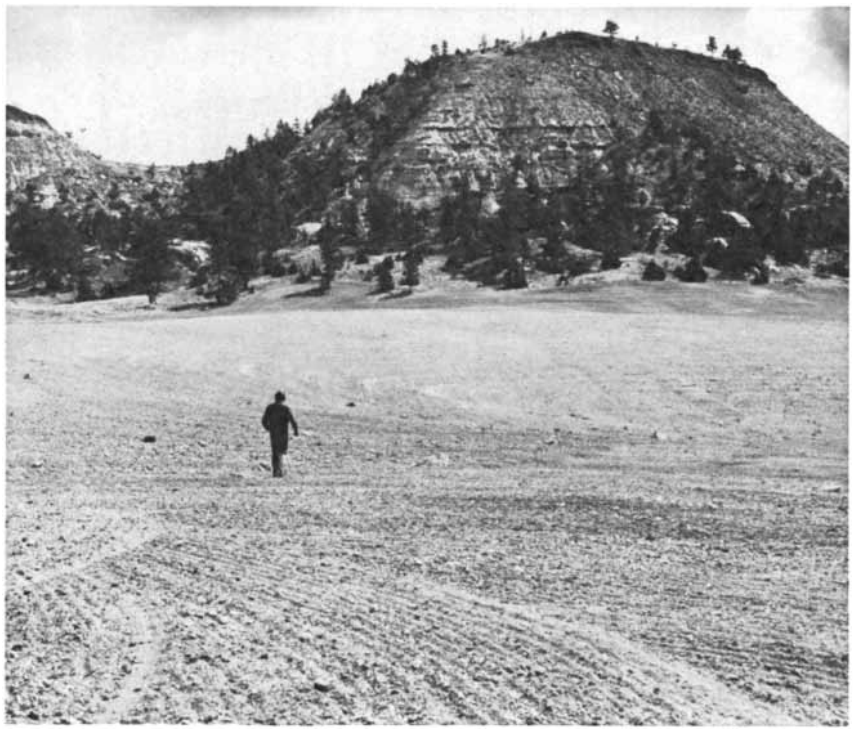
The environmental damage caused by strip-mining can be viewed in at least four ways. One is to accept the damage, on the basis that the cost to society of controlling it is excessive. The second is to insist that enough remedial work be done to reclaim the area after mining. The third is to forestall the problems by requiring preventive measures during the mining cycle. The last is to avoid the problems by not mining the area at all.

Some threats to the environment, such as the slowing of photosynthesis in leaves coated by the dust stirred up at the mine site, seem hardly worth the trouble involved in eliminating the cause, but others are clearly quite serious and must be balanced against the importance of coal to the national economy. Society can, either consciously or by default, treat strip mines as national sacrifice areas.

Most citizens and most coal-mining companies find the concept of sacrifice areas unacceptable, particularly in view of the fact that most mined areas can be reclaimed. For the past 20 years or so the general rule has been remedial action; when an environmental problem arose after the mining cycle had been completed, it was patched up. Usually this meant covering the mined area with a suitable soil material.

This "add on" method of reclamation proved to be inefficient, expensive and frequently unsuccessful. Accordingly the trend has been toward preventive measures such as segregating spoil, burying toxic material and incorporating grading operations into the mining cycle. As a result revegetation has been more successful and certain of the hydrologic problems have been avoided.

The policy of not mining areas that cannot be reclaimed is regarded as a harsh one by coal companies. It would be devastating to a couple of existing mines and would create hardships for companies that have invested heavily in such operations. Yet so much Western coal is easily available for mining that the nation can afford in the future to avoid mining areas that are in one way or another irreplaceable.



RECLAMATION OF STRIP MINE is in progress at the Big Sky Mine of the Peabody Coal Company in Montana. Here the spoil banks have been shaped and partly seeded with oats and alfalfa, which serve as cover crops for a mixture of native grasses. The view is southeast toward hills and coniferous trees that were not affected by the strip-mining operation.

Based on estimates made by the Western mining companies themselves it can be concluded that the cost of reclamation (from $500 to $5,000 per acre) has not jeopardized the competitive position of coal in the market. The higher estimate would add, to strike a rough average, less than 10 cents per ton to the price of Western coal. Moreover, most operators of Western coal mines hold the view that reclamation does not interfere with production, although they do believe that it reduces productivity. (Production, which is output in tons per day, should not be confused with productivity, which is output in tons per man-day. Production will not necessarily decrease when productivity decreases.)

Certain issues other than reclamation must be considered in any discussion of Western coal mining. One is the concern being voiced in the mining states over the fact that much of the money for and the direction of the mining activity will come from outside the region. Another has to do with the shortage of water in the West. Numerous objections to what may be in effect an allocation of scarce water resources for the production of energy for other states have been made, and more can be expected as coal production increases. Although there appears to be ample water for reclamation, the conversion of coal into electricity requires large quantities of water and will force the reallocation to energy production of water now dedicated to agriculture and recreation. At the same time voices are heard in the East warning that the shift to Western mines will be a severe blow to Eastern mines.

Such issues are more political than economic. So too is the question of how much reclamation should be undertaken and what timetable should be followed in the work. The choices that will shape the development of coal mining in the West and the reclamation of the mined lands will be made less in the marketplace than in the political arena. It seems clear, however, that large amounts of coal can be removed from a relatively few large mines in the Western states, that such operations can be limited to sites that can be reclaimed within an acceptable period of time after mining and that the cost of reclamation can be absorbed in the price of the coal.

Colicins and the Energetics of Cell Membranes

The active transport of selected substances into the cell needs energy. Colicins, antibiotics made by bacteria, can stop active transport and can therefore be used to study how it is achieved

by Salvador E. Luria

Beyond the study of genes and gene action no biological problem presents a greater challenge than unraveling the diverse and subtle functions of cell membranes. Early in the evolution of life the invention of membranes must have come in sequence and significance next to the invention of genes. The seclusion of genes within a resilient envelope made it possible for them to function in an artificial and protected environment. The cell had come into existence.

The structure and function of cell membranes are being studied in many laboratories around the world by many techniques. One of the central problems is to explain how certain substances are actively transported through the membrane, a process that requires a considerable investment of cellular energy, whereas other substances are rigorously excluded. As often happens in research, useful information about a refractory problem is obtained as a by-product of an investigation originally undertaken with other objectives. It was by such a roundabout route that my co-workers and I at the Massachusetts Institute of Technology gained some insight into the way the cell membrane mobilizes the energy needed for active transport in the course of studying a family of antibiotic substances named colicins.

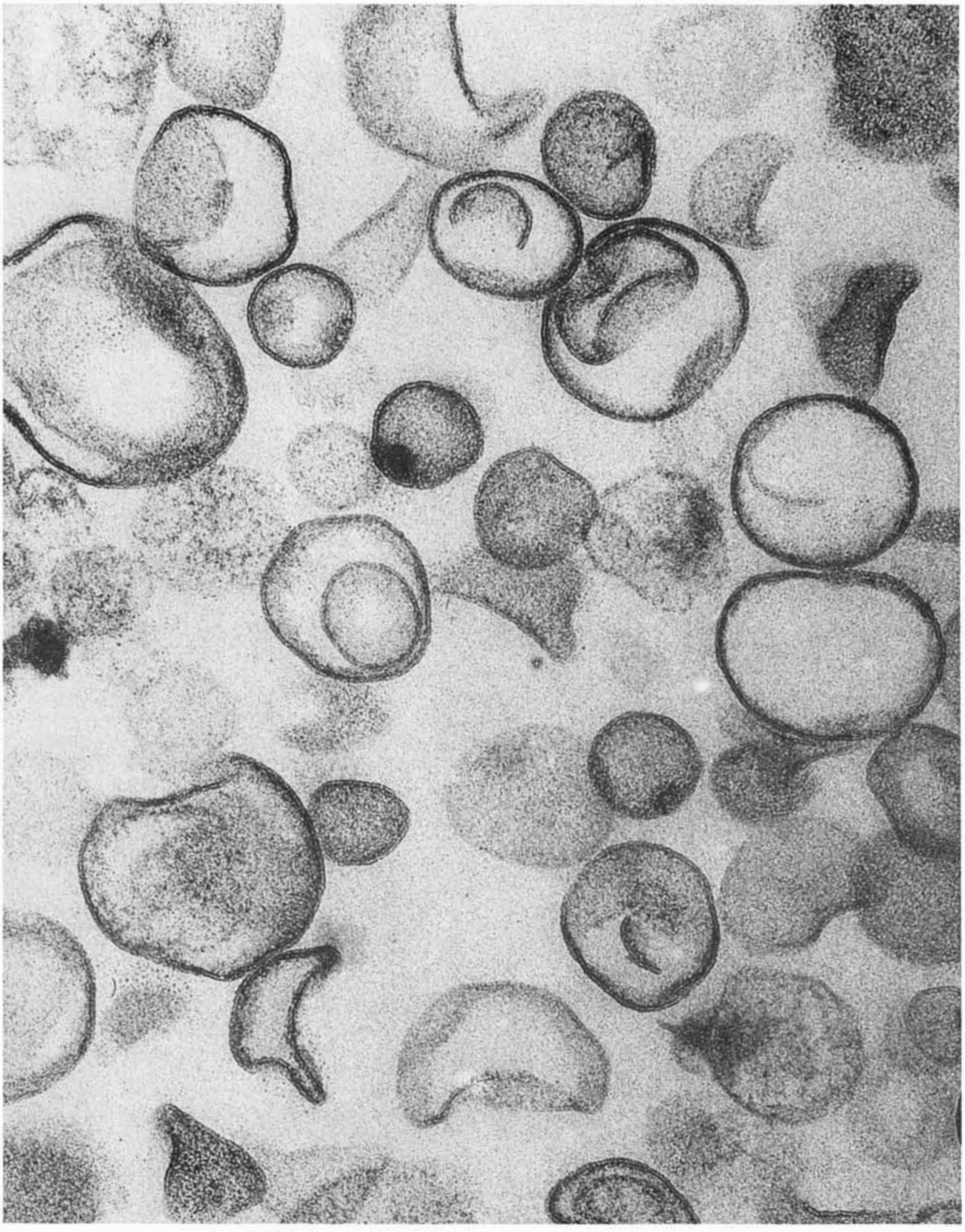
Colicins are a class of proteins manufactured by many bacteria of the *Escherichia coli* group. Each colicin is the product of one gene; the colicin genes are usually present in the special pieces of genetic material known as plasmids. Colicins kill the cells of bacterial strains related to the strains that make them but not the cells of unrelated strains. There are many different colicins, probably hundreds of them. No one has yet identified their biological role. They may be related to certain proteins of bacteriophages (the viruses that infect bacteria) or to proteins of bacterial membranes. This unsolved problem need not concern us here.

Before I describe what we have learned about active transport with the help of colicins let me summarize briefly how cell membranes are organized. Their main structural component is a double layer of phospholipid molecules. These molecules have water-attracting heads and water-repelling tails, so that in an aqueous environment they line up in a bilayer with their heads pointing toward the water and their tails pointing inward, away from the water [*see illustration on page 32*]. When a phospholipid is shaken with water, its molecules form a cloud of closed vesicles, or bubblelike arrays, because they seek a state of minimum free energy with all their heads in the water, either outside or inside the vesicle, and all their tails tucked away in the middle of the bilayer. That is why one can puncture a cell with a needle without causing it to burst or collapse: the molecules of the bilayer move toward one another to seal the hole.

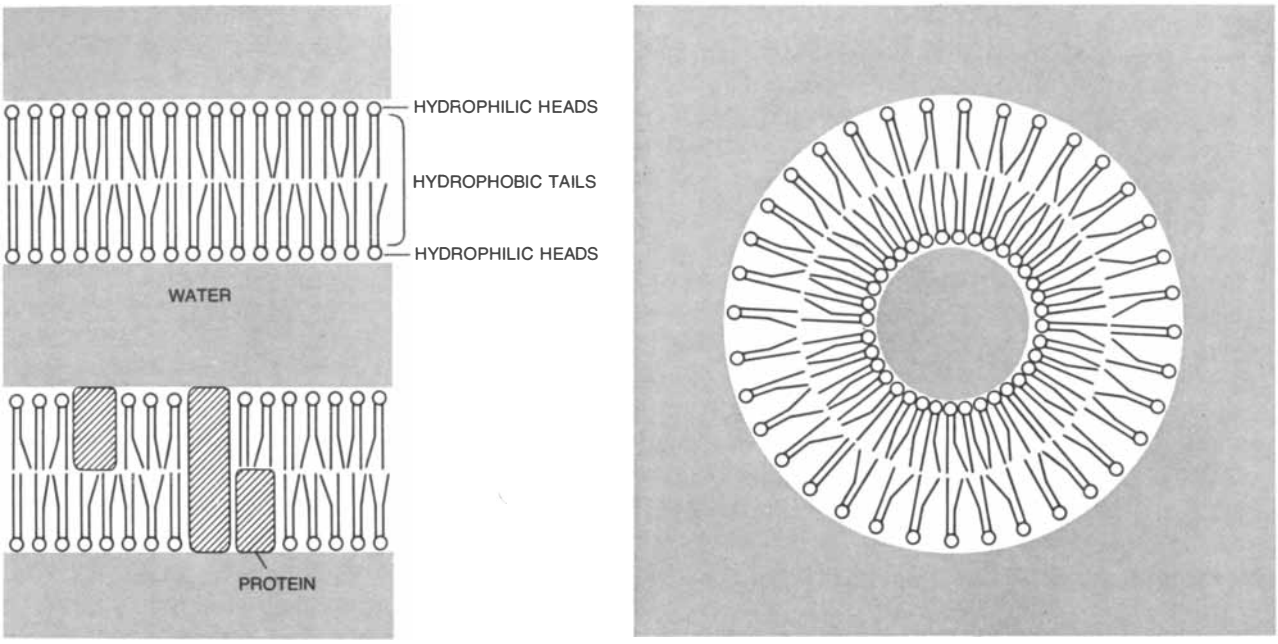
This self-sealing material is only the passive, mechanical part of a cell membrane. Substances are transported into a cell or out of it by protein molecules embedded in its outer membrane. As the cell grows, the components of the lipid bilayer are synthesized within the membrane by enzymes that also are embedded in the membrane. The membrane is a living, actively functioning structure. Moreover, it is not a static structure, a mosaic in which each tile is fixed where it happened to land or to be made. Cell membranes are quite fluid. Their components are remarkably free to move sideways within the two-dimensional layer. The functional activities of membranes may therefore involve changes both in the conformation of the membrane proteins and in the arrangement and association of these proteins.

That is the background to an array of membrane problems that intrigue the biochemist. How are the complex functions of the membrane coupled to and supplied with chemical energy? Consider a closed membrane vesicle, for example a bacterial cell, immersed in a dilute solution of potassium chloride. Although the lipid bilayer is impermeable to potassium ions, the membrane has protein channels that can transport such ions through the membrane. Actually live bacteria can concentrate potassium ions until the concentration inside the cell is as much as 1,000 times higher than the concentration outside. Such active transport, the accumulation of a substance against a concentration gradient, requires energy, just as the pumping of a liquid uphill against gravity requires energy. A water pump is actuated by an electric motor or some other source of mechanical energy. Cellular active transport is conducted by molecular pumps actuated by chemical energy. Poisons that interfere with cellular energy production inhibit active transport.

Active-transport systems are only one class of membrane functions that involve energy coupling. The activity of nerve cells and other excitable cells depends on the existence of electric membrane potentials generated by the expenditure of energy. Muscle contraction calls for the transfer of calcium ions in



MEMBRANE VESICLES, empty "bubbles" spontaneously reconstituted from the membranes of disrupted cells of the bacterium *Escherichia coli,* are shown in cross section in this electron micrograph. The two-layer structure of the cell membrane is clearly visible. The layers consist of molecules with water-attracting heads and water-repelling tails (*see illustration on next page*). Thus when fragments of cell membrane are shaken with water, the bilayer structure tends to seek a state of minimum free energy where the water-repelling tails are shielded from water. The minimum energy state is a bubble. Vesicles were prepared by H. Ronald Kaback of Roche Institute of Molecular Biology; micrograph was made by Vincent T. Marchesi of National Institute of Arthritis and Metabolic Diseases. The magnification is 40,000 diameters. At this magnification an *E. coli* cell would be 10 centimeters long.



TWO LAYERS OF CELL MEMBRANE consist of phospholipid molecules (*top left*). Each molecule has a hydrophilic (water-attracting) head and two hydrophobic (water-repelling) tails. In the membrane bilayer the tails face inward. The membrane is able to accommodate protein molecules of various shapes (*schematically indicated at bottom left*). In the presence of water the phospholipid bilayer forms a closed vesicle (*right*), a configuration that minimizes water-fat contact. Proportion of unsaturated fatty acids (*bent tails*) and temperature determine fluidity of bilayer and indirectly control the activity of the proteins in it or on it.

and out of membranous bags, a transfer that is energy-coupled. Transduction—the conversion of the energy of light or of mechanical stimuli into chemical and electrical signals in sensory cells—is another example of the coupling of the stimulating energy to changes in cellular membranes, leading in turn to the stimulation of sensory nerves.

How is this energy coupling achieved? In certain membrane-associated processes the chemical energy is provided by the splitting of the universal energy currency of living cells: adenosine triphosphate, or ATP. Transferring one phosphate group from one mole of ATP (475 grams) to water releases enough usable energy to melt 100 grams of ice. That amount of energy can be made available for pumping substances across a membrane. A much studied example of ATP's role in this process is found in the activation of muscle fibers. In order to remove calcium ions from muscle fibers to the membranous bags, where calcium is stored when the fibers relax, a particular protein molecule picks up two calcium ions and one molecule of ATP from outside the bag. One phosphate group is then transferred from ATP to the protein in such a way that when the phosphate comes off, it releases energy. Finally, the protein "flips" its calcium ions into the bag.

This neat picture, the outcome of years of sophisticated biochemical work in many laboratories, has one blank area in it. How does the energy released on the splitting of the phosphate group become available for the transfer of calcium ions? One can visualize, for example, a distortion of the carrier protein that enables it to rotate within the membrane and thereby deliver the ions into the bag. Alternatively the protein might be altered, possibly with the help of neighboring molecules, in such a way that a channel would be created through which calcium ions held by electrostatic forces could be led. Both in the study of enzyme action and in the study of membrane transport every biological process becomes a problem of protein structural chemistry: how protein molecules alter their configuration when they participate in chemical reactions.

The splitting of ATP into ADP (adenosine diphosphate) and phosphate is not the only source of chemical energy for pumping substances across membranes. As we know from the work of Saul Roseman and his colleagues at Johns Hopkins University, certain bacteria have developed a remarkable trick for taking in sugars such as glucose using a phosphate donor other than ATP. Of even greater significance, H. Ronald Kaback of the Roche Institute of Molecular Biology has discovered that in bacterial membranes the active transport of many substances—including potassium ions, amino acids and some sugars—is energized by the oxidation of various chemical substances without requiring the transfer of phosphate groups. The energizing mechanism is coupled more or less directly to the oxidation process, that is, to the transfer of electrons from a higher potential to a lower one, for example from lactic acid to oxygen. The transfer of electrons from any one of many organic substrates to oxygen is the major source of ATP in animal and plant cells. In bacteria the electron-transfer process can in addition provide energy for active transport directly, without going through ATP.

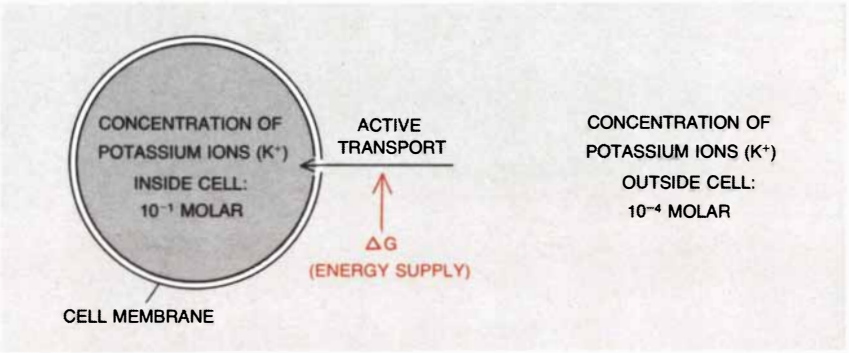
We are therefore led to visualize an energized state of the bacterial membrane that serves as storage for energy released by electron transfer. The energized state can be utilized to provide energy for active transport and also to generate ATP for cellular functions. Alternatively, by the reverse process, ATP made in the cell can be utilized to generate the energized membrane state.

A theoretical model of the energized state that is currently favored by many workers is the one proposed by Peter Mitchell of the Glynn Research Laboratories in England. In this model energy released by the transfer of electrons or the splitting of a phosphate group from

ATP would be stored in the form of a proton gradient, created by a mechanism that splits water so that protons (H^+ ions) accumulate on one side of the membrane and hydroxyl ions (OH^-) on the other [*see illustration on next page*]. The proton gradient contributes to the establishment across the membrane of an electric potential of about 200 millivolts, with the inside being negative. The energy stored in a proton gradient, as in an electrical condenser, could be used to pump substances into the cell in a variety of ways, for example by the association of one proton or more with a specific carrier molecule, which thereby becomes capable of transporting its substrate across the membrane. Such a model still leaves open the question of the actual molecular changes involved in the carrier's taking up the substrate, ferrying it across the membrane and releasing it into a region of higher concentration, such as the interior of a cell.

Against this background I shall now describe what we have learned about active transport from our work with colicins, which we began studying in 1963. Colicins were discovered some 50 years ago by the Belgian bacteriologist André Gratia and were later investigated by Pierre Fredericq in Belgium and by Masayasu Nomura in the U.S. They seem to fall into three classes, according to how they kill susceptible bacteria. For each class there is a specific biochemical target, that is, a cellular function that is blocked by colicin action. One class of colicins, designated *E2*, damages DNA. A second class, *E3*, damages the ribosomes, which are an essential component of the machinery for protein synthesis. Here we shall be concerned not with the *E2* and *E3* classes but with the third group, exemplified by colicin *E1* and colicin *K*, which are similar in the way they act and whose action is relevant to energy mechanisms in membranes.

When susceptible *Escherichia coli* cells take up colicin *E1* or colicin *K*, an entire series of things seem to go wrong. The synthesis of macromolecules—proteins, DNA, RNA and glycogen—stops almost immediately. This effect was observed some 20 years ago, and it suggested that the colicins damage some basic cellular mechanism. When I started to work on colicins in 1963, I was motivated by the possibility that these substances affected some master control mechanism of cellular syntheses. What I soon found was that the range of action of the *E1* and *K* colicins was even broader. The exposure of bacteria to colicin



$$\Delta G = \text{ENERGY OF CONCENTRATION}$$

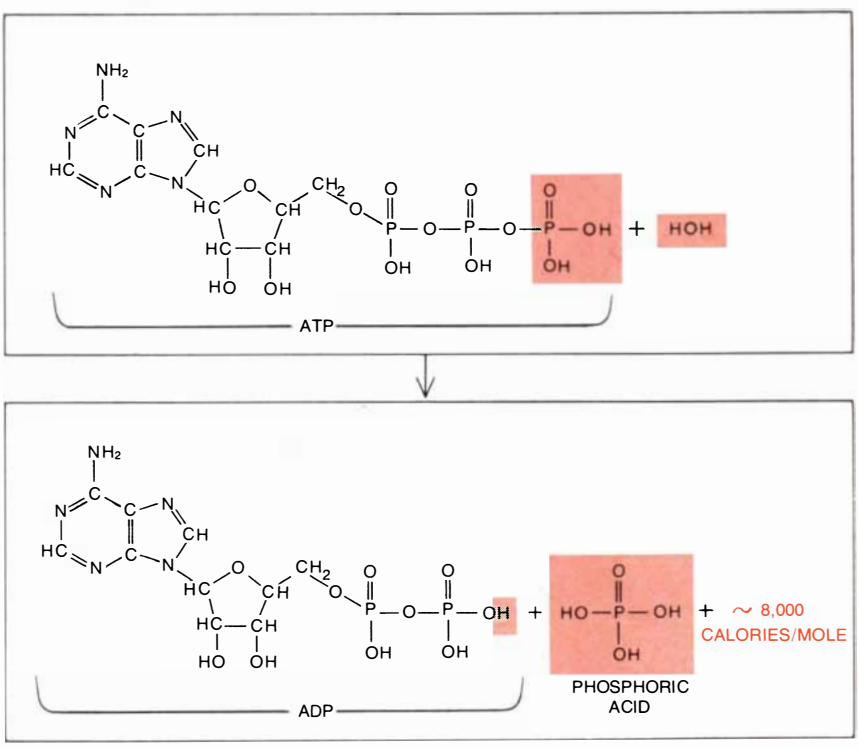
$$= 1{,}386 \log_{10} \times \frac{\text{CONCENTRATION INSIDE}}{\text{CONCENTRATION OUTSIDE}} \text{ CALORIES/MOLE}$$

$$\text{FOR : } \frac{\text{CONCENTRATION INSIDE}}{\text{CONCENTRATION OUTSIDE}} = 10^3$$

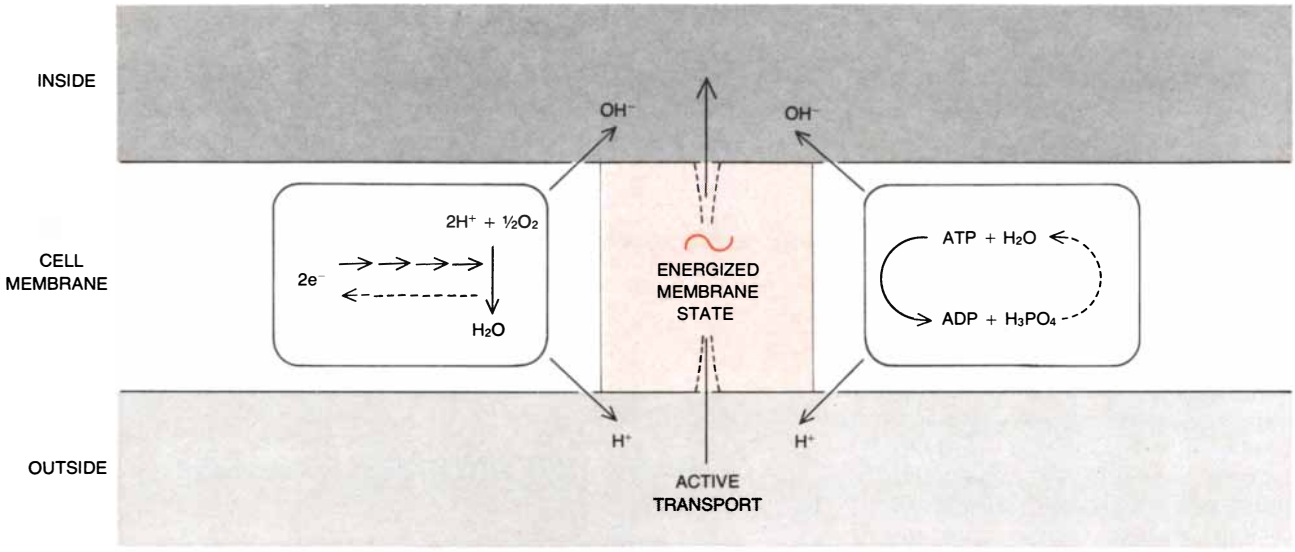
$$\Delta G = 3 \times 1{,}386 = 4{,}158 \text{ CALORIES/MOLE}$$

ENERGY IS REQUIRED to move any substance from a dilute region to a more concentrated one. Inside cells the concentration of many substances is hundreds or thousands of times higher than it is in the surrounding fluid. The cell is able to achieve such concentrations by active transport, which pumps selected substances through the membrane against a "head" that is higher inside the cell than outside. Free energy, ΔG, required can be calculated by equation. A mole of a substance is an amount equivalent to its molecular weight in grams. A major source of chemical energy available to the cell is shown below.

$$ATP + H_2O \rightarrow ADP + H_3PO_4 + \sim 8{,}000 \text{ CALORIES/MOLE}$$



CHEMICAL ENERGY is released by the cleaving of adenosine triphosphate (ATP), the ubiquitous energy currency of the cell. The released energy is made available when a phosphate group from ATP is transferred to water, yielding adenosine diphosphate (ADP) and phosphoric acid. Energy of ATP can be stored and used as it is needed for active transport.



ENERGIZED MEMBRANE STATE is generated either by the transfer of electrons from various substances to oxygen (*box at left*) or by the hydrolysis of ATP to form ADP and phosphoric acid (*right*). Both processes release energy. According to the chemiosmotic theory put forward by Peter Mitchell of the Glynn Research Laboratories, both processes are so oriented in membrane that they cause protons (H^+) to accumulate outside the membrane and hydroxyl ions (OH^-) to accumulate inside. In that way released energy is stored as a proton gradient. The resulting "protonmotive" force energizes the active-transport mechanism, indicated by the funnels. The protonmotive force can also energize reverse reactions of ATP hydrolysis and electron transfer (*broken arrows*).

E1 or colicin *K* promptly blocked active transport for the sugar lactose, various amino acids and potassium ions. The cells continued to take up and accumulate glucose, whose active transport, as I have mentioned, is energized by a special mechanism. This ability showed that the cells remained intact, even though they could not take up the other substances.

We soon found that what was defective was only the active phase of transport, the energy-demanding accumulation of various substances against a concentration gradient. The molecular mechanisms that exchange substrates across the cell membrane without the expenditure of energy were still functional. These results suggested that what the colicin did was to inhibit some phase of energy utilization.

The results were obtained in collaboration with my student Kay Fields, who is now at University College London. Since then a series of findings by our group (including at various times Gregory Brewer, David S. Feingold, Anton and Els Jetten, Joan Lusk, Charles Plate, Sohair Sabet and Joan L. Suit) has led us to our present view of the relation between colicins *E1* and *K* and the energy-coupling systems in the bacterial membrane.

It may be helpful to describe the nature of these experiments in somewhat more detail. Molecules of colicin attach themselves to a specific receptor on the bacterium. Sabet, working in Carl A. Schnaitman's laboratory at the University of Virginia School of Medicine before joining our group, isolated the receptors for some of the colicins and showed that they are protein molecules located in the bacterium's outer wall, which consists of lipopolysaccharide. The outer wall is a tough, comparatively inert envelope. The metabolically active membrane—the site of such processes as active transport, electron transfer, ATP production and the synthesis of various components of the envelope—is the cytoplasmic, or inner, membrane.

When the colicin is attached more or less firmly to a receptor, the bacterial cell is in what we call Stage I. The cell is killed when it enters Stage II. As long as the cell remains in Stage I it is still functionally normal and can be "rescued" by adding to the mixture of cells and colicin certain agents, such as the enzyme trypsin, that digest the colicin. The transition is defined by experiments in which one measures how many cells can be rescued by trypsin added at various times after the addition of colicin. The results are straightforward: The transition from Stage I (rescuable) to Stage II (killed) is a first-order, or "one hit," reaction, whose rate is directly proportional to the amount of colicin. The interpretation is also straightforward: What kills a cell is the action of one molecule of colicin. Increasing the amount of colicin only increases the probability of killing events per unit of time.

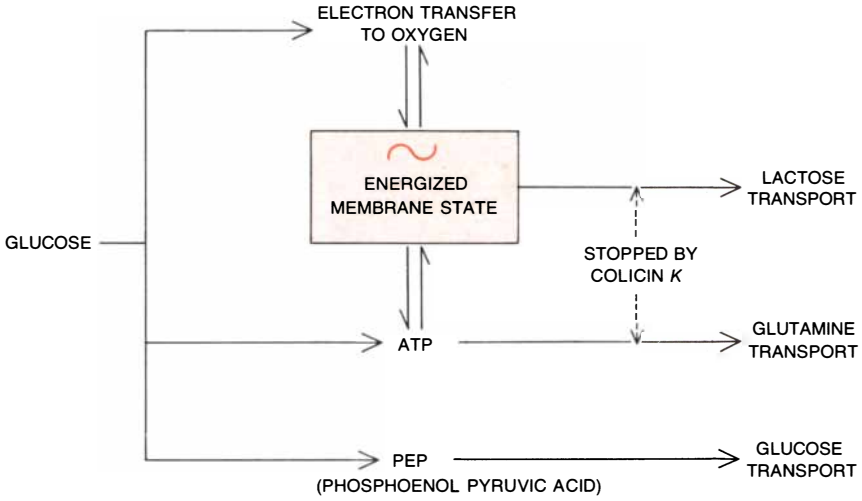
Before coming to the biochemistry of the killing process I should point out that the transition between Stage I and Stage II is itself interesting. In the first place, as Plate showed, its rate depends sharply on the physicochemical state of the lipids in the cytoplasmic membrane. If we make the membrane lipids less fluid, either by lowering the temperature or by forcing the cells to incorporate an unusual fatty acid in their lipids, the killing transition is greatly retarded. For colicin to kill a cell the cell membrane must be in a fluid state. This fact suggests either that the colicin must actually be transported through the lipid layer or that the reactions that follow the attachment of colicin require that the lipids be in a fluid state.

Even more interesting is the fact that the killing requires that the cytoplasmic membrane be energized. Any chemical treatment that interferes with the flow of energy in the membrane keeps the colicin-treated cells in Stage I, that is, it keeps them rescuable by trypsin. Why is membrane energy needed for the transition from Stage I to Stage II? I shall put off giving an interpretation until I have further described how the bacterial cells are killed by colicins.

I have mentioned that the killing of bacterial cells by colicins *E1* or *K* inhibits the functioning of various active-

transport systems. The inhibition is detected within a matter of seconds after the cells reach Stage II, when they can no longer be rescued by trypsin. Another event also takes place: the level of ATP in the cell is reduced between 30 and 50 percent, depending on the conditions of the experiment. Since ATP is the energy currency of the cell and many processes are likely to be sensitive to the amount of it that is present, it seemed possible that the lowering of the ATP level was the primary effect of colicin *K*.

We followed this appealing lead for quite a while, but it went nowhere. In the past year or so we have acquired a better understanding. We had been working with normal *E. coli* bacteria, and we decided for a number of reasons to try certain mutant strains that lack the enzyme ATPase (adenosine triphosphatase). This is the membrane enzyme that both catalyzes the synthesis of ATP, using the energy of electron transfer in the cytoplasmic membrane, and splits ATP to provide energy to the membrane. Bacteria without ATPase are, so to speak, schizoid with respect to energy: they can use glucose or other sugars to make ATP inside the cell and can also use any one of a variety of substances as a source of electrons to energize the membrane, but they are unable either to make ATP using the energy of electron transfer or to use ATP to supply energy to the membrane.

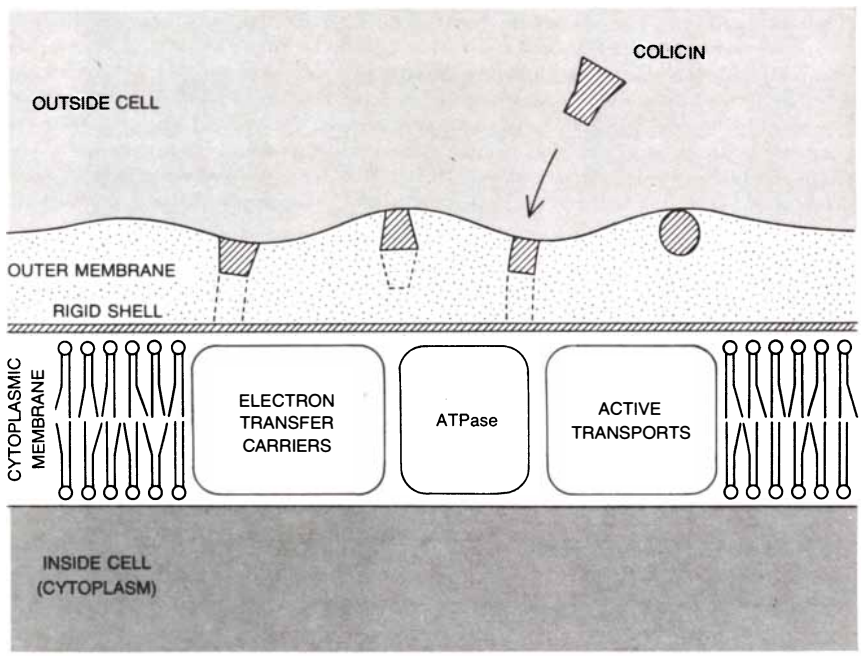


THREE ACTIVE-TRANSPORT SYSTEMS are available to *E. coli* cells that are supplied with glucose as a nutrient. The energized membrane state suffices for the active transport of lactose and many other substances, including the ions of potassium and magnesium. The transport of a second class of substances, including glutamine, requires ATP as such. The transport of a third class of substances, such as glucose, requires phosphoenolpyruvic acid (PEP). Bacterial product colicin *K* inhibits first two transport systems but not the third.

The action of colicin *K* on the ATPase-less bacteria turned out to be significantly different from the action on normal bacteria, and the differences were illuminating. The ATP levels went up instead of down and the synthesis of proteins and nucleic acids continued instead of stopping, but the various kinds of active transport were just as completely inhibited as they were in normal bacteria. The blocking of protein synthesis and nucleic acid synthesis, which we had thought was the main cause of cell death, was actually only a side effect of colicin action, probably reflecting the decreased ATP levels. The key action of colicin, we finally discovered, was on the utilization of membrane energy.

Why should colicin make the ATP levels go down in normal bacteria and up in ATPase-less mutants? We believe colicin *K*, by de-energizing the membrane, causes a drain of energy. If the ATPase enzyme is present, it wastes the cellular ATP in a vain attempt to re-energize the membrane. The situation can be compared to one where a pump exhausts a water reservoir in an attempt to replenish a leaky water tank. In the mutant bacteria that lack ATPase the leakage of energy due to colicin does not occur; the ATP level within the cell actually rises and the synthesis of macromolecules can continue. Such cells are dead only because a monkey wrench has been thrown into the machinery that supplies membrane energy.

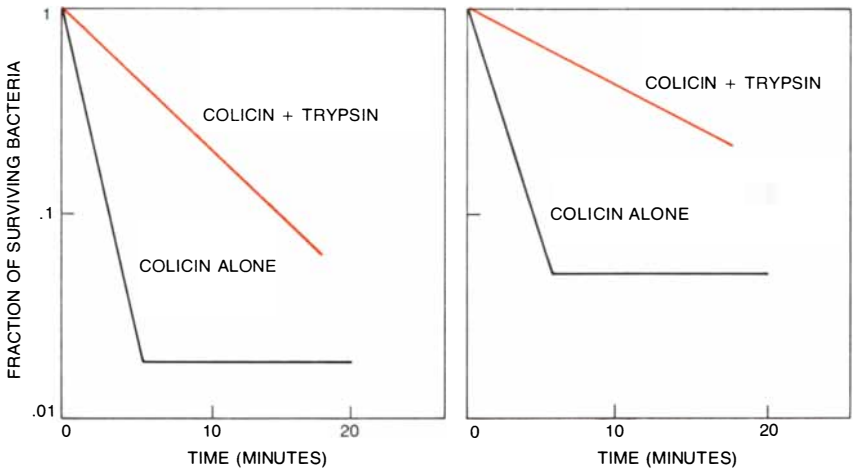
That interpretation has been supported by an elegant experiment performed by Lusk, who is now at Brown University. Reasoning that potassium and magnesium ions are probably the essential



BACTERIAL ENVELOPE has three major components: an inner cytoplasmic membrane, which has a backbone consisting of phospholipid bilayer; a rigid shell of peptidoglycan, which gives the cell its specific shape, and an outer membrane, which contains specific receptors (*hatched*) for various substances such as bacterial viruses and colicins. In some way the receptors convey their corresponding substrates to the cytoplasmic membrane. Embedded in the cytoplasmic membrane are protein molecules that serve a variety of functions. Arrangement that enables them to operate in production-line fashion is not known.

substances the cell must pump in from the outside, she treated the mutant bacteria that lacked ATPase with colicin *K* and then placed them in a culture medium containing high concentrations of potassium and magnesium. She found that in this medium the mutant cells, which otherwise would have been killed, survived, divided and gave rise to colonies of healthy, but still mutant, descendants!

How does the colicin specifically affect the coupling of membrane energy and active transport? There are a number of substances, such as cyanide, that de-energize membranes by blocking the transfer of electrons. Colicin *K* does not do that: in colicin-treated bacteria the rate of flow of electrons from various substrates to oxygen is normal. Other substances, known as uncouplers, de-energize membrane functions by blocking the conversion into usable membrane energy of the energy from electron transfer. These substances facilitate the passage of protons through membranes and abolish the proton gradient that provides energy storage in membranes. Colicin *K* does not act in that way either: it does not abolish the proton gradient. Moreover, it inhibits some transport systems that are insensitive to uncouplers. Brewer, experimenting with an indicator substance whose fluorescence reflects transmembrane electric potentials, found that what colicin *K* does is to lower the potential. That result would be expected from any action interfering with the creation or maintenance of the energized state, either by ATP or by electron transfer.



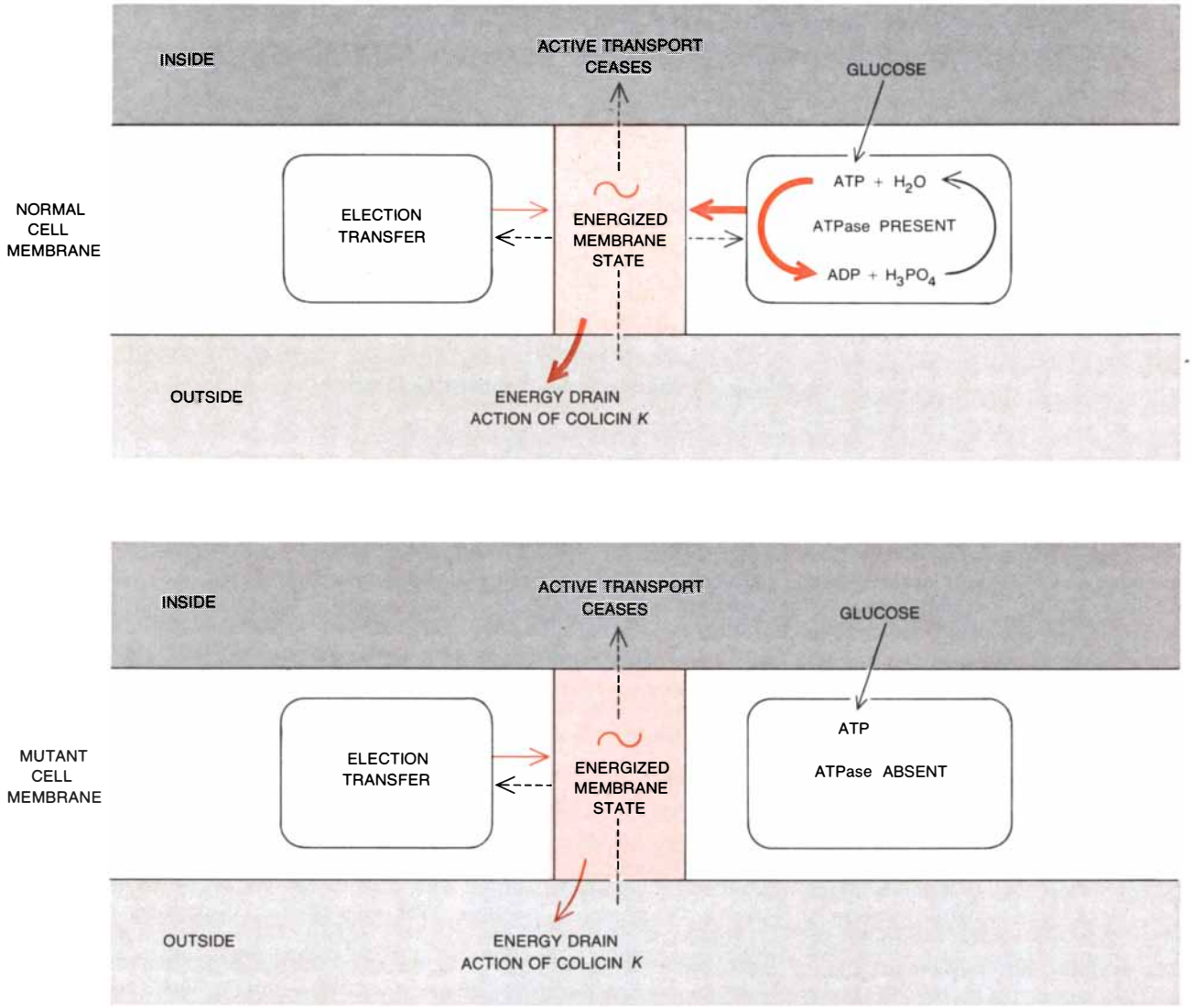
LETHALITY OF COLICIN *K* to *E. coli* is determined by comparing survival rates of cells exposed to different concentrations of colicin and seeing how many can be "rescued" by adding trypsin, an enzyme that destroys colicin molecules. Bacterial cells are mixed with colicin *K* at a concentration of one microgram per milliliter (*left*) or .5 microgram per milliliter (*right*). After five minutes both mixtures are diluted. Samples of the dilute mixture are removed at intervals and are assayed directly for their ability to produce colonies on agar (*black curves*). The surviving colonies represent bacteria that did not receive a killing dose of colicin. The colored curves show the fraction of bacterial cells that can be rescued by mixing them with large amounts of trypsin. The colored curves therefore indicate the proportions of cells that had not yet been killed at the moment trypsin was added. The fact that colored curves are straight lines whose slopes are proportional to amounts of colicin indicates that action of one colicin molecule is enough to kill one *E. coli* bacterium.

	ATPase PRESENT	ATPase ABSENT
PROTEIN SYNTHESIS	STOPS	CONTINUES
DNA AND RNA SYNTHESIS	STOPS	CONTINUES
ATP LEVELS	DECREASE	INCREASE
MOTILITY	STOPS	STOPS
ACTIVE TRANSPORT OF GLUCOSE	CONTINUES	CONTINUES
ACTIVE TRANSPORT OF GLUTAMINE, LACTOSE, ETC.	STOPS	STOPS

EFFECTS OF COLICIN *K* ON BACTERIA differ markedly depending on whether the *E. coli* cells are normal cells or are mutant cells that happen to lack adenosine triphosphatase (ATPase). ATPase is an enzyme that can catalyze either the synthesis of ATP, using the energy of electron flow in the cytoplasmic membrane, or the reverse reaction: the hydrolysis of ATP to provide energy to the cytoplasmic membrane. When colicin *K* is added to cells that contain ATPase, the synthesis of protein, DNA and RNA stops and the level of the ATP inside the cell falls sharply. When colicin *K* is added to mutant cells, it has little effect on synthesis of proteins, DNA and RNA; level of ATP in cells actually rises.

One way of looking at the coupling of membrane energy to active transport or to the synthesis of ATP is to postulate that energy is funneled inside the membrane to various systems, not directly by changes in the electric charge and conformation of ATPase or of the transporter molecules but through the agency of one protein or more whose deformation is somehow conveyed to the actual transporters. Colicin *K* might act on some of the intermediate steps and thereby inhibit a number of different transport systems. This hypothesis predicts that one should be able to find mutant bacteria in which the postulated intermediate steps are altered. Indeed, Plate has succeeded in isolating some *E. coli* mutants that have become resistant to colicin *K* and have also become altered in one way or another in the coupling of membrane energy to various transport functions. At least one such mutant mimics the action of colicin *K* and may alter the primary target on which the colicin acts. These findings support the idea that energy coupling involves a number of different steps and opens the way to using the method of genetic analysis for the study of membrane energy mechanisms. The program is now to isolate a series of mutants each of which is defective in one or another of the components of the energy-coupling system and to identify the corresponding biochemical functions.

As I have indicated, one property common to colicins of different classes is that they can kill only bacteria whose membrane is energized. In other words, the transition between Stage I and Stage II requires membrane energy. Anton Jetten, who has studied the phenomenon in detail, has found that in the absence of oxygen the ATPase-deficient bacteria take up colicin but are not affected by it, even though the bacteria are well supplied with ATP. In the absence of oxy-



DIFFERENCE IN COLICIN-*K* ACTION on normal *E. coli* cells and on mutant cells that lack ATPase throws light on how energy is supplied to produce the energized membrane state that is needed for active transport. In normal cells (*top*) colicin *K* stops active transport by draining the energized state of the membrane. In a fruitless attempt to maintain the energized state ATP is hydrolyzed to ADP inside the membrane and wasted. As a result the level of ATP inside the cell falls. In a mutant bacterium that lacks ATPase (*bottom*) active transport also stops after exposure to colicin *K*, because of drainage of the energized membrane state, but there is no hydrolysis of ATP inside the membrane and hence no wastage. Inside cell ATP continues to be made from glucose. Level of ATP actually rises, probably because damaged cell uses less of the substance for growth and general metabolic processes.

gen the membrane is not energized. As soon as oxygen is restored the bacteria start dying.

While we were puzzling over the meaning of this finding, a discovery from Kaback's laboratory provided a suggestive analogy. Kaback and his colleagues were studying in *E. coli* the chemical interaction of a certain type of sugar and its transporter molecules in the membrane. They found that there was no interaction unless the membrane was energized, as though energy was needed for the transporter molecules to come in contact with the sugar molecules. The requirements for the chemical interaction were identical with those for colicins in the transition between Stage I and Stage II.

It is tempting to propose a bold generalization and suggest that the energizing process in the membrane causes the various proteins that act as transporters or receptors to become accessible to their respective substrates. Changes in membrane potential, for example, could cause conformational changes in protein molecules to make them stick out of the membrane or pull back into it. Such changes might also be involved in the functioning of ion channels whose opening and closing are the critical events in the excitable membranes of nerve and muscle.

The accessibility of receptors to substrate cannot, of course, be the whole story in the utilization of membrane energy. Active transport, which involves not just the passage of a relatively small number of ions across a membrane but a massive accumulation of substrates against concentration gradients, must also call for the expenditure of energy for the release of the substrate within the cell. This too may be accomplished by conformational changes in membrane proteins. The unscrambling of the molecular events that give cellular membranes their functional properties promises to be an arduous but nonetheless fascinating task.

X RAYS FROM SUPERNOVA REMNANTS

An exploding supernova hurls a shell of gas into the interstellar medium. In the region where the gas of the shell meets the gas of the medium, X rays are generated that yield information about both

by Philip A. Charles and J. Leonard Culhane

Since the discovery of the first celestial X-ray source in 1964 approximately 170 such objects have been detected and catalogued. Some of them are associated with supernova remnants: an expanding shell of gas thrown off in the catastrophic explosion of a massive star at the end of its life cycle. In a number of the remnants, including the Crab Nebula in the constellation Taurus, the remaining small, dense core of the star collapsed further until it became a pulsar: a rapidly spinning neutron star ejecting high-energy electrons into its surroundings. When the electrons spiral along the lines of force of the star's magnetic field, they radiate by means of the synchrotron process, emitting radio waves, visible light and X rays.

Until comparatively recently it was believed that other supernova remnants that emit X rays, such as Cassiopeia A and the remnant of Tycho's nova of 1572, must radiate in a similar way. There was one perplexing problem with the hypothesis: the amount of energy radiated by the Crab Nebula is hundreds of times greater than the amount radiated by Cassiopeia A and the remnant of Tycho's nova, even though these remnants are much younger than the Crab Nebula. Clearly they have a source of energy that is much different from the Crab Nebula's central pulsar powerhouse.

In August, 1972, the Orbiting Astronomical Observatory satellite *Copernicus* was launched, carrying three grazing-incidence X-ray telescopes of the Mullard Space Science Laboratory at University College London. With those instruments we and our colleagues have obtained new high-resolution data on a number of supernova remnants. The X-ray map of Cassiopeia A we have made, together with a spectrum of the remnant plotted from the same data, suggest that the X rays are radiated not by some central source but by hot gas produced by shock waves from the original explosion traveling through the interstellar medium.

What causes a star to become a supernova? Although it is not yet completely clear why some stars should explode cataclysmically whereas others do not, the sequence of events that leads to the explosion is fairly well understood. The nature of the life cycle of a star is determined by two major influences. The first is the force of gravity. The star is born from a cloud of gas that contracts as a result of the mutual gravitational attraction of its constituent particles. That gravitational force ensures that the collapse will continue inexorably. As the cloud contracts, however, the temperature in its interior rises steadily. From 100,000 to 100 million years later, depending on the cloud's initial mass, the temperature is high enough for thermonuclear reactions to begin deep within the star. These fusion reactions are the second major influence on the life cycle of the star. From this point on it is the balance between the star's gravity and its thermonuclear reactions that determines its evolutionary path, and the star evolves with periods of gravitational collapse being halted from time to time by the energy that is available from the fusion reactions.

However large the star's reserves of energy may be, they are not unlimited. The first fusion reactions transmute hydrogen into helium. Since hydrogen is initially the most abundant element in the star, the opening phase in the star's life lasts for a long time. When the hydrogen is exhausted, the star collapses until its internal temperature is high enough to transmute helium into carbon. When the helium is exhausted, the process is repeated for heavier elements. As the star begins to fuse those elements, however, each individual reaction between the heavier elements yields less energy than the equivalent reaction between lighter elements. In addition, the abundance of each heavier element available for the fusion reactions is less than the abundance of the preceding lighter elements. Thus the periods during which the star's gravitational collapse can be balanced by the fusion reactions get shorter and shorter until the star approaches the end of its nuclear fuel.

At that point what happens depends on the star's mass. A star less massive than the sun can evolve slowly and directly to the white-dwarf stage, in which it has an incompressible core composed largely of tightly packed electrons. For a star several times heavier than the sun the last stages of evolution can proceed very rapidly and sometimes can end violently.

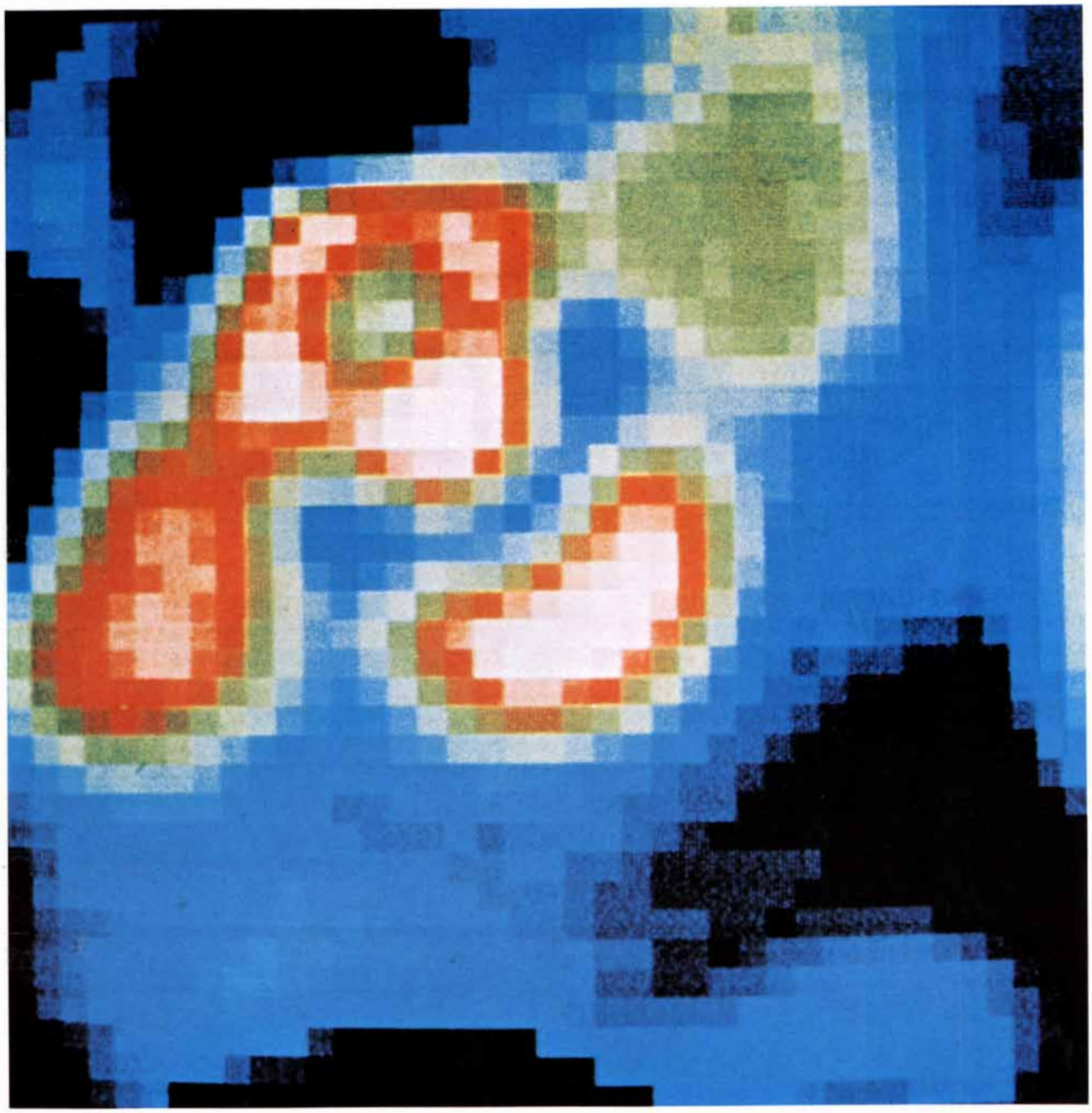
In most cases where the star has consumed its last reserves of nuclear fuel the gravitational collapse finally becomes the dominant influence. For a brief time, perhaps for only a few seconds, the collapse continues unchecked, hastened by the escape of neutrinos and other nuclear particles that carry large amounts of energy away from the core of the star. The matter in the core is finally compressed into a superdense state where electrons and protons no longer exist as independent particles but are merged so that the entire core is composed of neutrons. Such a neutron star has a density comparable to the density of an atomic nucleus: 10^{15} grams per cubic centimeter.

At the end of the life cycle of a particularly massive star even the extremely high density of the tightly packed neutrons is insufficient to halt the final gravitational collapse. In that case the star

may collapse even further until it becomes a black hole, an object whose gravitational field is so strong that even any light it emits is unable to escape. Until quite recently black holes existed only in the realm of theoretical speculation. Within the past few years, however, strong evidence from observations made in the X-ray region of the spectrum indicates that there may be such a massive collapsed object in the constellation Cygnus [see "X-Ray-emitting Double Stars," by Herbert Gursky and Edward P. J. van den Heuvel; SCIENTIFIC AMERICAN, March].

Little is known about the details of the object's final phase of collapse. It is believed that as the collapse begins, the star becomes unstable. The instability quickly grows until the star blows off its outer layers in a gigantic explosion. The ejected material, which sometimes amounts to as much as 90 percent of the star's original mass, begins its journey into the interstellar medium, while the remainder of the star settles down to a stable existence, either as a small but relatively normal star or as a neutron star.

The Crab Nebula is mute evidence of

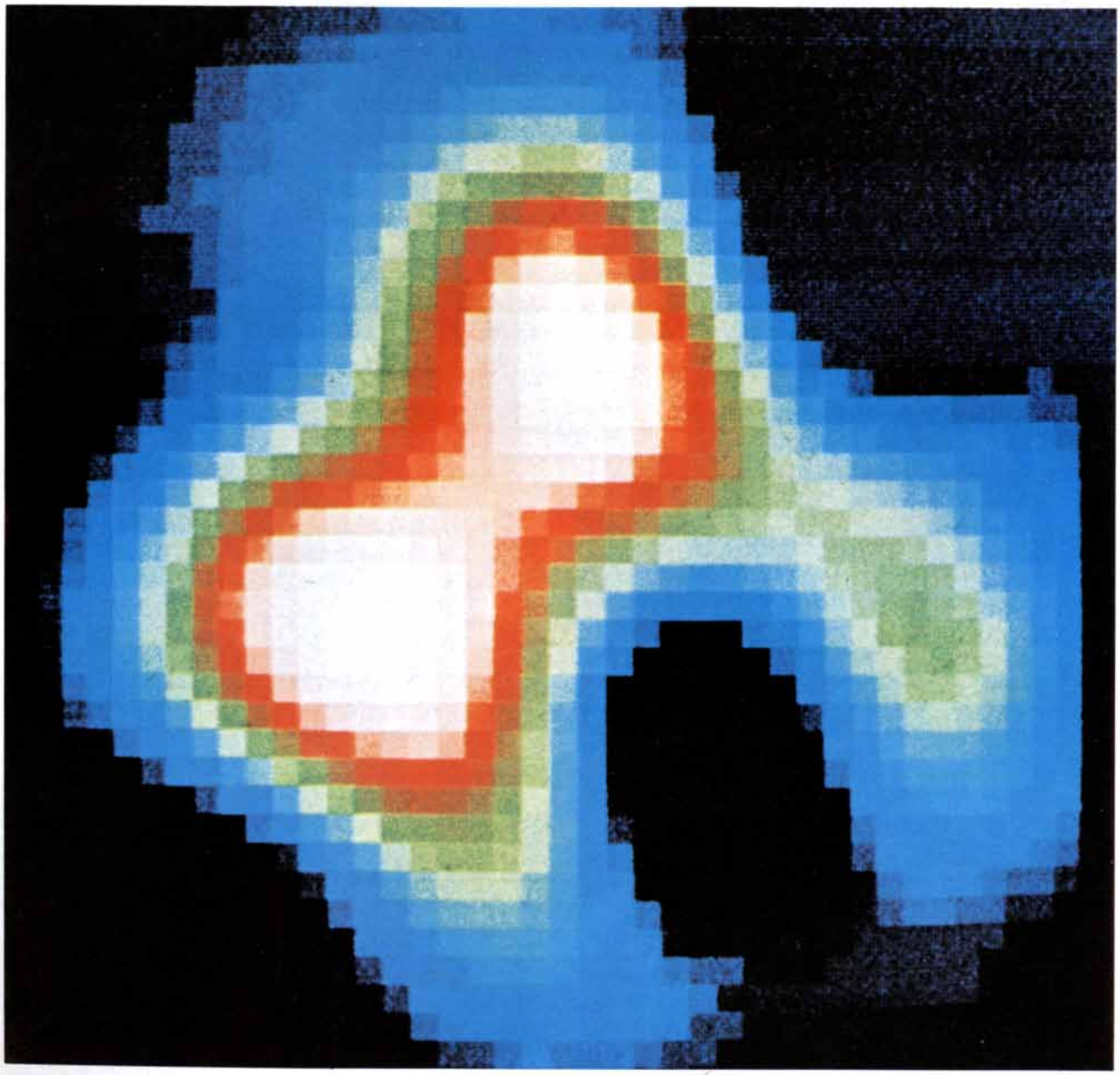


X-RAY MAP OF PUPPIS A, the remnant of a supernova that exploded in the constellation Puppis and whose light reached the earth 4,000 years ago, was made from data obtained from grazing-incidence X-ray telescopes of the Mullard Space Science Laboratory aboard the Orbiting Astronomical Observatory *Copernicus*. Richard J. Borken of the University of Wisconsin displayed the data on a cathode-ray tube and photographed it to produce map. Colors represent distribution of X-ray intensity across the source: white areas have the greatest intensity and blue areas the least. Brightest areas are apparently regions where shock wave from original explosion has encountered a dense cloud of gas in interstellar medium, which has then become a more intense source of soft X rays.

a star that went through this sequence of events, and it is one of the most intriguing supernova remnants known. It radiates 10,000 times more energy than the sun, although the supernova that created it exploded nearly 1,000 years ago, in A.D. 1054. It seemed impossible to explain how the nebula could be pouring out such vast quantities of energy until 1967, when the first pulsar was discovered in the constellation Vulpecula.

It was Thomas Gold of Cornell University who suggested that a pulsar was a rapidly spinning neutron star with a strong magnetic field. The neutron star rotates rapidly because it has retained much of the angular momentum it possessed as a normal star, although it may have a diameter of only 20 kilometers. The lines of force of the star's magnetic field are dragged around with the star as it spins. The pulsar emits electrons, and its large rotational energy accelerates them to speeds approaching the velocity of light. If the pulsar is embedded in a nebula, the electrons are presumably hurled into the nebula and spiral along its own magnetic lines of force, emitting radiation over an enormous range of wavelengths. Moreover, as the pulsar gives up its energy to the nebula, its rotation rate gradually decreases.

In 1968 a pulsar was discovered in the center of the Crab Nebula and was found to be indeed the source of the nebula's energy in both the radio and the visible regions of the spectrum. The star spins once every .0331 second, and it is gradually slowing down at a rate of 3.5×10^{-8} second per revolution per day. The detailed shape of the X-ray spectrum and the detection of polarized X-ray emission from the nebula in 1972 by Robert Novick and his colleagues at Co-

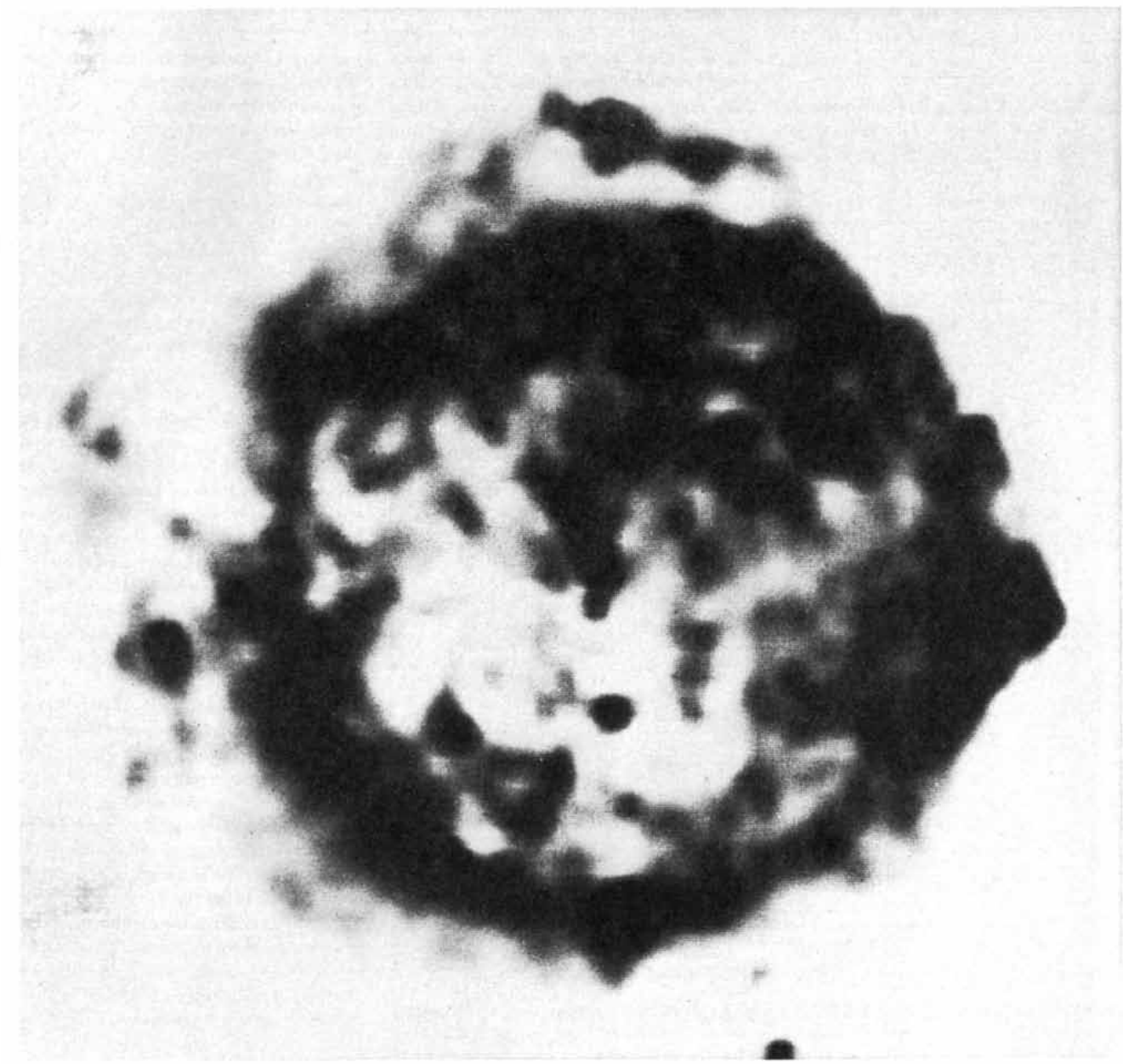


X-RAY MAP OF CASSIOPEIA A was also constructed by Borken, again using data obtained from the Mullard Space Science Laboratory grazing-incidence X-ray telescopes aboard *Copernicus*. Cassiopeia A is a young object; the supernova that created it would have been observed about 1700 if its light had not been obscured by interstellar material. The pronounced double structure of Cassiopeia A is characteristic of such a young remnant. Its angular diameter is only five minutes of arc, only 1/35th the angular size of the Cygnus Loop. Because the X-ray telescopes have a field of view of three minutes of arc, the resolution of the X-ray map is low.

lumbia University confirm the prediction that the synchrotron process is operating within the nebula. Furthermore, the amount of rotational energy lost by the pulsar is essentially equal to the amount of energy radiated by the entire nebula, which is convincing evidence in favor of the hypothesis that the source of the Crab Nebula's energy is the pulsar.

Many questions about the details of the interaction of the pulsar with the nebula nonetheless remain. For example, it is not at all clear how the electrons leave the neighborhood of the pulsar and begin to interact with the more extended magnetic field within the nebula. The question might be resolved if one could obtain a map of the Crab Nebula in the X-ray region of the spectrum. Such a map would enable one to determine how the energetic electrons are distributed within the nebula. The diameter of the nebula as it is seen from the solar system, however, is quite small: between one minute and two minutes of arc. (The apparent diameter of the moon is 30 minutes of arc.) In order to learn anything about the distribution of electrons one would need a map with a resolution of a few seconds of arc. Such a resolution is extremely difficult to achieve with existing X-ray telescopes.

It happens, however, that the Crab Nebula lies in the path of the moon, and approximately once every 10 years there is a "season" lasting for several months during which the moon occults, or eclipses, the nebula a number of times. As the edge of the moon passes in front of the nebula, it hides (or exposes) more and more of the X-ray emission. One can thus monitor the amount of X-ray emission with respect to time. From a knowledge of the moon's position and motion one can calculate the location and



RADIO MAP OF CASSIOPEIA A, made by Ivan Rosenberg in 1970 using the Cambridge One-Mile Radio Telescope and produced in this form by Steven Gull, has much better resolution than the X-ray map of the same object shown on the opposite page. As a result details of the expanding shell of gas are particularly clear, and "knots" of radio emission are visible. Knots may have arisen because of an instability between dense gas of the expanding shell and relatively hot, shocked interstellar matter it is sweeping up, which caused the shell to break up into filaments. If X-ray map had higher resolution, it is believed it would show same kind of detail.

size of the region emitting the X rays.

In 1974 Frederick D. Seward and his colleagues at the Lawrence Livermore Laboratory of the University of California observed a lunar occultation of the Crab Nebula with a large X-ray detection system borne aloft by a sounding rocket. They collected data on the distribution of the X-ray emission across the nebula between the energies of 500 and 15,000 electron volts. Their observation confirms the results we obtained from our instruments on *Copernicus:* the distribution of the X-ray emission suggests that the X rays are being uniformly produced and radiated from a spherical region within the nebula. The center of the sphere, however, is displaced some 10 seconds of arc from the position of the pulsar.

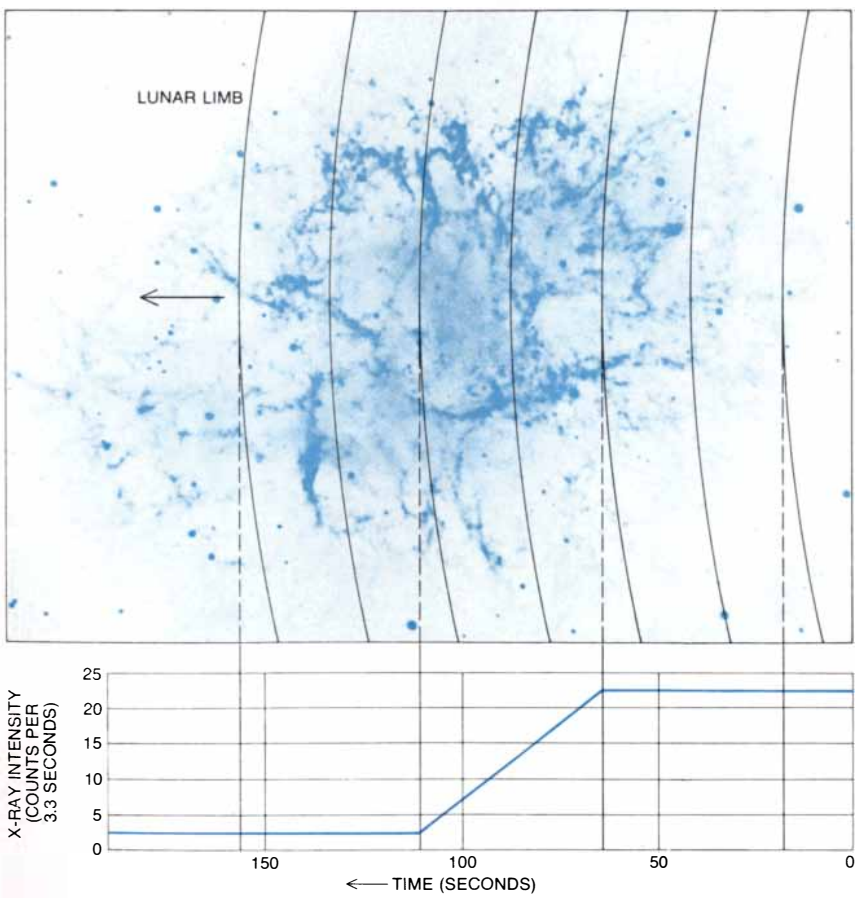
Seward and his co-workers point out that in order for X rays to be so uniformly generated within such a large volume, the electrons producing them must be accelerated throughout the entire region rather than only in the immediate neighborhood of the pulsar. If that is so, then the way in which the spinning neutron star supplies energy to the nebula must be reexamined. Aaron Barnes of the Ames Research Center of the National Aeronautics and Space Administration and Jeffrey D. Scargle of the Lick Observatory have suggested that the ionized gas of the Crab Nebula may be regarded as an electrically conducting fluid. The neutron star contributes energy to the nebula in the form of magnetohydrodynamic shock waves. As the waves propagate through the gas somewhat like ripples through water they are slowly damped as their energy is absorbed by high-velocity electrons and protons in the nebula. The particles are further accelerated and radiate their energy by means of the synchrotron process. In this way the energy is transferred from the neutron star to the surrounding region.

The possible significance of magnetohydrodynamic waves has been further emphasized by Walter Lewin and his co-workers at the Massachusetts Institute of Technology. They observed a lunar occultation of the Crab Nebula in the energy range between 20,000 and 150,000 electron volts with a scintillation counter carried above most of the earth's atmosphere by a large balloon. Their apparatus monitored X rays at much higher energies than the instruments in either Seward's rocket or the *Copernicus* satellite did. They found that there are several areas emitting the highest-energy X rays, and that those areas coincide with many of the wisps that are brightest in the visible region of the spectrum [*see bottom illustration on opposite page*]. It is possible that electrons ejected by the pulsar are further accelerated in the wisps by the mechanism suggested by Barnes and Scargle and that they therefore emit X rays of higher energy in those regions. Hence although the basic role of the central neutron star as the powerhouse of the Crab Nebula remains unchallenged, the X-ray observations show that we still need to investigate in much greater detail how the energy is transferred.

The small apparent diameter of the Crab Nebula has made it a difficult object to map with any technique not employing lunar occultations. The lunar-occultation technique, however, is obviously limited to the objects that happen to lie in the path of the moon. Although very few of the 170 known X-ray sources are so placed, several of them have a much larger angular diameter than the Crab Nebula does. It is therefore possible to study their structure with X-ray telescopes.

Since X rays pass freely through most materials, one cannot manipulate them in a telescope as one manipulates light. X rays can, however, be reflected if the angle between the incoming photons and a smooth polished metal surface is less than about two degrees. Moreover, if the reflecting surface is a section of a paraboloid, it will bring the X rays to a focus, and the X-ray detector can be placed at the focus of the paraboloid. The detector can be quite small, which has the advantage of reducing its response to stray cosmic-ray particles that can be mistaken for X rays.

The Mullard Space Science Laboratory X-ray-telescope system on *Copernicus* has three reflectors, each of which focuses X rays in a different range of

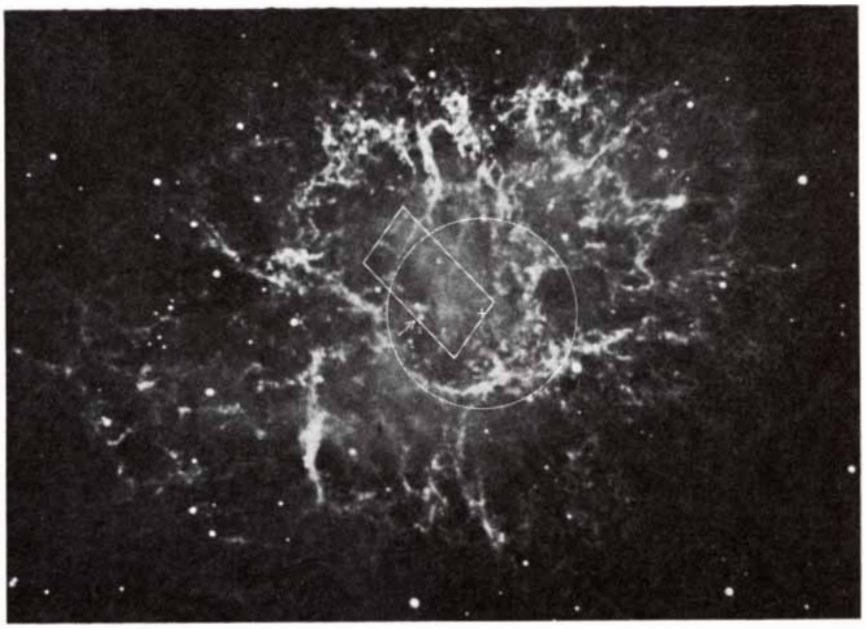


MOON CAN HELP TO MAP X-RAY SOURCES that have a very small angular diameter if the source happens to lie in the path of the moon as it is seen from the earth. The Crab Nebula is one such source. It is occulted, or eclipsed, by the moon approximately every 10 years. The occultation takes only a few minutes, but it happens several times during each occultation "season." As moon progressively covers (or uncovers) the face of the nebula, moving from west to east (right to left), amount of X-ray emission received is monitored with respect to time. Data, when combined with information about the moon's position and motion, yield extremely accurate information about the distribution of X rays in nebula.

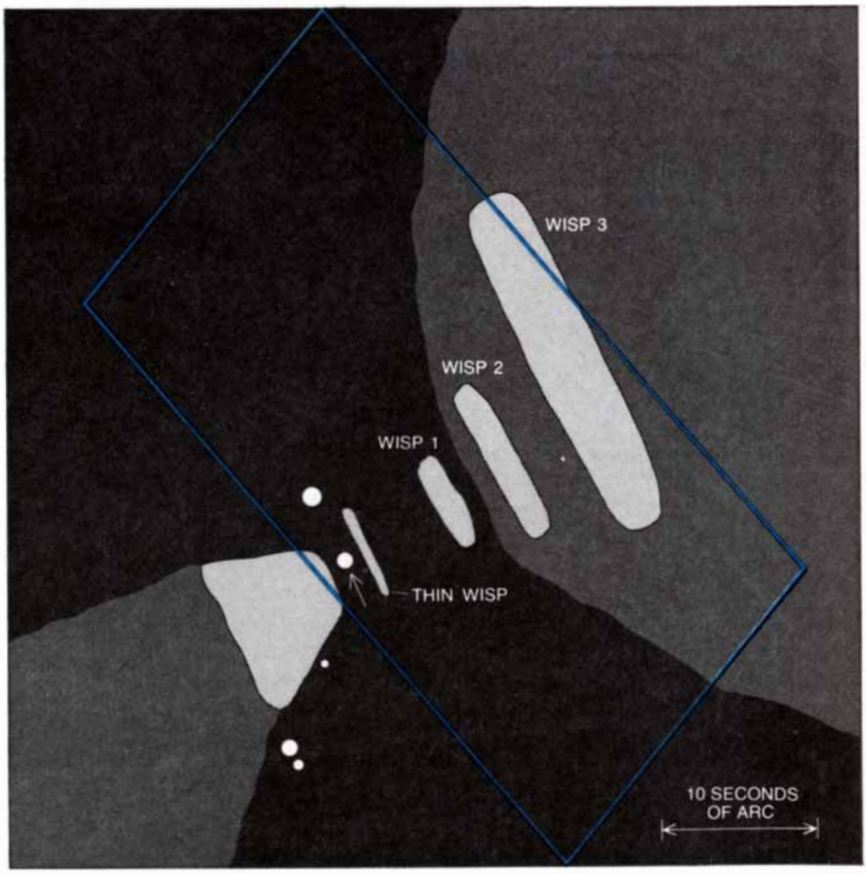
energies. The satellite provides a highly stable platform that makes it possible to point the X-ray telescopes with an angular precision of better than one second of arc. The field of view of each telescope can be altered by command from the ground so that it can cover an area of sky with a diameter ranging from as little as one minute of arc to as much as 12 minutes. Hence both compact X-ray objects and extended sources can be mapped.

Among the supernova remnants we have studied with the *Copernicus* X-ray telescopes is the young remnant Cassiopeia A. This object was found in the 1940's to be a strong radio source; later it was found to be an X-ray source as well. It has an angular diameter of approximately five minutes, a sixth the apparent diameter of the moon. We mapped it with the telescopes' field of view limited to three minutes of arc [*see illustration on page 40*]. Cassiopeia A is the remnant of a supernova that was not observed on the earth. The light of the supernova's explosion would have reached the earth, however, about 1700, not too long after Tycho's nova of 1572. Although we have not made an X-ray map of the remnant of Tycho's nova, both Cassiopeia A and the remnant of Tycho's nova have a very similar structure in the radio region of the spectrum. The structure of these two young remnants differs markedly, however, from the structure of the Crab Nebula, particularly because of the absence of a central source of electrons such as a pulsar. Recent calculations by Steven Gull of the University of Cambridge suggest that the structure of such young remnants could have been created by the shock wave from the original supernova explosion passing through the interstellar medium in the following way.

After a supernova explodes, the ejected material expands through the interstellar medium, sweeping up the low-density dust and gas in its path. The expanding shell therefore accumulates more material and begins to slow down. After about 100 years the amount of material swept up by the shell is approximately equal to the amount initially ejected, and the material at the leading edge of the shell is decelerating at a significant rate. The material behind it is still moving quickly through the more rarefied region swept clean by the leading edge. As the fast material enters the denser shell from behind it will be slowed down suddenly, heating the gas in front of it and forming a second shock front behind the dense shell. As the second shock front slows down it will ap-



CENTER OF X-RAY EMISSION (+) does not coincide with the position (*arrow*) of the pulsar (a rapidly rotating neutron star) in the Crab Nebula, as revealed by the lunar-occultation mapping technique. Circle encloses the volume of the nebula that is emitting relatively low-energy X rays; it has a diameter of 73 seconds of arc and is substantially smaller than the visible nebula. The parallelogram is a region that emits particularly hard X rays.



ENERGETIC X RAYS ARE EMITTED FROM WISPS OF GAS in the Crab Nebula, as is shown in this enlargement of the parallelogram from the illustration above. Center of X-ray emission is displaced to the west of pulsar (*arrow*) and is relatively close to one of the wisps of gas (*Wisp 2*) that is very bright in visible light. Sudden changes in pulsar's rotation rate are observed to induce even more activity in the wisps. Evidently electrons ejected from the pulsar are further accelerated in wisps and emit X rays by synchrotron process.

OBJECT	AGE (YEARS)	DISTANCE (LIGHT-YEARS)	DIAMETER (LIGHT-YEARS)	ANGULAR DIAMETER OF X-RAY EMISSION (MINUTES OF ARC)	EVOLUTIONARY PHASE	X-RAY BRIGHTNESS BETWEEN 2 KeV AND 6 KeV (CRAB NEBULA = 1,000)	NOTES
CASSIOPEIA A	300	9,100	15	5	1–2	60	—
REMNANT OF TYCHO'S NOVA	400	9,800	20	7	1–2	10	NO X-RAY MEASUREMENTS HAVE BEEN MADE TO DETERMINE REMNANT'S SPATIAL STRUCTURE
CRAB NEBULA	900	6,500	3	2	1–2	1,000	PULSAR NP 0532 IS PRESENT IN NEBULA
PUPPIS A	4,000	7,200	55	25	2	8	—
VELA X	10,000	1,600	130	300	2–3	10	PULSAR PSR 0833 − 45 IS NEARBY
CYGNUS LOOP	20,000	2,500	120	170	2–3	—	EMITS NO X RAYS ABOVE THE ENERGY OF 1 KeV
IC 443	60,000	5,000	70	50	2–3	5	PULSAR PSR 0611 + 22 IS NEARBY

CHARACTERISTICS OF SUPERNOVA REMNANTS are summarized in order of increasing age of the remnants. The evolutionary phase refers to the phase in the evolution of the remnant suggested by the authors and illustrated on the opposite page. The X-ray brightness of each remnant is given in terms of the energy received between the energies of 2,000 and 6,000 electron volts. The Crab Nebula radiates far more energy than the two remnants that are much younger; clearly the object, with its central pulsar ejecting electrons into the nebula, radiates its X rays by a process much different from that by which the other remnants radiate.

pear to be moving inward with respect to the first; hence it is referred to as a "reverse" shock wave. The hot gas of the dense shell continues to be decelerated by the even hotter interstellar material immediately in front of it, which has just been heated by the front of the shock wave. It becomes unstable and in many places breaks up into filaments. This phenomenon could well account for "knots" that are observed in the radio structure of Cassiopeia A [*see illustration on page 41*].

Our X-ray map does not have sufficient resolution to show the details of the relations between the X-ray features and the radio ones, or to show whether or not there are features in the X-ray region of the spectrum that correspond to the knots observed at radio wavelengths. The detailed determination of the X-ray structure of Cassiopeia A must wait until imaging X-ray telescopes are available that have a resolution of seconds of arc. Nevertheless, even the crude comparison that is currently possible provides initial evidence that the X rays are emitted by shock-heated gas and not by high-energy electrons spiraling in magnetic fields.

Further evidence that this hypothesis is essentially correct is provided by studies of the X-ray spectra of remnants such as Cassiopeia A and the remnant of Tycho's nova. Although the proportional counters at the focus of the X-ray telescopes on *Copernicus* cannot resolve individual emission lines, the data gathered on Cassiopeia A can be roughly compared with the spectra one would expect from a hot gas on the one hand or from synchrotron radiation on the other. The comparison suggests that the X rays are being emitted not by the synchrotron process but by two volumes of hot gas at different temperatures [*see top illustration on page 46*]. Furthermore, Alan N. Bunner of the University of Wisconsin and his co-workers have combined high-energy X-ray data from the *Uhuru* X-ray satellite with measurements obtained at lower X-ray energies from a detector carried aloft by a sounding rocket; their observations of the remnant of Tycho's nova indicate the presence of gas at different temperatures.

A definitive test for the presence of hot gas would be provided by an instrument that could resolve individual emission lines in the X-ray spectrum, such as a Bragg crystal spectrometer. The density of the gas in a supernova remnant is low enough for the emission lines characteristic of a gas at a high temperature to escape from the emitting region without being absorbed by surrounding cooler gas. Although a few such experiments have been undertaken, the efficiency of crystals in diffracting the X rays into a spectrum is low, and no positive results have yet been obtained. Efforts along these lines are continuing, and since it does seem likely on the basis of the existing data that the X rays are being emitted by hot gas, emission lines should eventually be detected even where the remnants are younger than the Crab Nebula.

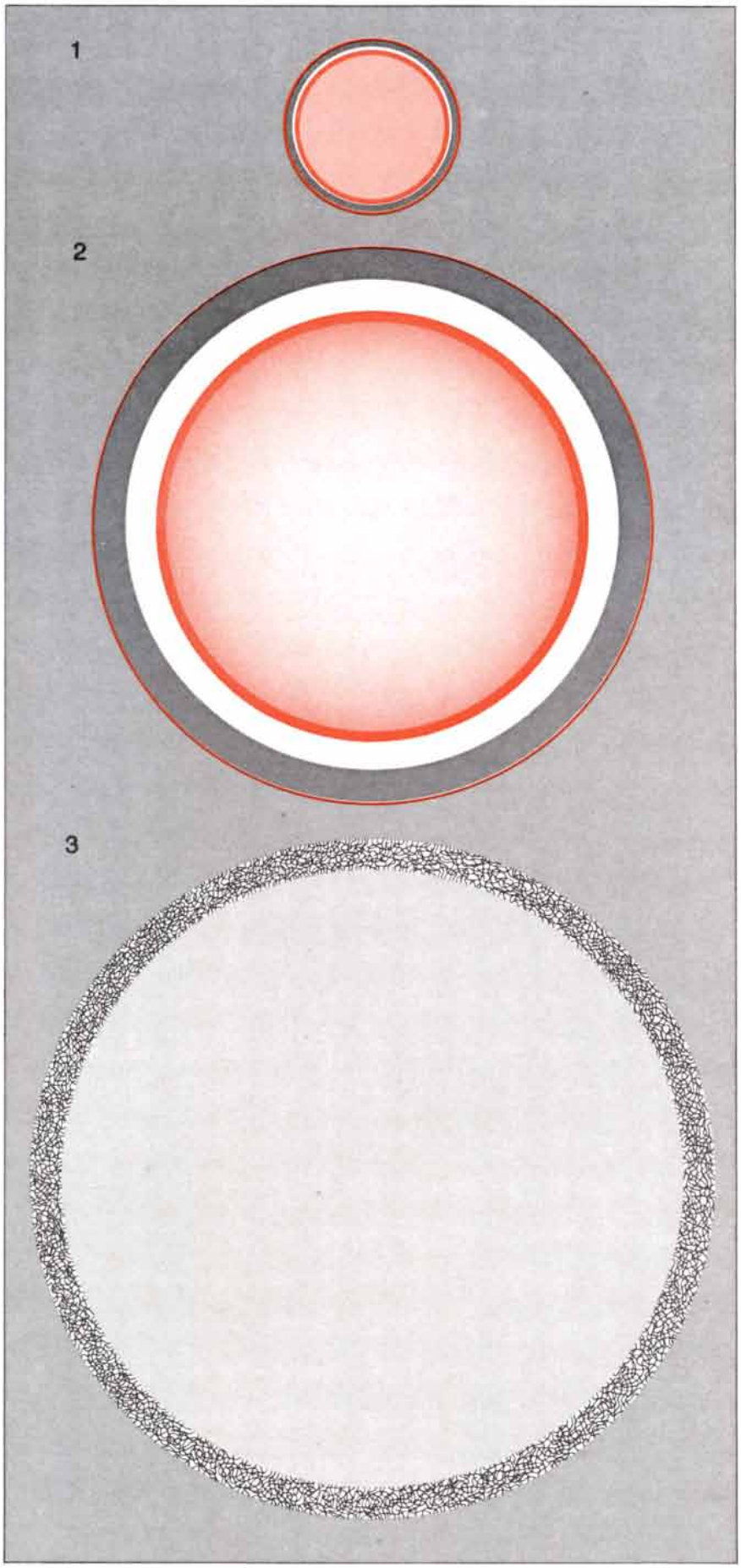
Toward the end of the evolution of a supernova remnant the mass of gas swept up from the interstellar medium and heated by the expanding shock front is very much larger than the mass of gas ejected in the original explosion. At this point the temperature of the material behind the first shock wave has cooled to less than 10 million degrees Kelvin. At that temperature there is little doubt that X rays will be emitted by the hot interstellar gas and not by the synchrotron process. Some electrons are still trapped in the interstellar magnetic fields that have been compressed by the shock wave. Although the electrons are not capable of generating X rays by the synchrotron process, they can still radiate by that process in the lower-energy radio region of the spectrum.

Older supernova remnants have been recognized as extended radio sources for some time, but it was largely through the work of Seward and his colleagues that extended X-ray emission from such objects was first identified. Some of the nearby old remnants such as the Cygnus Loop have a diameter of several degrees; studies of these objects with a detector having the small field of view characteristic of the X-ray telescopes on the *Copernicus* satellite would require prohibitively large amounts of observing time. An X-ray map of the Cygnus Loop has been made by Saul A. Rappaport and his co-workers at M.I.T. They painstakingly put it together from a series of scans of the nebula made by a rocket-borne large-area detector whose field of view was a tenth of a degree.

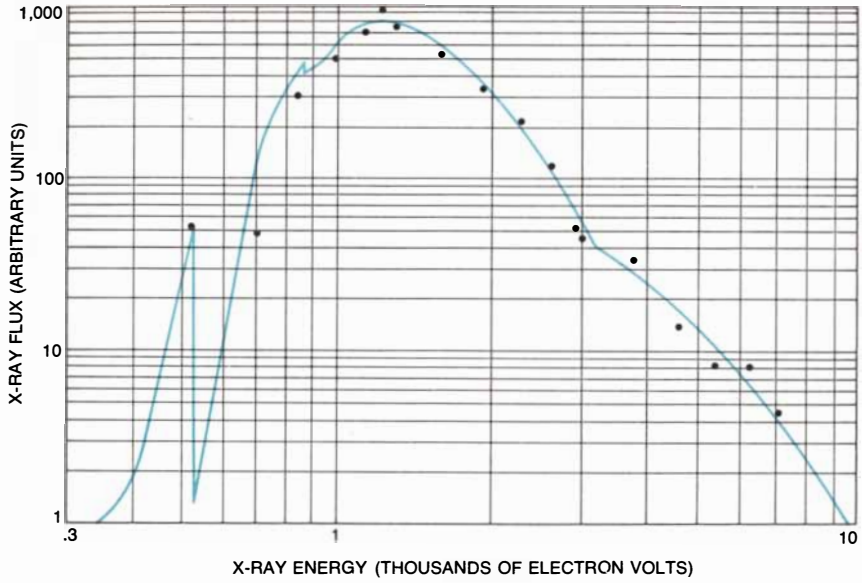
In the 20,000 years that have passed since the Cygnus Loop was originally created, the remnant has expanded to a diameter of more than 100 light-years. The gas behind the first shock front has cooled to a temperature of between two

million and three million degrees K. No trace of the material ejected in the explosion remains. Therefore the nonuniform structure of the X-ray-emitting regions reflects the existence of nonuniformities in the interstellar gas. If the density of the gas in the interstellar medium were uniform, then there would be no detectable X-ray emission from the expanding shock wave of the Cygnus Loop. That is because the velocity of the shock wave, as it is measured from spectroscopic observations of the visible filaments, seems to be too low to heat a gas to a temperature high enough for the production of X rays.

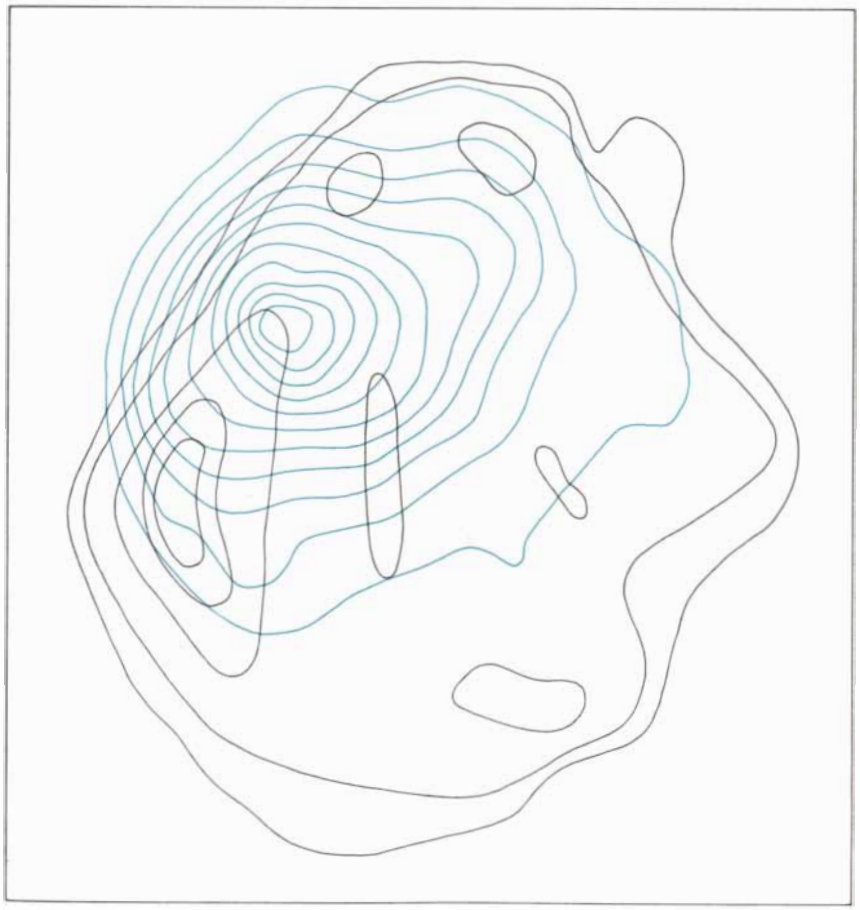
It is well known, however, that the medium between the stars of our galaxy is characterized by clouds of gas and dust. When the expanding shock wave from a supernova reaches such a cloud, it encounters a gradient in the density of the gas. Working with an X-ray map of the Cygnus Loop rather similar to the one obtained by the M.I.T. group, Gordon P. Garmire and his colleagues at the California Institute of Technology have shown that a hot, thin shell of gas can be formed when a shock wave of relatively low velocity encounters a dense cloud. On the basis of Garmire's calculations one can conclude that the bright areas of X-ray emission on the map correspond to regions of high gas density in the interstellar medium. In those areas where the gas density is uniform and



EVOLUTION OF A REMNANT of a supernova is depicted at three stages. Ten years after the initial explosion (*1*) the shock wave (*solid color*) is still freely expanding through the interstellar medium (*light gray*) at a speed of some 15,000 kilometers per second. At this point the amount of interstellar material swept up by the shell (*dark gray*) is insignificant compared with the amount of ejected gas; thus the ejecta form only a thin shell (*light color*) just behind the initial shock wave. After approximately 100 years (*2*) the amount of material swept up is comparable to the amount initially ejected, and the material has decelerated the shock wave to a velocity of about 8,000 kilometers per second. High-velocity ejecta catch up with the shell and form a "reverse" shock wave (*dark color*) that is separated from the initial one. Between 10,000 and 20,000 years later (*3*) expanding shell of nebula has lost a great deal of energy by radiation from hot material and is slowed to a velocity of 500 kilometers per second. Temperature of the initial shock wave has fallen to below five million degrees Kelvin, and gas is primarily emitting soft X rays. At this point remnant may be 100 light-years across and outer shell is broken up into filaments.



X-RAY SPECTRUM OF CASSIOPEIA A that would be expected from theory if the remnant is composed of hot gas at two different temperatures (eight million and 30 million degrees K.) is given by the solid line. Observations of actual spectrum obtained from *Copernicus* are shown as dots. Hotter gas is in the initial shock wave and cooler gas is in the reverse shock wave. Sharp dip to the left is due to absorption by interstellar oxygen.



X-RAY AND RADIO MAPS OF PUPPIS A are superposed to illustrate how the bright features in different regions of the spectrum are not aligned. The important point is that the region emitting X rays (*color contours*) is smaller than region radiating radio waves (*black contours*) and may represent original shock wave encountering a dense interstellar cloud.

low the X-ray emission is weak or nonexistent.

Another possible example of an encounter between a supernova shock wave and an interstellar cloud can be seen in a comparison of X-ray and radio maps of the supernova remnant Puppis A [*see bottom illustration at left*]. It is clear that the bright X-ray features do not coincide with the bright radio features. The intense X-ray emission may well have arisen when the expanding shock wave encountered an interstellar cloud. The edge of the X-ray-emitting region and the boundary of the shock wave appear, however, to be separated in the areas where the temperature of the gas is not high enough to give rise to X rays.

Still another example of a nonuniform distribution of X-ray emission can be seen in the old remnant IC 443. A comparison of observations from *Copernicus* and from the seventh Orbiting Solar Observatory (OSO-7) suggests that essentially all the X-ray emission comes from one intense knot of filaments. Other observations suggest that there is a dense interstellar cloud in that sector of the remnant. Therefore the localization of the X-ray emission arises from the supernova shock wave's interacting with the gas in the cloud. Hence by making X-ray maps of old supernova remnants we can study the density structure of interstellar clouds. Moreover, by examining the X-ray spectra of the remnant in detail we should be able to secure direct information about the abundances of the elements in the interstellar medium.

In only a few years observations of the X-ray emission from supernova remnants have transformed our understanding of those objects. Although the pulsar in the Crab Nebula remains unchallenged as the power source for the entire object, the X-ray maps strongly suggest that the electrons are accelerated again in the body of the nebula away from the pulsar. Moreover, young remnants such as Cassiopeia A and the remnant of Tycho's nova seem to comprise large amounts of hot gas radiating X rays, contradicting earlier suggestions that the X rays were emitted by the synchrotron process. Further studies of those young objects will enable us to examine the precise nature of the interaction of the material ejected in the original explosion with the surrounding interstellar gas. Finally, the X-ray maps of the old remnants are beginning to tell us a great deal about the structure of the interstellar medium at considerable distances from the site of the original supernova.

The factory, 1889

Pleased users, 1975

Glass Photographic Plates

Still making them. Need any?

Bill Miller, the man at right above, has not been the easiest customer to please. Never made much money on him, but he sure has brought out the best in us. Just retired from Hale Observatories, where they use a plate camera with a 200-inch aperture to take pictures for an odd reason: mere curiosity about how the universe is constructed.

In an observatory as in a toothpick factory (or photographic materials factory), one must quit dwelling on the ultimate purpose of the work and get on with it, despite conditions that prevail. At most observatories, these include the fiscal status of old, one-of-a-kind peripheral equipment that still handles glass plates satisfactorily and could be adapted to film only at the expense of much time away from the work fighting off other claims on the necessary funds. Compared with this, dimensional stability is a lesser reason astronomers want us to continue coating emulsions for them on glass.

Demand for astronomical emulsions, urgent though minuscule, has not slackened despite the triumphs of radio astronomy, x-ray astronomy, and electronic detectors for what lies between those domains. The deficiencies of the photographic emulsion in temporal resolution might have to take the blame for delaying acquaintance with pulsars, but in spatial resolution and breadth of view the advantages of direct photography still hold. Truth to tell, emulsion technology has not stood still. Some things we have learned in recent years about making the most of weak trickles of photons on silver halide have, in effect, tripled the apertures of the world's telescopes.

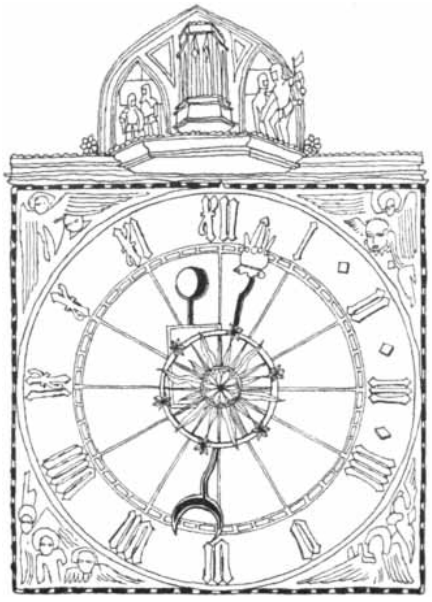
* * * *

Photographic emulsions on glass also serve the needs of mask-making for integrated circuits (very tiny images, very big business), of mapping from aerial photography (flatness), of transmission electron micrography (no outgassing from the base), of holography (rigidity), and of sundry other scientific, technical, and artistic endeavors on equipment designed in simpler times and still working just fine.

If this brings all sorts of questions to mind, please do not ask them before carefully studying Kodak Publication No. P-140, "Characteristics of KODAK *Plates for Scientific and Technical Applications," available on request from Dept. 412-L, Kodak, Rochester, N.Y. 14650. Perhaps you should also request Kodak Publication No. P-29, "*KODAK *16 mm, 35 mm, and 70 mm Films." Film does have its advantages. There was a good reason we changed our name the day before Christmas of 1889.*

Kodak

SCIENCE AND THE CITIZEN



The Nobel Prizes

The 1975 Nobel prizes in science were awarded to three biologists for discovering how viruses interact with the genetic material of the cell, to three physicists for experiments and theories that clarify the architecture of the atomic nucleus, to two chemists for researches on the architecture of organic molecules and to two economists for developing mathematical tools for optimizing the allocation of resources. Each of the four prizes carries with it a cash award of $143,000, to be divided among the recipients in each category.

The prize in physiology or medicine was shared by David Baltimore of the Massachusetts Institute of Technology, Renato Dulbecco of the Imperial Cancer Research Fund in London and Howard M. Temin of the University of Wisconsin. The careers of the three men have been closely linked. After studying medicine and physics in Italy, Dulbecco came to the U.S. in 1947 and worked in the laboratory of Salvador E. Luria at Indiana University. Thereafter he worked for many years at the California Institute of Technology and then at the Salk Institute before moving to London. Dulbecco has developed model systems in which animal tumor viruses are used to transform normal cells into cancer cells in vitro (see "The Induction of Cancer by Viruses," by Renato Dulbecco; SCIENTIFIC AMERICAN, April, 1967). He has emphasized that the value of the model systems is that they enable one to examine the earliest steps by which a cell becomes cancerous; they do not demonstrate that human cancer, in its many forms, is necessarily of viral origin.

Temin was a doctoral student under Dulbecco at Cal Tech. While he was working with an animal virus whose genome, or complete set of genes, consists of RNA rather than DNA, he came to suspect in the early 1960's that the viral RNA was transcribed into DNA inside infected cells. In this way a piece of DNA equivalent to the viral RNA could be incorporated into the DNA genome of the infected cell and replicated with it when the cell divided. Temin's suggestion ran counter to the prevailing belief that RNA could be copied only into other RNA and that DNA alone could give rise to DNA. Convinced of his hypothesis, Temin began searching for an enzyme capable of transcribing RNA into DNA. When he found the enzyme in 1970, he learned that it had been independently discovered by Baltimore. The two papers announcing the discovery were published in the same issue of *Nature*. The enzyme is called RNA-directed DNA polymerase or sometimes reverse transcriptase (see "RNA-directed DNA Synthesis," by Howard M. Temin; SCIENTIFIC AMERICAN, January, 1972).

Baltimore, who worked for three years with Dulbecco at the Salk Institute, has made many important findings on the way viruses, particularly poliomyelitis and meningitis viruses, attack mammalian cells. He was the first to discover, for example, that the RNA genome of the poliovirus is originally translated into a single giant protein, actually a polyprotein, that is subsequently disassembled into biologically active smaller proteins (see "The Molecular Biology of Poliovirus," by Deborah H. Spector and David Baltimore; SCIENTIFIC AMERICAN, May).

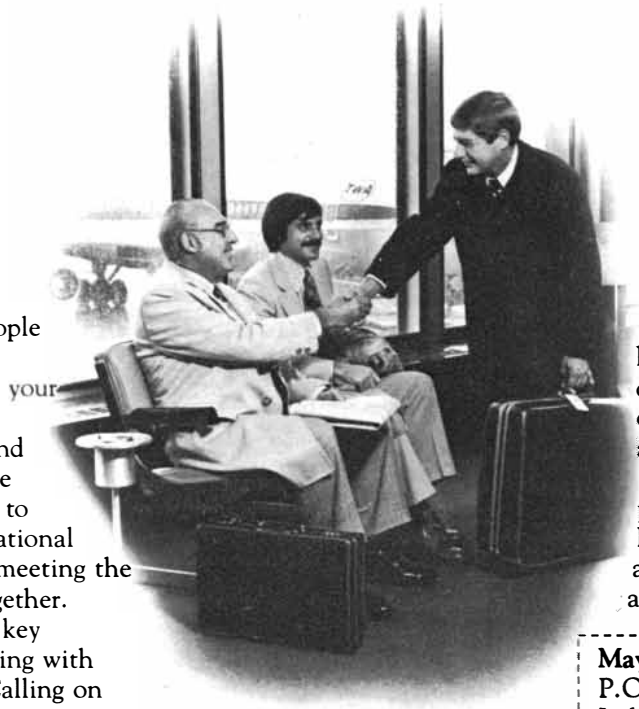
The prize in physics was awarded to James Rainwater of Columbia University, Aage Bohr of the Niels Bohr Institute in Copenhagen and Ben Mottelson of the Nordic Institute for Theoretical Atomic Physics, also in Copenhagen. In the late 1940's Rainwater discovered experimentally that the electric quadrupole moment of certain atomic nuclei was as much as an order of magnitude larger than the value predicted by the spherical-shell model of the nucleus (for which Maria Goeppert-Mayer and J. H. D. Jensen received a Nobel prize in 1963). This result suggested that some nuclei are ellipsoidal rather than spherical. Rainwater therefore proposed an aspherical model of the nucleus. Bohr and Mottelson refined Rainwater's proposal into a comprehensive mathematical model showing how nucleons (protons and neutrons) circulating in the outer shell of an atomic nucleus can give rise to systematic distortions in the shape of the nucleus as a whole. Their analyses show that certain deformed nuclei ("hard" nuclei) hold their shape and rotate, whereas others ("soft" nuclei) tend to vibrate.

The prize in chemistry was given to John Warcup Cornforth, director of research of the Milstead Laboratory of Chemical Enzymology in Sittingbourne, England (supported by Shell Research, Ltd.), and Vladimir Prelog of the Swiss Federal Institute of Technology in Zurich. A student of Sir Robert Robinson of the University of Oxford, who won the Nobel prize for chemistry in 1947, Cornforth has specialized in the synthesis of naturally occurring steroid molecules such as cholesterol and cortisone. After demonstrating their synthesis by the "brute force" laboratory methods of organic chemistry, he determined to uncover the subtler methods by which they are synthesized in living cells. In a series of papers he described the enzyme systems and the chemical steps the cell uses to synthesize the 27-carbon compound cholesterol from the two-carbon starting material acetic acid.

Prelog, who was born in Sarajevo in what is now Yugoslavia, received his doctorate from the University of Prague and spent several years as an industrial chemist before joining the faculty of the University of Zagreb. With the German invasion of Yugoslavia in 1941, he moved to Zurich. Prelog is well known among chemists for elaborating a general theory of stereochemistry, drawing on a lifetime of work on the geometry of organic molecules. He has been a pioneer in defining the structure of medium-size molecular rings, with from eight to 12 carbon atoms, which are much more flexible and harder to study than the six-member ring of the benzene molecule.

The Nobel prize in economics was given to Leonid V. Kantorovich of the Institute of Economic Management in Moscow and Tjalling C. Koopmans of Yale University. The two men worked independently on the application of the analytical technique later known as lin-

The Mayflower approach to international complications.



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ear programming to the economic problem of allocating resources. Kantorovich took the first theoretical steps in 1939 and over the years expanded his ideas in a number of publications, including his most widely known work, *The Best Use of Economic Resources.* During World War II, Koopmans applied the basic ideas of linear programming to the optimization of the scheduling of Allied ship convoys. After the war refined mathematical techniques of linear programming were developed by George B. Dantzig, who is now at Stanford University. Koopmans, an econometrician, is credited with seeing the broad implications of linear programming for a wide range of classical economic problems involving the market, prices and the allocation of resources. The modern applications of linear programming have been made possible by the computer.

An Accelerating Universe?

Fifty years ago the American astronomer Edwin P. Hubble demonstrated the remarkable fact that the universe is expanding: distant galaxies are moving away from us and from each other, and the more distant they are, the faster they are receding. In the cosmological theories prevailing today this expansion is attributed to the momentum imparted to all matter in the "big bang" some 15 or 20 billion years ago. It is implicit in almost all such theories that the expansion must be slowing down, but now James E. Gunn of the Hale Observatories and Beatrice M. Tinsley of Yale University have presented arguments showing that the rate of expansion may be increasing.

The requirement that the expansion of the universe be decelerating is based on the assumption that gravitation is always an attractive force. When a ball is thrown into the air, its upward velocity decreases from the time it is released; even if the ball could be thrown hard enough to escape the earth's gravitational attraction, it would decelerate continuously as it moved away. By the same reasoning it has generally been assumed that the gravitational forces between the galaxies must slow their recession from one another. A major question of cosmology has been whether those forces are sufficient to halt the expansion and eventually initiate a cycle of contraction (as when the ball falls back to the earth) or whether the expansion must continue forever (as when the ball escapes).

Writing in *Nature,* Gunn and Tinsley reexamine an entire class of models of the evolution of the universe. They argue that the most recent observational data, compiled by Gunn and J. B. Oke, also of the Hale Observatories, exclude all models that lead to eventual collapse; the universe must expand forever. Indeed, in all the models that fit the data closely the expansion is accelerating.

Their calculations establish several additional properties of the universe. It must be "closed" but unbounded, that is, the curvature of space must be positive, analogous to that of a sphere. The acceptable models also imply that the average density of matter in the universe must be greater than earlier estimates suggested, although it would still be much too small to bring about gravitational collapse.

For the expansion of the universe to be accelerating, the net forces between galaxies must be repulsive. Even though that result contradicts the observed properties of gravitation, it can be incorporated into the general theory of relativity. It requires that a term be inserted into the equations that describe the gravitational field, a term called the cosmological constant. The term was first employed by Einstein in 1917 to predict a static universe, and it has appeared in a few other models since then. In general, however, cosmologists (including Einstein) have endeavored to eliminate it from their theories. The physical meaning of the constant is unclear, and it diminishes the elegance of the general theory; Gunn and Tinsley note that as a result many investigators find the constant itself as repulsive as the forces it generates.

Because the prediction of accelerating expansion is contrary to expectation, Gunn and Tinsley conclude that the first reaction to their work is that "something must be terribly wrong." They go on to discuss possible sources of error in their data and in their interpretation of those data. One possibility is that they have overestimated the distances of galaxies. The distance estimates are based on measurements of luminosity, and it has recently been suggested that luminosity may change if large galaxies commonly "eat" smaller ones. The magnitude and even the direction of the change are unknown, however, and only further observation will determine whether or not this or any other possible error could change the outcome of the calculations.

Lifesaving Punch

The list of first-aid procedures that the medical profession encourages laymen to undertake is short because of the profession's concern that tactics applied in ignorance may do more harm than good. Now, however, the Commission on Emergency Medical Services of the American Medical Association has cautiously endorsed the "Heimlich maneuver" as a first-aid procedure when someone is choking on a foreign object. The maneuver is described by Henry J. Heimlich, the Cincinnati surgeon who developed it, in *The Journal of the American Medical Association,* which also publishes the commission's statement.

In the Heimlich maneuver you put the thumb side of your fist or the heel of your palm against the victim's upper abdomen, between the navel and the bottom of the rib cage, and make a quick upward thrust. The action elevates the diaphragm, thereby compressing the lungs and forcing air up through the trachea. The air expels the foreign object. Heimlich recommends the fist method if the victim is standing or sitting; get behind him and wrap your arms around his waist, so that you can apply the strength of both arms to the upward thrust. If the victim has collapsed, put him on his back, kneel astride his hips, put the heel of your palm against his abdomen and then push upward with both hands. Repeat several times if necessary. If you are the victim, use the fist method on yourself.

Heimlich writes that since he first described the technique he has heard of 162 people whose lives were saved by the maneuver and that "no instance has been reported where the maneuver was not successful." Since an observer may think a person who is choking is having a heart attack, Heimlich recommends that "the victim grasp his neck between thumb and index finger of one hand" as a universal signal that he is choking.

Best Friend

The oldest-known fossil of the domesticated dog was until recently one excavated some 10 years ago at Jaguar Cave in Birch Creek Valley, Idaho. It is estimated to be 11,000 years old; the animal had presumably accompanied one of the bands of Old World hunters who were then entering the New World from Asia. At the same time that the Jaguar Cave fossil dog was being identified as a domestic animal, however, a competitor for the title of the oldest domesticated-dog fossil, excavated in Iraq in the 1950's, was traveling a parallel route through the identification machinery.

The specimen from Iraq, a jaw with teeth, was unearthed in a cave at Palegawra in the course of an expedition di-

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Good use of photography makes the most of a good project —even if you have to make your own camera.

Elizabeth Davis, junior at Commerce (Texas) High School, daughter of musicians, did just that. Her project impressed the regional judges enough to send her to the 1975 International Science and Engineering Fair, where we laid further honors and a little cash on her for her photography, to say nothing of her science. She extracted Eocene pollens from an open-pit quarry, and her beautiful side-by-side color photomicrographs compared them with pollens she collected from living plants. No difference in pollens.

rected by Robert W. Braidwood of the University of Chicago. During the 1960's it was sorted from among hundreds of other fossils brought from Palegawra to the U.S. for study by its excavator, Bruce Howe. A colleague, Charles A. Reed of the University of Illinois, identified the fossil as belonging to the genus *Canis*. The jaw was next referred to Barbara Lawrence of Harvard University, a student of canine origins who had earlier identified the Jaguar Cave dog as a domesticated species. Lawrence came to the same conclusion with respect to the Palegawra cave jaw.

The fossil had been found less than two feet below the cave floor, however, and it was possible that it was a modern bone accidentally buried there. The jaw was therefore sent to the British Museum (Natural History) for an estimate of its true age by the museum's specialists in fluorine analysis. (Buried bones accumulate fluorine from groundwater at a predictable rate.) The age estimate was completed last year; it coincides with the time when men first occupied the Palegawra cave, about 14,000 years ago.

The determination of age therefore shows that the Iraq dog is some 3,000 years older than the Idaho one. It is strong evidence for the view that the original association between men and dogs had nothing to do with the kind of herding that modern working dogs do. The Idaho dog owners were hunters, not herders, and the Iraq ones lived in their cave at least 3,000 years before the domestication of sheep and goats. Moreover, the original bond between man and wolf that gave rise to the modern commensal relation between man and dog must have been established many generations before the first appearance of the skeletal changes that distinguish *Canis lupus* from the *Canis familiaris* of Palegawra.

Digitalis and the Brain

Digitalis, a preparation of the leaves of the purple foxglove (*Digitalis purpurea*), is an old herbal remedy whose value has been confirmed in contemporary medical practice and explained—but only partly—by pharmacological research. Its efficacy in treating dropsy, or edema caused by congestive heart failure, was reported in the 16th century, and its administration was put on a rational basis at the end of the 18th century by the observations and reports of the English physician William Withering (see "William Withering and the Purple Foxglove," by J. Worth Estes and Paul Dudley White; SCIENTIFIC AMERICAN,

June, 1965). Digitalis has a direct, biochemical effect on heart muscle: it strengthens the muscle's contractions and thereby relieves congestive heart failure. For some time it has been clear that the drug also has indirect, neural effects. A large body of recent research and clinical reports suggests that these neural effects are more important than had been realized, according to an editorial in the journal *Circulation* by Richard A. Gillis of the Georgetown University Schools of Medicine and Dentistry, David L. Pearle of the Veterans Hospital in Washington and Barrie Levitt of the New York Medical College.

The best-known neural effect of the drug is "vagomimetic": it enhances the activity of the parasympathetic nervous system, and specifically of the vagus nerves, which tend to slow the heartbeat and to smooth out certain irregularities in it. Digitalis also sensitizes the receptors in major arteries that detect an elevation in blood pressure and counteract it by signaling the brain to increase vagal output and decrease the output of the oppositely acting sympathetic nervous system; digitalis thus enhances the action of the pressure receptors. Finally, it now appears, digitalis in large doses acts in the brain to stimulate the sympathetic system.

Gillis, Pearle and Levitt point out that direct effects on the heart had been thought to be responsible not only for strengthening contraction but also, at least in part, for slowing the heart rate and controlling irregularities in it. Apparently that is not so. Recent animal experiments suggesting that neural action alone is responsible for those effects of the drug have now been confirmed by studies of human patients with a heart transplant: digitalis does not slow the heartbeat in a transplanted heart, which has no sympathetic or parasympathetic innervation.

Recognition of the large role of the central nervous system in the action of digitalis should improve digitalis therapy and also explain some of the drug's toxic effects, write Gillis, Pearle and Levitt. For example, the response of a patient with a depressed autonomic nervous system to the drug will be different from that of another patient. A patient receiving antihypertensive drugs that depress the sympathetic system may overreact to digitalis. And a serious toxic effect of digitalis, cardiac arrhythmia, can probably be explained by the large-dose effect on the sympathetic system and may therefore be subject to treatment by drugs that depress the central nervous system.

THE ARROW OF TIME

Why does time never go backward? The answer apparently lies not in the laws of nature, which hardly distinguish between past and future, but in the conditions prevailing in the early universe

by David Layzer

It seems easy to distinguish the past from the future: memory provides us with a record of the past, but we have no certain knowledge of the future. When events are interpreted according to the most fundamental laws of physics, however, the distinction between past and future all but disappears. Intuitively we perceive the world as being extended in space but "unfolding" in time; at the atomic scale the world is a four-dimensional continuum extended in both space and time. We assign special significance to a particular moment, the present, which we view as the crest of a wave continuously transforming potentiality into actuality and leaving in its wake the dead past. Microscopic physics gives no special status to any moment, and it distinguishes only weakly between the direction of the past and that of the future.

Our intuitive perception of the world as unfolding in time cannot be dismissed as being merely subjective. It has objective counterparts in a variety of processes, including biological, geological and astronomical ones. There is evidence for it in the physiological processes underlying memory, in the growth, development and differentiation of living organisms, and in organic evolution, where random variation and natural selection have generated an immense and constantly increasing variety of ever more highly organized living forms. The earth's crust records the vicissitudes of 4.5 billion years of evolutionary change, and the cratered surfaces of the moon, Mars and Mercury preserve a chronological record of similar duration. Normal stars, red giants, supernovas and white dwarfs represent stages in the evolutionary life cycle of a single star. Finally, the recession of distant galaxies suggests that the entire universe is a product of an evolutionary process: it seems to have sprung from an exceedingly dense, undifferentiated state in the finite past.

All these processes have a quality in common: they generate order, or information; they transform a simpler state into a more complex one. In the phrase of Sir Arthur Eddington, they indicate which way "time's arrow" is pointing; they define what I shall call the "historical" arrow of time.

Paradoxically, the direction of time can also be defined by a class of diametrically opposite processes: those that destroy information and generate disorder. If I drop a lump of sugar into a cup of hot tea and stir, the spatial concentration of the sugar molecules, the organized motion of the tea and the difference in temperature between the tea and its surroundings represent macroscopic information, or order. As the sugar dissolves and the tea comes to rest and begins to cool, that information gradually disappears. The irreversible processes that destroy macroscopic information (in this example molecular diffusion, viscosity and heat conduction) are manifestations of the second law of thermodynamics. This law states that all natural processes generate entropy, a measure of disorder. The irreversible destruction of macroscopic order defines what I shall therefore call the "thermodynamic" arrow of time.

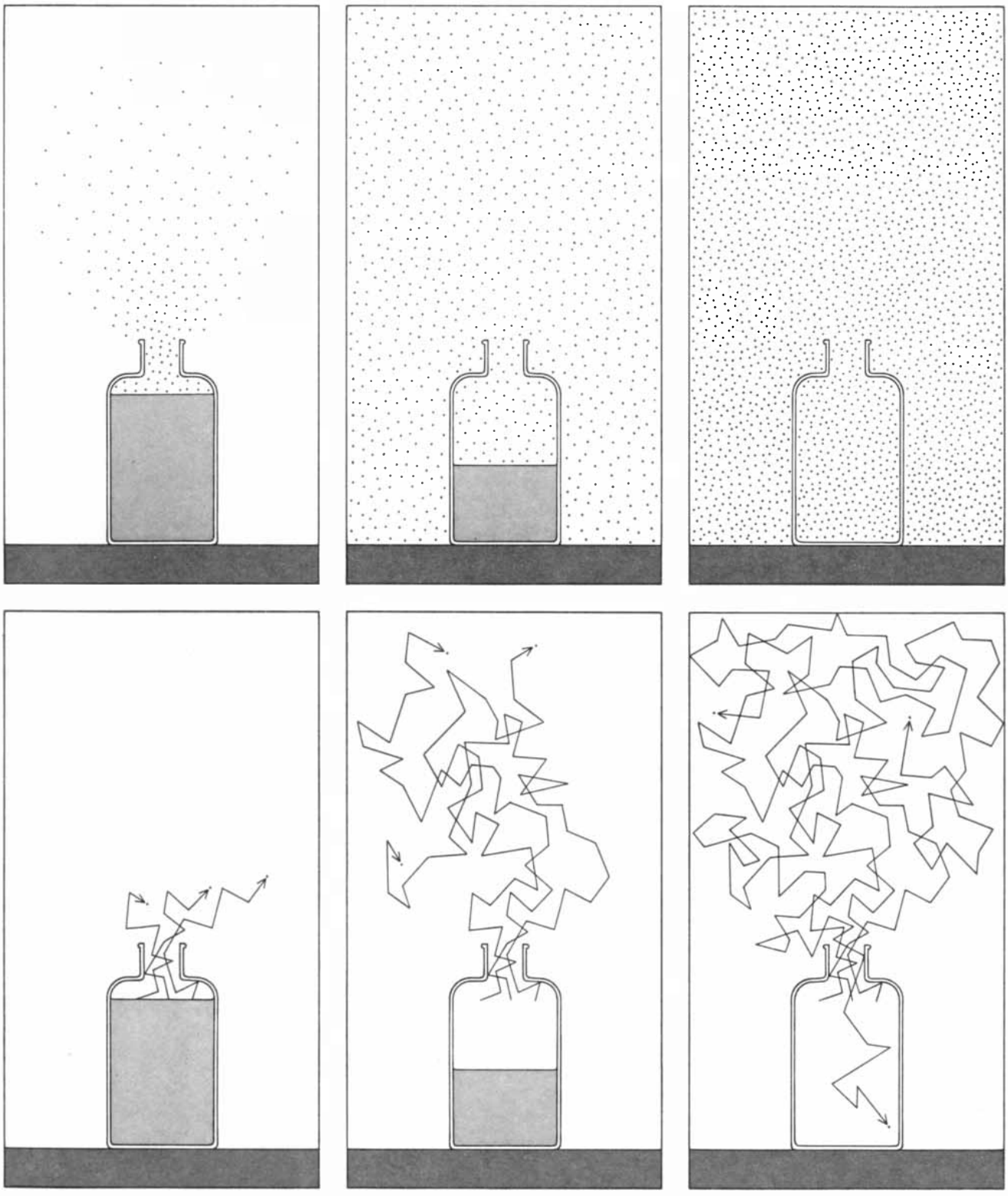
Neither the historical nor the thermodynamic arrow of time can be observed at the microscopic level. The motion of a single sugar or tea molecule generates neither information nor entropy. "Order" is a macroscopic concept, a property of systems made up of many particles; it has no meaning when it is applied to individual atoms or molecules. In the physics of elementary particles the world changes but does not evolve.

I shall argue that neither the macroscopic view of the world as a system degenerating toward complete disorder nor the microscopic view of the world as a changing but nonevolving system of interacting particles and fields is required by fundamental physical laws. I submit that both views derive instead from auxiliary assumptions about the nature and origin of the universe. I propose to replace those assumptions with others that I believe are simpler and equally consistent with observation. The resulting model of the universe, although different from the one accepted by most physicists, resolves the apparent contradiction between the historical and the thermodynamic arrows of time, and it reconciles both with the almost time-symmetric character of physical laws at the microscopic level. The theory implies that the universe is unfolding in time but not unraveling; on the contrary, it is becoming constantly more complex and richer in information.

Irreversibility

The historical and the thermodynamic arrows of time both derive from processes that always have the same direction; they are defined by events that cannot be undone. What makes these processes irreversible? All phenomena can ultimately be described as the interactions of elementary particles; if the laws that govern those interactions do not distinguish between the past and the future, what is the source of the irreversibility we observe in the macroscopic world?

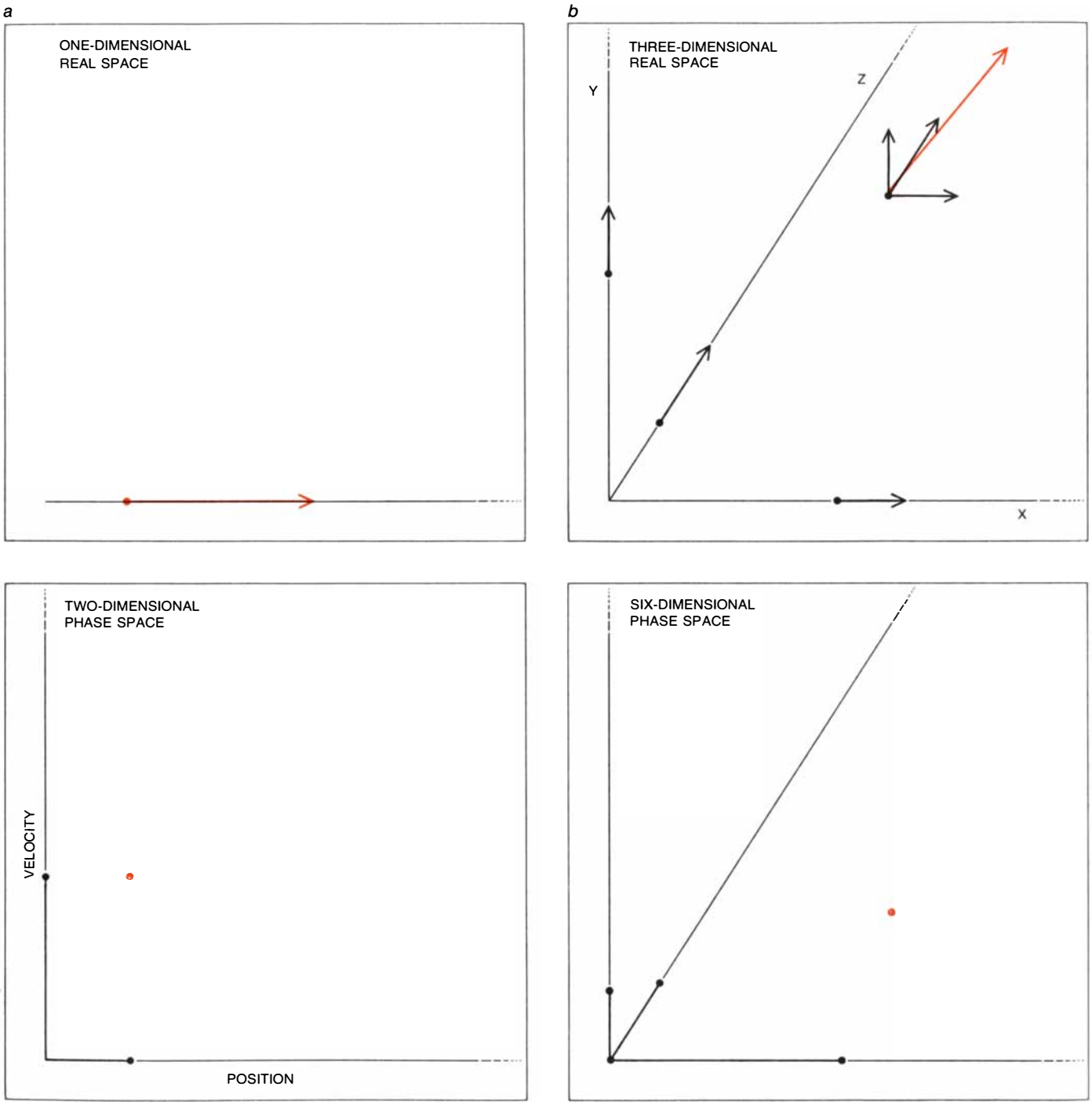
One possibility is that the underlying microscopic laws are not in fact perfectly time-symmetric. Evidence that a temporal asymmetry exists at the level of subatomic particles can be found in the decay of the neutral K meson. One of



THOUGHT EXPERIMENT concerning the diffusion of perfume reveals an apparent paradox: the process as a whole always proceeds in the same direction, but it is defined by microscopic events each of which is freely reversible. The bottle of perfume is opened in a hypothetical sealed room that cannot communicate with the outside world. The top series of drawings, when read from left to right, shows molecules beginning to escape the surface of the liquid and gradually filling the room, until eventually all the perfume has evaporated. When the drawings are read in the opposite direction, they represent a process never seen in nature: all the molecules spontaneously reassemble and condense in the bottle. In the bottom drawings the same experiment is depicted in microscopic detail. Individual molecules escape the surface and follow complicated zigzag trajectories that take them to all parts of the room. This sequence of events could well proceed in reverse order, since if every molecule reversed its direction, they would all retrace their paths and return to the bottle. A molecule following a reversed trajectory would obey all the laws of physics, and indeed it would be impossible to determine by examining the path of a single molecule whether it was part of a forward experiment or a reversed one.

several possible decay modes of that particle seems to violate some symmetry of nature, and the usual interpretation of the event is that the violated symmetry is time-reversal symmetry [see "Experiments in Time Reversal," by Oliver E. Overseth; SCIENTIFIC AMERICAN, October, 1969]. The apparent violation, however, is quite weak: it is observed less than 1 percent of the time. Moreover, *K* mesons are found only in experiments in high-energy physics; they are not constituents of ordinary matter, and they play no role in the macroscopic processes that define the historical and the thermodynamic arrows.

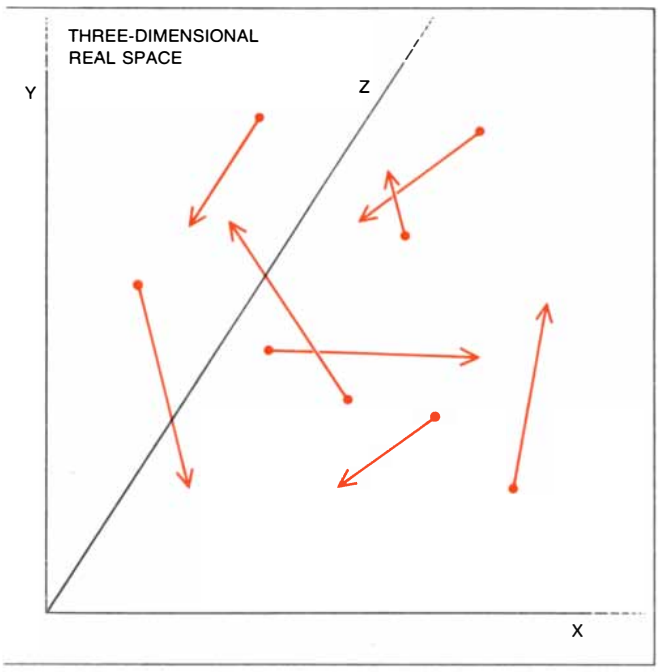
If the root of irreversibility is not to be found in the laws that govern microscopic events, it must derive from constraints on how those events take place. Laws and constraints are complementary as-



CONCEPT OF PHASE SPACE is employed to represent the dynamical state of a system of particles. Any particle can be described by a vector (*colored arrows*), which defines its position and velocity. For a particle in a one-dimensional universe (*a*) two numbers suffice to specify these quantities, and the state of the particle can be represented in a phase space having two dimensions. Every possible state of the particle corresponds to the location of some point in the phase space. A particle with freedom of movement in three dimensions (*b*) requires six numbers for the specification of its state, since both position and velocity have components on three axes. The corresponding phase space must therefore have six dimensions. Since it is not possible to construct a real space with more than three dimensions, the phase space is represented here by a three-dimensional "slice" of the six-dimensional space. In a system made up of many particles six numbers are required to specify the state of each particle, so that the corresponding phase

pects of the physicist's description of nature. Laws describe the regularities underlying phenomena; they are few in number and each applies over a wide domain. Constraints serve to select from the set of all events governed by a given law the particular phenomenon of interest. The laws define what is possible, the constraints what is actual or relevant. The constraints can take the form of initial conditions, boundary conditions or symmetry conditions.

As an illustration of how laws and constraints jointly shape phenomena, consider the motions of the planets in the solar system. From Newton's law of gravitation one could calculate all the past and future positions of the planets, given their positions and velocities at some initial moment. Newton's law explains why each planet moves in an elliptical orbit



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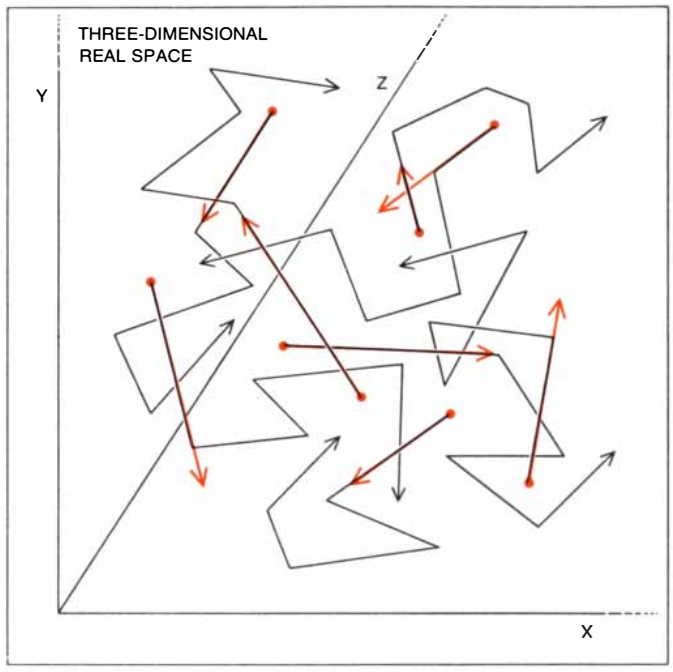
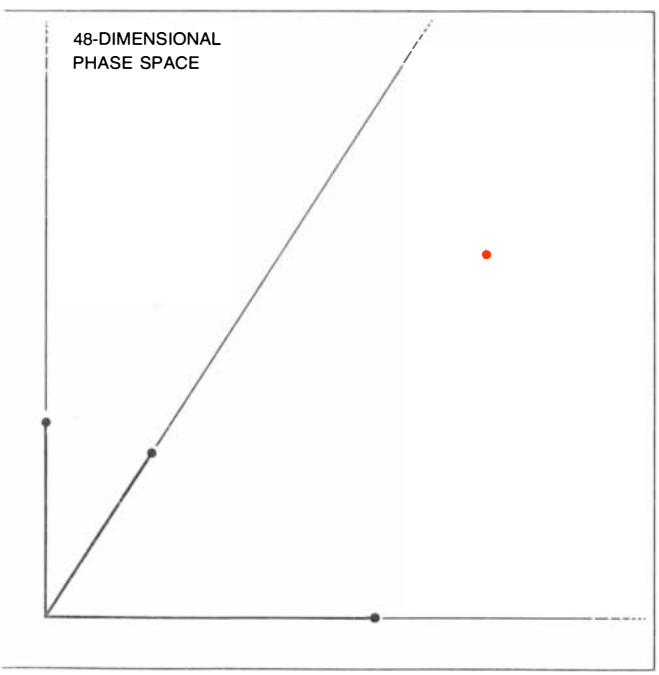
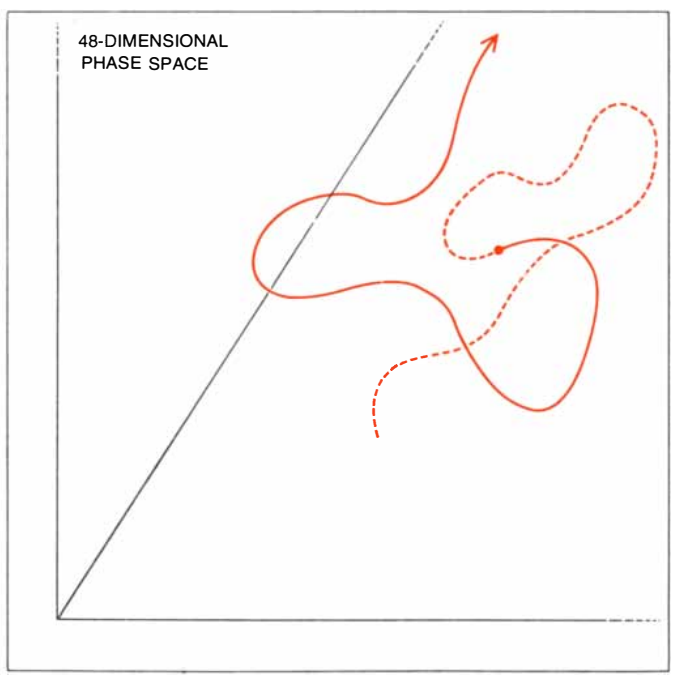
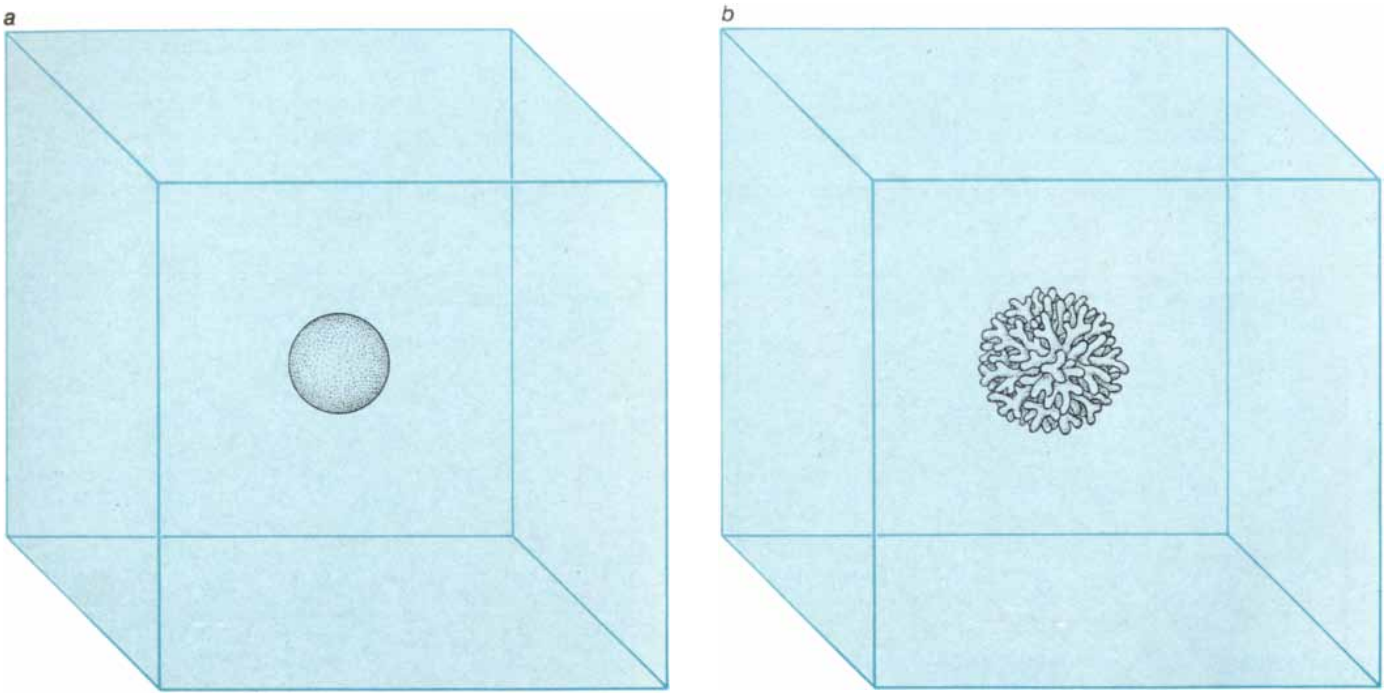






space must have a number of dimensions equal to six multiplied by the number of particles. For example, a system of eight particles (*c*) could be represented by a point in a phase space having 48 dimensions. All the information needed to specify the state is embodied in the location of that single point, and every possible state corresponds to a unique point in the 48-dimensional space. The axes of the three-dimensional slice shown are chosen arbitrarily from among the 48. As a system of particles evolves (*d*), its dynamical state changes, and the change is reflected in the movement of its representative point in phase space. The path of the point in both the past and the future is entirely determined by its initial position, and the dynamical history of the system of particles can therefore be predicted in complete detail. Moreover, the point in phase space can follow the same path in either direction, so that the motions of the particles are fully reversible. Once again three dimensions have been selected arbitrarily from among 48.



PROBABILISTIC REPRESENTATION of a system composed of many particles gives a more realistic portrayal of the system's behavior. Probability is represented by a fluid in phase space; the mass of fluid in any region corresponds to the probability that the point representing the state of the system will be found in that region. In the experiment with perfume diffusion all the probability fluid is initially confined to a small volume, since all the molecules of perfume are confined to the bottle. The form of the fluid is actually a hypersphere having $6n$ dimensions, where n is the number of perfume molecules, but it is represented here by a sphere having

with the sun at one focus, why a line connecting the sun to a planet sweeps out equal areas in equal times and why the squares of the planets' orbital periods are proportional to the cubes of their orbital diameters. It could explain those observations for any planetary system. On the other hand, the law of gravitation does not explain why the orbits of the planets are nearly circular, why the orbital planes nearly coincide or why all the planets revolve around the sun in the same direction. As Newton himself recognized, these regularities must arise from initial conditions.

To explain the regularities we would need a theory of the formation of planets. Such a theory could not supply the detailed initial conditions of the solar system, but it would specify certain statistical properties of the primordial systems from which planetary systems, including our own, have evolved. This theory would itself proceed from particular initial conditions, which would in turn exhibit statistical regularities inviting theoretical explanation at a deeper level. In that way we would be led to formulate a series of increasingly general cosmogonic problems, whose solutions would yield increasingly general explanations of the statistical regularities of the astronomical universe. This hypothetical chain of cosmogonic theories must ultimately terminate in a set of constraints, including initial conditions, for the universe as a whole. It is in those cosmological constraints that we can expect to find the seed of irreversibility.

Information and Entropy

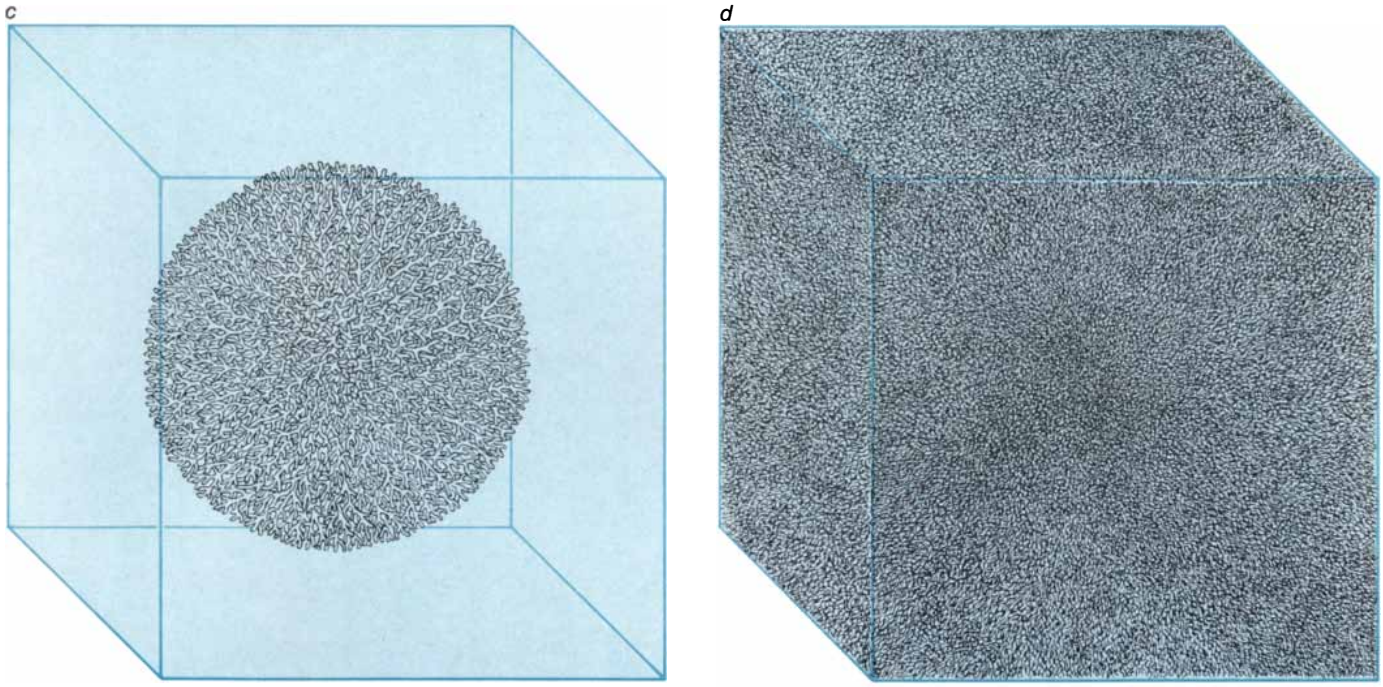
The processes that define the historical and the thermodynamic arrows of time generate information and entropy respectively. As Claude E. Shannon of the Massachusetts Institute of Technology showed in 1946, information is a property of statistical descriptions of physical systems. It is measured in bits, or binary digits; one bit is the quantity of information needed to decide between two equally likely possibilities. Information can also be regarded as a property of physical systems themselves, a measure of how highly organized they are. A fundamental theorem proved by Shannon shows that the information content of a system is the minimum number of bits needed to encode a complete statistical description of the system.

The concept of entropy is closely related to the concept of information. Entropy was first defined (by Rudolf Clausius and Lord Kelvin) in the context of thermodynamics, and it measures the displacement of a system from thermodynamic equilibrium; at equilibrium the entropy assumes its maximum value for given values of temperature and density.

Employing a formula first derived by Ludwig Boltzmann and J. Willard Gibbs, Shannon defined an entropy of information theory, which measures the uncertainty associated with statistical descriptions of a system. The thermodynamic entropy of Kelvin and Clausius and the statistical entropy of Boltzmann, Gibbs and Shannon have identical mathematical properties: they are aspects of a single concept.

Entropy and information are related by a simple conservation law, which states that the sum of the information and the entropy is constant and equal to the system's maximum attainable information or entropy under given conditions. Expressed mathematically, the law states: $H + I = \text{constant} = H_{\max} = I_{\max}$, where H (the Greek letter eta) and I represent the actual values of entropy and information and $H_{\max}$ and $I_{\max}$ are the maximum possible values. Thus a gain of information is always compensated for by an equal loss of entropy.

Suppose some physical system has eight (or 2^3) possible states; in binary notation they could be labeled 000, 001, 010, 011, 100, 101, 110 and 111. The specification of a particular state, for example the one labeled 101, requires three binary digits, which is the quantity of



three dimensions (*a*). As the system evolves, the probability fluid must migrate to more distant regions of the phase space, but because the trajectories of all the particles are determined the fluid is incompressible; it cannot expand as a gas does. Instead it puts out "fingers" (*b*), which become more elongated and more numerous (*c*) as the number of possible states of the system increases. Eventually the entire hypervolume is filled with small branches of fluid, although the total volume of fluid remains constant. From a macroscopic point of view the distribution of fluid now seems uniform, although it is far from uniform when it is examined closely (*d*).

information associated with the description "The system is definitely in the state 101." The uncertainty or entropy associated with this description is evidently zero. At the other extreme, if we had no information about the state of the system, we would be compelled to assign equal probabilities to each of the eight possible states. In this case the information is zero. Since the sum of the entropy and the information in the system is constant, the entropy must now be three bits. In general, if a system has 2^r possible states, where r is an integer, the maximum quantity information or entropy is equal to the logarithm to the base 2 of 2^r, or r.

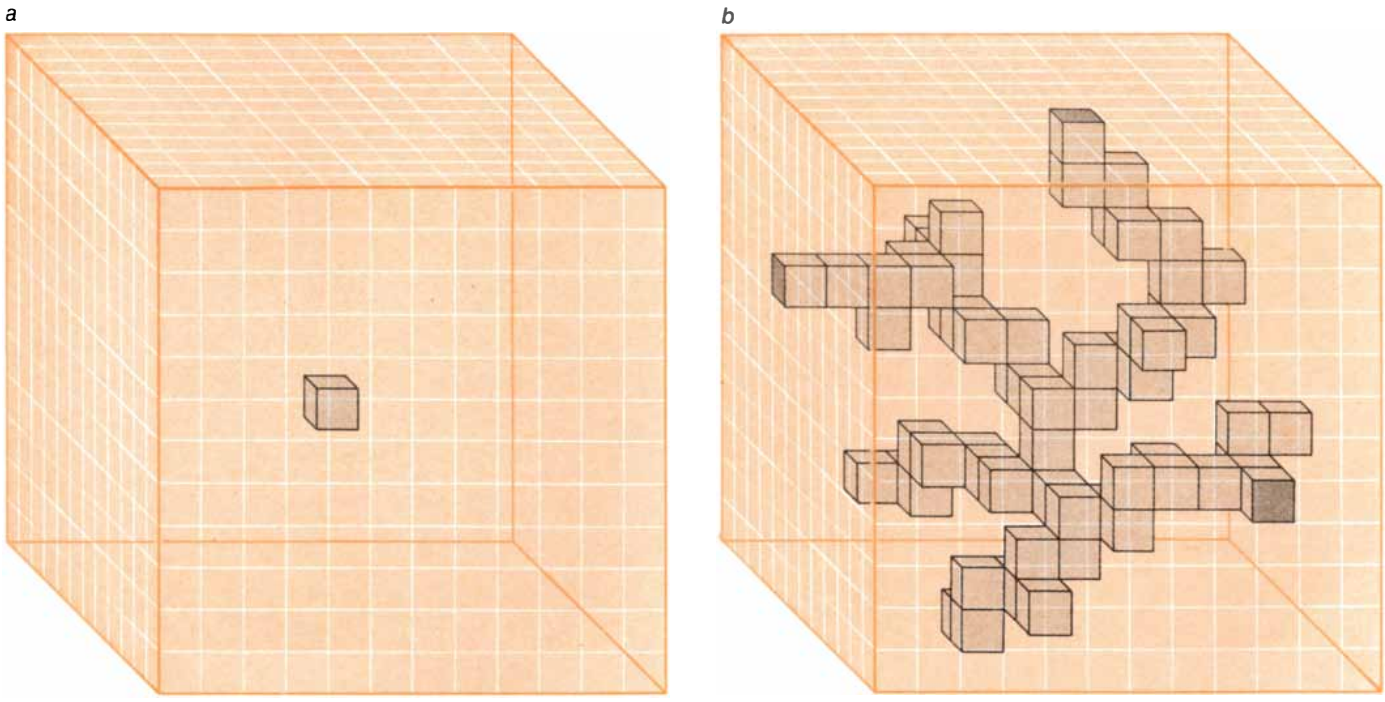
A Thought Experiment

For real systems the number of possible states can be very large, but it is not infinite. The number of states, and therefore the maximum quantity of information, is limited by the uncertainty principle formulated by Werner Heisenberg. The principle states that there is an irreducible uncertainty in our knowledge of the position and momentum of any real particle; the state of the particle cannot be specified with greater precision than our uncertainty allows. As a consequence of the uncertainty principle any finite physical system can be completely described with a finite quantity of information.

In order to understand the connection between cosmology, entropy and information let us conduct a simple thought experiment. In one corner of a room in which the air is perfectly still I open a bottle of perfume. A little later my partner in the experiment, standing in the opposite corner, reports that he can smell perfume. Molecules of perfume have evidently escaped from the surface of the liquid and, colliding with other molecules and following complicated zigzag paths, have made their way across the room. If we wait long enough, all the perfume will evaporate and perfume molecules will be found distributed uniformly throughout the room [*see illustration on page 57*].

Experience and the second law of thermodynamics tell us that the process is irreversible: no matter how long we wait, the perfume molecules will not spontaneously reassemble in the bottle. In principle, however, such an event is not impossible. Imagine that the entire experiment could be recorded on film in microscopic detail, so that we could follow the motions of each perfume molecule individually. We might see a particular molecule in the liquid accelerated by a collision so that it is able to escape from the surface. It then collides with thousands of other particles in the air, and with the sides of the container and the walls of the room, each time changing its speed and direction. At length we find it, still in motion, in a distant part of the room. If such a film were viewed in reverse, we would see the perfume molecules retracing their complicated trajectories, converging on the perfume bottle and there uniting to form a liquid. If we singled out a particular molecule, we would find that its trajectory obeyed all the laws of physics, since the laws that govern molecular motions are symmetric with respect to time reversal. Nothing about the trajectories of individual molecules would enable us to distinguish between the actual film and the reversed one. Why, then, would we be reluctant to accept the reversed film as a record of a real event?

The obvious and conventional answer is that in the reversed film the initial conditions are exceedingly special. At the beginning of the reversed film each one of an enormous number of molecules is on a trajectory that will eventually lead it to converge on a certain small volume of space (the perfume bottle) to the exclusion of all other similar volumes (the rest of the room). Such an initial state is extremely improbable, and that has often been taken as sufficient explanation of the irreversibility of thermody-



INFORMATION THEORY provides a quantitative interpretation of the distribution of probability fluid. The phase space is divided into small cells of equal hypervolume, and in the initial state all the fluid is assumed to be confined to one cell (*a*). The information required to specify that distribution is equal to the logarithm to the base 2 of the number of cells. As the system of particles evolves, probability fluid occupies progressively more cells (*b*), and eventually the distribution becomes uniform; each cell contains an equal volume of fluid (*c*). The state of the system is then indeterminate, and no information is required to specify it. When the

namic processes. It is possible to pursue the matter further, however, and ask what makes those initial conditions so unlikely.

Phase Space

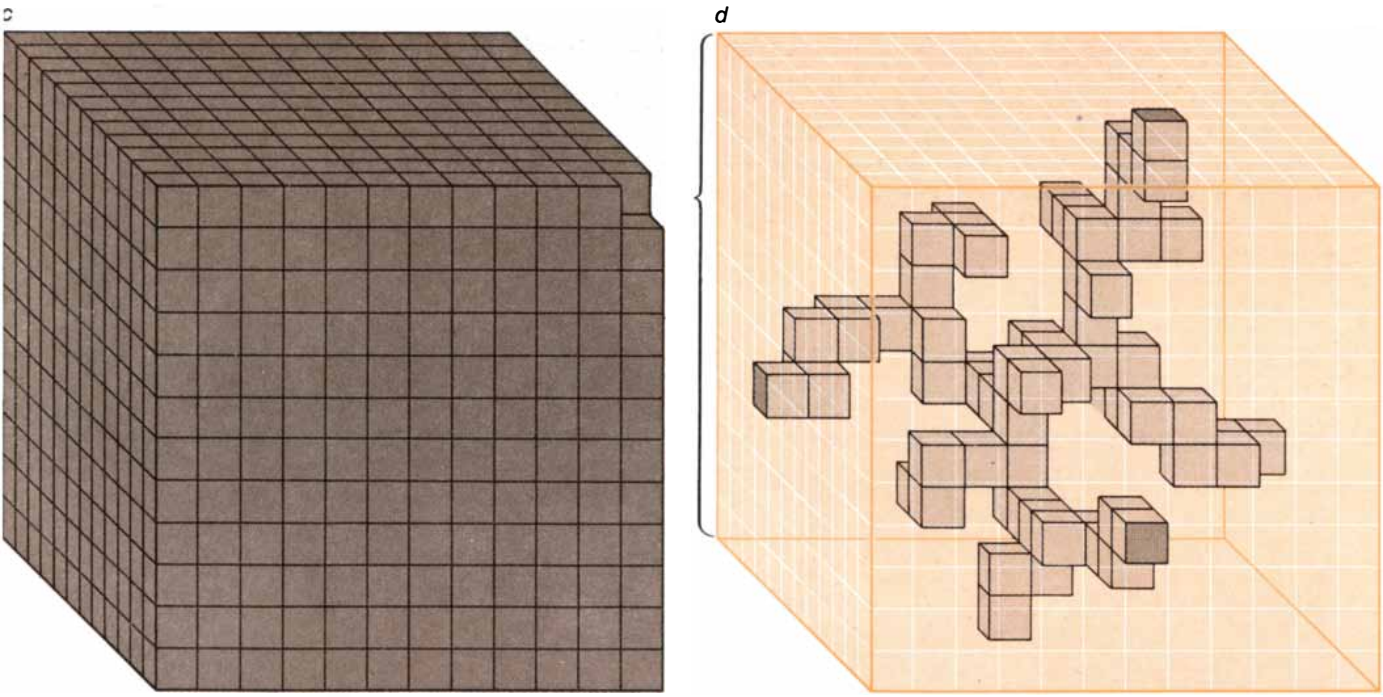
In order to discuss the question we need a convenient means of representing the changing dynamical state of a system containing a vast number of particles. The concept of phase space meets this need.

The dynamical state of a single particle is completely described by its position and its velocity. To express those quantities we need six numbers: three coordinates for the position and three components of the velocity. In Cartesian coordinates the numbers correspond to position and velocity along the x, y and z axes. We may think of the six numbers as the six position coordinates of a point in a space having six dimensions, the particle's phase space. To every point in the phase space there corresponds a unique dynamical state of the particle in real space, and as the particle moves in real space its representative point traces a curve in phase space. If we know the particle's position and velocity at any one moment, we can predict all its subsequent motion with arbitrary precision; in other words, the dynamical history of the particle is completely determined by its initial conditions. Similarly, in phase space the entire curve is determined by its starting point. Moreover, the path of the point in phase space cannot intersect itself or form branches (although it can describe a closed curve). If it did intersect itself, there would be a state of the particle (the state at the point of intersection) with more than one possible subsequent state, and the dynamical history of the particle would not be uniquely determined.

We can use the same technique to describe a closed system of many interacting particles. The dynamical state of a system of n particles is specified by $6n$ numbers: the three position coordinates and the three velocity components of each of the n particles. We may think of these numbers as the coordinates of a point in a space having $6n$ dimensions; to describe the system we must specify the location of a single point in that phase space. Again, the dynamical history of the system is represented by a curve in phase space that is completely and uniquely determined by its starting point. Because of collisions and other interactions between the particles the curve in phase space may have a complicated or irregular shape but it cannot branch or intersect itself.

The diffusion of perfume molecules in our thought experiment is represented by a unique trajectory in a phase space having $6n$ dimensions, where n is the number of perfume molecules. (Typically n is very large; if there is just a gram of perfume, it is about 6×10^{20}.) The trajectory links the points that represent the initial and final states of the experiment, but if we were to examine those points, we could make no qualitative distinction between them. Each point follows as a consequence of the other, and the description of the motions of the molecules is fully reversible.

The analysis of our thought experiment in phase space seems to abolish the arrow of time and to imply an absolute determinism that leaves no room in the future for novelty. That description, however, is unrealistically precise. It assumes the existence of much more information about the system of perfume molecules and air molecules than we could possibly acquire. We do not know the precise initial positions and velocities of the 6×10^{20} perfume molecules, even within the limitations of the uncertainty principle. We know only that all of them are initially confined to a certain small volume, the bottle. As a result we cannot specify the precise coordinates of the system's representative point in phase space; all we can say is that it must lie somewhere within a certain small vol-



phase space is examined at finer scale, however, it is found that the distribution of fluid is far from uniform. By dividing each cell into many smaller cells (d) one can show that the amount of information needed to specify the state of the entire system remains unchanged; it is still equal to the logarithm to the base 2 of the number of cells. Information in the initial condition about the macroscopic state of the system has been converted into information about the microscopic state. It can be proved that if microscopic information is initially absent, all the macroscopic information in the system will be converted into microscopic information.

ume, or "hypervolume," of $6n$-dimensional space.

To represent this information let us replace the point in phase space by a blob of imaginary fluid that uniformly fills the small hypervolume corresponding to our actual knowledge of the initial state. The imaginary fluid represents probability, and the mass of fluid in any region of the phase space represents the probability that the dynamical state of the system corresponds to a point within that region [*see illustration on pages 60 and 61*].

How does the probability fluid spread in phase space as the perfume molecules diffuse in physical space? One might guess that it would simply expand in all directions, just as the perfume does, and ultimately fill all the available hypervolume more or less uniformly. Actually it behaves quite differently.

Because the motions of the perfume molecules are completely determined by their initial state (even if we do not know that state), the probability fluid must remain a single, continuous blob. If it were to break up into two or more separate blobs, there would be a dynamical history represented by a branching trajectory, which we have seen to be impossible. Moreover, the volume of the blob cannot change, because the volume is proportional to the number of distinguishable states allowed by the uncertainty principle, and that number cannot change as long as each state defines a unique dynamical history.

From these considerations we can conclude that the probability fluid is continuous and incompressible; it behaves more like a liquid than like a gas. It expands into the hypervolume not by changing its density, as a gas would, but by sending out "fingers" that grow longer and narrower and more numerous as the system evolves. Gibbs compared the process to the manner in which India ink slowly spreads in still water.

As the probability fluid extends fingers at smaller and smaller scales, the total hypervolume occupied by the fluid remains constant but the shape of the occupied region grows steadily more complex. After enough time has passed the fluid will appear to be distributed uniformly throughout the entire hypervolume; when the fluid is examined at a very small scale, however, it will be found that the distribution is still far from uniform. In this description of our thought experiment we have found a striking difference between the initial state and the final state. At the outset the probability fluid is confined to a small region of phase space, which it occupies uniformly; the rest of the hypervolume is empty. In the final state the fluid occupies the entire hypervolume. From a macroscopic point of view it appears to be distributed uniformly, but at microscopic scale its distribution is highly nonuniform.

Flow of Information

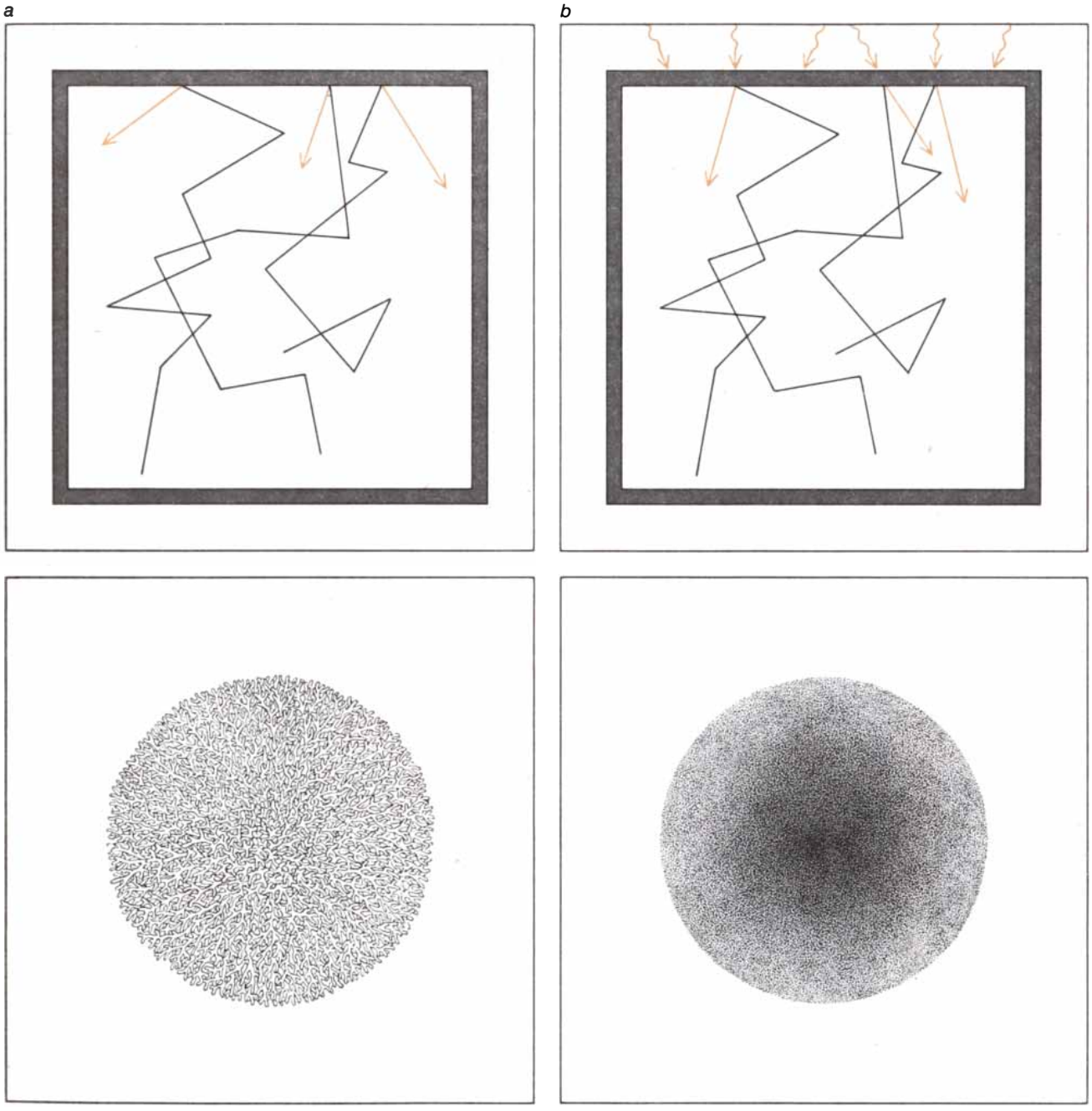
The distinction between a uniform and a nonuniform distribution of probability fluid represents a qualitative difference in the information content of the system. In order to measure the information we must divide the accessible region of phase space into small cells of equal hypervolume; for convenience we shall divide it into 2^r cells, where r is an integer [*see illustration on these two pages*]. Initially all the probability fluid is confined to one of the cells. The information required to specify that state is simply the number of binary digits needed to designate a particular cell. The required number of bits is the logarithm to the base 2 of the number of cells, or $\log_2 2^r = r$. Thus the initial state of the thought experiment can be represented by r bits of information.

In the final state, when the fluid is distributed uniformly among the cells, each of the 2^r cells contains the same volume of probability fluid. At that level of description the final state is completely indeterminate and no information is needed to specify it. In the evolution of

the system all the information contained in the initial state seems to have disappeared.

If we examine the distribution of the fluid on a finer scale, however, we can discover where the information has gone. If each cell contains an equal volume of fluid and the total volume of fluid has not changed, then within each cell the probability fluid must occupy only $1/2^r$ of the cell's volume. Although the density of the fluid has not changed, the shape of the occupied region is now very complex. By dividing the cell into sufficiently small "microcells" it can be shown that the information required to specify the distribution of the fluid in the entire region of phase space is again $\log_2 2^r = r$. The macroscopic information present in the initial state has not disappeared; it has merely been converted into microscopic information in the final state.

This conclusion can be made completely general and precise. No matter how we choose to partition the phase space into "macrocells," we can define macroscopic information as the information needed to specify the set of probabilities associated with these macrocells; the information needed to specify



RANDOM PERTURBATIONS from outside a system of particles tend to dissipate microscopic information. In a system that cannot communicate with its environment (*a*) the paths of all particles are forever determined, and the probability fluid in the system's phase space is incompressible. No real system, however, is completely isolated. Heat is communicated through the walls of any container, and particles inside a container can interact gravitationally with distant matter. As a result random disturbances destroy all information about the microscopic state of the system. Because the future state of the system can no longer be predicted from its present state the probability fluid is no longer incompressible (*b*); it expands like a puff of smoke to fill the entire region of phase space.

the distribution of fluid within the macrocells we define as microscopic. As the closed system of molecules evolves, the total quantity of information needed to specify the distribution of probability fluid in the system's phase space remains constant, but macroscopic information can be converted into microscopic information and vice versa.

What do these two kinds of information represent? We can identify macroscopic information with our knowledge of the statistical properties of the system, and microscopic information with our detailed knowledge of the individual molecules. In particular, microscopic information represents our knowledge of correlations between the velocities of particles. In our thought experiment microscopic information was initially absent, because in the initial state there were no correlations between molecular velocities; knowledge of the velocity of one molecule would not have enabled us to predict the velocities of any other molecules. As the system evolved, collisions created correlations between particle velocities, and all the macroscopic information present was ultimately converted into the microscopic information represented by those correlations.

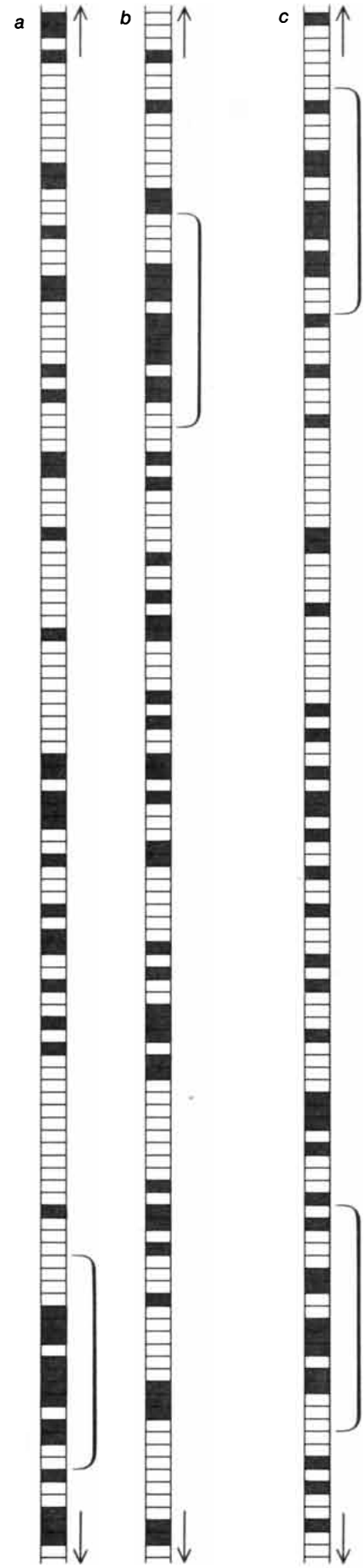
For certain kinds of physical systems and under certain initial conditions it can be shown that this process is inevitable. If microscopic information is initially absent from a closed system composed of many interacting particles, then the information needed to specify the system's macroscopic state must decrease steadily until it has all been converted into microscopic information. Since 1946 theorems with this general form have been established (for particular classes of physical systems and for particular definitions of microscopic information) by Nikolai Bogolyubov, Leon C. P. van Hove, Ilya Prigogine, Radu Balescu, Mark Kac and others.

Because macroscopic information invariably decreases in those situations where thermodynamic entropy increases, it is tempting to define thermodynamic entropy as negative macroscopic information. In fact, such a definition leads directly to the equation presented earlier: $H + I = H_{max} = I_{max}$. We now interpret H as thermodynamic entropy and I as macroscopic information. The entropy is then always positive or zero, and if the maximum entropy remains constant, as it must in a closed system, then the entropy must increase as the macroscopic information decreases. We have now traced the origin of the thermodynamic arrow of time to a property of the initial states of closed systems: The entropy of a closed system will increase only if macroscopic information is initially present in the system and microscopic information is initially absent.

Random Perturbations

Those special initial conditions may provide an explanation of the thermodynamic arrow of time, but it is hardly a satisfying one. Why are those particular initial conditions regularly satisfied in nature? Microscopic information seems easy enough to generate. Why does it appear only in the final states of natural systems and not in their initial states? What does it mean to say that microscopic information is absent from a certain state? One can always acquire such information by expending enough energy. Finally, what significance can we attach to the distinction between the macroscopic and the microscopic level of description? A plausible way of dealing with these questions was described in 1912 by the French mathematician Émile Borel. In recent years Borel's argument has been rediscovered and elaborated by John M. Blatt, by Peter G. Bergmann and Joel L. Lebowitz and by Philip Morrison.

Our conclusion that the microscopic information of a system increases as the macroscopic information decreases is valid only for closed systems, that is, systems that do not communicate with their surroundings. Borel showed that no finite physical system can be considered closed. For example, consider the room in which we conducted our thought experiment on the diffusion of perfume. Even if the room has no door or windows, and even if the walls are insulated



"TOY UNIVERSE" consists of a straight line extending infinitely in both directions and divided into small domains that are either occupied (*dark squares*) or empty (*open squares*). If the distribution of squares obeys certain statistical properties, it can be shown that the toy universe contains no microscopic information. The detailed properties of particular sequences of squares, for example, have no meaning. Such properties cannot distinguish one representation of the universe from another (*a*, *b*), since any sequence of any finite length can be found somewhere in all infinite representations. Nor can a particular sequence define a unique position in a single representation, since the same sequence is certain to be found elsewhere (*c*). The argument can be extended to the real universe, which satisfies the required statistical conditions.

and made very thick, the system of molecules cannot be isolated from the rest of the universe. Perfume and air molecules must collide with the walls, which are also in contact with the outside world. More important, it is impossible in principle to shield the molecules from gravitational interactions with distant matter. The effects of such interactions are exceedingly small, but they are not trivial. Borel calculated that the change in gravitational potential caused by displacing one gram of matter by one centimeter at the distance of the star Sirius would, in the course of one microsecond, substantially alter the microscopic state of a macroscopic volume of gas.

The unavoidable interaction of a nominally closed system with the rest of the universe operates as a small random perturbation that destroys correlations between the velocities of particles. The perturbation therefore dissipates microscopic information, and it perpetually re-creates the initial condition needed to ensure the decay of macroscopic information and the growth of thermodynamic entropy. Because the system is no longer isolated, its dynamical history is no longer completely determined. The probability fluid in phase space is no longer incompressible; it expands like a puff of smoke to fill the available hypervolume [*see illustration on page 64*]. In the real world, then, macroscopic information decays into microscopic information, but the microscopic information is dissipated by random perturbations.

The Cosmological Principle

Borel's argument hinges on the assumed randomness of interactions of supposedly closed systems with the rest of the universe. If the positions and velocities of all perturbing particles were known, we could expand the definition of a closed system to include the perturbing particles. That larger system, however, would itself be subject to external perturbations. Ultimately we would need to include the entire universe in our description. Given a complete microscopic description of the universe (within the limitation imposed by the uncertainty principle) there could be no qualitative distinction between the two directions of time, for such a description would be symmetric with respect to time reversal. Is it possible, however, even in principle, to compile such a description?

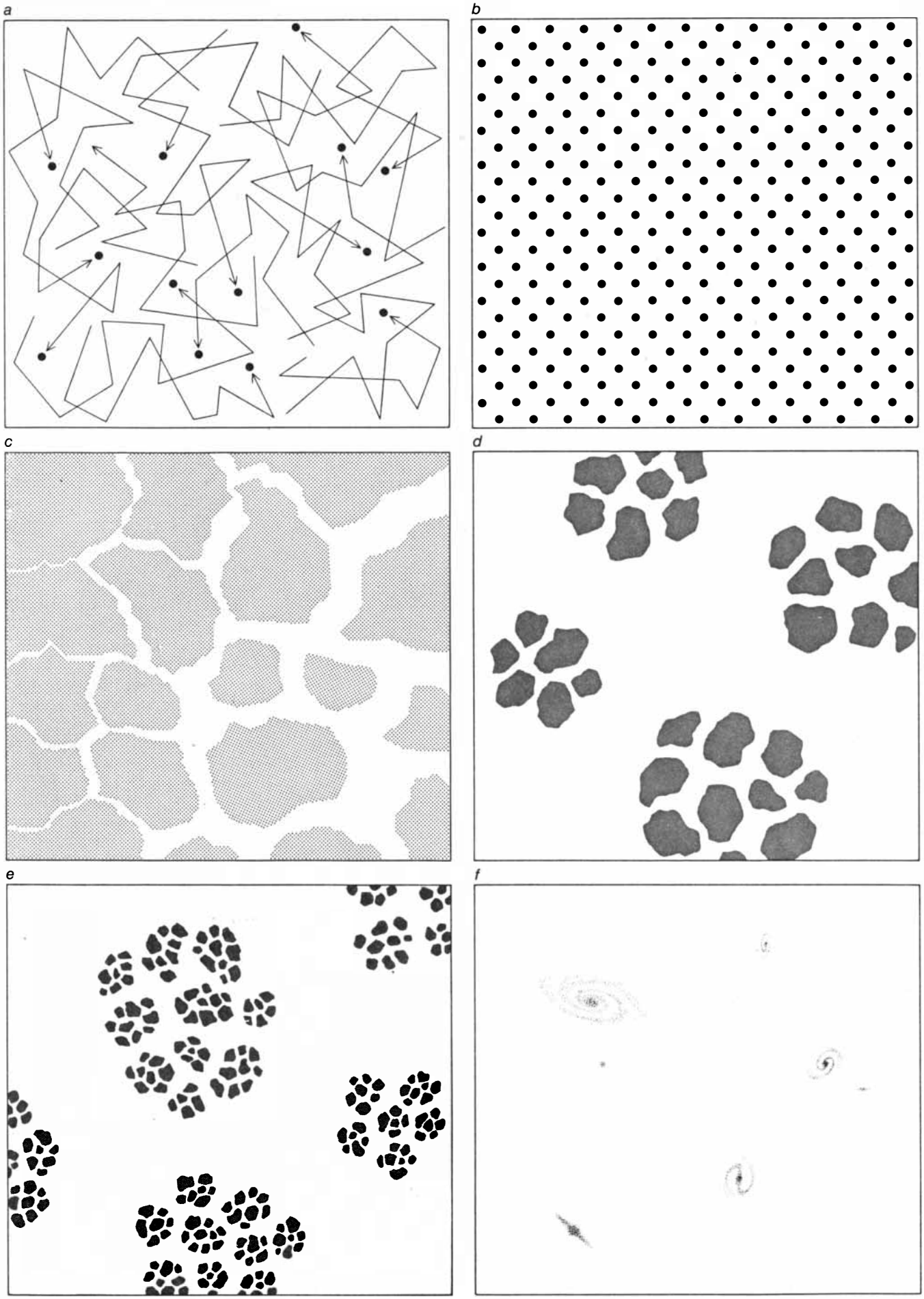
Every finite physical system admits of a complete microscopic description containing a finite quantity of information, and it may seem that the universe as a whole could also be described comprehensively. Whether such a description would contain a finite quantity or an infinite quantity of information would depend on whether the volume of the universe is finite or infinite. (Relativistic cosmology admits of both possibilities.) The universe, however, has certain distinctive properties not shared by its subsystems. In particular every finite subsystem of the universe is bounded, but the universe itself, whether it is finite or infinite, is assumed to be unbounded. Moreover, it seems to conform to what I shall call the strong cosmological principle, which states that no statistical property of the universe defines a preferred position or direction in space. The (ordinary) cosmological principle, so named by Albert Einstein in 1916, states that the spatial distribution of matter and motion in the universe is homogeneous and isotropic apart from local irregularities; the strengthened version adds that the local irregularities themselves are statistically homogeneous and isotropic. The strong cosmological principle is a direct descendant of Copernicus' thesis that our planet does not occupy a privileged position in the cosmos. It is the simplest and most comprehensive symmetry postulate one can make without contradicting observational evidence or established physical laws. It has an unexpected consequence directly related to our search for the origin of the thermodynamic arrow of time. I shall argue that the strong cosmological principle implies that microscopic information about the universe is objectively absent: it cannot be acquired or specified. This limitation of our knowledge represents a kind of cosmic indeterminacy, related to but distinct from the indeterminacy demanded by Heisenberg's uncertainty principle. It is a property of the universe as a whole but not of bounded subsystems, for which microscopic information can be freely specified or acquired.

The notion of cosmic indeterminacy can be illustrated by considering a "toy universe" of pointlike particles distributed randomly but with uniform average density along an infinite straight line. We can estimate the statistical properties of this one-dimensional universe with arbitrary precision; for example, we can estimate the mean number of points per unit length to any desired accuracy by taking averages over ever longer line segments. Can we specify any nonstatistical, or microscopic, properties of the toy universe? What would constitute a microscopic property? Suppose we are given two representations of the toy universe, identical in all their statistical properties. I assert that we define a microscopic property if we find some way to distinguish between the representations, since the only kind of information on which such a distinction could be based is nonstatistical, and hence microscopic, information.

In order to represent the influence of the uncertainty principle we must divide the one-dimensional universe into cells of equal length, the length representing the precision with which the position of a single particle can be specified. If we then specify the number of particles occupying each cell, the toy universe is represented by an infinite, doubly open-ended sequence of "occupation numbers." Microscopic information is now defined as information that would enable us to distinguish between two such sequences of occupation numbers having the same statistical (or macroscopic) properties. We might try to establish that two sequences are different by matching them up, cell for cell, along their entire length. Since neither sequence has a beginning or an end or any other preferred point, however, there are infinitely many ways to align them. It is impossible in principle to complete an infinite series of tasks, so that by this method we could never prove the impossibility of a match.

Alternatively, we could try to prove that the two sequences are identical. First we would select from one line of occupation numbers a sub-sequence of arbitrary length, then we would search for an identical sub-sequence in the oth-

EVOLUTION OF THE UNIVERSE represents a growth of macroscopic information. In a model devised by the author and his students the initial state of the universe is assumed to be devoid of all information and structure. In the period immediately following the "big bang" (*a*) the universe is in thermodynamic equilibrium, maintained by the rapid interaction of particles and radiation. After expanding for about 15 minutes, the universe crystallizes, or freezes, into an alloy of metallic hydrogen and helium (*b*). Because of the continuing cosmic expansion this solid universe shatters into fragments of approximately planetary mass (*c*), which form a "gas" in the sense that they interact frequently and randomly much like the molecules of an ordinary gas. In the planetary gas density fluctuations eventually develop (*d*) as groups of several fragments adhere; the fluctuations grow at larger and larger scales as groups of fragments themselves aggregate (*e*). Eventually a hierarchy of structures is formed, corresponding to stars, galaxies and clusters of galaxies seen today (*f*).



er line. In an infinite line any sub-sequence of finite length occurs infinitely often. The law of large numbers guarantees that our search must succeed after a finite number of trials. Moreover, we will succeed no matter how long a subsequence we choose, provided only that its length is finite. The two infinite sequences are operationally indistinguishable; if they were not, it would be possible to exhibit at least one sub-sequence of one that could not be duplicated in the other. Thus there is only one infinite sequence of digits with the statistical properties that define the toy universe. Two representations of the universe with identical statistical properties are indistinguishable. Since microscopic information, by definition, is what could make a distinction possible, we must conclude that it is objectively absent.

The argument can readily be extended to infinite models of the real, three-dimensional universe that satisfy the strong cosmological principle and the additional requirement that the scale of local structure be finite. The pattern of stars and galaxies visible from the earth is so complex and distinctive that it would seem to define our position in the universe as uniquely as a thumbprint defines its owner. In an infinite, statistically homogeneous and isotropic universe, however, it is certain that the same pattern of stars and galaxies recurs repeatedly. If our universe satisfies the strong cosmological principle, its meaningful properties are all statistical and its microscopic state is completely indeterminate. Since the time of Newton it has been implicit in cosmological thinking that the universe, in principle, admits of a complete microscopic description. We can now see that that need not be so. If there is enough symmetry in the universe, there is no place for microscopic information.

The Origin of Macroscopic Information

We have seen that the thermodynamic arrow of time results from the absence of microscopic information and the presence of macroscopic information in the initial states of closed systems. We found that microscopic information is objectively absent in a universe satisfying the strong cosmological principle; on the other hand, we have found no reason why macroscopic information should not also be lacking. Indeed, the complexity of the astronomical universe seems puzzling. Isolated systems inevitably evolve toward the featureless state of thermodynamic equilibrium. Since the universe is in some sense an isolated system, why has it not settled into equilibrium? One answer, favored by many cosmologists, is that the cosmological trend is in fact toward equilibrium but that too little time has elapsed for the process to have reached completion. Fred Hoyle and J. V. Narlikar have written: "In the 'big bang' cosmology the universe must start with a marked degree of thermodynamic disequilibrium and must eventually run down." I shall argue that this view is fundamentally incorrect. The universe is not running down, and it need not have started with a marked degree of disequilibrium; the initial state may indeed have been wholly lacking in macroscopic as well as microscopic information.

Suppose that at some early moment local thermodynamic equilibrium prevailed in the universe. The entropy of any region would then be as large as possible for the prevailing values of the mean temperature and density. As the universe expanded from that hypothetical state the local values of the mean density and temperature would change, and so would the entropy of the region. For the entropy to remain at its maximum value (and thus for equilibrium to be maintained) the distribution of energies allotted to matter and to radiation must change, and so must the concentrations of the various kinds of particles. The physical processes that mediate these changes proceed at finite rates; if these "equilibration" rates are all much greater than the rate of cosmic expansion, approximate local thermodynamic equilibrium will be maintained; if they are not, the expansion will give rise to significant local departures from equilibrium. These departures represent macroscopic information; the quantity of macroscopic information generated by the expansion is the difference between the actual value of the entropy and the theoretical maximum entropy at the mean temperature and density.

This argument does not depend on the cosmic expansion as such but on the finite rate at which density and temperature can change. The conclusion would be the same if the universe were contracting from a state of equilibrium instead of expanding: if the rate of contraction were greater than the rates of those processes that maintain thermodynamic equilibrium, both macroscopic information and entropy would increase. The result therefore does not fix the direction of the cosmological arrow of time with respect to the direction of the thermodynamic arrow. It does establish that macroscopic information and entropy are generated as the universe evolves away from a hypothetical state of local thermodynamic equilibrium.

Is it reasonable to suppose the universe ever was (or ever will be) in local thermodynamic equilibrium? In order to answer this question we must compare the rates of equilibration processes (those that generate entropy) with the rate of cosmic expansion or contraction. Neither rate is constant. As we proceed backward in time toward the big bang the rate of expansion increases, and at the origin of time—the cosmological singularity—the expansion rate is infinite. The rates of equilibration processes also increase, however, as we approach the cosmological singularity, because encounters between particles become more frequent with increasing density and temperature. In fact, in the period immediately following the singularity the rates of equilibration processes are much higher than the rate of cosmic expansion. As a result the big bang is an exceedingly gentle process; local equilibration processes easily keep pace with the changing macroscopic conditions of temperature and density during the first fraction of a microsecond. It is only for this brief initial phase in the evolution of the universe that local thermodynamic equilibrium can be assumed, but from that assumption it follows that the expansion of the universe has generated both macroscopic information and entropy. Thus the cosmological arrow, the historical arrow and the thermodynamic arrow all emerge as consequences of the strong cosmological principle and the assumption that local thermodynamic equilibrium prevailed at or near the initial singularity. Remarkably, neither of these assumptions refers directly to time or temporal processes.

One final question remains if this formulation is to be considered plausible: Does the cosmic expansion generate the particular kinds of macroscopic information that characterize the universe today? It is possible that some of the information was present from the outset, perhaps in the form of density fluctuations. The question cannot yet be answered with confidence, but it is important to note that there is no theoretical necessity for structure in the initial state. My students and I have developed a model of the evolution of the universe that begins with a state of complete thermodynamic equilibrium at zero temperature [*see illustration on preceding page*]. Hence it is at least possible that the astronomical universe, with all its richness and diversity, has evolved from

a state wholly devoid of information and structure. If we postulate the existence of such a primordial state, we can even dispense with the separate assumption of the strong cosmological principle. The statistical homogeneity and isotropy of the universe follow from the fact that all known physical laws are invariant under spatial translation and rotation.

Novelty and Determinism

We have now traced the thermodynamic arrow and the historical arrow to their common source: the initial state of the universe. In that state microscopic information is absent and macroscopic information is either absent or minimal. The expansion from that state has generated entropy as well as macroscopic structure. Microscopic information, on the other hand, is absent from newly formed astronomical systems, and that is why they and their subsystems exhibit the thermodynamic arrow.

This view of the world evolving in time differs radically from the one that has dominated physics and astronomy since the time of Newton, a view that finds its classic expression in the words of Pierre Simon de Laplace: "An intelligence that, at a given instant, was acquainted with all the forces by which nature is animated and with the state of the bodies of which it is composed, would—if it were vast enough to submit these data to analysis—embrace in the same formula the movements of the largest bodies in the Universe and those of the lightest atoms: nothing would be uncertain for such an intelligence, and the future like the past would be present to its eyes."

In Laplace's world there is nothing that corresponds to the passage of time. For Laplace's "intelligence," as for the God of Plato, Galileo and Einstein, the past and the future coexist on equal terms, like the two rays into which an arbitrarily chosen point divides a straight line. If the theories I have presented here are correct, however, not even the ultimate computer—the universe itself—ever contains enough information to completely specify its own future states. The present moment always contains an element of genuine novelty and the future is never wholly predictable. Because biological processes also generate information and because consciousness enables us to experience those processes directly, the intuitive perception of the world as unfolding in time captures one of the most deep-seated properties of the universe.

What Happens to the Human Lens in Cataract

Senile cataract is caused by abnormal stress that is superimposed on the normal aging of the lens of the eye. Prevention will require more knowledge of the structure and metabolism of the human lens

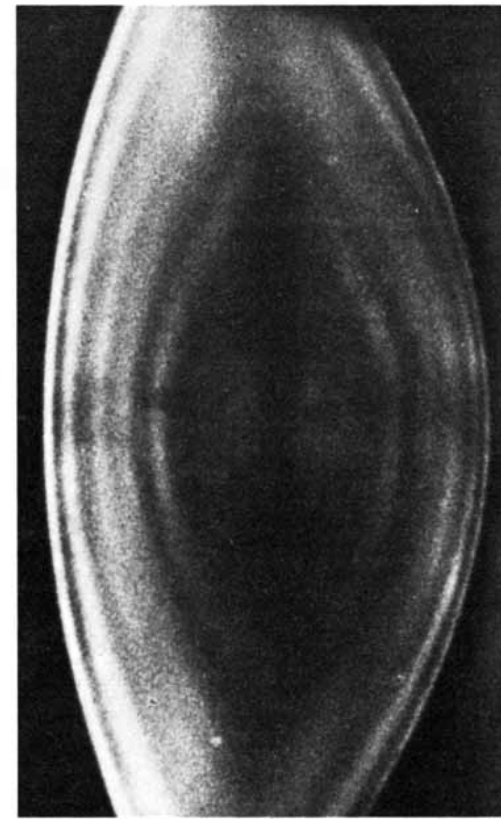
by Ruth van Heyningen

Every year the vision of well over a million people is clouded or occluded by cataract, a loss of transparency of the lens of the eye. There is a partial remedy for the disease: removal of the lens and substitution of a spectacle lens. There is no cure, however, nor is there any prospect of one in the foreseeable future. Moreover, there is no known means of preventing the most common form of the disease, senile cataract, which accounts for the vast majority of cases. To prevent a disease one must understand its causes. In the case of senile cataract there are almost certainly a number of contributory causes, which are superimposed on normal aging processes. The prevention of senile cataract therefore requires a much improved understanding of the structure of the human lens, of its metabolic processes and the changes induced in it by increasing age and external influences, and of the worldwide epidemiology of cataract. Some major advances in those areas have come within the past decade.

Not many reliable population surveys of the incidence of cataract have been made, but clearly senile cataract is far from being an inevitable accompaniment of old age. A five-year survey in the Oxford district of England revealed that only .2 percent of the men and .25 percent of the women over 65 were operated on for cataract each year; the average age of the patients was 73. Even at the age of 65, then, the chance of having an operation for cataract during the next 10 years is only one in 50 for men and one in 40 for women, and some figures for all England and Wales in 1958 showed much the same probabilities.

On the other hand, if the emphasis is put not on the small chance that any one person will develop a cataract that warrants surgical removal but on the total number of people who undergo the operation, the impact of cataract on the health and economy of a nation looks rather different. In England and Wales there were some 24,000 operations in 1958. In the U.S. only five other surgical operations are performed more frequently. And the cataract rates in Europe and the U.S. pale into insignificance when they are compared with the number of sufferers from cataract in some other parts of the world, such as the subcontinent of India. In the plains of the Punjab, for example, the incidence is dramatically higher and the age of patients is significantly lower: one study showed that 22.5 percent of the population from 50 to 59 years old either had a cataract or had already had a cataract removed, and the figure rose to 31.4 percent among people aged 60 or more. There are no entirely comparable statistics for the Oxford population, but a reasonable guess would be about 2 percent for men and women over 60. Far more data of this kind are required not only to measure the dimensions of the cataract problem but also to provide epidemiological clues to its causes.

Prevention would be much better than the present "cure," even though the operation for cataract is not a complicated one [see "Cataracts," by Sidney Lerman; SCIENTIFIC AMERICAN, March, 1962]. The surgery may well be dreaded by the patient, who must often wait and suffer deterioration of vision for many years after the first hint that a cataract is developing. The procedure's rate of success is high, but not every operation is completely satisfactory to the patient. After surgery both time and patience are required for adjustment to the restored vision. The thick spectacle lens that is necessary to compensate for the lens that has been removed produces optical aberrations: increased magnification of the image, decreased depth perception



NORMAL AND CATARACTOUS human lenses are contrasted in three slit-lamp photographs made by Nicholas A. Brown of the Institute of Ophthalmology of the University of London. The photographs show a

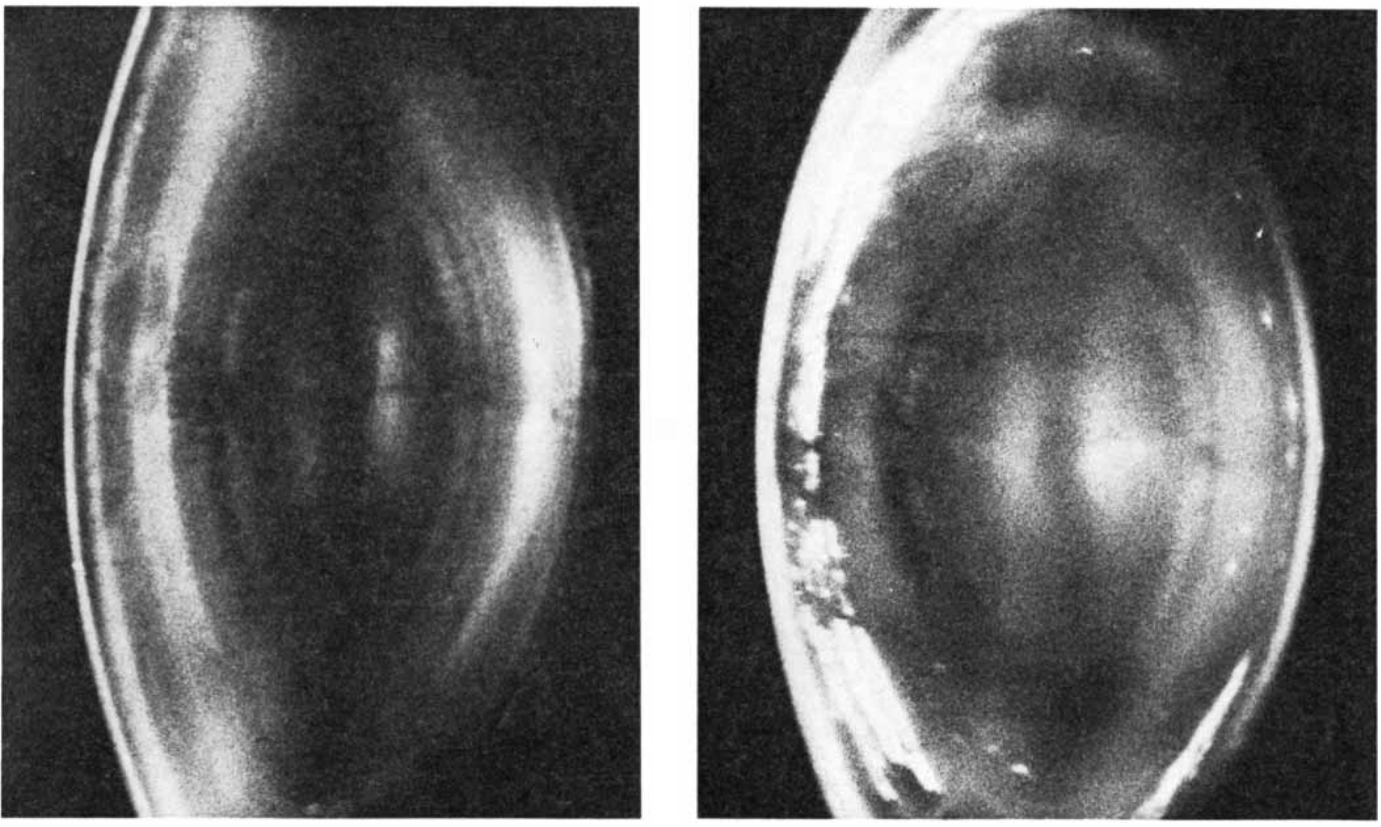
and disturbances of the field of vision. Some patients need many months to adjust to these effects and a few are unable to tolerate them.

Much of the trouble can be avoided if a contact lens is substituted for a spectacle lens. This measure is particularly advantageous for the patient who has a cataract removed from only one eye and still has a normally sighted eye; binocular vision and depth perception, which are diminished by the overmagnification of the spectacle lens, are better with the contact lens. Another stratagem, in which interest has recently been rekindled after some disappointments, is the implantation of a plastic lens within the eye to replace the cataractous lens. Both the contact lens and the implant can be only for the privileged few, however. Spectacles are the sole aid available to the overwhelming majority of cataract patients throughout the world.

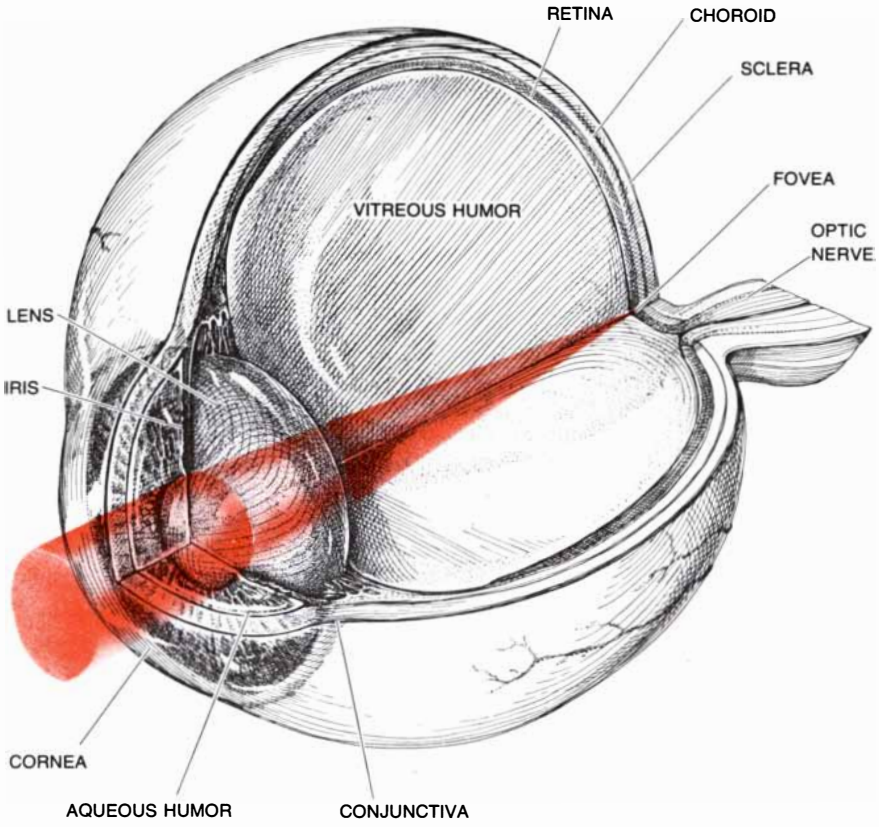
The normal human lens is a transparent, very pale yellow, fairly soft and resilient biconvex body encased in a strong, elastic collagenous capsule. It is suspended immediately behind the pupil of the eye by the short strands called zonular ligaments, which fuse with the capsule around the equator, or periphery, of the lens at one end and radiate outward to the ciliary muscle, where they are anchored. Rays of light from an object in the field of vision are focused on the light-sensitive retina by the cornea and the lens. The refractive power of the cornea and the relaxed lens suffices for distant vision and for objects as close as 15 or 20 feet. To bring closer objects into focus the lens must accommodate. The sphincterlike ciliary muscle contracts, forming a circle of smaller diameter and thereby diminishing the tension on the zonular ligaments. That relaxes the elastic capsule, and the resilient lens gets fatter: its diameter is reduced and its convex surfaces become more convex (the front surface in particular), so that the diverging light rays from the close object are bent more sharply and are focused on the retina. When the lens is in its relaxed state for viewing distant objects, on the other hand, the radius of the ciliary muscle is larger, the pull on the zonular ligaments is stronger and the lens is consequently flatter.

Deterioration of near vision with age is a normal and universal process. The healthy retina is apparently little affected by age; it is in the front of the eye that deterioration takes place, much of it in the lens. In youth the shape of the lens is altered readily by the accommodative process, so that objects within even a few centimeters of the eye are brought into sharp focus. The "near point" begins to recede in most people between the ages of 40 and 50, and the ability to accommodate is generally lost in the sixties. The nature of the anatomical changes in the lens that are responsible has been the subject of controversy for decades. It now seems likely that two changes are involved: the capsule becomes weaker and is more easily stretched, and the material of the lens becomes less easily deformed. Movement of the zonular ligaments therefore stretches or relaxes a much weakened capsule, which has an ever decreasing effect in altering the shape of the increasingly resistant substance of the lens.

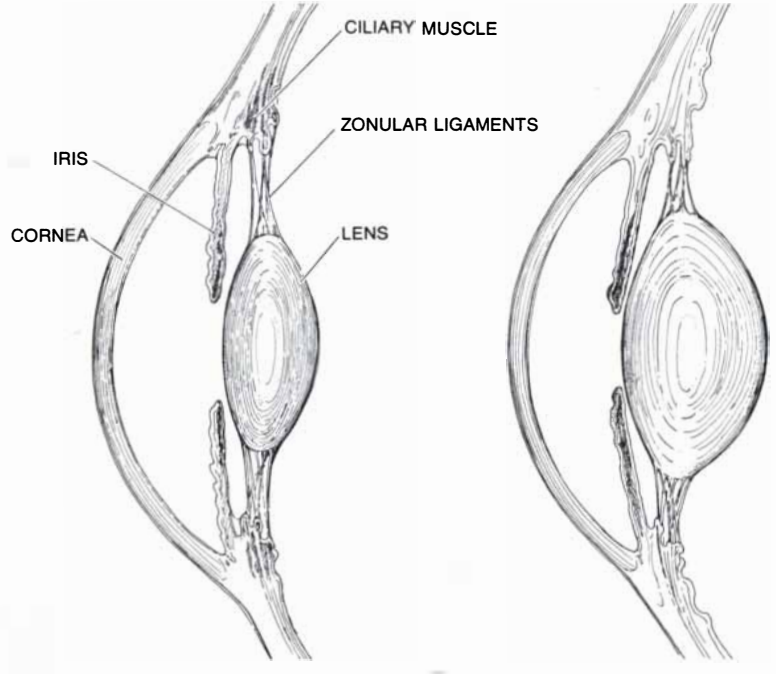
The eyeball reaches its full size at about the time of puberty, but the lens within it keeps growing throughout life. The continued increase in the size of the lens reflects its unique mode of growth. Most animal tissues contain a variety of



healthy lens in a 24-year-old (*left*), a healthy lens in a 45-year-old (*middle*) and a cataractous lens in a 50-year-old (*right*). The slit lamp is a low-power microscope. When a narrow beam of light is directed into the eye at an angle, scattering of light reveals an optical cross section of the lens; here the front surface of each lens faces to the left. The normal thickening of the lens that comes with age is evident, as are the cortical stripes, or concentric interior surfaces, in the two healthy lenses. The bright regions in the cataractous lens are cortical opacities: regions in the cortex, or outer layer of the lens, where light is scattered, interfering with vision.



HUMAN EYEBALL is partially sectioned to reveal the biconvex lens, which together with the cornea focuses rays of light on the retina. The iris is the diaphragm that regulates the size of the pupil. The aqueous humor brings oxygen and nutrients to the lens; the vitreous humor, a gel, maintains the shape of the eyeball. The sclera, choroid and retina are respectively the tough outer membrane, the vascular membrane and the sensory membrane whose nerve cells convert light intensities into nerve impulses for transmission to the brain.



LENS IS SUSPENDED by the zonular ligaments from the ciliary muscle. Constriction of the muscle causes accommodation: the fattening of the lens that focuses near objects on the retina. These views show the front of the eye in youth (*left*) and age (*right*). With age the pupil constricts (aside from its changes with light fluctuations); the shape of the ciliary muscle changes; the lens becomes larger (exaggeratedly so here) and more rounded.

cell types with different embryological origins, but the lens is derived entirely from one group of epithelial cells. The lens capsule is formed in the five-week-old human embryo, and thereafter the lens grows within the capsule as an isolated entity. A single layer of cuboidal epithelial cells covers the front surface of the lens substance; all growth originates in the successive divisions of a narrow band of those cells just in front of the equator. The newly made cells elongate gradually to form fibers, and the lens grows as these long, thin fibers are laid down and packed tightly around its periphery, just inside the capsule. The cortex, or outer part, of the lens therefore consists of the youngest fibers whereas the nucleus, or central core, consists of the oldest ones. At the front and the back of the lens the fibers, which may be as much as a centimeter long, meet in an intricate pattern of interdigitations called sutures [*see illustration on page 77*].

In order to fulfill its focusing function the lens must retain its shape and transparency, and active metabolic processes contribute to that end. The lens has no blood supply, being surrounded by the clear and colorless aqueous and vitreous humors. It is in the aqueous humor, which flows slowly past the lens, that the nutrients and the oxygen required for metabolism are dissolved. The energy-providing molecule adenosine triphosphate (ATP) is synthesized within the lens primarily by the anaerobic metabolism of glucose (glycolysis) and also by oxidative metabolism in the front layer of epithelial cells. The synthesis of proteins, nucleic acids and other molecules that are not provided by the aqueous humor is supported in turn by the ATP, which also powers osmotic regulation and the transport of ions and small molecules into and out of the cells and fibers. The lens, in other words, has a metabolism that is as finely tuned to its proper function as the metabolism of any other tissue; the lens is far from being the inert bag of proteins it has been said to be. It does, however, contain a great deal of protein. Its dry matter, constituting about a third of its total weight, is almost entirely protein: special lens proteins called alpha, beta and gamma crystallins, enzymes and membrane proteins, all of which are synthesized within the lens.

For a long time investigators and those who wrote about cataract assumed that what was learned about the lens of one species of mammal was directly applicable to the lens of other species, in-

This rolling research lab is helping America take advantage of an energy source that's been around for years.

The energy resource is coal. Right now, our country has nearly one-third of the world's coal reserves. This is twice the energy of Middle Eastern oil reserves.

However, burning coal presents some potential environmental problems. One of these is from pollutants known as oxides of nitrogen or "NOx" emissions.

Research against pollution.

To help industry and electric utilities reduce these pollutants, the U. S. Government awarded a research contract to Exxon Research and Engineering—a company with many years of experience in the science of burning fossil fuels.

This research is intended to help operators of electric power generating plants burn coal more cleanly. It will also help equipment manufacturers design new power plant boilers which will produce less pollution in the future.

The TIGER Van.

To help collect the data needed, Exxon designed and built the rolling research lab you see above.

It's called the "Traveling Industrial Gaseous Emission Research" vehicle—nicknamed "TIGER" van by the Exxon researchers who operate it.

Traveling from power plant to power plant, the TIGER van conducts on-site tests.

The five-man team of Exxon engineers and technicians aboard the van uses sophisticated probes to look inside power plant boilers and stacks. These probes collect emission samples and send them back to the TIGER van where they are analyzed and recorded.

The data is used to test new and different methods of burning coal to reduce pollution.

Some results are in.

Over the past four years, field tests have been conducted on 25 coal-fired plant boilers in these studies, as well as on oil- and gas-fired boilers. Exxon engineers have been able to reduce NOx emissions from coal-fired boilers by as much as 60 percent in short-term tests. Longer term tests are needed to confirm these results.

The published findings of this research have been made available to utility operators, boiler designers and others working in environmental and energy research.

The TIGER van—it's one way Exxon, the government, the electric power companies and boiler manufacturers are working together to help bring you more energy with less pollution.

EXXON

Which SX-70 for Christmas?

The luxury model with all the features? Or the one at about ½ the price?*

Give the SX-70 on the far left, and you're giving the world's most extraordinary camera in its most elegant form, with a brushed chrome finish and a luxurious wrap of genuine leather. This is the original SX-70, the camera that changed forever the way pictures are taken and developed.

All the history-making SX-70 features are incorporated in this deluxe model. The pictures are ejected instantly and develop themselves. You watch them come to life in minutes before your eyes. The camera has a reflex viewing system, so when you look through the viewfinder, you're actually looking through the lens at a big, bright, clear image. It focuses from infinity down to 10.4 inches (closer than almost any other camera will let you get without a special lens). It lets you take rapid-fire shots, one every 1.5 seconds. It folds flat, to slip into your pocket. And it accepts all the optional SX-70 attachments.

The SX-70 picture on the far left was taken by the deluxe model, the one on the right by the Model 3. Note the vibrant colors, the richness of detail in both.

Give the camera on the right, and you've saved yourself about half the cost of the original. What's different about it? Instead of chrome, the Model 3 has a black plastic finish. The wrap looks like genuine leather, but it isn't. This model has a different viewing system. Instead of focusing through the lens, you estimate the distance and set it. It accepts some of the attachments, but not all of them.

But the Model 3 performs brilliantly, delivering beautiful SX-70 pictures that develop as you watch.

Whichever one you choose (and there's an in-between model, too) you can give someone the thrill of discovering what millions of SX-70 Land camera owners already know: this is what picture-taking should have been all along.

Polaroid

*Comparison based on suggested list prices of the Model 3 and the original Model. Polaroid ®SX-70™

Conversation Pieces

Catts Cuts the Cost of Command Training

Every time there's a military budget squeeze, the Army is forced to cut back on field exercises. It's inevitable. In terms of logistics alone, live training is expensive. But there are much more serious costs in terms of lost opportunities for realistic practise, particularly in the difficult art of making command decisions at the battalion level.

Fortunately, something can be done about it and the Army is doing it... with CATTS, which is TRW's Combined Arms Tactical Training Simulator.

Instructors in command center.

To people who have already used this system, it is almost misleading to call it a "simulator." Because what impresses them most is its realism.

The students work in a standard mobile command post with fully functional communications equipment. In a separate area, teams of experienced controllers play the parts of subordinate units, adjacent units, higher headquarters, and a wily, well-equipped enemy force. Operating through a carefully programmed computer system, the controllers present their students with changing battlefield conditions, analyze their responses, and challenge them with new problems that range from bad weather, misunderstood orders, and supply foul-ups to unexpected increases in enemy strength.

The student is forced to think, sweat, and make life or death decisions under conditions of stress that very closely approximate real battlefield environments.

Student commanders in tactical operations center.

In addition to its realism, CATTS has a fundamental advantage over the old-time sand table and other less sophisticated systems. This is its objectivity. The computers model the effects of decisions and the computers have been programmed by independent specialists who are not involved in the training at all. This eliminates a lot of judgement calls at the operational level and frees the judges for the more important business of judging on the basis of actual results.

In order to develop CATTS, TRW started an independent research and development program of formidable size and complexity several years ago. This provided a solid foundation of experience on which the detailed models and software for CATTS were built. The result is an unusual capability that is now being applied to even more complex training needs within the Department of Defense. If you are interested in using TRW's skills in this area, you are invited to write and tell us about your specific needs.

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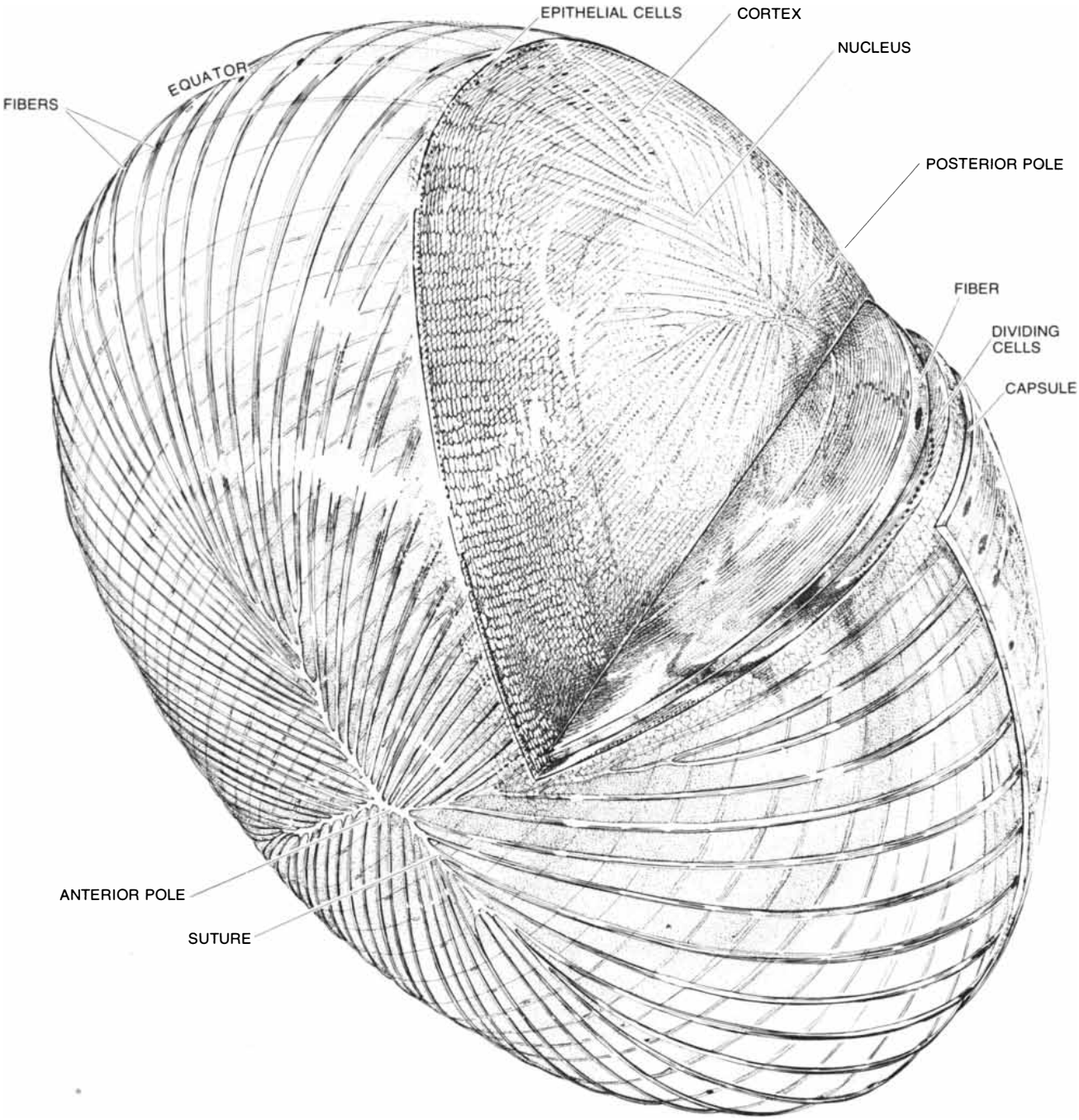
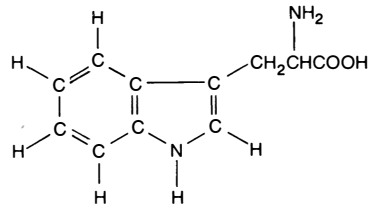
One Space Park Redondo Beach, California 90278

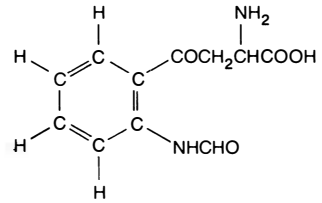
cluding man. In recent years it has become clear that this is not true, that such extrapolation should be made only with great caution and that more can be learned about cataract by concentrating directly on the lens of man, examining it either in the eye (with optical instruments) or after extraction by surgery or autopsy. The fact is that although the lenses of some primates such as baboons and monkeys are probably similar to the lens of man, there are important differences between the human lens and the lens of the usual research animals, notably the rat and the rabbit. Some of these differences may in themselves be significant clues to the causes of cataract in man.

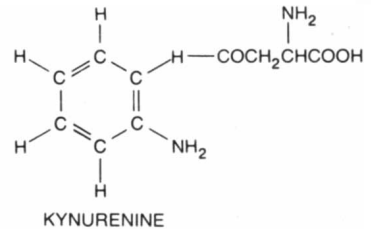
The one difference that has been generally recognized for many years is that the human lens keeps increasing in weight and thickness, whereas the lens of other animals does not. The human lens grows for a remarkably long period

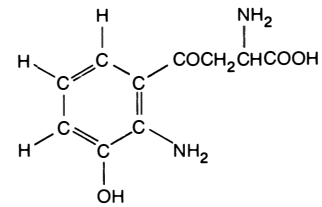


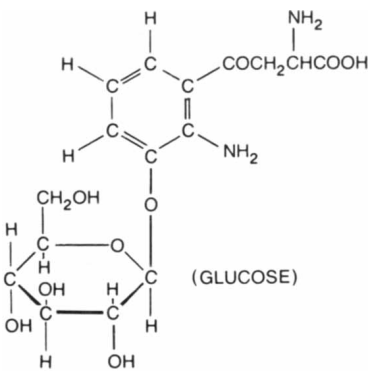
STRUCTURE OF HUMAN LENS is illustrated diagrammatically with the capsule, or outer covering, largely cut away to reveal the lens fibers. Growth of the lens originates with the division of the epithelial cells in a band near the equator. The new cells elongate to form fibers, up to a centimeter or so long and very thin, that wrap around the periphery of the lens and meet at the sutures, linear regions of complex interdigitation. The outer fibers are nucleated and are roughly hexagonal in section; as these fibers are displaced inward toward the center by newer cortical fibers they change shape and lose their cell nuclei. The lens is about two-thirds water; the dry weight is largely accounted for by specific lens proteins that are known as the alpha, beta and gamma crystallins.











of time, increasing in weight from about 90 milligrams at birth to 150 milligrams at age 20, 190 milligrams at 40 and 240 milligrams at 80.

The human lens is also distinguished from that of other mammals by its accommodative capacity and its structure. Only the lens of man alters its shape in accommodation. It is also unique in that it is not optically "empty." Concentric surfaces, parallel to the front and back surfaces, can be seen in photographs made through a slit-lamp microscope [*see illustration on pages 70 and 71*]. The surfaces are somewhat analogous to the growth rings of trees: they increase with the age of the individual. There must be a fundamental distinction, related to the power of accommodation, between the ultrastructure of the human lens and that of other mammalian lenses. Certainly the isolated lenses feel different. The nucleus of the lens of an adult rabbit, cow or rat is hard; only the cortex is soft. In contrast the normal lens of even an old human being has a rather soft nucleus, easily separated from the cortex but not much harder than it.

The difference in consistency is reflected in a difference in water content. The water content of the lens of other animals decreases regularly throughout life, particularly in the nucleus. The nucleus of the rat lens reaches a dry weight that is 66 percent of the total weight when the animal is two years old; at the same age the rabbit nucleus is about 50 percent dry weight and the cow nucleus is 45 percent. The dry weight of the human lens, on the other hand, stays between 32 and 36 percent from age 30 to age 90.

The most obvious characteristic of the human lens is that it is colored; the lens of most other animals is colorless. The human lens is a very pale yellow until middle age. The color intensifies slightly beginning in the sixth decade, diminishing the amount of blue and violet light reaching the retina and thus causing old people to see as green what is actually blue. The lens color is associated with proteins in the tissue and also probably at least in part with certain metabolites of the amino acid tryptophan that are present in the lens of man (and some primates) but absent from the lens in other species.

THE UNIQUE COMPOUND hydroxykynurenine glucoside is produced in the human lens by the pathway shown. The amino acid tryptophan is converted into hydroxykynurenine, which is then conjugated, or combined, with glucose. The compound may improve visual acuity by absorbing short-wavelength light before it strikes the retina.

The tryptophan derivative that is present in the highest concentration in the human lens is hydroxykynurenine glucoside, the product of the enzymic conjugation of glucose (from the aqueous humor) with hydroxykynurenine, a phenolic compound derived from tryptophan (also from the aqueous humor) by a pathway that is not found in the lens of the other animals that have been examined. This recently discovered glucoside is of particular interest because it strongly absorbs ultraviolet radiation, with a peak at 368 nanometers, and therefore keeps wavelengths of less than about 400 nanometers from reaching the retina. Short-wavelength radiation is most subject to dispersion and scattering, and so the presence of this molecular filter in the human lens reduces chromatic aberration and promotes the formation of a sharper image on the retina. The compound is also of interest because substances are ordinarily conjugated in mammals only preparatory to excretion, and the conjugation is usually with glucuronic acid. This tryptophan derivative in the lens is the only such glucoside that is known to be present as a normal constituent of a mammalian tissue.

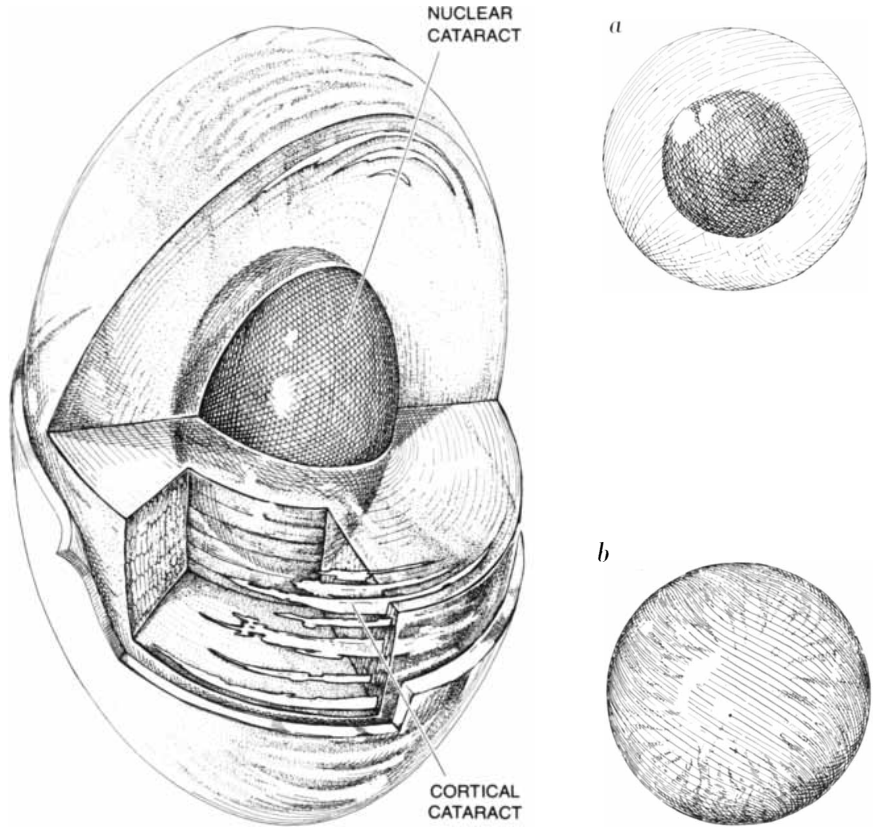
What physical and chemical changes in the lens destroy its transparency? What are we actually seeing when we look at an opacity in the lens? As recently as 10 years ago such questions were embarrassing to biologists, who simply did not know the answers. Now, thanks to the interest shown by physicists in the optical properties of the lens, we at least know how to describe an opacity, even though we still have only an inkling of why it appears at a given time and place.

A lens opacity—a cataract—is a region that causes light falling on it to be scattered. As a result the light from an object, which should pass directly through the lens to produce a sharp image, produces only a degraded image or, if the cataract is severe enough, no image at all. The transparency of the normal lens, in which light is scattered very little, depends on the smooth and gradual increase of the refractive index (which is a function of the protein concentration) from the surface to the center of the nucleus. A small amount of light entering the eye is scattered from the surface of the lens, where there is an abrupt change in the refractive index from the aqueous

humor to the capsule, and from the single layer of cells behind the capsule. There is also a little scattering from the concentric layers and from the sutures. Nevertheless, the normal lens is beautifully transparent, largely because its protein is uniformly dispersed within the fibers. A light-scattering blemish is a region where there is an abrupt or irregular change in protein concentration. There are two main types of senile cataract: cortical and nuclear. Frequently both types are seen in the same lens, developing at different rates and superimposed on the normal changes resulting from the increase in thickness and in color that comes with age.

In cortical cataract the regions of opacity in the outer layers of the lens are frequently visible to the examining ophthalmologist as well-recognized patterns described by such words as cuneiform, coronary, spokes and wedges. The opacity arises from a disturbance of the regular order of the fibers: they become swollen or distorted and gaps filled with fluid and debris form among them. That gives rise to large and irregular discontinuities in the distribution of the fiber protein, and thereby to discontinuities in the refractive index. In many lenses thus affected coincidental evidence of metabolic disturbance is provided by a sharp increase in sodium content. Cortical opacities interfere little with vision when they are at the equator of the lens, beyond the normal pupillary opening in the iris, and they may take many years to spread toward the center and seriously reduce vision. There is a fairly common type of cortical opacity, however, that does soon become disabling, and that is an opacity just under the capsule at the back of the lens and in the center of the pupil. Such a polar cataract may involve very little of the substance of the lens and yet interfere significantly with vision.

A nuclear cataract is the result of slow changes in the proteins in the core of the lens. In time the nucleus becomes deep yellow, brown or sometimes nearly black. Located as it is at the center of the pupil, the altered nucleus effectively interferes with vision, both because of the color itself and because aggregations of protein molecules are formed that are large enough to scatter light. Biochemical analysis shows that the folded peptide chains of the crystallins appear to have unfolded. In the process certain normally hidden sulfhydryl (SH) groups are exposed and oxidized, with the result that disulfide (S–S) links are formed between and within molecules. Together with unknown other covalent bonds these links tie protein chains together so that new proteins of very high molecular weight (more than 50 million daltons) are formed.

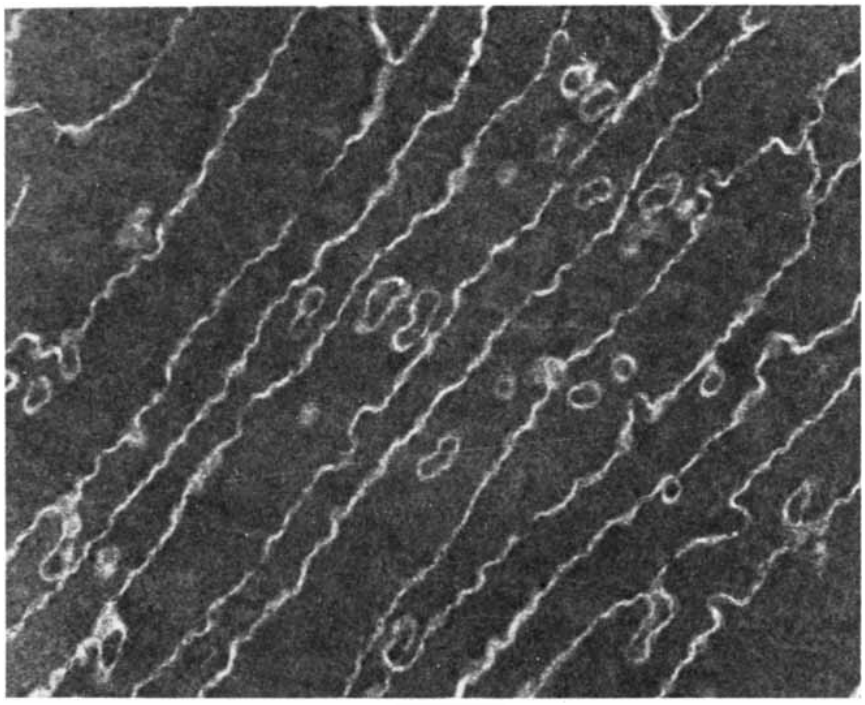


TYPICAL SENILE CATARACTS are related to the structure of the lens as shown in these highly schematic drawings. The nuclear cataract (*a*) involves changes in the proteins of the nucleus that darken its color and may also cause light to scatter. The cuneiform cortical opacity (*b*) forms when the regular order of fibers in the cortex is disturbed; gaps filled with water and debris form among fibers, altering the refractive index and scattering light.

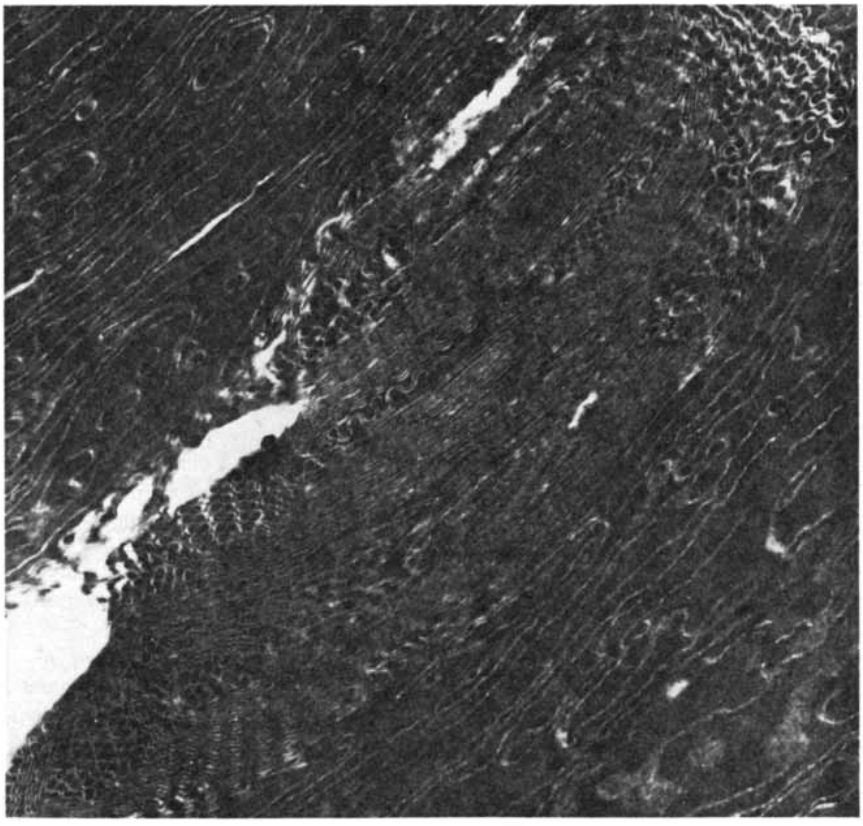
We still do not know what initiates the light-scattering changes in the cortex and the nucleus. It would appear that both forms of cataract are metabolic in origin. The reason the fibers become disarranged and separated in the cortex and not in the nucleus may be that the membranes of the cortical fibers are intact, whereas those in the nucleus have degenerated and present no barrier to the passage of substances that disturb the osmotic balance of the fibers.

It is clear that the aged lens suffers from disadvantages that may predispose it to cataract. First, the increase in the volume of the lens in relation to that of the aqueous and vitreous humors may mean that the supply of nutrients and oxygen is dangerously close to the lower limit of adequacy. Second, the lens substance becomes almost incapable of altering its shape and yet continues to be subjected to forces exerted by the zonular ligaments through the capsule. The eye attempts to accommodate but the lens resists deformation and thus is subjected to mechanical stresses. This is true in particular between the ages of 55 and 60, after which the capsule loses strength and less force is applied to the lens. Ronald Fisher of the Institute of Ophthalmology of the University of London has pointed to evidence that certain wedge-shaped opacities seen in the eyes of an old person may be indications of damage done to the lens fibers by mechanical strain during the late fifties.

As I have indicated, senile cataract is thought to be caused by stresses over and above the normal effects of aging. One such stress has been identified: diabetes. In the Oxford region between 1957 and 1962 a person with diabetes was from four to six times more likely to have a first cataract operation than a nondiabetic of the same age and sex. Similar findings have come from at least



NORMAL LENS FIBERS from a region just under the capsule near the front of the lens are enlarged 18,000 diameters in an electron micrograph made by A. J. Bron, K. J. Dilley and J. O. Habgood of the Nuffield Laboratory of Ophthalmology of the University of Oxford. The fibers, outlined by their membranes, lie in a rather regular array. The circles and loops represent various sections of ball-and-socket links between contiguous fibers.



ALTERED LENS FIBERS seen in cataract are similarly enlarged in this micrograph. The lens section includes part of a small, dense opacity that was just under the capsule at the front surface of a lens. There is an abrupt change from a region of rather normal fibers (*bottom right*) to the adjacent region of the opacity (*lower left to upper right*), where folded fiber membranes form closely packed multiple layers and other complex figures.

nine other surveys since 1920. It is clear that diabetes helps to cause senile cataract, and we now have a good idea of the mechanism by which it does so. The evidence comes from animal experiments; this is a case in which the results of work with animals can validly be applied to the human problem.

There is an enzyme in the lens, aldose reductase, that is almost inactive when the glucose concentration is at its normal level. In response to the raised level of glucose in the aqueous humor (as in the blood) that is characteristic of diabetes, however, the enzyme catalyzes the reduction of glucose to form the sugar alcohol sorbitol. The presence of sorbitol, which is removed only slowly by further metabolism and leakage, increases the osmotic pressure within the lens fibers, causing the lens to take up water from the aqueous and vitreous humors. When experimental diabetes is induced in the rat, thereby maintaining a high blood-glucose level, more sorbitol continues to be formed and more water continues to be drawn into the lens. The swollen fibers become disrupted; that in turn has further deleterious effects with which the metabolism of the lens is unable to cope, and eventually the lens loses its transparency.

In man a similar sequence of events is observed, albeit rarely, in poorly controlled juvenile diabetics, who may develop a rapidly progressive diabetic cataract. This rapid onset is not seen in older diabetics with cataract, but their lenses too are found to contain elevated levels of sorbitol. There is therefore a strong likelihood that sorbitol is the toxic factor in the development of cataract in diabetes and that it accounts for the higher rate of cataract operations in diabetics. (It should be mentioned that although aldose reductase is widely distributed in the tissues, it is only in the lens and possibly also in nerve cells and in the papillae of the kidney that osmotic damage is likely to be caused in diabetes by the accumulation of sorbitol.)

The senile cataract of diabetes, in which increased osmotic pressure in the lens is implicated, cannot be distinguished from senile cataract in nondiabetics. This fact leads to two interesting speculations. First, population studies show an increase with age in the level of blood glucose after a meal or after the ingestion of a dose of glucose; the increase may be as much as eight to 13 milligrams per decade of age. Perhaps sorbitol is the factor that precipitates senile cataract in some nondiabetic pa-

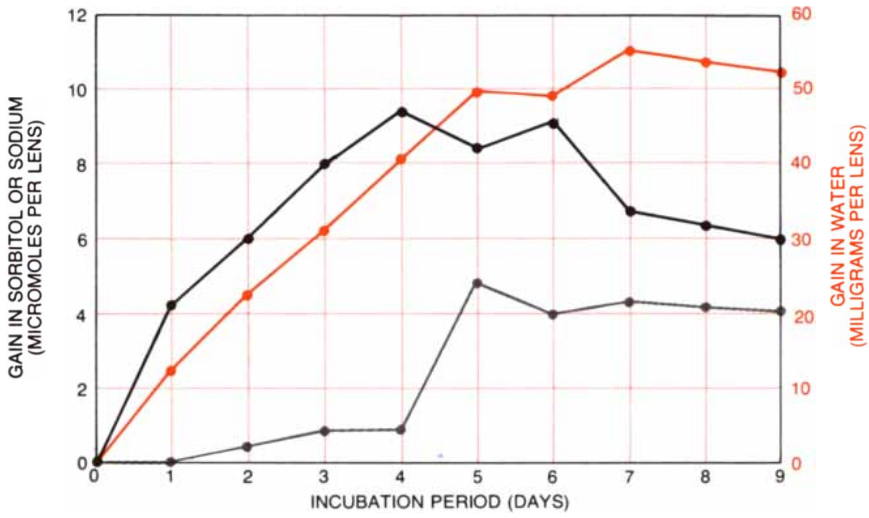
tients as well as in diabetics. Harmful osmotic stress on the aging lens fibers may be exerted by fluctuating levels of lens sorbitol brought about in response to fluctuating levels of glucose in the blood and the aqueous humor. Second, it is possible that quite other and still undiscovered factors may be responsible in some cases for an elevated osmotic pressure in the lens and therefore for cataract.

Heredity may be yet another factor in senile cataract. Many ophthalmologists and laymen believe cataract runs in families. Although there are a few families with interesting and easily discerned patterns of opacities, however, there is as yet no proof of a genetic factor.

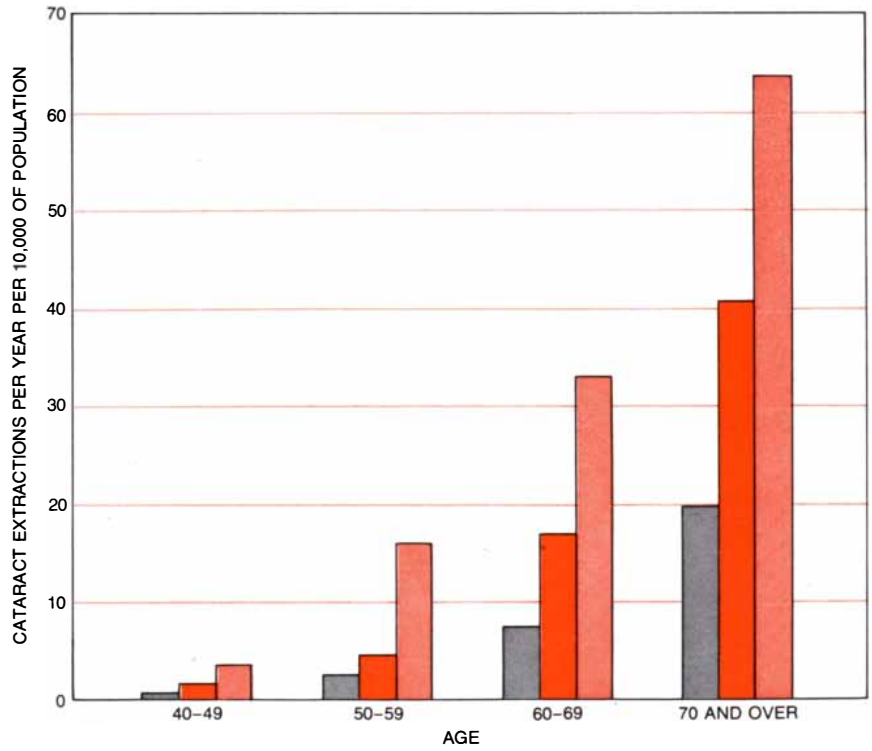
Racial determinants may be involved to an unknown extent. The rate of cataract extraction is substantially higher in Israel than it is in Oxford, and it is higher among Israelis of non-European origin than it is in those of European stock. These differences could stem largely from factors such as sex, visual requirements, diet and life habits. The overwhelming difference between figures from Europe and those for parts of India could be partly racial. On the other hand, when I saw 1,021 cataract operations performed during three weeks in January, 1970, at Sir Henry Holland Christian Hospital in Shikarpur in Pakistan, the patients were of many racial origins and the surgeons did not believe any one race was more susceptible than any other. A number of other possible causes have been suggested for the high rate of cataract extraction in parts of the Indian subcontinent: strong sunlight, dust, dehydration, premature aging and the mineral content of the water. Immunological and nutritional factors have also been implicated by some. The effect of sunlight, and in particular of its ultraviolet component, in browning the lens proteins is in many ways the most plausible hypothesis. Examination of the human lens nucleus has so far yielded no evidence of photo-oxidized proteins, however.

Occasionally the administration of a drug precipitates the development of senile cataract. With a number of drugs cataract has been the first serious side effect to be observed, causing the drug to be either withdrawn or prescribed less freely. (Cataract is sometimes acceptable to a patient if the drug is required for the treatment of some more serious disabling condition.) There are many cases in which cataracts have been produced experimentally by administering drugs and other chemicals to animals. Only recently the practice has been adopted of regularly examining the lenses of animals involved in preliminary trials of drugs so that compounds found to cause cataract can be abandoned at an early stage.

The fundamental study of cataract in man requires collaboration among ophthalmologists, laboratory investigators and statisticians. Such collaboration was once rare. The fact that it is now beginning to take place in various parts of the world is a hopeful sign of further advances in understanding the disease.



EFFECT OF SORBITOL, which may induce cataracts in diabetes, was demonstrated by Jin H. Kinoshita of the National Eye Institute, who incubated rabbit lenses in a high-glucose medium. For four days the sorbitol level (*black*) increases and water (*color*) is drawn in by osmosis; during this period the lens reverts to normal if placed in a low-glucose medium. After four days, however, the lens cannot maintain its ionic balance; sodium (*gray*) enters the lens, sorbitol leaks out, fibers are damaged and cataract results. These effects are not seen in lenses incubated in low-glucose mediums of equal osmolarity.



RATE OF CATARACT EXTRACTION was lower for men in various age groups in Oxford, England (*gray*), than it was for men in communities in Israel that were populated by people of European background (*dark color*) or of non-European background (*light color*).

Technology: Whale Oil, Arab Oil

No one who lived through it can forget the fuel shortage of 1974. But few remember that today's energy crisis is not the first one in our history.

Up until the middle of the last century the lights of the world were lit with whale oil. Machines were lubricated with whale oil.

Suddenly there wasn't enough. Whales were being killed faster than they could spawn. An energy crisis was imminent. Fears that the worst would happen were commonplace.

Then an unexpected thing happened. Technology came to the rescue. As whale oil supplies dwindled, the growing petroleum industry took up the slack.

Not only did the new petroleum solve the problem—it was *better* than its predecessor.

Technology has ultimately delivered more energy, less waste.

You may remember from your early education that James Watt invented the steam engine. Not so. It was the first really *efficient* steam engine that he invented. Energy efficiency has always been rewarded. Watt went into the history books and Savery and Newcomen, the real pioneers, went into oblivion.

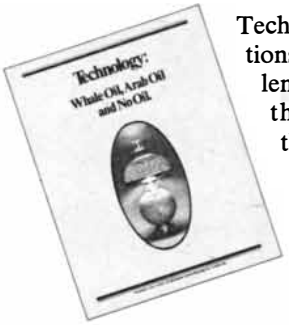
Watt's improved steam engine brought in a new energy technology. Huge numbers of steam-driven machines were produced. Because energy could be used so much more efficiently, much more energy was used. And the industrial revolution began.

Consider what modern communications technology has done to save energy.

Until the mid-1800's, all messages had to be delivered in person. Whether the messenger went on foot, by horseback or aboard ship, he was not very efficient in his use of energy. The railroads added some speed in return for a large increase in energy consumption.

Then Samuel Morse came along with a new communications technology – telegraphy. With

We believe in the promise of technology.



Technology has provided the solutions to many of society's problems. It is also often blamed for them. Some people believe there's too much technology today – that this very abundance is the basis for so many of our ills.

We believe the solutions to problems lie in the intelligent application of technology—that a misunderstanding of technology's role in man's advancement can only lead to a diminution of his ability to provide solutions.

Therefore, we're sponsoring a series of "white papers" to foster a clearer understanding of technology. Excerpts from the fifth of these papers are published above. If you'd like a copy of the complete text, please write Gould Inc., "Dialogue on Technology," Dept. S-5, 10 Gould Center, Rolling Meadows, Illinois 60008.

and No Oil.

the world wired for electric communication the inefficient messenger was no longer needed.

Then came the telephone, radio tube, and transistor. Communications became even quicker and energy efficiency became even greater.

But while each of these advances brought improved energy efficiency, they also increased energy demand. Does this bring us to an impasse? By using less, will we always end up using more?

Turning the corner on total energy consumption.
Enormous technological advances have taken place in just the last few years.

With communications satellites and laser beams working at full potential and with advanced computers organizing the whole—it may be possible to transmit messages with an efficiency unheard of today. Changes are in the works that by comparison relegate today's communications technology to the same class as yelling from mountaintop to mountaintop.

What will happen when there is no more oil?
When that day comes, hopefully it won't matter. New technology will have an answer for tomorrow's Arab oil crisis just as it did for yesterday's whale oil crisis.

Imagine every individual with a portable phone that gives access to every number on earth. Think of the printed word transmitted in a fraction of a second at the press of a button. Consider a single world-computer that holds the library of mankind and is available to anyone at any time.

There is no need to transfer mass when an image can be transferred instead.
The conference room of tomorrow may be peopled with "images" of individuals who are actually sitting at home continents away. Business trips may amount to walking across the room to the transfer machine. Automation, telemetering, and television monitoring may replace rental cars and plane tickets.

People may not need to go anywhere, so "no oil" becomes a lesser problem.

Carried to its logical extreme, this trend could disperse population and relieve urban congestion. Every place on earth would be "where it's at."

Science and technology can solve many problems. If they don't, what else will?
This scenario—the technological solution—is as possible as the more negative speculations that have recently made the news. The difference is that this one offers hope for mankind.

Similar innovation offers hope of solving our problems of food supply, raw material depletion, and living on a crowded planet. Nothing like this can ever come about by turning our backs on technology. Without it, we are scared, cold, hungry animals. With it, we can change the world.

SISTER-EXCHANGE MARRIAGE

Among the Koman peoples of Africa the bridegroom promises a sister to the family of the bride for marriage. The practice is an organic part of the economic, social and moral system

by Wendy James

Marriage everywhere is a social contract, incorporating not only legal or quasilegal entitlements but also moral concepts of fair treatment and honorable behavior. Comparative studies of marriage tend either to stress the variations in its contractual content from one society to another (monogamy, polygamy and so on) or view it in organizational terms, with each marriage link forming a component of a wider pattern of social structure (endogamy, exogamy and so on). Although these studies of the legal and structural aspects of marriage are necessary, they are not sufficient for understanding a particular form of marriage as a social institution. Concepts and personal evaluations of a moral kind—how people "ought" to behave and why—are also much to the point.

Among the Dinka cattle herders of the southern Sudan, for example, the marriage contract is ratified essentially by the transfer of cattle from the lineage of the groom to that of the bride. The meaning of the transfer is not self-evident. To an outsider it may look like "wife-purchase," but to the Dinka it is not a matter of purchase; it is the main element in the forging of a new family bond between the lineages, and it is followed, significantly, by a return transfer of cattle (although not the same ones) from the bride's people to the groom's. Later the main herd of cattle received by the bride's lineage may enable her brother to marry, and so her family becomes intimately linked with his bride's. Cattle themselves are more than mere beasts to the Dinka, who value them highly in their imaginative life and kill them only in religious rituals. The bridewealth payment is clearly more than trading cattle for women.

In some parts of the world no bridewealth payment is made, but the marriage contract is sealed by the return of a woman and the establishing of a double marriage bond. The bridegroom is expected to find a sister or some other close relative to convey to the family of his bride, one of whom will marry her. The exchange may be arranged by lengthy consultation among the elders, or it may be a spontaneous agreement or a hasty improvised adjustment among the young people themselves. The system can be termed sister-exchange marriage.

On the surface sister-exchange has often appeared to be a simple institution, easy to explain as a primitive form of marriage contract. For example, Sir James Frazer saw it as economic common sense at an early time in human history, before men had property. A sister was the most valuable asset a man had, and he would naturally bargain her away for a wife. Robin Fox follows Frazer in giving sister-exchange an early place in social development, but he ascribes it to collective and adaptive rationality rather than individual (and male) decision making. Claude Lévi-Strauss has treated sister-exchange as a particularly clear and simple manifestation of a principle of mutuality or reciprocity that runs, sometimes at an unconscious level, through all systems of kinship and marriage (and other components of culture).

Regarded as a set of behavioral rules of diagrammatic simplicity (*A* marries *B*'s sister, *B* marries *A*'s), sister-exchange does appear to be elementary. No diagram, however, can indicate the complexity of life lived under its terms. Even if the inevitable demographic complications are clear and the ways in which people get around them are understood, it is not obvious why people adhere stubbornly to the system. If, on the other hand, we think of the fuller implications of sister-exchange as a social contract, that is, the implications that reach beyond formal definition to the sphere of moral concepts, it becomes more complex to describe but easier to appreciate intuitively. I have recently done some research among the Koman-speaking peoples of the Sudan-Ethiopia border, where this kind of marriage, although complex and full of quarrels, was considered an ideal. Its pursuit involved concepts of egalitarian rights, justice and honor that cannot be patronizingly dismissed as simple or primitive and that have proved durable in Koman history, even after the disappearance of sister-exchange as such in some areas.

The peoples speaking languages of the Koman group number between 60,000 and 100,000. They live in scattered and sometimes remote communities in the foothills and valleys of western Ethiopia and its border with the Sudan. These woodland savannas are shunned by the Ethiopian highlanders as being hot, malarial and wild, and by the Sudanese as being wet and hilly. The Koman peoples make good use of the light, open woodland. Living at a low density of population, they practice subsistence hoe culture of sorghum, maize, beans and root crops, shifting their tiny hamlets and fields a short distance every few years. They keep a few domestic animals, although the tsetse fly and other hazards make it impossible to herd cattle in some areas, and they hunt wild game on foot with spear, bow and arrow or gun. The woodland provides them with honey, wild fruits, herbs, roots and building materials, and the rivers, although they are seasonal in places, yield some fish.

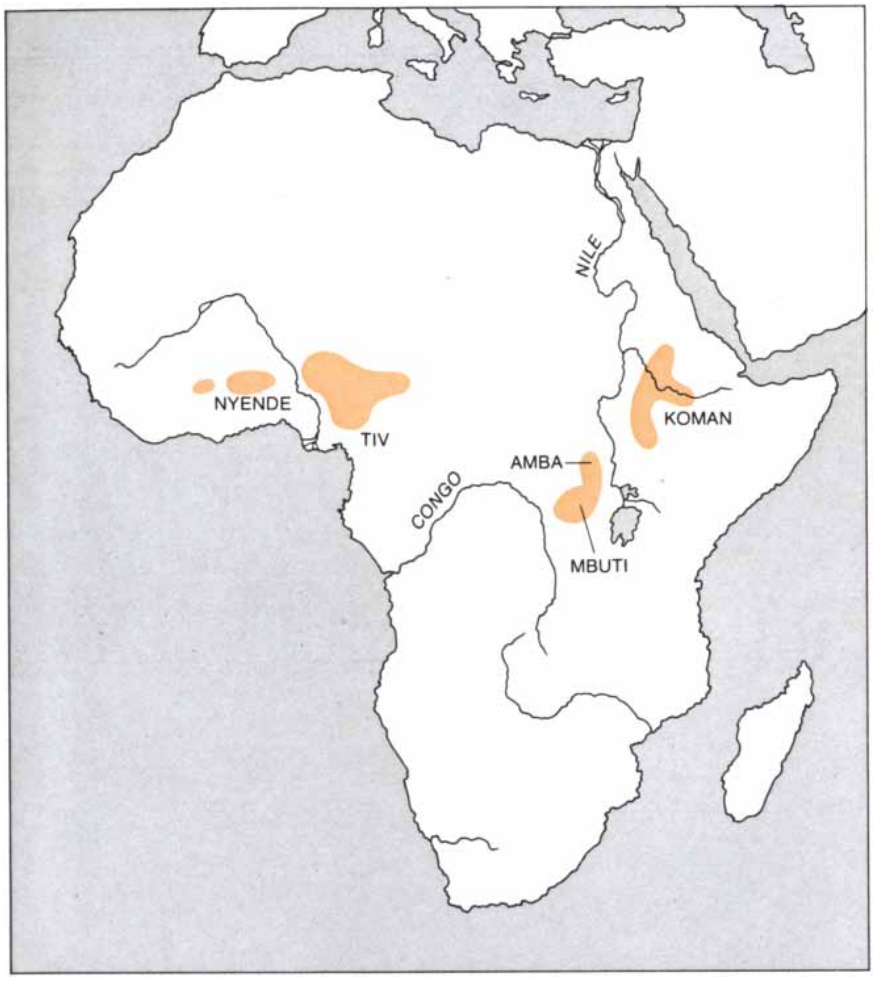
In spite of appearances the Koman peoples do not live in isolation. They have long had links with the Amhara and the Galla of Ethiopia, and with the

Arabs and the Nilotes of the Sudan. In almost every hamlet either the Arabic or the Galla language is known at least to the men, and in the south the Nilotic Anuak language is widely known. The Koman peoples nonetheless retain their own family of languages as well as their way of life, since many of their contacts with outsiders have been violent, and the memory of the slave trade is still fresh.

My field research has been conducted among three Koman groups: the Gumuz, who practice a thoroughgoing system of sister-exchange; the Komo, who have partly replaced exchange marriage by a system of bridewealth payments, and the Uduk, who appear to have abandoned exchange, to have refused to accept a bridewealth system and to have found an alternative system of their own. Before looking further at these marriage systems it is necessary to understand the three peoples' attitudes toward exchange and transaction in general. The productive effort of all the Koman is devoted to the goal of self-sufficiency and the conservation of resources rather than to economic growth and trade. The work of cultivation is organized largely on the basis of neighborly cooperation; the major tasks in each man's fields are carried out by groups of his relatives and neighbors, who return to a meal, and if possible a beer party, prepared by his womenfolk. The product of the fields, like that of the chase, is not kept within the household but is shared, and much of it goes back into the cycle as food and beer for the next year's work parties.

Mutual assistance and sharing impose obligations on the individual, but at the same time they provide a certain security for him in time of need. In this kind of society, perhaps even more than in others, no man or woman can exist independently. Bonds of mutual trust and reliance are vital. Conversely, profit-oriented barter or cash transactions are usually avoided within the community, and if there are any such transactions, they are more likely to be with outsiders. The exchange of goods and services within the community is not subject to any strict accounting; it is expected to take place in a spirit of generosity and not one of bargain hunting. Although that is not al-

GRAIN HARVEST is carried in baskets from the fields to the threshing ground by women of the Uduk, a Koman people who live along the border between the Sudan and Ethiopia. Some of the Koman practice exchange marriage almost exclusively; some also make bridewealth marriages. The Uduk have developed their own marriage system.



SISTER-EXCHANGE MARRIAGE was, or is still, practiced among the Nyende of Dahomey, the Tiv and other peoples in Nigeria, the Amba of Uganda, the Mbuti pygmies of the Ituri forest and the more than 60,000 Koman peoples of the Sudan-Ethiopia border. The author has worked mainly among three Koman peoples: the Gumuz, the Komo and the Uduk.

ways the case, it remains an honorable standard by which actions can be judged. In this subsistence economy money plays a peripheral role; it is not needed for survival. On occasion the Gumuz take cotton and grain to the market, the Komo take honey and fish and the Uduk take sesame. In so doing they may acquire money, but it has the character of a windfall and is spent on consumption goods such as clothes. It is not saved or invested in any systematic way, and you cannot avoid your obligations to your neighbors by collecting it. The network of relations in which the Koman find themselves is an egalitarian one, and therefore a claim against a neighbor that appears to restore a balance after an act of unfairness will be considered justified.

The Gumuz, who live in the valley of the Blue Nile, are the most numerous of the Koman peoples. They also have the most elaborate and internally coherent system of sister-exchange marriage. The exchanges take place between patrilineal clans, and they are normally arranged by clan elders, who have considerable authority over the younger men and women. If a marriage takes the form of an elopement and there is no subsequent exchange, it is described as "stealing" and could provoke violent retaliation. The matter may be put right a few years later when an exchange girl is found, or even in the next generation, when a daughter of the "stolen" woman may be paid back to replace her mother. Then the daughter may be used in an exchange, as her mother should have been.

Elaborate arrangements may be made for borrowing and lending girls for exchange within the clan or between closely linked clans. When you borrow a girl from a clansman to exchange for a wife, you should eventually give your own daughter (whose birth is made possible by the exchange) back to your clansman or his son as a replacement; your daughter can then herself be exchanged. There are thus sets of debts linking people over the generations, both between clans and within clans. Once an exchange-marriage link is made it is fairly durable in itself; if one wife dies, a replacement may be found (and even a second replacement if the first replacement dies). Small girls, promised in exchange, may go to live with their future husband's people and be brought up there in anticipation of their eventual marriage. It is common for a widow to be inherited by one of her husband's brothers. Fathers exercise a fairly strict control over the marriage of their daughters, allocating them to one or another son or nephew, or even exchanging them for a second wife for themselves.

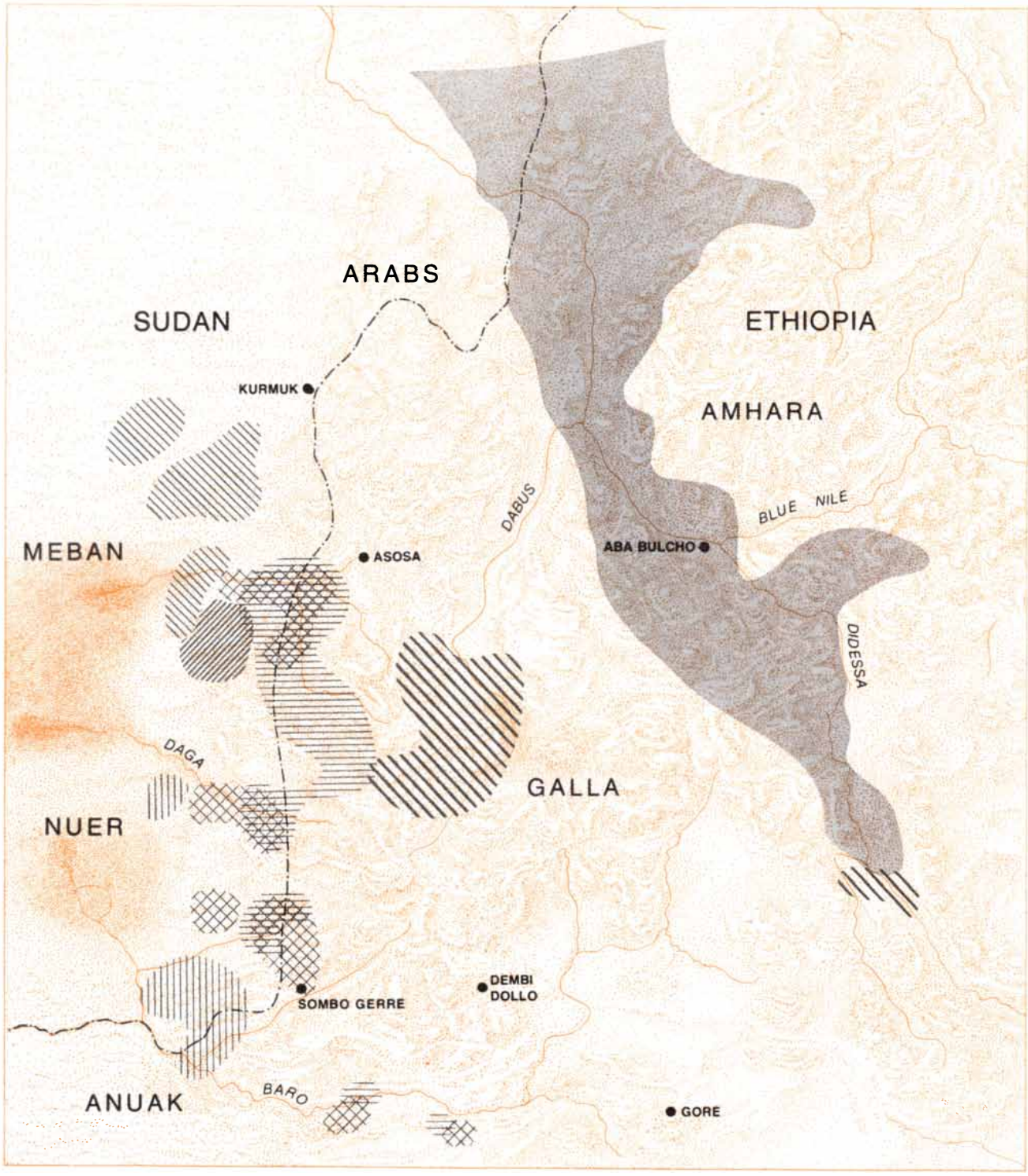
Everyone among the Gumuz is caught up in this network of exchanges; there is no alternative mode of marriage contract. In a sample of 371 marriages surveyed this past summer only two could be described as bridewealth marriages, and both were highly exceptional. One old man's father had bought his bride out of slavery years ago, paying for her with goats and salt, and one young man had recently paid a large cash sum to the mother of his wife. That was because the mother had refused to allow any of her in-laws to use her daughter as an exchange. (Some years earlier the in-laws had killed a son of hers.) She insisted on keeping the money as compensation to herself. As can be imagined, marriage arrangements among the Gumuz are major political matters, linked both with feuds between clans and with peacemaking.

The Komo are of particular interest because their marriage system is now changing. Past disturbances and present government pressure have scattered the patrilineal clans of the Komo, and the authority of the elders is much weaker than it is among the Gumuz. The position of women, particularly the younger women, is more independent. The majority of Komo marriages are still exchange marriages, but a growing proportion of them are accomplished by bridewealth payment.

Komo informants believe that sister-exchange has been practiced from very early in their history. If you ask them why they like to make these exchanges, they are likely to reply: "Are we not all the children of exchanged girls? So we must ourselves exchange." As among the Gumuz, a man is expected not to marry into his own (patrilineal) clan or into the clan of his mother. The result is that exchanges are not repeated generation

after generation between the same groups of people or the same clans. For each clan a new fan of marriage links is made in each new generation. The Komo allow polygamy (that is, a particular man may be married to more than one wife at a time), but a woman may be the wife of only one man until that marriage is dissolved.

When the Komo speak of their wives and sisters or their *mash* (the girl they exchange for a wife), they are not thinking of women as commodities. For them the marriage system turns on the positive value of women, who are central to its functioning. A woman's work complements that of her menfolk, and when a girl marries, her father and brothers will miss her at this practical level. Conversely, when a new wife joins a hamlet, it is as a working woman that she will be



DISTRIBUTION of seven Koman-speaking peoples on opposite sides of the Sudan-Ethiopia border is generally along the Blue Nile and its tributaries in the east, or adjacent to permanent and semipermanent streams that flow westward in the southern part of the Sudan. The data regarding Komo marriages are mainly from studies in the village of Sombo Gerre.

judged by the community as a whole. Beyond these everyday considerations a woman is precious as a potential mother of children. Her honorable position, in her own community or her husband's, flows from this, and as a potential mother she sees herself as the pivot of the exchange-marriage arrangements.

The Komo think of a woman as the source from which the local community, and the society as a whole, will be replenished and grow. They regard the physical bonds between a child and his mother as being stronger than those between the child and his father, and they see the natural continuity of society as passing from mother to daughter. A sister's potential for childbearing is regarded as belonging "naturally" to this female line. Marriage arrangements, however, cut across this "natural" line of descent, and exchange marriage in particular results in the transfer of a sister's potential offspring from the guardianship of her own people to that of her husband's people. If an exchange-marriage contract breaks down, the rights to a sister's children may revert to the "natural" line, primarily to her brother. Clans among the Komo, the named groups in terms of which history and politics are discussed, are based not on this idea of "natural" descent through women but on patrilineal links from father to son. They are regarded as having been built up through repeated sister-exchange marriages.

Sombo Gerre is a modern Ethiopian village inhabited mainly by Komo. (The total population is 117.) Many of these people have been refugees, some of them more than once. It is a reconstituted traditional community, including some people from the larger town of Gambela, and in its present form it is about six years old. There has long been social insecurity in this region, and it was exacerbated during a period of disturbances in the southern Sudan from 1956 to 1972. In spite of these troubles the traditional values remain powerful. Sister-exchange still provides the point of reference for discussions of family and marriage, even though a few marriages have been secured with a cash bridewealth for many years, and even though official Ethiopian policy for the past two years has been to replace sister-exchange with cash payments. The sums provisionally agreed on with local Komo leaders were 150 Ethiopian dollars for a woman not previously married or from 50 to 80 dollars for one previously married.

This policy appears quite rational from the viewpoint of the administration, which wants to integrate the Komo further into Ethiopian society and to bring them into the cash economy. Representatives of the official side argue that cash payments will be fairer, since under the old system a man without a sister could not marry. The old system, however, has remarkable flexibility for redistributing "brothers" and "sisters"; I have not come across a single case of a man being unable to marry at all through "not having a sister." The Komo look at the situation quite differently: the older generation cannot see cash payments as being an honorable way of transferring a wife, either for those who receive the woman or for those who receive the cash. And a man of the younger generation whose sister is about to marry is likely to react by demanding just and full compensation and insisting on a girl in return, or a large amount of money, rather than lose face by accepting a paltry first installment of bridewealth. From a woman's point of view the new style of marriage for cash imposes far lighter wifely obligations: the basic loyalty to a brother may override the tie to a husband, whereas in the exchange system loyalty to a brother paradoxically strengthens the marriage tie. (If you treat your husband badly, the other woman may treat your brother badly.) Marriage relations are therefore becoming much more fragile, and the vengeful element of pursuing rights and justice within the terms of the old reciprocal contract is becoming more evident as the honorable status of the exchange contract is being officially eroded.

Some details of the situation in which the Sombo Gerre people find themselves (as of late last year) illuminate these aspects of the marriage question. The total number of married couples, including 20 couples for whom the marriage arrangements were incomplete, was 151. About two-thirds of all these marriages were contracted through sister-exchange, and full sisters were handed over in nearly half of the exchanges. The rest were exchanges involving more or less distant clan relatives, sometimes in a younger generation, and in a few cases girls were exchanged who were related through a father's sister or some other clanswoman. This happens, for example, when a woman of the previous generation has married but has then returned with her children to her original home because the exchange was not properly completed. Her daughter, with whom her brother's son has grown up, is then eligible as an exchange for the son's wife.

There are four main clans represented in Sombo Gerre, and in living or recently deceased generations there are exchange-marriage links between all of them. There are also links with some of the less well-represented clans in the village. Most of the exchange links, however, are with villages up to 50 miles away, either across the border in the Sudan or in the region of Gambela. From one point of view the links hold together the scattered fragments of Komo society. There are also exchange links with other Koman groups such as the Kwama and the Shita, but not with the indigenous Nilotes, Galla or Arabs.

The integrating aspect of the marriage exchange is seen further in the fact that even where an individual exchange has been dissolved through the breakdown of a marriage or death, a value may be attached to the relationship that goes beyond the individuals concerned. Thus when a husband dies, his widow may be inherited by his brother; that maintains the exchange link and the complementary marriage. Here is an example I encountered at Sombo Gerre. Atwis of the Pwogo Kabach clan married Dingitu, and his brother's daughter was married to Zado, the paternal half brother of Dingitu. Zado died, but his brother Bameto was able to take his place, and thus the long-lived and fruitful marriage of Atwis and Dingitu was preserved. As another example, Abos of the Gali clan inherited Basida, the widow of his younger brother, who had died while hunting. Conversely, when a woman dies, a sister may substitute for her.

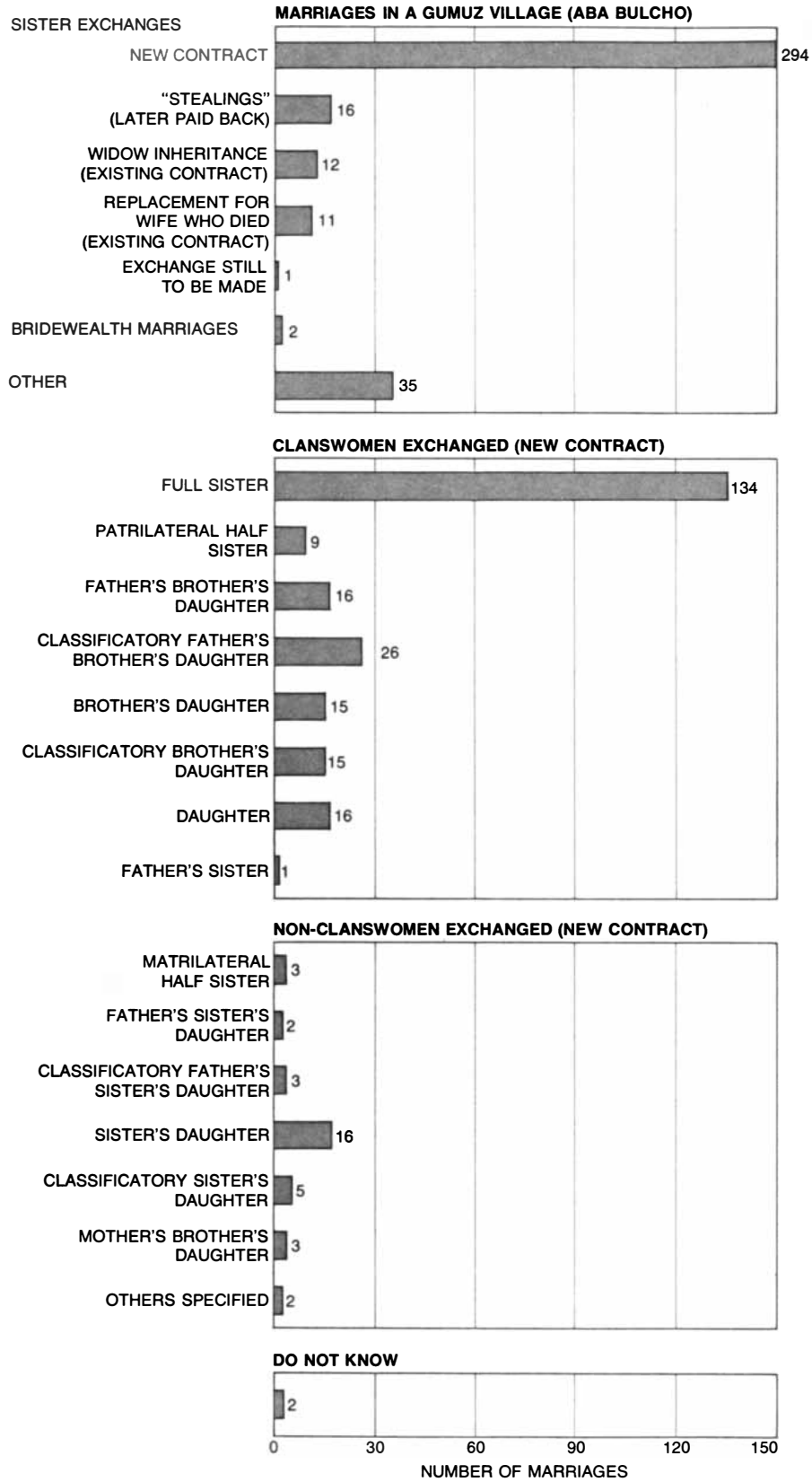
The principle of the preservation of an exchange relationship appears even more clearly in the two marriages of Moga [*see illustration on page 92*]. He first married Naiko (Kwanta's father's sister's daughter), and in exchange Kwanta married Tirbi, Moga's younger sister. Then Tirbi died, and Moga's wife Naiko was taken home by her parents because of the death. A little later Naiko also died. Hence the doubly bereaved brothers-in-law decided to arrange a fresh marriage exchange. Moga exchanged his elder sister, Kanato, for Kokosh, a full sister of Kwanta's.

The Gali clan of Sombo Gerre represents a group whose members were mostly brought up in the larger town of Gambela. Some of them are still living there; for example, Dante is a trader living in the town who has contracted three marriages with bridewealth. It is interesting to note, however, that those returning from the town to the village are caught up again in the exchange-marriage system. In the case of Abos, whom I have already mentioned, it was

partly responsibility for his deceased brother's widow in an exchange context that drew him back from the town. His son Dwop and his half brother's son Mustafa both entered exchange marriages after returning from the town, where they had earlier married on a bridewealth basis.

The concept of conserving human resources bulks large in Komo thinking on the subject of their womenfolk. They talk of marriage in terms of losing sisters rather than gaining wives, and if a sister is lost and no substitute or adequate marriage payment is made, her children are claimed back by her own people. A sister may return with her children after the dissolution of a marriage, and sometimes one or two children are claimed back by their mother's people if her exchange partner has been barren. Claims of this kind, which may lead to children's growing up with their mother's clansfolk and forming with them a "body" for the purpose of future exchange marriages, are seen as being only just, in spite of individual feelings. Reciprocal divorce is also seen as being just, even when one couple may not wish to be separated. If the contract has been broken, it is regarded as being right that natural claims should prevail, and that children should return to the body of their mother's brothers rather than being brought up in the body of their father's people.

An example will make this clearer [*see illustration on page 93*]. Adebe's third sister, Midi, was married to a man who never provided any exchange or bridewealth, and soon after giving birth to a son she died. Adebe took over responsibility for the child, Abunsa, who has lived and worked with him ever since. The boy, Adebe says, is now part of his own body, and it is his duty to find Abunsa either a girl to exchange or a sum of cash so that he can marry. If he does this, the boy's future children will also belong to Adebe's body. Adebe's two married daughters are also living with him, each with an infant; that is because their husbands have not yet provided any exchange or bridewealth, although Adebe is demanding it. If there is no such reciprocation, the daughters' children will also grow up as part of Adebe's body. When I asked Adebe what he would do if he received money for his daughters' marriages, he replied that he would give the money from the first to his sister's son, Abunsa, to marry, and from the second to his younger brother to marry again. (This brother, Nadir, has no daughters of his own.) I asked whether he would not spend the

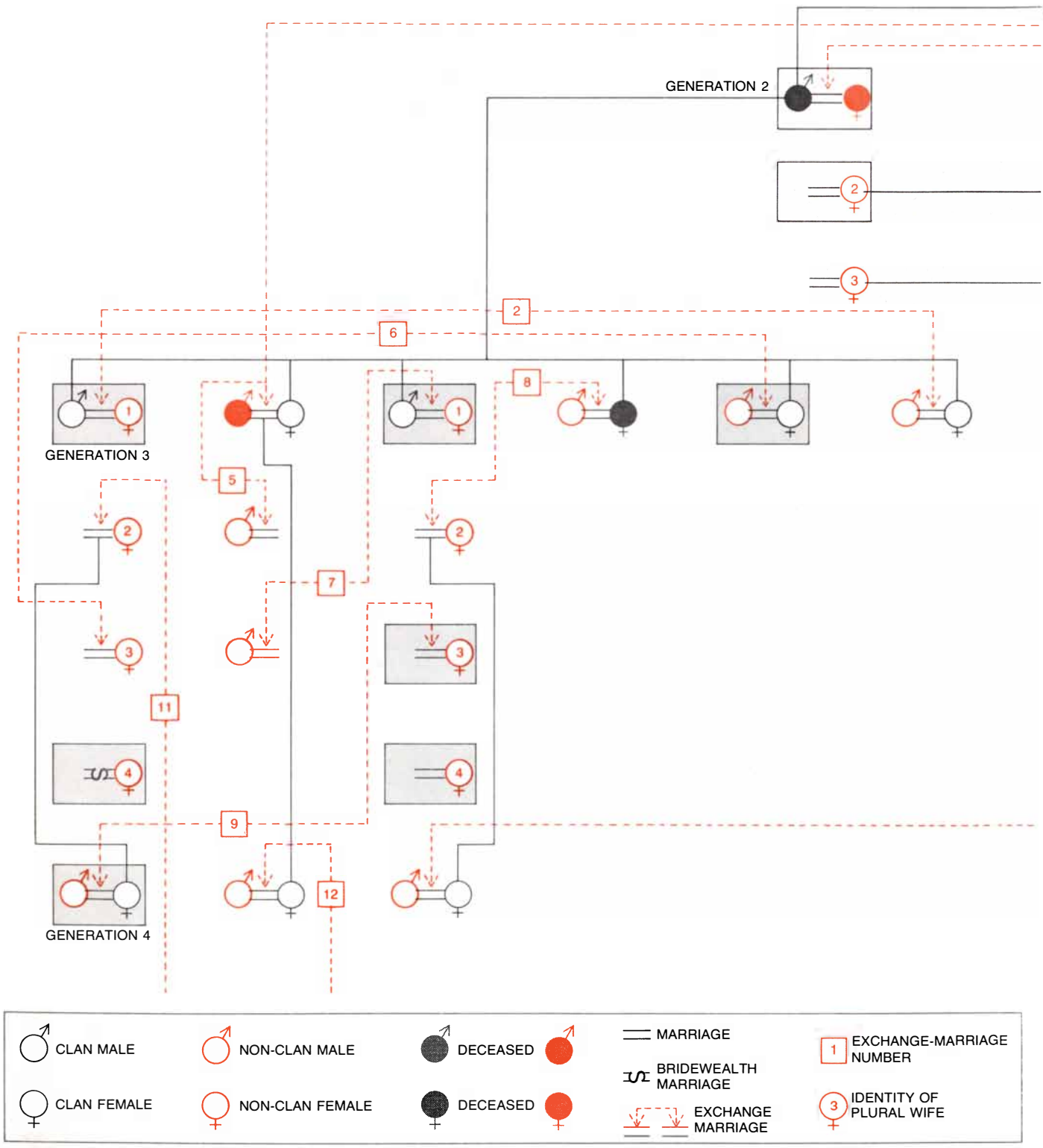


SISTER-EXCHANGE predominates among the Gumuz, as this collection of marriage data from heads of households in the village of Aba Bulcho indicates. Of 371 marriages embracing four generations almost 90 percent involved recent exchanges or exchange follow-ups, such as replacement of a deceased wife or inheritance of a widow. Fewer than 10 percent of marriages involved "stealing" without a subsequent exchange, and in many instances an eventual "paying back" was anticipated. Only two bridewealth marriages were known, both involving peculiar circumstances. The substantial number of daughters (lower-generation women) exchanged indicates the degree of clan and family authority among the Gumuz.

money on himself, and he replied: "When I married, my sister was exchanged for my wife. Therefore if I receive money for the children God has given me, I cannot eat it. I must give it to others."

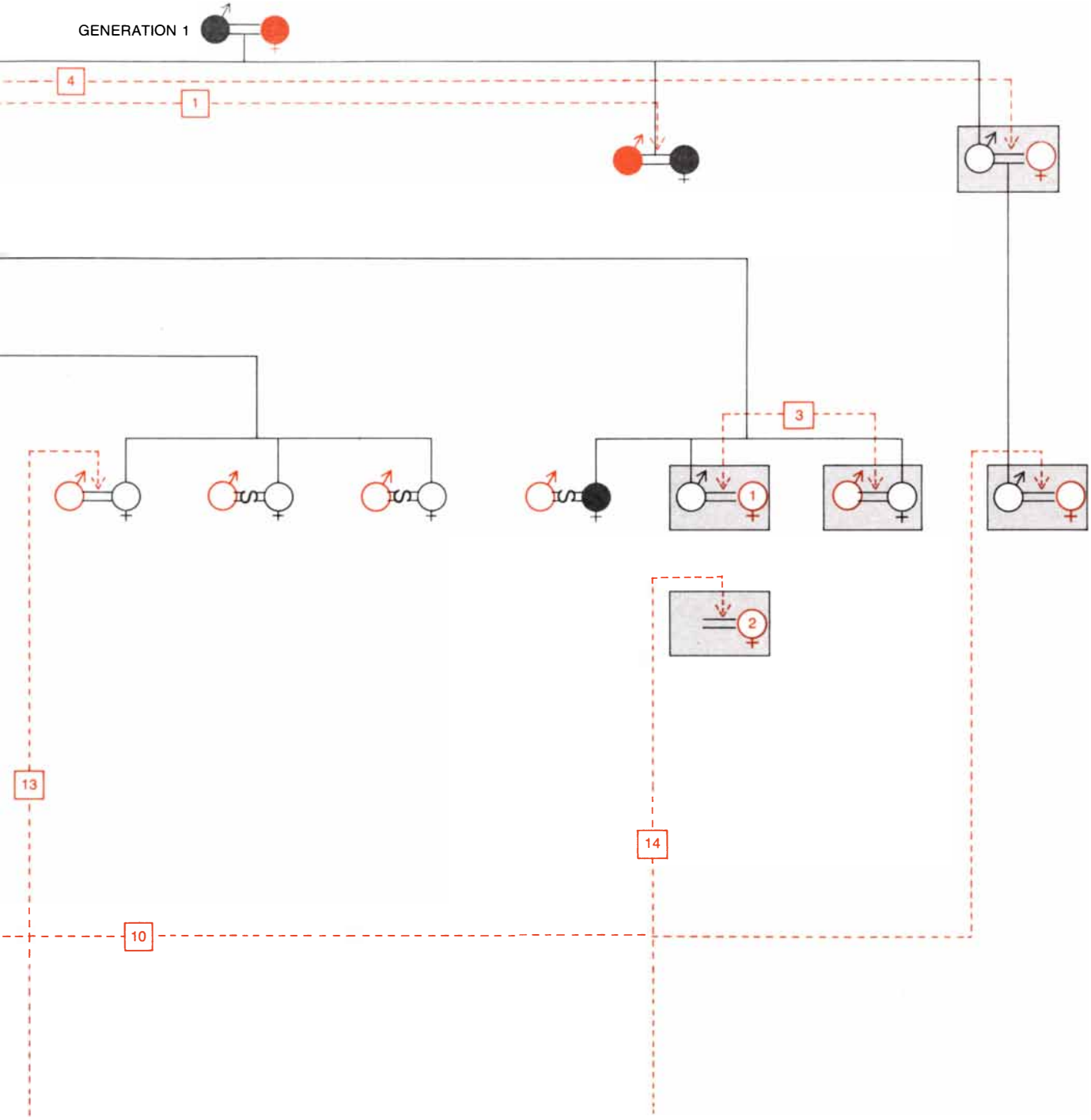
Adebe's judgments are typical of the older generation of Komo. Money received as bridewealth was to be set aside to be used for further marriages in the family; for Adebe to spend it on himself would clearly be dishonorable. For some of the younger men, however, marriage with cash payments is becoming something of a reckless game, in which the idea of individual rights is being pursued in a "pound of flesh" style at the expense of the moral bond also supposed to be present in the marriage contract.

Consider the strategies of Agede, a member of the Pwogo Kabach clan and Adebe's sister's son. His father was in the village of Tsokolmas, two or three days' walk from Sombo Gerre, and



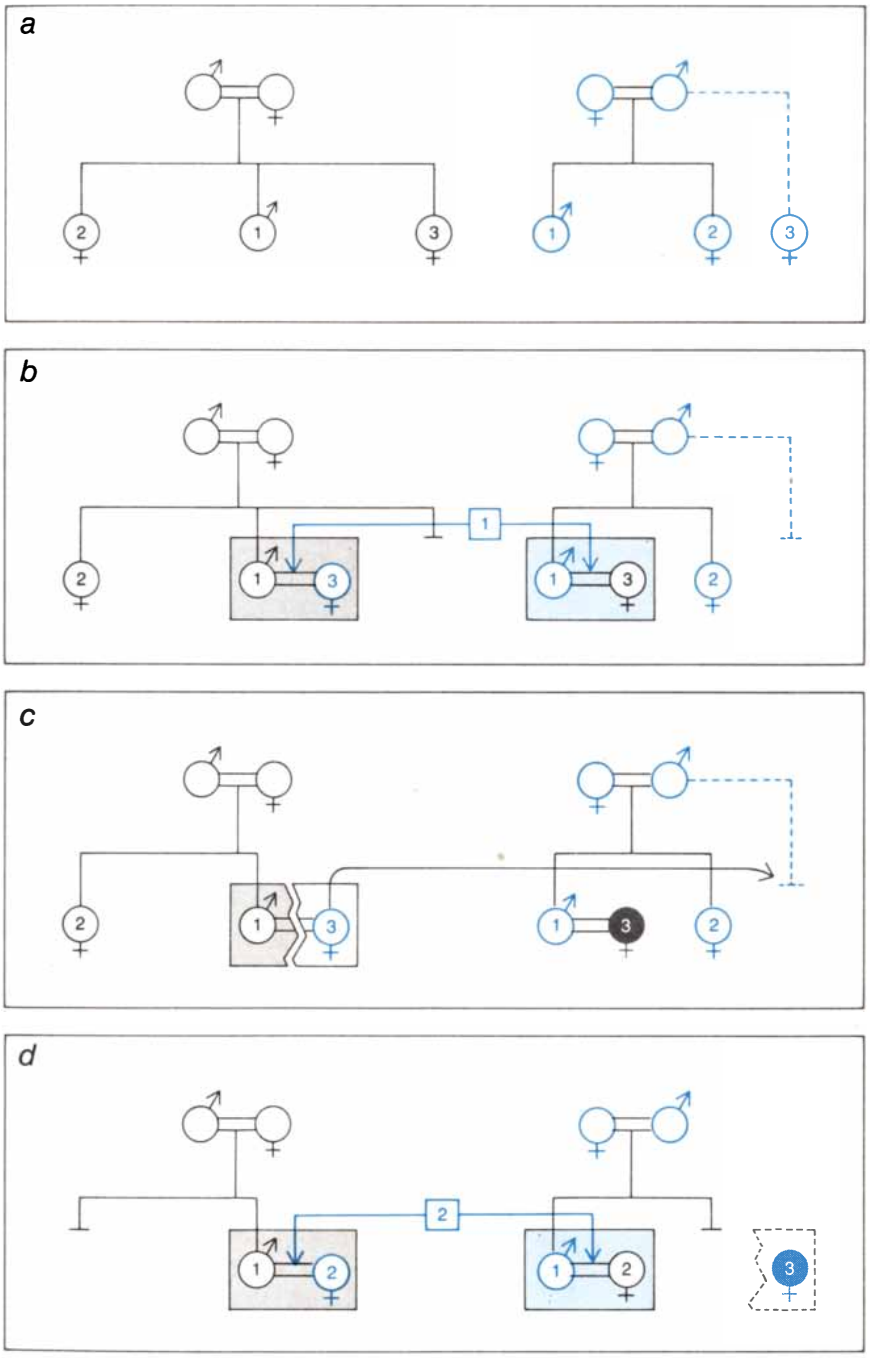
Agede was taking an independent position on his marriage and that of his sisters. His eldest sister had eloped to Tsokolmas three years earlier, and Agede had asked for cash rather than an exchange. The husband's family had already paid 80 Ethiopian dollars, but Agede was demanding 200 dollars. When I asked why he should want so much, he explained rather roguishly that his sister now had a son and a daughter, so that they numbered three altogether. The little girl would in time be married for money, and the little boy too would bring in money for his father. "They will be rich, and I want my 200 dollars now."

Agede's second sister had married in Tsokolmas about two years later, but he has not yet asked for any payment; he himself recently ran off with a girl from Tsokolmas, for whom he plans to pay bridewealth when he has collected what is owed on his sisters. Not only would he make a nice profit on these arrangements



MARRIED MEMBERS, living and dead, among four generations of the Pwogo Kabach clan living in and near the village of Sombo Gerre appear in this simplified genealogical chart. All 13 spouses of the third generation, four men and nine women, are the offspring of two brothers; one brother (*right*) has only one wife and the other (*left*) married three times. Of the 31 marriages shown on the chart only four were bridewealth arrangements, whereas 24 were sister-exchange marriages. Horizontal arrows numbered from 1 through 10 (*color*) connect the 10 women marrying into the clan with the 10 clanswomen marrying out. Vertical arrows numbered 11 through 14 (*color*) identify the other four exchanges; reciprocal marriages lie off chart. Boxes (*gray*) identify village residents.

but also he is pursuing another large sum in connection with his first marriage several years ago. It had been an exchange, but his wife had died childless and his sister had had a child. Agede waited a year and asked for another exchange wife; when he was refused, he took his sister back from her husband. She escaped to her husband several times but was always marched back by her brother. Eventually the husband brought 50 dollars as bridewealth, and although Agede's clan elders in Sombo Gerre accepted the money, he himself refused it. His own father supported him in demanding 300 dollars, an outrageous sum, on the grounds that a couple who loved each other so much should be prepared to pay up.



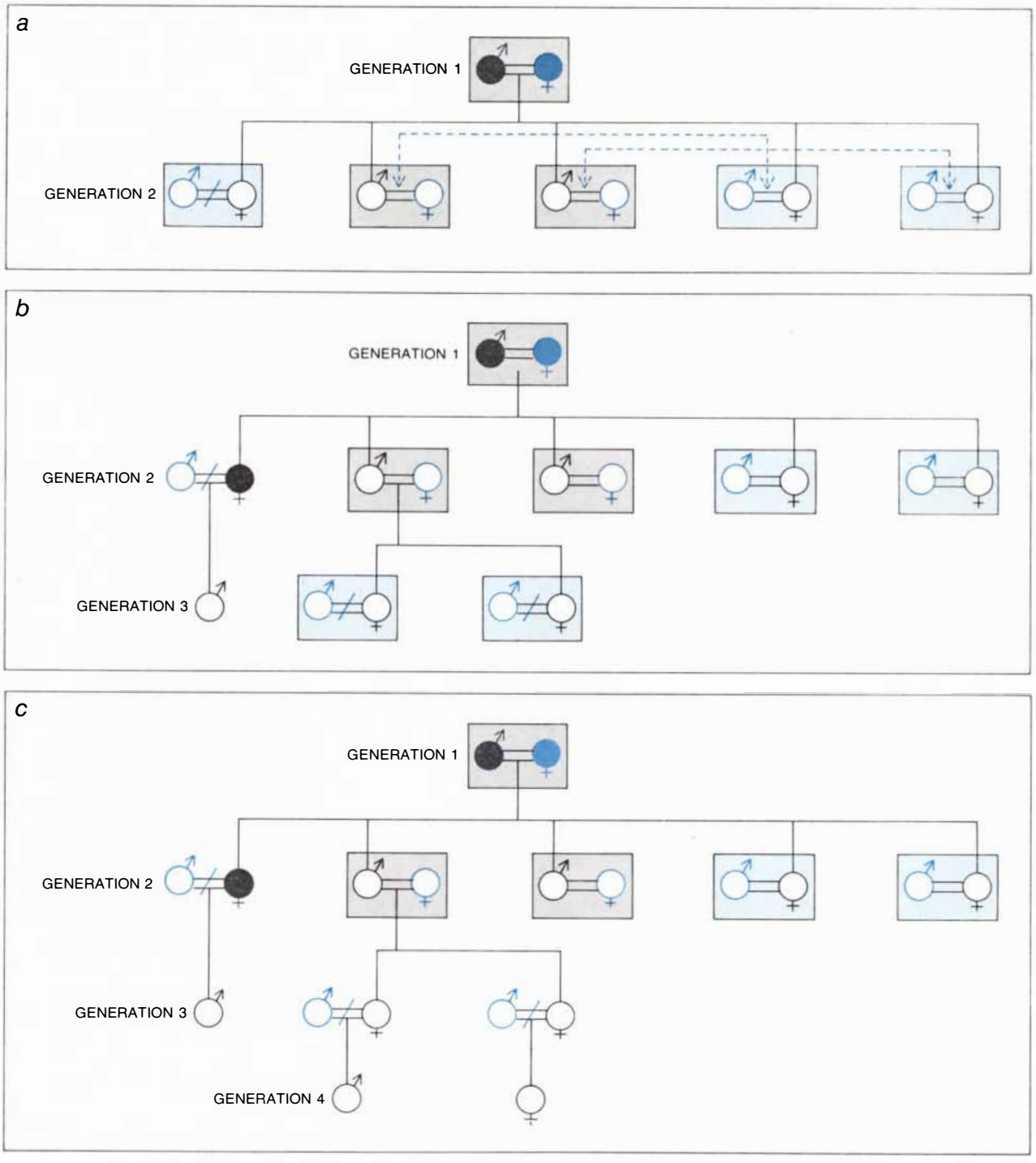
PRINCIPLE OF PRESERVATION in sister-exchange marriage is evident in the successive events diagrammed here. Two families (*a, top*) are that of Moga (*1, left*) and his sisters Kanato (*2*) and Tirbi (*3*), and that of Kwanta (*1, right*), his sister Kokosh (*2*) and his nominal sister Naiko (*3*), actually his father's sister's daughter. When Moga married Naiko and Kwanta married Tirbi (*b*), the families were united by the exchange of sisters. Tirbi soon died, unbalancing the exchange (*c*), and Naiko was taken home pending reestablishment of the balance. When Naiko died (*d*), the original exchange was voided. The families' relations were preserved because Moga exchanged his sister Kanato for Kwanta's sister Kokosh.

Far from being a simple integrating institution, sister-exchange, like any other contract, defines an area of potential conflict through the pursuit of rights by either side. Traditionally one of the main sources of conflict is the situation of a girl who is married off to complete an exchange, perhaps to an older man she does not know. Her position is seen by the Komo as being an unhappy one, particularly when the courting couple who took the initiative in arranging the exchange are content with each other; she will not want to hurt her brother by refusing to live with her allotted husband. She sometimes does refuse, however, and her immediate kinfolk, perhaps her father, will take her side against the elders of her clan who have agreed to the exchange. It was this kind of situation that led to an armed confrontation and a death late last year in the border region between the Sudan and Ethiopia. Retaliation is only to be expected when a promised exchange does not materialize. If a feud results, one death is avenged by another or is repaid by the transfer of a woman without marriage.

The modern state of affairs, in which cash is increasingly playing a role, widens the base for dispute over marriage. The older notions of fair claims and just rights appear shabby when they are translated into money. As long as the basic structure of Komo production and economic exchange remains outside the cash sphere, however, the use of cash in marriage will not have profound effects on the society. Cash received in marriage will be set aside for further marriages, and it will be absorbed into the existing framework of economic and social morality.

The abandonment of sister-exchange as such will not draw the Komo into the highland cash economy of Ethiopia. It is more likely that their society will come to resemble that of the Uduk, their neighbors in the Sudan, whose language is very close to theirs and who once lived in closer contact with them. Most of the Uduk people do not practice exchange marriage, and they say they never have. They do, however, know of it. They call it "revenge marriage," and occasionally certain villages practice it in this spirit. The honorable exchange agreements of the Gumuz and Komo elders are absent, and the young Uduk villagers play at revenge elopements.

The circumstantial evidence suggests



EROSIVE EFFECT of bridewealth marriages on interclan links is evident in this sequence of events affecting the family of Adebe (*left*), the elder of two brothers. Of Adebe's three sisters (*a, top*) two (*right*) were exchanged to provide wives for Adebe and his brother Nadir. Midi (*far left*), the third sister, was married to a man who failed to complete his contract, neither providing a bridewealth payment nor exchanging a spouse from his clan. Midi bore a son, Abunsa, and then died (*b*). Because the contract was incomplete her brother Adebe kept his nephew and is rearing him within his own clan pending contract completion by the boy's father. Adebe's wife meanwhile had borne two daughters (*left*) and both were married to men who also left their marriage contracts incomplete. The daughters and their offspring, a boy and a girl, now live with Adebe (*c*); he is raising the children within his clan until their fathers can complete contract obligations and claim them.

that the Uduk practiced sister-exchange in the past, but that the practice has broken down in the course of repeated refugee movements. Today the Uduk social system is firmly based on the principle of matrilineal continuity, which, as I have noted, is an underlying feature of Komo thinking, and which appears to have become dominant with the loss of the exchange-marriage contract. The Uduk have resisted official attempts to make them pay bridewealth; to them it is a mercenary transaction that is comparable to slavery. The disappearance of exchange marriage for pragmatic reasons has not changed the fundamental notions of just and proper social relations that the Uduk share with the other Koman peoples.

The social systems of the patrilineal Gumuz and Komo and the matrilineal Uduk are superficially different but can be seen to be closely related in terms of a shared morality in matters of personal and group reciprocity, particularly in economic and marriage relations. The Komo occupy a position intermediate between the Gumuz, with their strong patrilineal clans, clan authorities and fully operative exchange-marriage system, and the Uduk, with their lack of exchange, weak family authority and freer status of women. By avoiding bridewealth altogether the Uduk have, at least in a negative way, kept their kinship arrangements free from outside interference.

There are two other main regions of Africa where sister-exchange marriage is practiced, or was until recently. One is the "middle belt" of West Africa, which was depopulated by the Saharan and Atlantic slave trades. Sister-exchange was common among the plateau peoples of Nigeria and in northern Cameroon, and recently it has been reported that it is still being practiced by the Nyende of northern Dahomey. The best-documented case in the region is that of the Tiv people of Nigeria, where in 1927 sister-exchange was abolished by the British colonial authorities; they regarded it as being complex, litigious and unfair to women. Abolition did not, however, solve all the problems for which sister-exchange had been held responsible; indeed, it created new problems. In missionary eyes the "morality" of the Tiv did not seem to improve. On the other hand, the Tiv writer Akiga has explained how sister-exchange later came to be seen as the basis of a lost morality. Sister-exchange was viewed as the original form of marriage from which the people had sprung, and the means whereby a man's house could expand and go forward. His daughters were divided among his sons for them to exchange for wives, so that no name should be lost to the house. A wife was actually known in her husband's house by the name of the sister she replaced, and that sister was regarded as the true mother of the wife's children. It was at the door of the true exchange wife that a shrine guarding the fertility of women and the land was set up. When sister-exchange was abolished and men let their daughters go for a price ("with a sob in their throat"), people said the land had been spoiled. Subsequent social and economic changes, particularly get-rich-quick attitudes that affected the stability of family life, were blamed by the Tiv (with some justification) on the abolition of exchange marriage.

The second main region of Africa where we find essentially the same system is in the northeast of the Zaïre (Congo) Basin. Sister-exchange was banned among the Amba, who live just inside Uganda and adjacent to the Bantu kingdom of Toro, but the society still holds the values that gave meaning to this mode of marriage. It is still practiced by the Mbuti, the pygmy hunters of the Ituri forest. The Mbuti have intermittent relations with the settled Bantu villagers, who try to extend their control over the shy hunters by (among other things) paying bridewealth for their women. No such marriage, whatever wealth may change hands, is regarded as being binding by the Mbuti. For them the only permanent bond is forged by the exchange of sisters among themselves.

The case of the Mbuti can be regarded as a paradigm of the situation in which the marginal populations of West Africa and the Sudan-Ethiopia borderlands find themselves. The survival of the community as such is linked with preserving its kinship and marriage relations from penetration by the goods and cash systems of more powerful outside societies. The substitution of a wife for a sister is the touchstone of a wider structure of production and economic exchange based on direct reciprocity, which is itself rooted in ideas of honor, self-reliance and egalitarian justice.

The African examples suggest that although sister-exchange marriage may look simple, it has deep roots. Perhaps in general what appear to be simple principles of social life have greater moral force and therefore greater historical tenacity than we sometimes realize.

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The Microstructure of Polymeric Materials

Future advances in the manufacture of synthetic polymers will depend not only on mastering their complex chemistry but also on finding new ways to control the arrangement of their molecules during processing

by D. R. Uhlmann and A. G. Kolbeck

Materials can be classified as metals, ceramics or polymers, or composites of the three. The first two classes include materials that have been technologically important since the time of the early potters and blacksmiths. The manufacture of metal and ceramic articles utilized raw materials from the earth such as sand, limestone, metal-rich ores and even an occasional meteorite. The raw materials were transformed into finished products by means of processes involving both chemical and physical changes, frequently brought about by high temperatures.

The utilization of polymers prior to the 20th century was largely confined to what are now called natural polymers. In these materials biological processes not amenable to direct control account for the critical steps in the transformation of raw materials (water, oxygen, carbon dioxide and certain minerals) into finished products such as wood, leather, wool and cotton. The role of the artisan, or materials technologist, in dealing with these materials was confined to finishing operations such as the tanning of leather and the weaving of textiles. It is only in this century that scientists have developed a detailed understanding of the structure and properties of polymers and have mastered the techniques for producing synthetic polymers. This new knowledge has led to the development of a polymer industry with a current annual production of some 26 billion pounds of synthetic materials in the U.S. alone.

Most of the developments of the past four decades in synthetic polymers have been dominated by understanding and controlling the chemistry of the materials. Polymer chemists have achieved outstanding success in tailoring the molecular architecture to produce desired properties. It seems apparent, however, that future developments in the field will result from increased reliance on the ability to vary the microstructure of polymeric materials in order to effect changes in properties.

Here we shall describe some of the important microstructural features of synthetic polymers and shall explain some of the relations that have been established between the microstructures of these materials and their properties. We shall emphasize mechanical properties, since these have been explored in the greatest depth. It is expected, however, that during the coming decades increasing attention will be directed to other properties of polymeric materials, such as their electrical and optical properties. Microstructural changes will surely have a profound effect on those properties as well.

We shall be concerned exclusively with thermoplastic polymers, which are characterized by the lack of extensive cross-linking between the long-chain polymeric molecules. Unlike thermosetting polymers, thermoplastic polymers can be melted and re-formed by the application of heat, and it is in these materials that the effects of microstructural variations on properties are most pronounced. Familiar thermoplastic polymers include polyethylene, polypropylene, polyvinyl chloride, polystyrene, polymethyl methacrylate, polycarbonate and nylon, to name only a few.

Thermoplastic polymers can be divided into two classes: amorphous and semicrystalline. Some polymers do not have enough chemical regularity to allow the molecules to pack in regular arrays. As a result such polymers, which include conventional polystyrene and polymethyl methacrylate, cannot crystallize to any appreciable extent; when they are cooled from the molten state, they form amorphous solids, or glasses. Glassy solids can also be formed from polymers such as polycarbonate and the common polyester polyethylene terephthalate, which have sufficient chemical regularity to allow crystallization but which crystallize so slowly that moderately rapid cooling from temperatures above the melting point will yield amorphous solid materials.

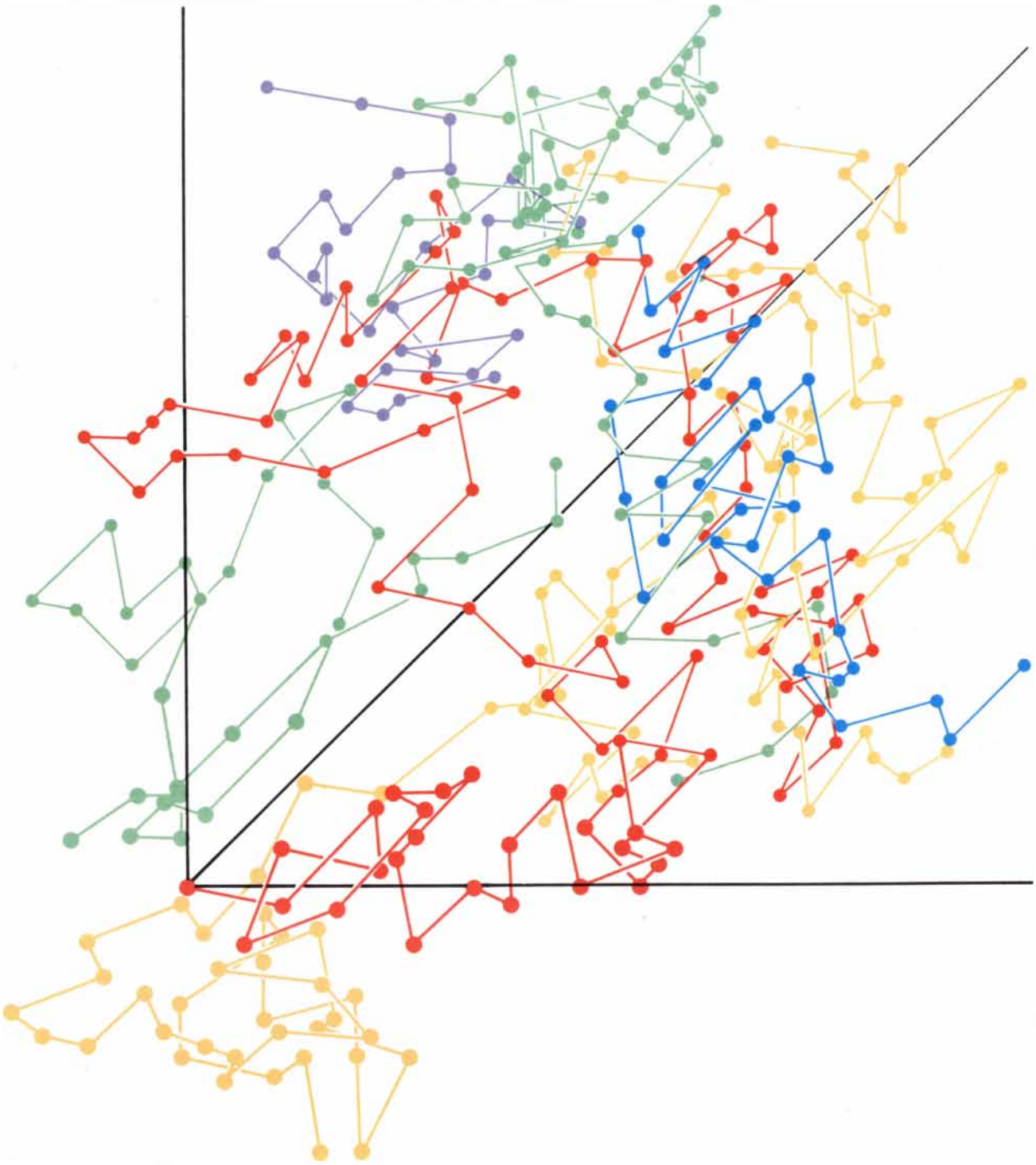
Once obtained in the glassy state, both crystallizable and noncrystallizable polymers exhibit similar microstructural features. The most widely accepted model for the microstructure of most unoriented amorphous polymers is a random coil [*see illustration on opposite page*]. This model, derived from a statistical representation of the molecules as flexible chains, rests on the assumption that the relation between any two links in the chain separated by more than a few units along the chain is essentially random.

The random-coil model predicts that each long-chain molecule will assume the form of a loose ball, with a diameter that increases as the square root of the number of segments in the molecule. The otherwise vacant space within each coil is taken up by neighboring molecules, and various degrees of entanglement and intertwining are expected not only among segments of different molecules but also among segments of a given molecule. In rather loose but graphic terms, the random-coil structure can be described as similar to an agitated, greatly tangled mass of spaghetti.

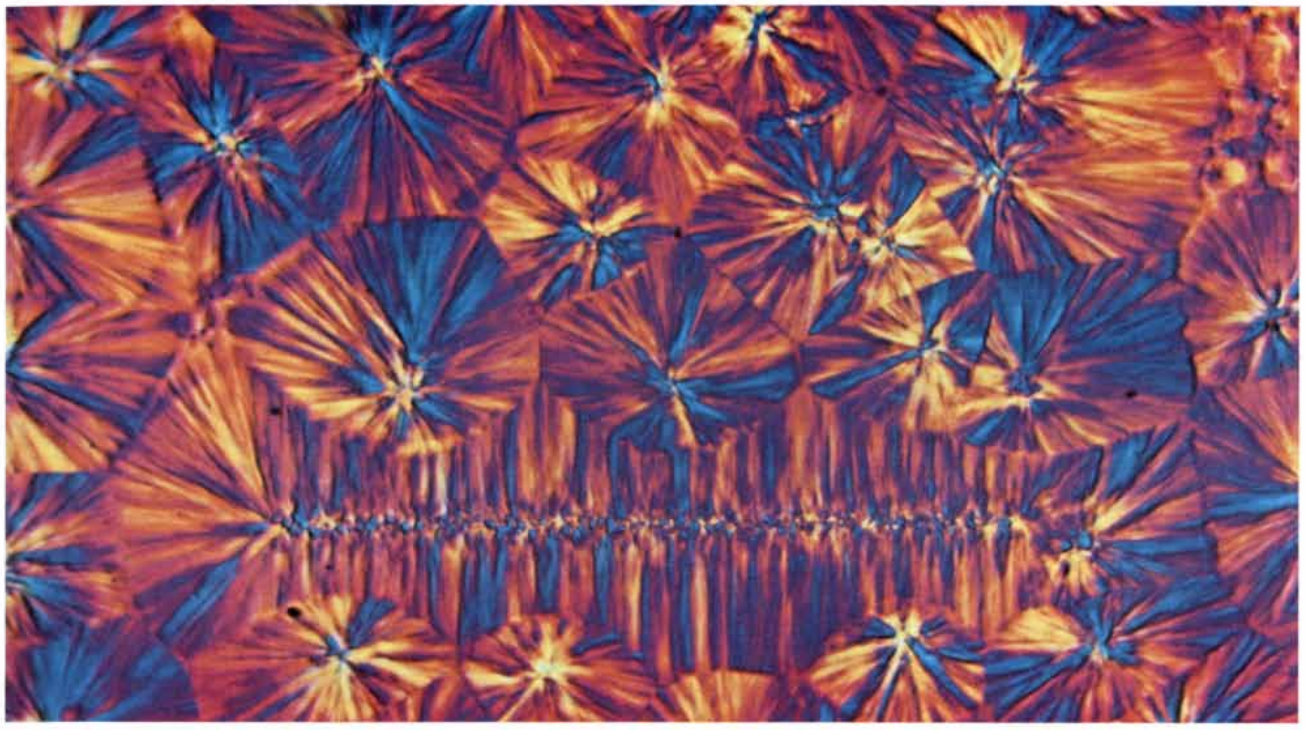
Several alternatives to the random-coil model have been proposed for amorphous polymers. Notable among them is the suggestion, based on observations of microscopic heterogeneities in a number of glassy polymers, that the materials contain local regions of high order. The

degree of ordering suggested is intermediate between that of a random-coil structure and that expected for a crystalline structure. The results of a variety of studies, conducted with techniques such as small-angle neutron scattering and small-angle X-ray diffraction, indicate that the heterogeneities seen in the electron microscope are probably not characteristic of the bulk polymers; accordingly the random-coil model is generally preferred as a representation of the structure of amorphous polymers. The observed heterogeneities are believed to be potentially important features of the surfaces of the materials, and their investigation may provide valuable information on surface-sensitive properties.

When glassy polymers are formed under quiescent conditions (that is, in the absence of any orienting influence



RANDOM-COIL MODEL of the microstructure of an amorphous polymeric material predicts that in the absence of any outside influence each long-chain molecule will coil into the shape of a loose ball intertwined with segments of neighboring molecules. In this schematic diagram, based on a computer-generated plot, the degree of polymerization (that is, the number of links in each colored chain) is characteristic of such common polymers as nylon and polyester. In the diagram the chains occupy less than 10 percent of available volume; in an actual polymer the space would be almost completely filled, resulting in a much more tangled appearance.



TYPICAL MICROSTRUCTURAL FEATURES observed in semicrystalline polymers can be seen in this photomicrograph of a thin film of polypropylene. The "sunburst" structures are called spherulites; their boundaries would be circular if it were not for the fact that they encounter neighboring crystallites as they grow outward from a central core. The linear formation is said to have a row-nucleated structure; in this case the platelike crystallites have grown outward from an elongated nucleation site. The photomicrograph was made in polarized light by David Hamer at the Celanese Research Company; the magnification is approximately 400 diameters.

CRAZES AND SHEAR BANDS, two types of local deformation observed in rigid glassy polymers under stress, are both visible in this photomicrograph of a sample of polyvinyl chloride. The sample has been stretched about 10 percent in the horizontal direction. In this view the crazes appear as the black lines at right angles to the direction of stress; the shear bands are the bright diagonal streaks oriented at approximately 45 degrees to the stress direction. In general the formation of such inhomogeneous structures increases the toughness of an amorphous polymeric material, since energy must be dissipated as the molecular chains become more aligned within the deformed regions. The enlargement of this photomicrograph, made by the authors, is approximately 570 diameters.

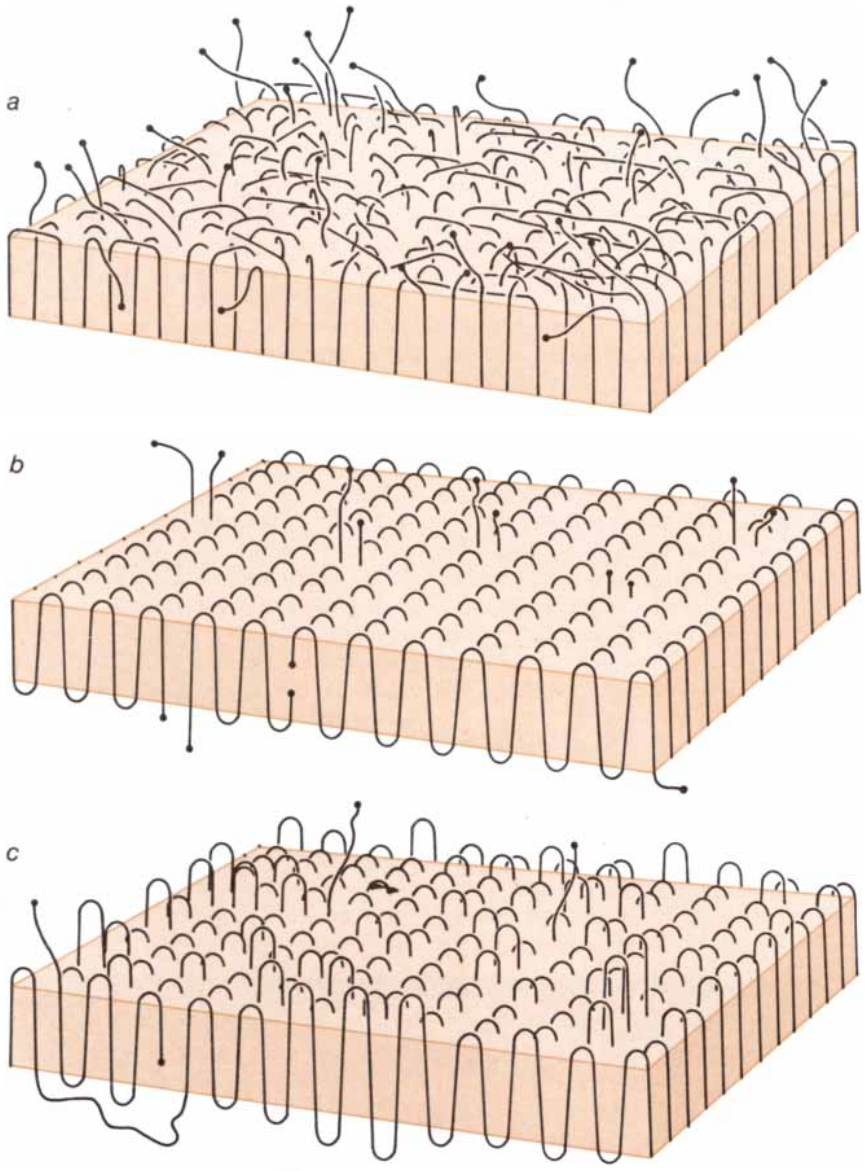
such as stretching), their macroscopic, or bulk, properties are isotropic: the same in every direction. Because they are long chains, however, the polymer molecules themselves are inherently anisotropic: their properties along the chain are different from their properties at right angles to it. As a result polymeric materials can be made to exhibit anisotropic behavior on a macroscopic scale if they are subjected to processing conditions that lead to a preferred alignment of the molecular chains parallel to one external direction or more. The degree of molecular alignment, and hence of bulk anisotropy, can be determined experimentally by measuring orientation-sensitive properties, such as the refractive index, at various directions in the material. The form and the degree of molecular orientation play central roles in determining the mechanical properties of these materials.

Two types of microstructure are observed in semicrystalline polymers, depending on how the molecules are aligned during the crystallization process [*see top illustration on opposite page*]. The spherulite, or "sunburst," microstructure normally results from crystallization under quiescent conditions, whereas the row-nucleated, or "shish kebab," microstructure results from crystallization under conditions of flow, where the chains become oriented parallel to one another. In both cases the basic microstructural unit seems to be a platelike crystallite. These crystals are aligned radially in the spherulites and at right angles to the direction of flow in the row-nucleated structures.

Isolated platelike single crystals can be produced by precipitating polymers from dilute solutions. In such single crystals the molecules are aligned along the thinnest dimension of the plate. Since the extended lengths of the molecules are generally many times greater than the thickness of the plates, it has been inferred that the molecules must fold at the surfaces of the plates in order to reenter them at different points. There is controversy over the tightness and regularity of the folds, and a variety of configurations have been suggested for the single-crystal plates [*see illustration on this page*].

Single crystals grown from dilute solutions turn out to be less dense than one would expect for perfect crystals of the same polymers, which suggests that some of the material is not arranged in regular crystalline arrays. This amorphous component is presumably concentrated at the surfaces where the molecules fold. For bulk polymers the difference between the measured densities and the densities of perfectly crystalline materials is even greater; hence the bulk polymers are properly described as being semicrystalline. Representative values for the percentage by volume of crystals in a number of semicrystalline polymers are high-density polyethylene, 75 percent; low-density polyethylene, polypropylene and nylon, 50 percent.

Platelike features have been observed in electron-microscope studies of both spherulitic and row-nucleated bulk polymers. The thickness of the plates and the orientation of the molecular chains within the plates are consistent with the thickness and orientation observed in single crystals grown from dilute solutions. The degree and nature of the chain-folding within the plates, together with their internal perfection, are, however, appreciably different in the bulk material from the corresponding properties in the crystals grown from dilute solutions. Those differences reflect differences in the conditions of crystalliza-



SEVERAL CONFIGURATIONS have been suggested for the microstructure of the platelike single crystals that can be formed by precipitating polymers from dilute solutions. In such crystals the molecules are aligned along the thinnest dimension of the plate. The long molecular chains presumably fold in some way at the surface of the plate and reenter them at different points. Three possibilities are depicted. In *a*, sometimes referred to as the "switchboard" model, the chains reenter at random. In the other configurations, both "adjacent reentry" models, surfaces where the chains fold are either smooth (*b*) or rough (*c*).

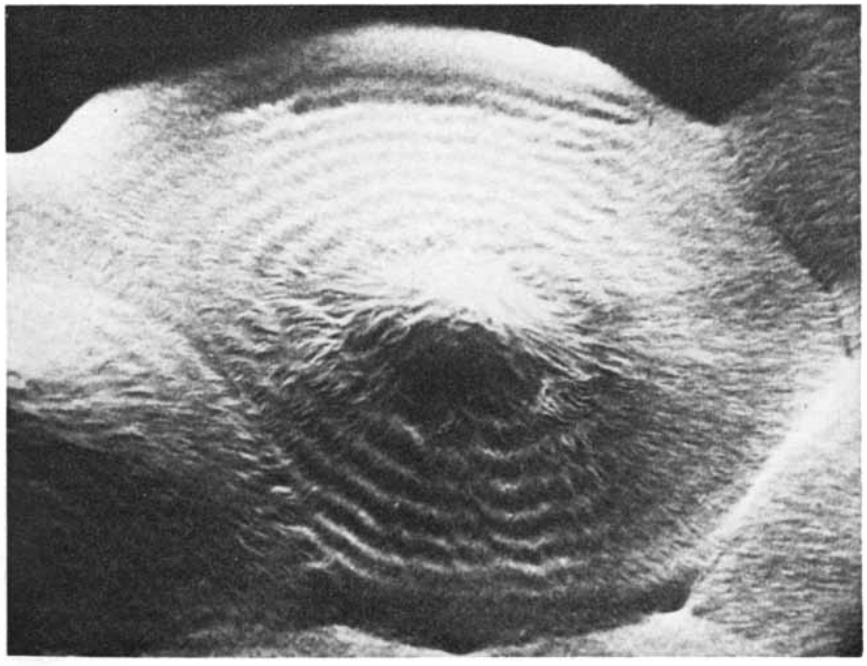
tion, particularly in the concentration of chain segments and in their competition for growth sites at the interface between the liquid phase and the solid phase.

Even the simplest polymer crystallized under quiescent conditions is a highly complex composite material. During cooling from the molten state crystals begin to form at isolated nucleation centers throughout the material. The nuclei grow by adding chains segmentally from the liquid, and the growth front becomes split into a spherical array of radiating plates. Hence the central region of a spherulite is structurally different from the rest of the material. The plates grow out radially from the central region of the spherulite, with the chain direction within each plate being perpendicular to the growth direction. The plates often branch as they grow; in many cases they are observed to twist cooperatively about the spherulite, forming alternating concentric bands when they are viewed edge on and then flat on [*see illustration below*].

The growth of polymer spherulites involves in addition to branching and twisting the segregation of nonpolymeric components and noncrystallizable polymeric components into the regions between the plates. The nonpolymeric components include various stabilizers, process aids, fire retardants and residues of polymerization catalysts that are present in nearly all commercial polymers. The structural components known as tie molecules are particularly important in determining the mechanical properties of semicrystalline polymers. They are lengths or bundles of molecules, extending from one plate to another, that can serve to concentrate and distribute stresses throughout the material. The microstructure of spherulitic polymers is also significantly affected by the phenomenon of secondary crystallization: the further development and modification of crystallinity that takes place when one growing spherulite encounters another.

When a polymer crystallizes under conditions of flow, the alignment of the chain segments brought about by the flow leads to a nonspherulitic crystalline microstructure [*see top illustration on opposite page*]. The alignment of the chains in flow results in the formation of elongated crystals that are aligned in the direction of flow. These crystals are much longer than the thickness of the plates, but generally they do not represent fully extended molecules. Such elongated crystals (or elongated crystal-amorphous composites) may comprise 5 percent or less of the polymer. They are, however, effective in serving as nucleation sites for the crystallization of the rest of the material, and the orientation of the elongated crystals, or row nuclei, controls the orientation of the plates that form subsequently. Specifically the plates grow outward from the row nuclei, with their growth directions at right angles to the direction of the flow. If the degree of alignment before crystallization or during crystallization is high enough, the plates do not display the radial twist characteristic of spherulitic crystallization and low-stress flow crystallization. Under conditions of high-stress flow the microstructure consists primarily of flat plates aligned perpendicularly to the flow direction, with the chain orientation within the plates being closely parallel to the flow direction.

When dilute solutions of polymers are stirred during crystallization, "shish kebab" structures result [*see bottom illustration on opposite page*]. These structures bear some notable similarities to the row-nucleated structures in bulk polymers crystallized under flow: what one might call the "shishes" correspond to the elongated crystals of the row structure, and the "kebabs" correspond to the plates. As with the spherulitic microstructures, the row-nucleated microstructures include complicating factors, such as tie molecules, noncrystallizable components and various nonpolymeric additives.



THREE-DIMENSIONAL VIEW of a polymer spherulite is provided by this scanning electron micrograph of a specimen of high-density polyethylene lightly etched in a xylene solution. The concentric bands correspond to the twisting, ribbonlike crystallite plates viewed edge on and then face on in successive rings. The crystallization process began at a nucleation site inside the humplike structure at center. As the crystal grew, the growth front became split into a spherical array of radiating plates. The plates then began to twist "cooperatively" around the radii of the spherulite, forming the alternating concentric bands seen here. Micrograph was made by the authors; the magnification is some 2,800 diameters.

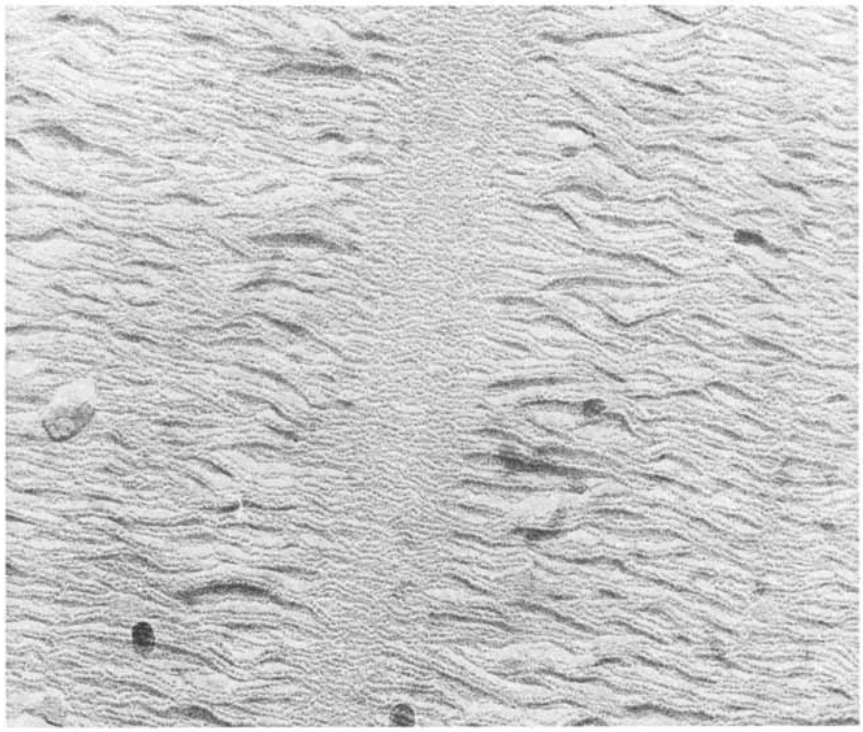
In sum, both spherulitic and row-nucleated polymers are complex composites of crystalline and noncrystalline material, whose microstructures depend strongly on both chemistry and processing history. The properties of polymers can be varied over wide ranges by changing the microstructural features. Let us consider some examples of those variations.

Amorphous polymers exhibit several types of mechanical behavior depending on their chemical composition, distribution of chain lengths, molecular orientation and degree of branching or cross-linking. Other important influences include the temperature and the time scale of the experimental measurements. The observable range of mechanical behavior can be illustrated by considering the variation of stiffness with temperature for a typical amorphous polymer [*see illustration on page 102*]. At temperatures below the glass-transition temperature (the temperature at which the molten material begins to turn into a glass) amorphous polymers have a fairly high degree of stiffness, which changes only slowly with temperature. In that

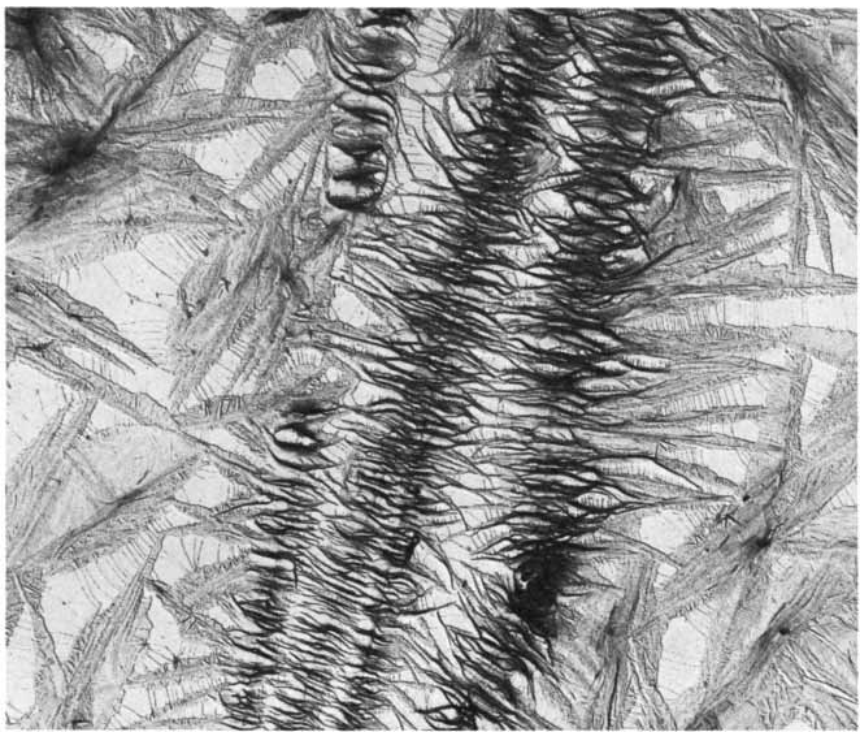
temperature range the polymer behaves elastically at low strains. At higher strains, however, it is permanently deformed. At temperatures near the glass transition the stiffness changes rapidly with temperature; the material is said to be leathery. At temperatures above the glass transition a second region of nearly constant stiffness is observed. In that region the material becomes "rubbery," and recoverable strains of up to several hundred percent can be imposed on it. At temperatures above the rubbery region the polymer behaves as a viscous fluid. All amorphous polymers exhibit a similar variation of stiffness with temperature; only the temperatures at which the various transitions in behavior occur and the degree of stiffness in each temperature region vary from polymer to polymer.

Most amorphous polymers of commercial importance exhibit either glassy or rubbery behavior, and the great differences in the mechanical properties of these two types of amorphous polymer can be associated with particular chemical and microstructural features of the materials. The rubbery behavior of polymers is related to their long-chain character. Two factors are particularly important. First, the distance between the ends of the chain in the random-coil configuration is far less than the fully extended length of the chains (thus allowing large elongations). Second, the thermodynamically more stable state is the coiled configuration (thus providing a driving force for a return to the original state when the stress is removed). The force required to stretch a rubber (that is, to elongate the initially coiled molecules) is associated primarily with the fact that the entropy in the coiled state is significantly greater than the entropy in the extended state.

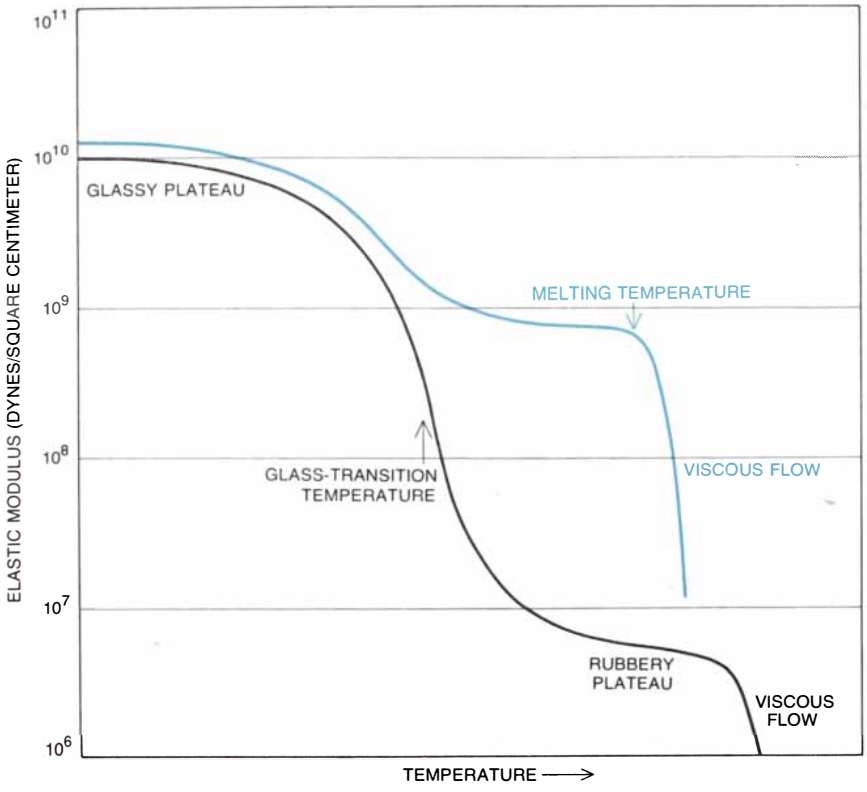
Polymers that exhibit rubbery behavior at room temperature include polyisoprene (natural rubber) and polybutadiene (a synthetic rubber). In practice it is necessary to add chemical crosslinks to rubbery polymers in order to eliminate viscous flow and obtain completely recoverable extensibility. Most thermoplastic polymers will become rubbery at temperatures above the glass transition, but the rubbery behavior will be of little technological value when the glass transition is at temperatures well above the ambient temperature. Furthermore, other factors become important in determining the technological usefulness of a rubber, including resistance to abrasion, tendency toward crystallization, chemical inertness and adaptability to reinforcement with "fill-



ROW-NUCLEATED MICROSTRUCTURE can result from crystallizing a polymer under conditions of flow. In this transmission electron micrograph of a surface replica of an extruded polyethylene film both the primary orientation of the molecular chains and the resulting elongated crystal are aligned in the direction of flow (*toward the upper right*). During the later stages of crystallization platelike crystallites grow outward from the central nucleation site at right angles to the direction of flow. The plates are barely visible in this micrograph made by Ian L. Hay of Celanese. The magnification is 80,000 diameters.



"SHISH KEBAB" MICROSTRUCTURE similar to the row-nucleated configuration depicted at top was formed by crystallizing polyethylene in a stirred xylene solution. The central core crystal and the platelike crystallites growing outward from it at right angles are clearly seen in this transmission electron micrograph made by Robert B. Williamson of the University of California at Berkeley. The crystals are enlarged some 1,700 diameters.



VARIATION OF STIFFNESS with temperature is indicated for a typical amorphous polymer (*black curve*) and a typical semicrystalline polymer (*colored curve*). The general shape of the two curves is characteristic of a wide range of chemically different polymers.

ers": substances added to most commercial rubbers to improve their mechanical properties. The most common filler is carbon black, which often makes up from 20 to 25 percent of the volume of the material.

At temperatures below the glass transition the energy barriers to the motion of chain segments are substantial and rubbery behavior is not observed. Instead either brittle or tough-ductile characteristics are seen. Brittle polymers, such as polystyrene and polymethyl methacrylate at room temperature, fracture under much smaller strains than those that can be imposed on rubbery polymers. In general such polymers are much more rigid at temperatures below the glass transition than they are in the rubbery state and for a given strain must be more highly stressed.

Rubbery polymers generally deform homogeneously, with the local strain at any point in the material being comparable to the total strain on the specimen. Many rigid polymers, on the other hand, deform inhomogeneously, developing regions in which the local strains are much larger than the average strain on the specimen. Two types of small-scale inhomogeneous deformation, crazing and shear banding, are observed in glassy polymers [*see bottom illustration on page 98*].

Crazing involves the formation of localized zones, oriented at right angles to the direction of stress, that are characterized by large strains with respect to neighboring regions. The large deformations in the crazed regions lead to an alignment of the molecular chains parallel to the direction of stress. The oriented chains become grouped into bundles separated from one another by a maze of interconnected voids. Crazes scatter light and are readily visible to the unaided eye as whitened planes perpendicular to the direction of stress.

Shear banding is the appearance of localized deformation zones at angles near 45 degrees to the direction of stress. Within these bands there is a high degree of chain orientation. Although shear banding is generally not accompanied by the formation of voids, the bands are readily visible because of differences in the indexes of refraction between the oriented material within the bands and the unoriented material outside them.

Crazing and shear banding represent energetically dissipative processes, and any increase in energy dissipation corresponds to an increase in the toughness of the material. When amorphous polymers are stressed, most of them show only a few crazes and shear bands before they fracture; such polymers are quite brittle. If the microstructure of the polymer is altered so that the initiation of crazes and shear bands is facilitated, however, the polymer will be made tougher. In developing glassy polymers with increased toughness, rubber particles can be added to the materials in controlled amounts and sizes. The material then consists of rubbery inclusions in a glassy matrix. The surfaces of the rubber particles serve as sites of stress concentration, where the local stress exceeds that required for the formation of crazes and/or shear bands. Materials in which extensive crazing and shear banding predominate over gross fracture are characterized by greatly enhanced toughness. A familiar example of a rubber-modified glassy polymer is high-impact polystyrene.

The brittleness of glassy polymers can also be changed significantly by imparting an orientation to the materials by allowing them to flow at temperatures above the glass transition and then "freezing in" the orientation by cooling. An example of this class of polymeric materials is hot-stretched polystyrene. That polymer can be greatly elongated in the direction of hot-stretching before it breaks, in marked contrast to the brittle behavior of ordinary polystyrene.

The second group of glassy polymers, exemplified by polycarbonate and amorphous polyethylene terephthalate, is characterized by a high degree of elasticity (comparable to that of the brittle glassy polymers) and by the ability to elongate considerably under tension before fracturing (comparable to the ability of some rubbery polymers to elongate). When polymers of this type are stretched, a diagram of the stress-strain relations shows an elastic region at small strains and then a region of yielding. The diagram next shows a region of continued elongation of the specimen at a nearly constant stress, a region that extends to the point of fracture [*see illustration on opposite page*].

The yielding of a stretched specimen of polymer is usually accompanied by the formation of a necked zone with a distinctly smaller cross-sectional area and a degree of deformation much higher than that of the neighboring regions of the specimen. The yielding process is inhomogeneous, with the neck often forming in a region of intense shear banding. The drawing out of the specimen proceeds by the propagation of the necked region toward one end or both ends of the specimen, and the specimen

usually fractures when the necked region has consumed the entire sample. The formation and propagation of a stable neck is characteristic not only of amorphous polymers but also of many semicrystalline polymers.

Within the necked regions of the amorphous polymers the molecular chains have a high degree of alignment parallel to the direction in which the material is being drawn. Outside the necked region the chain orientation is only slightly different from that in the starting material. The degree of orientation in both the necked and the unnecked regions changes little during the drawing process; only in the narrow zone making up the "shoulders" of the necked region do appreciable deformation and realignment of the chains take place.

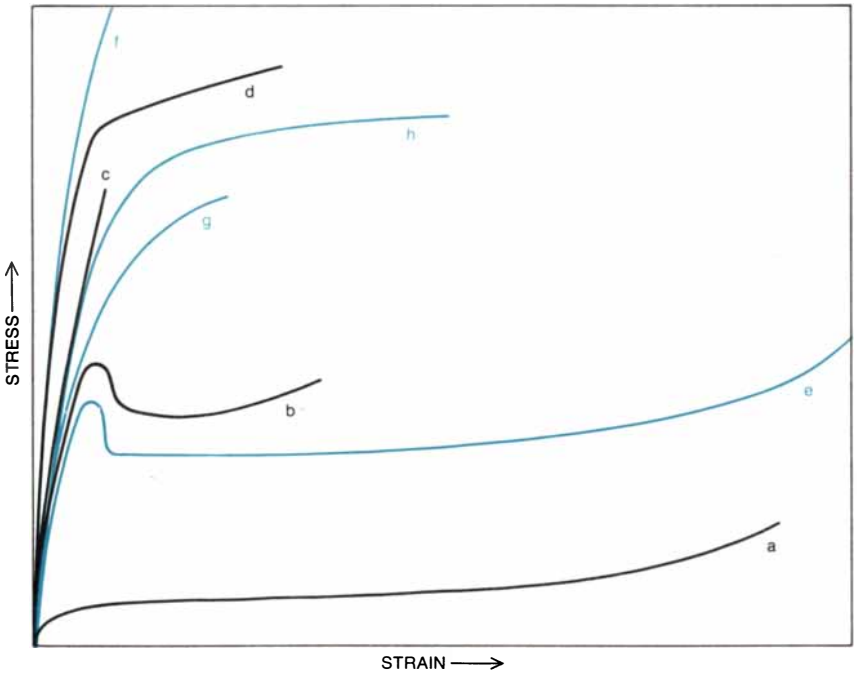
The mechanism by which the randomly oriented chains outside the necked region are transformed into highly oriented chains within the neck is imperfectly understood. In qualitative terms the formation of a stable neck requires that the polymer be capable of internal slippages and structural rearrangements such that reorientation of the chains will take place more easily than fracture. The chemical structure of the polymer is an important factor in determining whether drawing behavior or brittle behavior is observed. In particular, large side groups on the polymer chains can inhibit the flow process necessary for drawing, with the result that drawing often leads to brittle fracture. In polymers that do not have side groups significantly larger than the lateral extent of the chain, on the other hand, the molecules can flow enough during drawing to allow stable necks to form.

In addition to the strain-softening process, which gives rise to the yield phenomenon through the localized flow of the material, the formation of a stable neck requires a strain-hardening mechanism. In other words, once the neck begins to form, the cross-sectional area decreases and the local stress on the reduced cross section increases. In metals the formation of a neck generally results in the fracture of the specimen because of the increased local stress. In polymers the alignment of the chains in the shoulders of the neck produces a material that is better able to support the applied stress, resulting in a stabilization of the neck.

When polymers are drawn under constant load conditions rather than constant strain-rate conditions, several necks can form at different segments of the specimen and can propagate simultaneously. This reflects the fact that under constant load conditions yielding is not accompanied by a drop in the stress, and hence the critical stress for yielding can be achieved at several points along the length of the specimen.

Since the microstructure of semicrystalline polymers is complex, the relations between their microstructure and their properties are also complex. Certain direct experimental tools, chiefly X-ray diffraction and electron microscopy, can be used to characterize changes in the crystalline component of the microstructure during deformation. Because of the availability of these tools, most discussions of the microstructure and mechanical properties of semicrystalline polymers are directed toward the behavior of the crystalline component. The phenomena observed during cold-drawing are, however, closely similar in many respects for both amorphous and semicrystalline polymers. The long-chain character of the materials has a critical influence on their deformation behavior, and consideration of only the crystalline component cannot provide a complete explanation for the mechanical properties of semicrystalline polymers.

Polymers that have crystallized spherulitically exhibit two types of mechanical behavior, depending on whether the amorphous component of the material is above or below its glass-transition temperature. If the material is below the glass transition, it is characterized by a degree of stiffness similar to but slightly higher than that of the equivalent com-



TYPICAL STRESS-STRAIN CURVES for four amorphous polymers (*black curves*) and four semicrystalline polymers (*colored curves*) were obtained by testing samples of each material under tension at a constant strain rate to the point of fracture (*end of each curve*). Elastomeric rubbers (*a*) can be drawn to strains of up to several hundred percent and relaxed completely with no permanent deformation; some polymers of this type, such as natural rubber (polyisoprene), crystallize at large strains and hence become stronger. Tough-ductile polymers such as polycarbonate (*b*) begin to undergo permanent deformation at strains of between 5 and 10 percent by forming a necked zone corresponding to a local yielding maximum on the stress-strain curve; fracture strains on the order of 50 to 200 percent are typical of this class of polymers. Brittle polymers such as unoriented polystyrene (*c*) generally fracture at larger stresses but at strains of only about 5 percent. Polystyrene that is "preoriented" by hot-stretching at temperatures above its glass-transition temperature (*d*) can be drawn to much larger strains than polystyrene in the unoriented condition. Melt-crystallized spherulitic polymers such as high-density polyethylene (*e*) are also characterized by the formation of a neck corresponding to a maximum on stress-strain curve; thereafter they can be greatly elongated at a nearly constant level of stress. Semicrystalline polymers oriented in one direction, such as fibers (*f*), typically have high fracture stresses at small elongations. Semicrystalline films oriented in two directions (*g*) have stress-strain curves somewhere between those of the spherulitic and the fibrous materials. Hard-elastic materials (*h*) also exhibit high yield stresses and high elongations, but in contrast to the spherulitic polymers the strains in these materials are largely recoverable.

pletely glassy polymer; typically such a material behaves in a brittle manner, with the material fracturing at strains of a few percent. Both polyethylene terephthalate and polycarbonate can be crystallized to spherulitic microstructures with the amorphous component in the glassy state at room temperature. When these polymers are deformed, they are extremely brittle and are virtually worthless as practical materials. In the amorphous state without well-developed crystallinity both polymers can be drawn to large strains without fracture. The difference in behavior reflects the presence of the randomly oriented crystalline phase, which prevents the structural rearrangement required for the materials to sustain large deformation.

A spherulitically crystallized polymer whose amorphous phase is above its glass-transition temperature can generally be drawn to large strains by a process that is macroscopically similar to the yielding and necking behavior of ductile amorphous polymers. Examples of drawable semicrystalline polymers are polyethylene, polypropylene, polyoxymethylene and nylon. In the case of high-density polyethylene, which is typically about 75 percent crystalline, the material can be drawn at room temperature to strains as great as 1,500 percent without fracture.

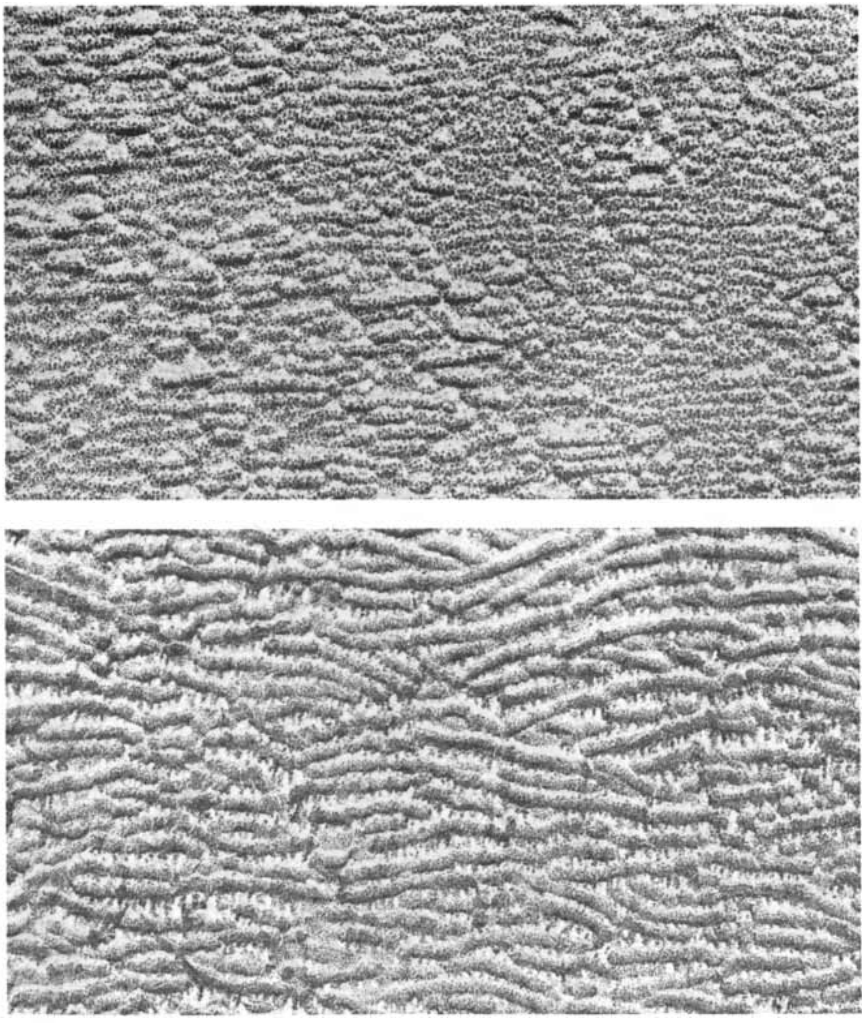
The presence of the amorphous phase in the rubbery state (above its glass transition) is a necessary but not a sufficient condition for the drawing of semicrystalline polymers. For example, polyethylene prepared by crystallization for long periods at temperatures only slightly below the melting point is quite brittle. The high-temperature crystallization treatment leads to the formation of large spherulites and comparatively perfect crystals. Hence a second important requirement in obtaining semicrystalline polymers that are capable of considerable elongation without fracture seems to be the provision of imperfections within the material, particularly in the crystalline regions.

The imperfections thought to be most important in contributing to the high deformability of semicrystalline polymers are the tie molecules that provide molecular links between adjacent crystal plates. Rapid crystallization promotes the formation of many tie molecules. Their presence affects the mechanical properties by distributing the stresses more uniformly through all the plates, thus improving the ductility of the material as a whole.

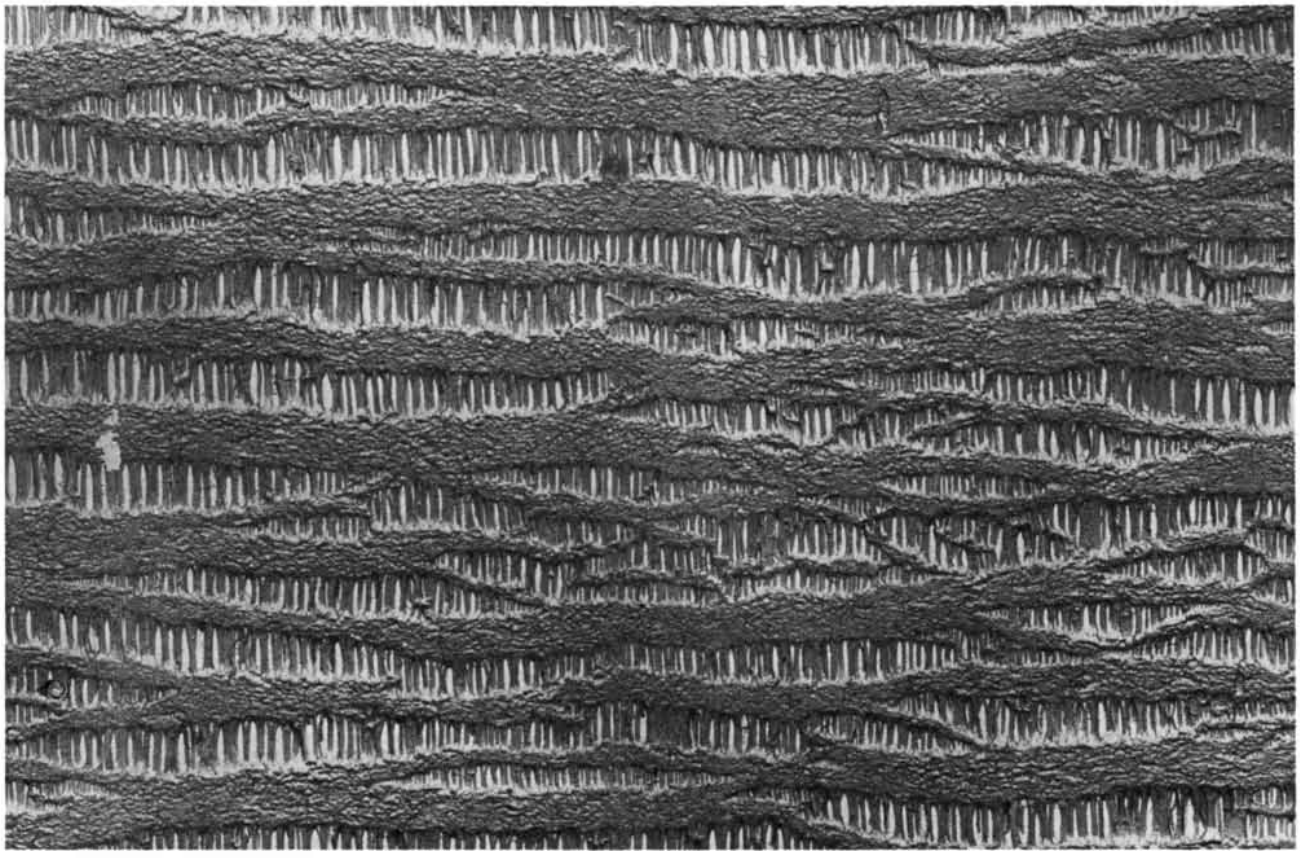
As with amorphous polymers, the portions of semicrystalline polymers inside and outside the necked region change little during the drawing process. Most of the deformation is confined to the borders of the neck. Within this fairly narrow zone the microstructure is transformed from a randomly oriented spherulitic structure into a highly oriented fibrillar structure with the chains oriented preferentially along the drawing direction. The mechanism by which the randomly oriented structure is converted to the highly oriented structure is complex. Among the deformation processes known to be important under at least some conditions are the separation of spherulites at their boundaries, slippage along the flat surfaces of the crystallites and slippage due to dislocations within the plates themselves.

At some point in the yielding process there is a drastic reorganization of the plates. They appear to break up into small blocks, and the blocks stack in the drawing direction, with the chains closely parallel to that direction. In the process the distance from the center of one plate to the center of the next (or from the center of one block to the center of the next) changes to a new value, which is characteristic of the drawing temperature and not of the initial thickness of the plates. This phenomenon suggests that some form of recrystallization takes place during the breakup and reorganization of the plates.

The blocks of plates are arranged in small microfibrils aligned parallel to the direction of stress. The fibrillar structure



EFFECT OF STRETCHING on the microstructure of a hard-elastic polypropylene film can be seen in these two electron micrographs, which show the material in the unstretched state (*top*) and after stretching by approximately 80 percent in the vertical direction (*bottom*). In both cases the molecular chains are aligned predominantly in the vertical direction, which corresponds to the original direction of stress during crystallization; the horizontal ridges are believed to correspond to the edges of the crystalline plates. When the material is stretched, these plates evidently splay apart in the direction of tensile stress, forming voids between the plates. When the stress is released, the microstructure reverts to the configuration shown in the micrograph at top. Magnification is about 110,000 diameters.



EFFECT OF ANNEALING the hard-elastic polypropylene film in the stretched condition is evident in this electron micrograph, which shows the same structure as that seen in the lower illustration on the opposite page but at a considerably lower magnification. (The illusion of higher magnification results from the fact that the microstructure has coarsened considerably in the annealing process.) Annealing stabilizes the material in the open configuration even after the tensile stress is removed. Voids (*white spaces*) are visible between the small bundles of polymer chains. Micrographs on these two pages were made by Hay of Celanese.

is reflected in a notable weakness of the fully drawn polymer in directions transverse to the drawing direction. Drawn semicrystalline polymers can often be split into fibers, but the scale of such fibers is generally much coarser than that of the microfibrils.

In contrast to the weakness of drawn polymers at right angles to the direction in which they are drawn, such materials are very strong parallel to that direction. It follows that there must be a large number of oriented tie molecules connecting the stacked plates. In addition to these features of the crystalline phase, the amorphous component of drawn semicrystalline polymers also exhibits a comparatively high degree of orientation. Our present understanding of the nature of this amorphous orientation is, however, rather limited, and the role of the amorphous regions in the drawing of semicrystalline polymers remains to be elucidated satisfactorily.

In several notable respects the stacked-fibril structure of drawn semicrystalline polymers is similar to the row-nucleated structure of flow-crystallized materials. Both consist of plates stacked in the primary orientation direction with the molecular chains parallel to that direction; both have a fibrillar structure; both have high strength in the chain direction because of the molecular links between the plates. The processes by which these structures are formed, however, are very different, and the detailed structural features undoubtedly reflect that difference.

Highly drawn semicrystalline polymers are widely used as textile fibers. In the commercial production of textile fibers from polymers such as nylon the materials are generally extruded into fiber form and crystallized at quite low flow stresses. Following crystallization the nylon fibers are drawn, and in the process the structure is transformed to a highly oriented form with greatly improved mechanical properties. The microstructural changes that take place during the drawing process are similar in many respects to those that occur during the drawing of bulk polymers.

After drawing, synthetic fibers are often given additional treatments to produce a desired texture. For textile applications the desirable properties of bulk and body are imparted to the fibers by a combination of heat treatment and deformation. The fibers are forced to assume new geometries by stratagems such as twisting them around a mandrel. The combination of heat and deformation leads to permanent changes in the crystalline microstructure of the material to accommodate the new geometry. After the fibers are untwisted from the mandrel they retain a tendency to coil up because of the microstructural changes induced during texturing.

In the manufacture of some polymer products, particularly films, the tendency of material oriented in one direction to fibrillate is a severe drawback. The polymer is therefore processed to align the chains in two directions. For example, polyethylene terephthalate films oriented in two directions are made by first quenching the film directly from the melt into the glassy state, avoiding appreciable crystallization. The material is reheated above the glass-transition tem-

perature, stretched in one direction and then stretched in a second direction at right angles to the first. The material crystallizes to some extent during the hot-stretching, but the final highly oriented, highly crystalline material is produced by allowing it to crystallize at a still higher temperature while holding it in the stretched condition.

Methods other than stretching can be applied to the production of highly oriented semicrystalline polymers with useful mechanical properties. One method involves extruding the solid polymer at high pressure through a die, which greatly reduces the cross-sectional area of the material. With high-density polyethylene the cross-sectional area can be reduced by a factor of 30 or more. That reduction compares with one of about 10 to 15 times when the material is drawn. Solid-state extrusion seems to proceed primarily by the deformation of the preexisting spherulitic microstructure, presumably by the same mechanisms that operate during drawing. The larger reductions in the cross-sectional area achieved in extrusion lead, however, to a higher degree of molecular orientation and a greater elasticity than can normally be obtained by drawing. Other interesting properties can be developed by extruding a solid polymer. For example, materials produced in this way are significantly more transparent than the corresponding spherulitic or drawn polymers.

Highly oriented polymers can also be produced by crystallization under conditions of flow. The mechanical properties of these polymers are of particular interest. When fibers or films of polymers such as polypropylene or polyoxymethylene are crystallized under the appropriate flow conditions, the materials have a stiffness similar to that of semicrystalline polymers. At the same time they exhibit a high degree of elastic recovery when the stress is removed. The stiffness of these "hard elastic" materials is greater by about three orders of magnitude than that of conventional rubbers. Rather than being substantially amorphous in the unstretched state, they are characterized by a high degree of crystallinity. The mechanism proposed to account for this unusual behavior assumes that the plates stacked along the direction of orientation function as a set of leaf springs arranged in series. When the material yields, the plates bend elastically in response to the stress, and the elastic bending is recoverable when the stress is removed.

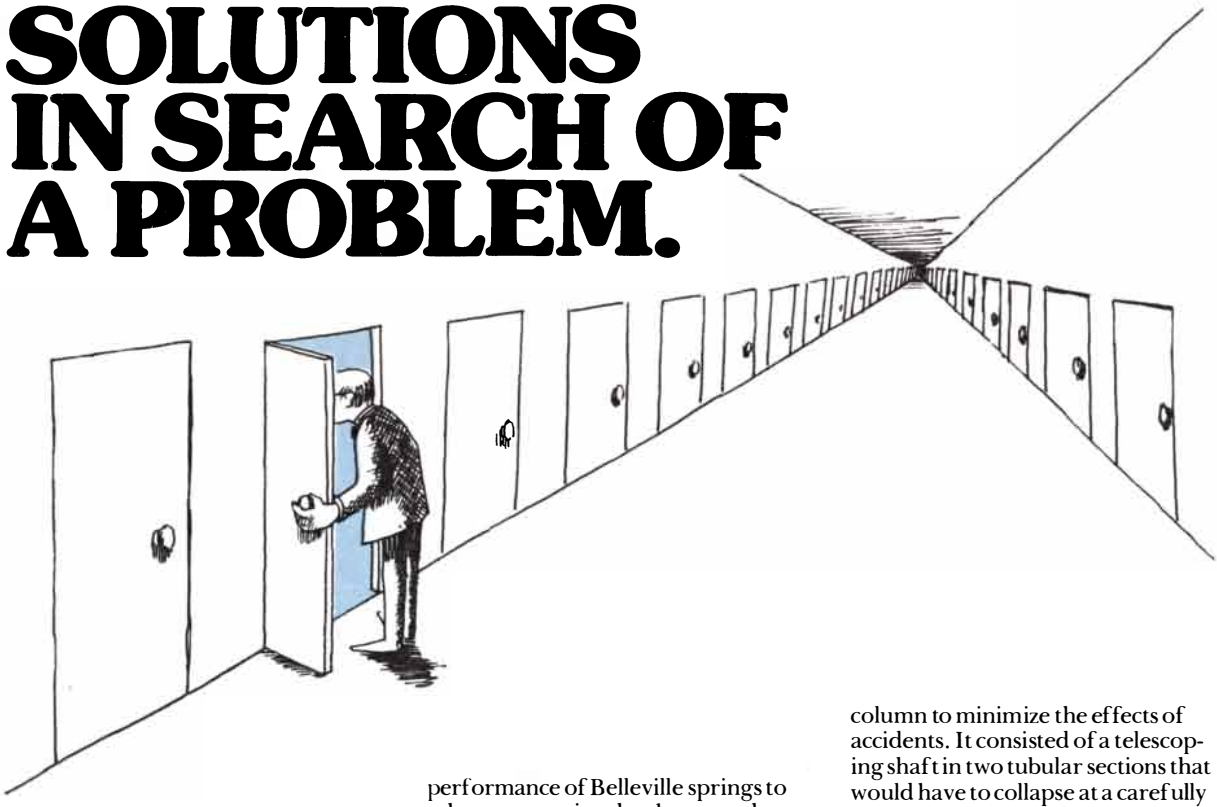
The microstructure of hard-elastic materials in the undrawn state is characterized by arrays of plates lying mainly at right angles to the original direction of stress during crystallization. After stretching, the plates appear to tilt and splay apart, so that there are voids between them [*see illustration on page 104*]. The development of these voids, reflected by a decrease in density, has been used to advantage in the manufacture of films with microscopic pores. The structure of the films is stabilized against the closing of the pores by annealing the stretched material at high temperature. The size of the pore can be varied by varying the strain and the conditions of annealing.

The overall phenomenon of crystallization under flow is one of increasing importance in polymer technology. As the speed of various polymer processes is increased, the stress on the materials often increases as well. In some instances materials with unconventional microstructures and properties result.

In this article we have confined the discussion to polymers with flexible chains, which are capable of assuming many configurations. Before closing, however, it should be noted that a second class of polymers is important in many biological systems and in several technological applications. The second class includes polymers with comparatively stiff chains, which can have only a few configurations. Such polymers are soluble only in solvents that overcome intermolecular attractions; when they are dissolved, they form liquid-crystalline phases at concentrations above some critical value. Examples of these polymers include the alpha-helix polypeptides and poly-p-aminobenzamide. Polymers of this type, spun from rather uncommon solutions, have been shown to yield fibers with exceptional properties—in some cases with a stiffness approaching that of steel and with a tensile strength exceeding that of piano wire.

It is clear that a wide range of mechanical properties can be obtained from thermoplastic polymers—even from a single polymer. It is also clear that the properties of a given polymer depend strongly on its microstructure as well as on its chemical structure. The microstructure can readily be varied by changes in the process conditions, and the tailoring of both chemistry and processing to achieve microstructures with technologically desirable properties will undoubtedly be one of the outstanding challenges to polymer technologists in the coming decades.

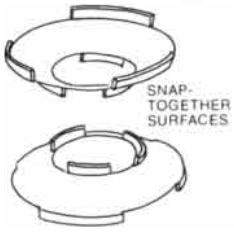
SOLUTIONS IN SEARCH OF A PROBLEM.



In a rational world, first comes the problem then the solution. Right? Right...but not always. Sometimes the solution comes first and the problem has to be searched out. A 100-year-old idea, for example, can be adapted to break through technological limitations imposed by older engineering materials. Which brings us to our story.

Merci, M. Belleville

Back in 1866 one Julien Belleville patented a coned metal disc spring that we now call, to no one's surprise, a Belleville spring. It has a convex saucer shape and a center hole. Under load it flattens and returns to its original shape when the pressure is off, even as you and I.

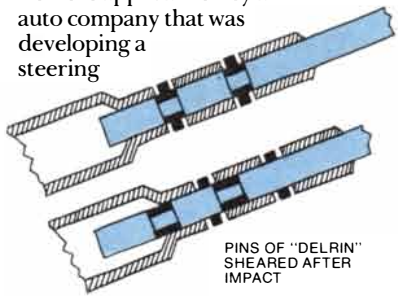


So, we've been working on Belleville springs made of an engineering plastic—Delrin® acetal resin. We've designed springs of "Delrin", molded them as individual discs and as large sheets with *snap-together surfaces.* And we've even extended the performance of Belleville springs to other geometries, thanks to another pretty good invention, the computer.

We've got a lot of answers—for possible use in door closer springs, springs in switches, relays and push buttons, furniture innersprings and, from one of our engineers who thinks young, pogo sticks. Maybe you have a new or even old idea that can expand in function and usefulness when it's matched with our engineering plastics technology.

Born to fail

That isn't the name of a soap opera. Rather it describes an unusual technique: planned failure. We've always known that "Delrin", because of its reproducible properties, could be designed to fail at a predetermined stress. Then several years ago we were approached by an auto company that was developing a steering column to minimize the effects of accidents. It consisted of a telescoping shaft in two tubular sections that would have to collapse at a carefully predetermined stress.



Together with the company we worked out the technology of injection molding "Delrin" into the tubular sections as part of the mold. The design depended on "Delrin" shear pins and bearing collars.

And so we have another apt illustration of a solution looking for a problem and in this case finding it.

Invitation to a Dialog

Surprising breaks with tradition can happen when you look at your problem and our engineering plastics technology with a new, unrestricted curiosity. If our expertise in the properties and uses of engineering plastics may be of help, you can continue this dialog by either writing Dick Johannes, Du Pont Co., Plastics Department, Rm. D-13064, Wilmington, DE 19898 on your company letterhead, or calling Dick at (302) 774-5826.

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THE SAND WASPS OF AUSTRALIA

Australian species of the genus Bembix are unexpectedly diverse. One reason appears to be that they have evolved to fill ecological niches that in other parts of the world are filled by other genera

by Howard E. Evans and Robert W. Matthews

The nomadic aborigines of Australia, entirely ignorant of the vast superstructure we call ecology, lived in a degree of intimacy with nature that modern man can hardly hope to attain. To the aborigines each living thing was significant, at times as a source of food, at times as a symbol of the past or a portent of the future. It is not surprising that one of their ceremonial chants, sung to the clacking of sticks and the deep notes of the *didjeridu* (a large wooden musical pipe), was a song to an insect of their arid country: *woiju*, the sand wasp. *Woiju*, the song goes, digs a hole in the ground where it sleeps, then comes out and flies away. *Woiju* is not good to eat, but it is not to be feared. Rather, it is revered as a close associate of the earth, from which all life comes and to which all life returns.

A traveler through the Australian outback, if he is even remotely attuned to the life around him, soon becomes aware of the abundance of sand wasps. Expanses of sand perforated by their burrows are alive with their comings and goings. These wasps are not, however, uniquely Australian. They belong to the genus *Bembix*, which is well known to students of insects.

Unlike social insects such as ants, bees and social wasps, the sand wasp is a solitary creature. The males dig a sleeping burrow that enters the sand at an angle of from 20 to 40 degrees and has a small mound at the entrance. Females that do not have a brood nest also make a sleeping burrow, and often the burrows of male and female wasps are side by side. Both males and females feed on the nectar of flowers or other sugar solutions secreted by plants and fruits. The male is not a predator at all, but the female captures prey to feed the larva in her brood nest.

Studies of *Bembix* species in North America have revealed that the members of the genus share stereotyped patterns of behavior. Each species, however, shows its own distinctive variation on that pattern, particularly in the way the female builds her brood nest. All North American sand wasps prey exclusively on flies (Diptera).

There is good reason to believe the genus *Bembix* originated in North America, since all genera closely related to it are found there. In recent geologic times one or more stocks presumably entered Eurasia and Africa, where they have flourished. There are 23 species in North America; in Eurasia and North Africa there are more than 50, and some 90 species have been found in Africa south of the Sahara. *Bembix* has also radiated to South America, but there it has largely been replaced by other genera of the tribe Bembicini. The Australian species are probably descended from several separate stocks that arrived by way of the East Indian islands.

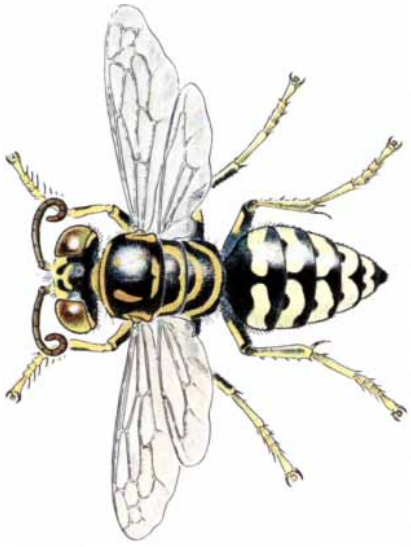
When we began our studies, the number of recorded species of *Bembix* in Australia was about 35. With support from the National Science Foundation and with the cooperation of many institutions and individuals in Australia we were able to observe the nesting behavior of sand wasps for about 12 months in the summers of 1969 and 1972. Although we obtained behavioral data on only 20 species, we were able to identify a total of 80 species. Since several species are known only from a few specimens, it is likely that there are more species yet to be discovered.

How is it that so many more species of *Bembix* coexist in Australia, a continent with few natural barriers and much uniformity in landscape, than in North America, which has a great diversity of environments? As we shall see, many Australian species have broken out of the behavioral straitjacket characteristic of their relatives in North America. The result has been an unexpected degree of adaptive radiation.

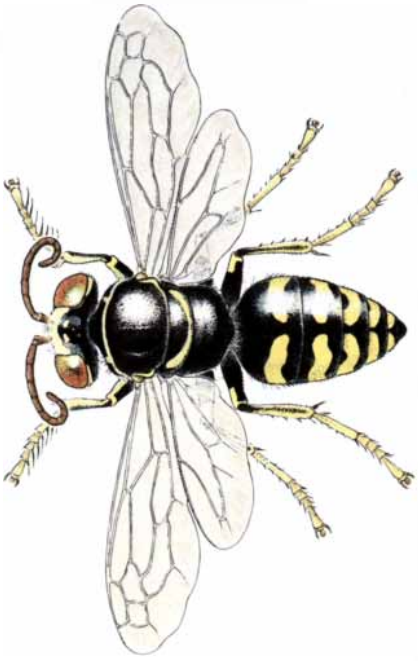
The Australian species of *Bembix* can be said to form two major groups: large species with individuals that are generally more than 16 millimeters in length and small species with individuals that are smaller. Like the sand wasps of North America, all of which can be considered as belonging to the large group, the large Australian sand wasps tend to be segregated by species either geographically or ecologically. That is, at any one site only a single species is usually found; a mixture of two or more species living side by side is rare. The large Australian sand wasps live primarily along the east and west coasts of the continent. They are found in coastal dunes, in sandy strips along the water, in eroded gravel slopes and so on. And like their North American relatives they prey exclusively on flies and build simple brood nests.

Small sand wasps, on the other hand, are found primarily in the sandy ridges of Australia's arid interior. They prove to be atypical of their genus in many ways. We regularly found up to six species nesting side by side in a sand dune, and in some locations it was possible to collect as many as 20 species. Some of the species are so similar in size and in color that it is difficult to tell them apart. The patterns of the brood nest, however, are often distinctive. After a little experience we found that it was easiest to identify some species by the external appearance of the nest.

Bembix is a large genus, and the use of conventional Latin names for new species presents certain drawbacks. We have found it a source of annoyance that some very distinctive Australian species



FEMALE SAND WASP of the species *Bembix littoralis* is depicted at the left. The females vary in length from 10 to 15 millimeters. This species occurs throughout virtually the entire Australian continent. The appearance of the brood nest constructed by the female is distinctive of the species (*photograph at right*). The mound is from 11 to 17 centimeters long and about two centimeters high.



BEMBIX VARIABILIS, another widely distributed species of sand wasp in Australia, disperses the mound that accumulates from excavating the burrow of the brood nest, leaving a characteristic zigzag pattern (*photograph at right*). The *variabilis* females (*left*) vary in length between nine and 16 millimeters. The species is particularly well adapted for living on broad expanses of sand.

BEMBIX PALMATA, carrying a fly, is seen at the entrance to its brood nest. The female lays an egg on the first fly placed in the nest and brings additional flies from day to day to feed the larva. The *palmata* female builds her nest in coarse sand or in gravel from eroded slopes. The species is large and females are typically from 14 to 20 millimeters in length.

PREY TAKEN BY VARIABILIS FEMALES varied considerably in different regions of Australia. Throughout most of the continent *variabilis* is a predator of flies (Diptera) (*upper photograph*). In parts of northern Australia, however, some populations of *variabilis* hunt damselflies (Odonata), which suggests that the species is in evolutionary transition.

have been given easily confused names such as *flavifrons, flavipes, flavilabris* and *flaviventris.* Consequently for new species we chose aboriginal names that seemed to us both appropriate and euphonious, for example *coonundura* (from *coon undura,* a "dragonfly woman" in an aboriginal legend), *burraburra* (an aboriginal word meaning quick), *goyarra* (a Western Australian aboriginal word meaning sandy) and *wangoola* (an aboriginal word from New South Wales meaning to dig). These names were proposed as nouns in apposition to the generic name *Bembix* (from the Greek for buzzing insect).

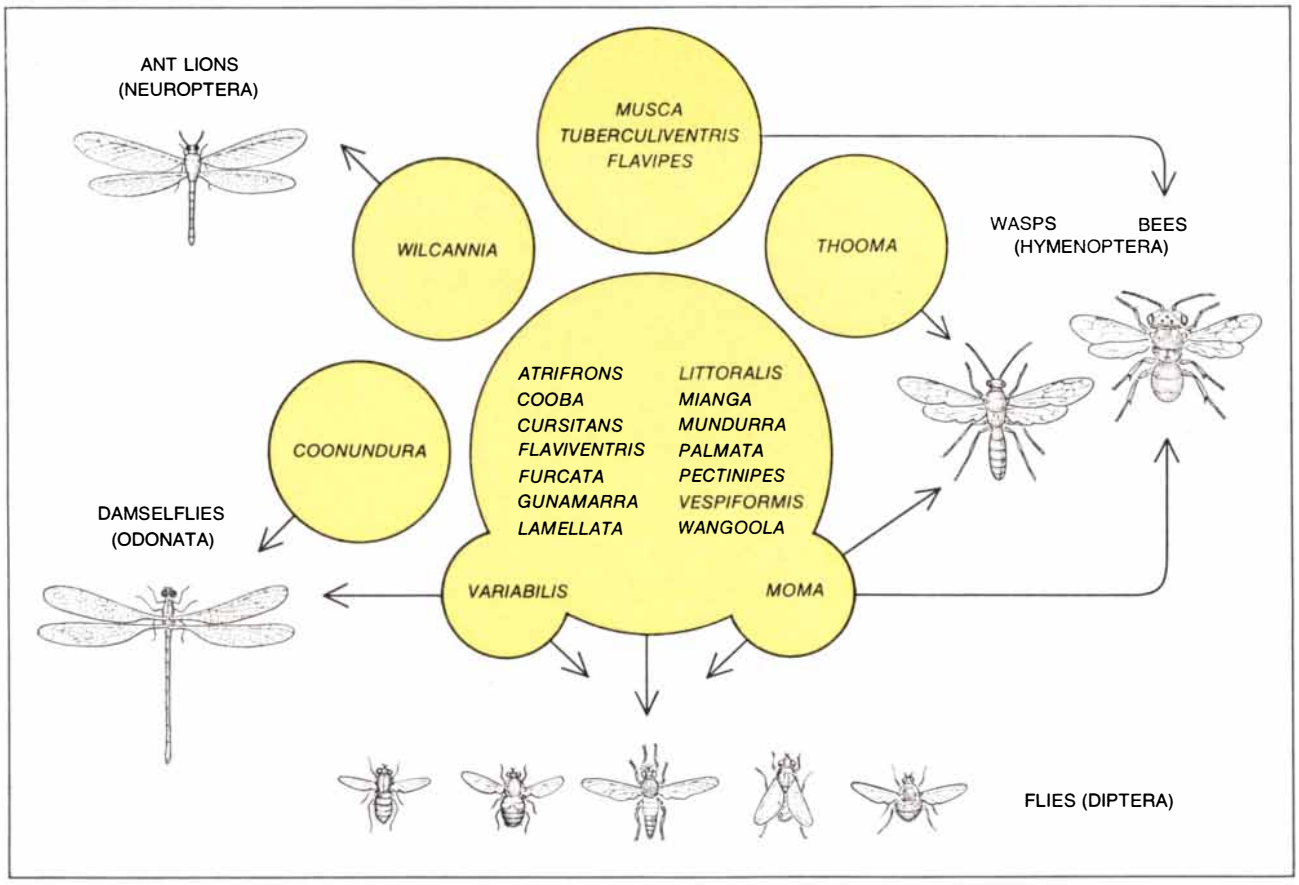
The majority of the smaller sand-wasp species in Australia, like their larger relatives, prey on flies. Some species, however, have become specialists on other insects and thus avoid competition for prey.

In 1931 William Morton Wheeler of Harvard University discovered in the sandy ridges around Lake Violet in the interior of Western Australia a species of *Bembix* that preyed on insects of the order Odonata (damselflies) rather than on insects of the order Diptera. One of our first objectives was to attempt to confirm Wheeler's discovery. When we visited Lake Violet, however, it was dry and no damselflies were to be found. (It is believed that the immature damselfly remains dormant deep in the soil under such lakes, which often are dry for several years.) While we were digging up old nests we found cells containing the remains of damselflies and viable cocoons of sand wasps. We watered the cocoons and reared wasps of the same species (*coonundura*) as those collected by Wheeler.

We also made another discovery at Lake Violet: a sand wasp that preyed on thynnid wasps. We named the new species *thooma,* from a word for the sand-hill creatures of the aboriginal "dream circle." Later we found the same species 1,000 miles to the east, preying on exactly the same kind of wasp. It turned out that this was to be the first of many examples of a prey constancy in a species in spite of the breakdown of prey constancy in the genus.

Other surprises followed. A species that the Austrian entomologist Anton Handlirsch had named *musca* (inappropriately, since *musca* is the Latin word for fly) preyed exclusively, we discovered, on social stingless bees of the genus *Trigona.* We later found two related species of sand wasps that preyed on stingless bees.

If *Bembix* in Australia has evolved to



PREY PREFERENCES of 22 Australian *Bembix* species are shown. Most species hunt only dipteran flies. Two species in transition, *variabilis* and *moma*, hunt flies and other insects. The remaining six species are specialists on orders of insects other than dipteran flies.

occupy the food niches filled elsewhere by other genera, we could hope to find some species of *Bembix* in transition. Indeed, we did find two such species and there may well be more. *Bembix moma* is very common in the Darwin area, but it also occurs widely in the interior. (*Moma* is an aboriginal word for ghost, an allusion to the pale maculations of this small species that make it blend with the sand.) On our first encounter with this sand wasp we found that it preyed on both bees and wasps. In one *moma* nest we even found a dead female of a larger species of *Bembix*. In the Northern Territory we later discovered that some members of *moma* also prey on flies. Since flies are the usual prey of *Bembix*, we believe that *moma* is in a period of transition, broadening its responses to include bees and wasps in its spectrum of prey. Presumably *musca* passed through a similar stage before becoming a specialist on stingless bees.

The second example of a species in transition is *variabilis*. We studied this species in 20 localities in five states and two territories, compiling some 370 records of prey. We found that *variabilis* females hunt at least 14 different families of Diptera. We also found that *variabilis* in the Northern Territory near Darwin preys on damselflies as well as on dipteran flies. And along the Ord River, some 300 miles southwest of Darwin, we discovered *variabilis* nests that contained nothing but damselflies.

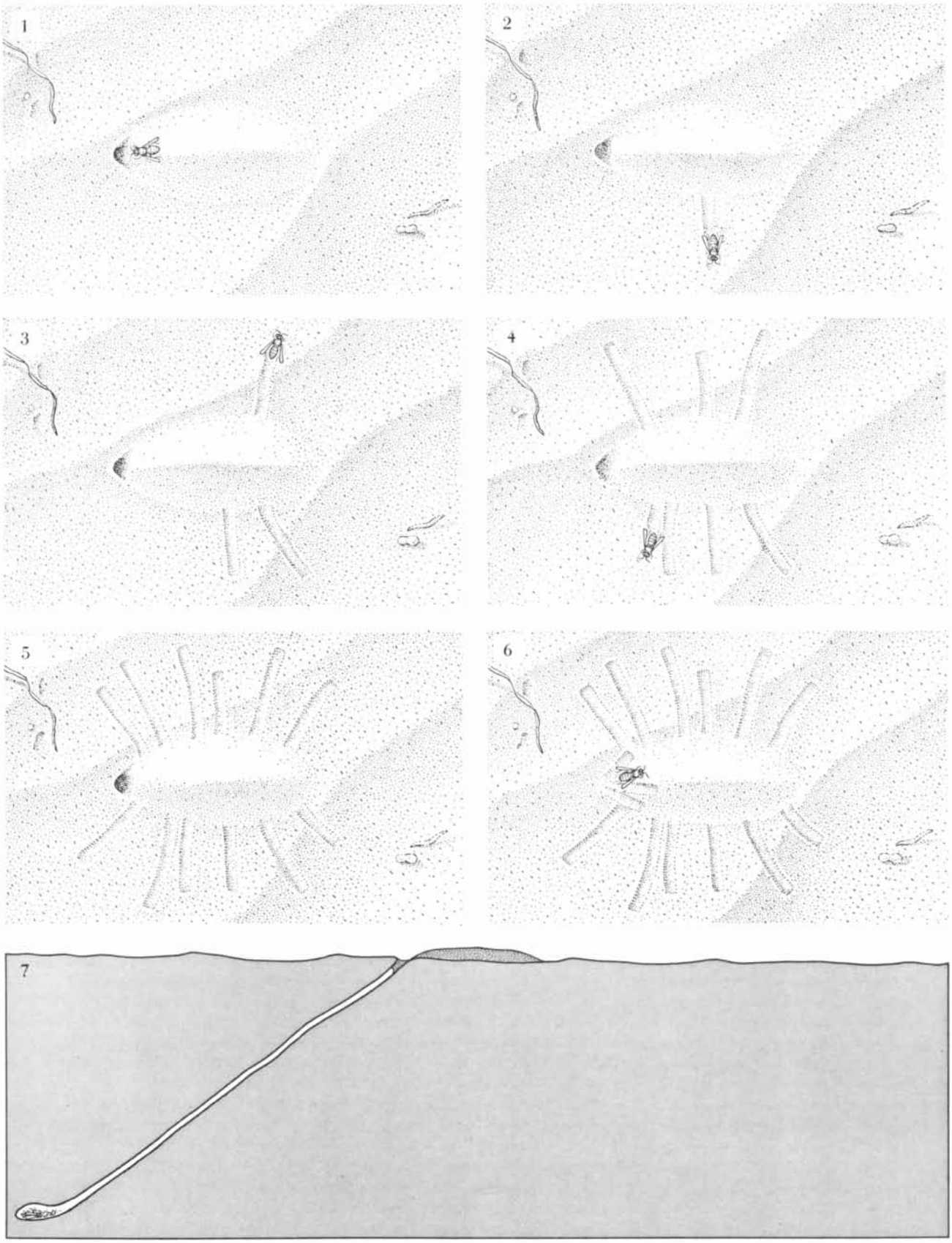
During the dry season in northern Australia *variabilis* appears to nest only near permanent water, where damselflies are often abundant. It shares its nesting habitats with another common species that is an exclusive fly predator, *littoralis*. By preying on damselflies *variabilis* not only avoids competing with *littoralis* for the limited supply of flies in the dry season but also avails itself of considerably larger prey species. Some 40 or 50 dipteran flies are needed to feed a larva to maturity; apparently 20 or 25 damselflies will suffice.

There are characteristic differences in the nest-building behavior of the females of the different species of sand wasps in the interior of Australia. One of the most striking differences is in the way the female wasp modifies the mound of sand that accumulates at the mouth of the burrow to her brood nest. The *variabilis* female, for example, builds her brood nest on flat or sloping sand. The burrow is from 20 to 40 centimeters deep; it is rather crooked and sometimes makes a broad loop so that the brood chamber is nearly under the entrance. The burrow is from seven to eight millimeters in diameter. The brood chamber is slightly wider, from nine to 12 millimeters in diameter, and it is from six to 12 centimeters in length.

After the burrow and brood chamber are finished, the female disperses the mound that has accumulated near the entrance to the burrow, leaving a distinctive pattern of zigzag lines on the sand [*see illustration on page 114*]. She then digs a short blind burrow nearby, which is left open. Sometimes additional false burrows are dug.

The true burrow is closed at all times except when the female is actually bringing prey into the nest. Unlike most Australian species of *Bembix*, which lay their egg directly on the body of the first prey brought into the nest, the *variabilis* female glues her egg to several grains of sand inside the brood chamber.

No prey is brought into the nest by



NEST-BUILDING BEHAVIOR of the *littoralis* female is depicted. The brood nests are started on flat or gently sloping sand. The female first digs the burrow (*1*). When the burrow and brood chamber are finished, the female backs onto the mound, turns about 90 degrees and moves down the side of the mound, scraping sand onto it (*2*). She takes flight, lands at the entrance and repeats the mound-building behavior (*3 and 4*). The end result is a ridge of sand with grooves on each side (*5*). She then closes the entrance to the burrow, creating several more short grooves that radiate from it (*6*). The burrow and brood chamber are shown in cross section (*7*).

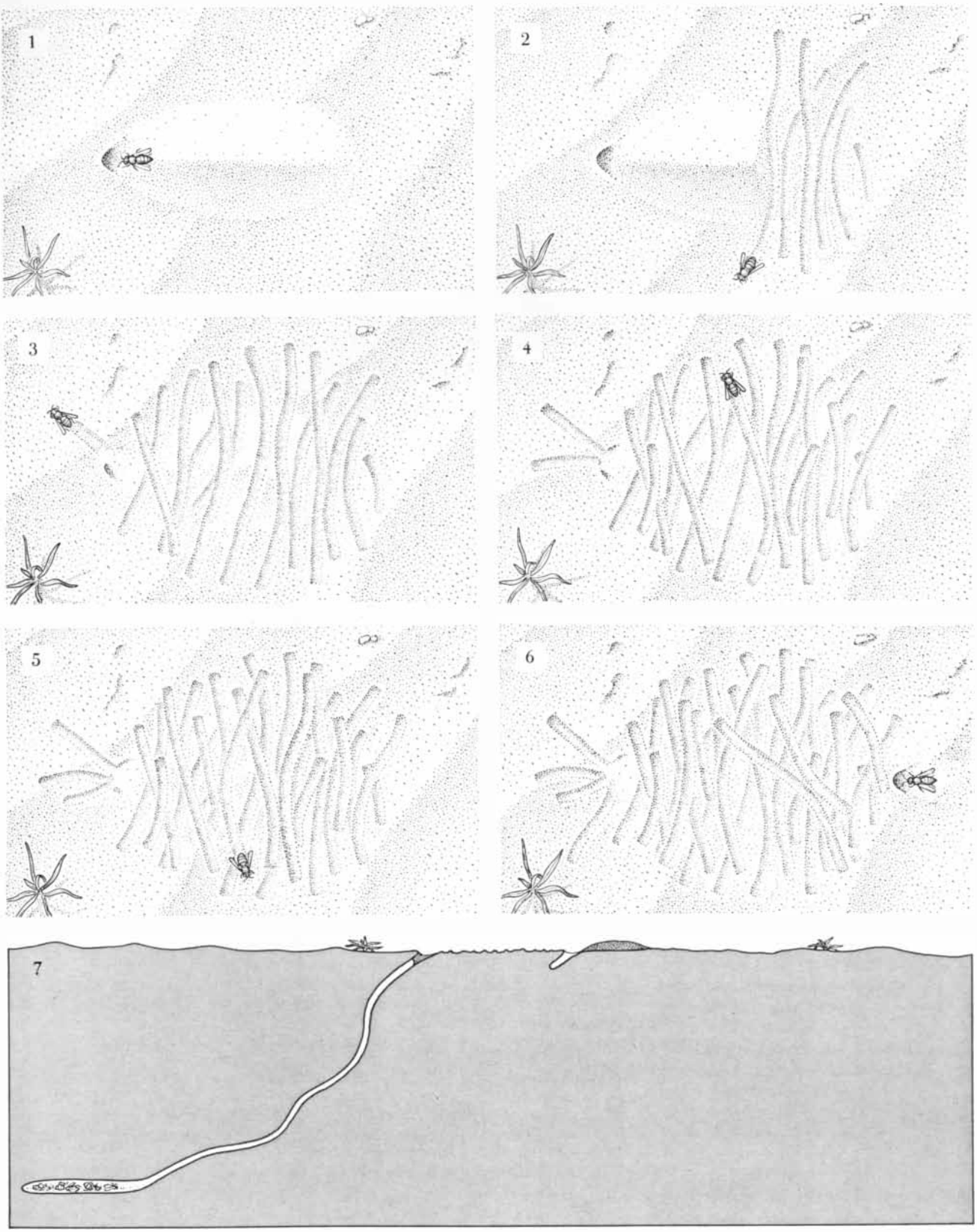
the *variabilis* female on the day of oviposition, but on the following day the female places one or two prey close to the egg. On succeeding days additional prey are brought in and placed more or less in single file along the chamber. The female continues to provision the nest after the egg has hatched. The larva progressively eats the prey in front of it. When the larva is nearly full-grown, the female packs the burrow with sand and closes the entrance on the surface. The larva remains in the brood chamber. When it is full-grown, it spins a thick cocoon in which it rests until it is ready to emerge as a mature wasp.

The newly constructed brood nest of another common sand wasp of central Australia, *atrifrons*, also has a highly distinctive species-specific pattern. The sand from the burrow is dispersed in a wide arc well away from the entrance. A smaller area immediately in front of the entrance is completely swept clean of fresh soil. On the opposite side the *atrifrons* female digs a characteristic radial pattern of lines that converge on the burrow's entrance.

One of the most puzzling types of nest-building behavior we encountered was that of *littoralis*, a widely distributed species we have already mentioned. Following the completion of the burrow the female does not disperse the mound that has accumulated. Rather, she moves backward from the burrow's entrance onto the mound, makes a turn of about 90 degrees, moves down the side of the mound and scrapes sand onto it. She then takes flight, lands at the entrance and repeats the mound-building sequence. The final result is a high ridge of sand with a pattern of grooves on each side [*see illustration on opposite page*]. The ridge is from 11 to 17 centimeters long, four to seven centimeters wide and about two centimeters high.

We observed this curious mound-building behavior by *littoralis* females throughout central, western and northern Australia. Along the east coast, however, from New South Wales through central Queensland, many *littoralis* females did not scrape sand onto the mound, or did so only to a limited extent. It is worth noting that where *littoralis* females do not build mounds they do not nest alongside other species of *Bembix*. In areas where their nests are intermingled with those of other species they tend to build nests with the characteristic *littoralis* pattern.

Evidently when several species of *Bembix* nest side by side, there is some value in having distinctive patterns at



BROOD NEST is built by the *variabilis* female on flat or sloping sand, often close to the nests of other species of *Bembix*, such as *littoralis*. The burrow is from 20 to 110 centimeters long and is often crooked. The sand excavated from the burrow forms an elongated mound (*1*). When the burrow and brood chamber are finished, the female then lands on the far end of the mound and works forward, turning from side to side and scraping sand vigorously (*2*). She makes another flight, lands and repeats the scraping over a slightly different course. The sequence is repeated (*3, 4 and 5*) until the mound has been completely dispersed and a distinctive pattern of zigzag lines is created in front of the burrow's entrance. The opening of the burrow is covered with sand. Finally, the female lands at the back of the leveled mound and digs a short blind burrow (*6*). The bottom drawing (*7*) shows the nest in cross section.

nest entrances. Perhaps the pattern serves as a landmark. On the other hand, many species of *Bembix* remove all external evidence of their nest and are still able to find it.

Dispersal of the mound that accumulates during the digging of the burrow may originally have served the purpose of making it harder for natural enemies of the sand wasp to find the nest. In Australia, as in other parts of the world, *Bembix* wasps are attacked by parasites and nest scavengers. The natural enemies of *Bembix* include mutillid wasps (sometimes called velvet ants), bee flies and certain small flies of the families Sarcophagidae and Chloropidae. Australian sand wasps are also preyed on by beetles of the family Stylopidae. These parasites are frequently seen projecting from between the rear dorsal parts of adult sand wasps of both sexes.

The blind burrows of the *variabilis* nest are believed to play a role in deluding parasites. We have often observed flies entering and laying eggs in these false openings. Conceivably the distinctive nest patterns of many species of *Bembix* also serve as a form of protection against parasites and predators. It can be assumed that individual species of *Bembix* evolved in a situation where one particular natural enemy predominated, and that each species developed a pattern of behavior that reduced the success of the enemy. When several species of *Bembix* nest side by side, a diversity of nest patterns may prevent nest parasites and predators from developing specific responses to any one configuration.

It appears that the behavioral diversity found in the Australian sand wasp is the result of a variety of selective pressures: competition for prey, natural enemies and the presence of ecological niches that elsewhere in the world are filled by other genera. We believe that recurrent periods of extreme drought in Australia may have forced various species of *Bembix* into isolated refuges where they developed sexual isolating mechanisms and differences in behavior that later made it possible for them to coexist side by side. When more favorable climatic conditions enabled them to again expand their ranges, the different species continued to coexist where ecological conditions allowed them to do so. The continued adaptation of certain species such as *variabilis* offers a unique opportunity for the study of selection pressures and the origin and spread of new elements in the behavioral repertoire of *Bembix*.

MATHEMATICAL GAMES

A random assortment of puzzles, together with reader responses to earlier problems

by Martin Gardner

Here are five engaging problems, entirely unrelated to one another. As always, the answers will be given next month. The problems are followed by some unusual reader responses to problems previously discussed in this department.

1. A pair of tests with symbols. Every intelligent, mathematically proficient person who ever took an I.Q. test has surely been annoyed by questions that involve a row of symbols and a request to identify the symbol that "does not belong" to the set. Sometimes there are so many different ways a symbol can be different from the others that brighter students are penalized by having to waste time deciding which symbol is "most obviously different" to the person who designed the test.

It was irritation over such ambiguity that prompted Tom Ransom, a puzzle expert of Toronto, Ont., to devise a delightful parody of the test. The reader is asked to inspect the five symbols in the illustration below and pick out the one that is "most different."

A whimsical companion to Ransom's paradox appears as a puzzle sequence in N. J. A. Sloane's invaluable *Handbook of Integer Sequences* (Academic Press, 1973). Can you sketch the sixth figure in the series shown in the top illustration on the opposite page?

2. Slicing the cake. A cake has been baked in the form of a rectangular parallelepiped with a square base. Assume that the square cake is frosted on the top and four sides and that the frosting's thickness is negligible (zero). We want to cut the cake into n pieces so that each piece has the same volume and the same area of frosting. The slicing is conventional. Seen from above the cuts are like spokes radiating from the square's center, and each cutting plane is perpendicular to the cake's base.

If n is 2, 4 or 8, the problem is easily solved by slicing the cake into two, four or eight congruent solids. Suppose, however, that n is 7. How can we locate the required seven points on the perimeter of the cake's top? If you solve it for 7, you will be able to generalize to any n.

This pretty problem is given by H. S. M. Coxeter on page 38 of his classic *Introduction to Geometry*. Coxeter does not answer it, but it should give readers little difficulty. The general solution is surprisingly simple.

3. Two cryptarithms. Many readers wrote to say they enjoyed solving Alan Wayne's cryptarithm given in this department for September. Here are two more elegant cryptarithms by the same master that have not been published before. The first is in French, the second in German. Each letter represents just one decimal digit, and we adopt the usual convention that 0 must not begin a number. Both have unique solutions.

```
  VINGT        EIN
+  CINQ     +  EIN
   CINQ        EIN
 TRENTE        EIN
               VIER
```

4. Lewis Carroll's "sonnet." In 1887 Lewis Carroll included in a letter to Maud Standen, a "child-friend," a six-line poem that he called an "anagrammatic" sonnet. (He was using "sonnet" in an older sense, meaning any short piece of verse. See the Oxford English Dictionary's second definition.) "Each line has four feet," Carroll wrote to Maud, "and each foot is an anagram, *i.e.*, the letters of it can be rearranged so as to make one word." Most of the anagrams, he said, had been devised "for some delicious children" he had met the previous summer at Eastbourne.

Here is the "sonnet":

As to the war, try elm. I tried.
The wig cast in, I went to ride
'Ring? Yes.' We rang. 'Let's rap.'
We don't.
'O shew her wit!' As yet she won't.
Saw eel in Rome. Dry one: he's wet.
I am dry. O forge Th' rogue Why
a net?

In most cases there is little doubt about the correct word. For example, the first foot, "As to," could be "oast" or "stoa," but more likely Carroll meant the commoner word "oats." For several of the feet, however, the intended word is not clear. No solution by Carroll has survived, and to this day there is contention among Carrollians over the precise set of 24 words Carroll had in mind. Readers are invited to make their own list to compare with the conjectures that will be given next month.

5. Third-man theme. Two kings are the sole occupants of a chessboard [*see bottom illustration on opposite page*]. The task is to add a third man, creating a position that meets these provisos:

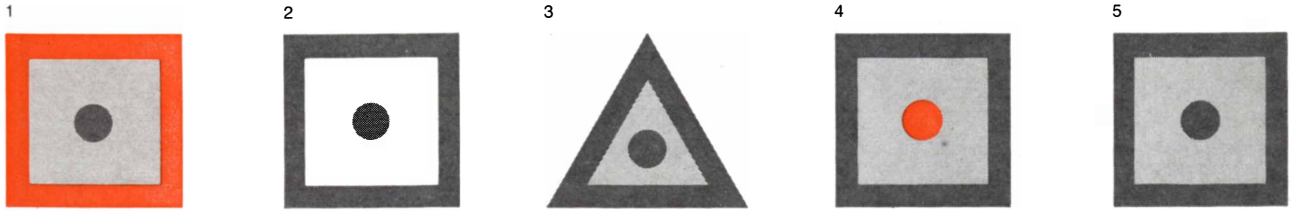
a. Neither king is in check.

b. The position can be reached in a legal game.

c. Neither side can make a legal move.

Note carefully the wording. It asks not for a double stalemate but only for a position in which neither side can move. The solution is unique.

This sophisticated little problem appeared in a recent issue of *The Problemist*, where it was credited to G. Husserl of Israel. Newman Guttman called it to my attention. The original problem



Tom Ransom's I.Q. test: Which symbol is the "most different"?

N. J. A. Sloane's puzzle: What is the sixth figure in the series?

asked for the minimum number of men that must be added to the board to meet the conditions, but I have made the problem easier by stating that the minimum is one.

In discussing Anatole Beck's hex in June, I gave an inaccurate description of Beck's proof that opening on an acute corner cell is a loss for White. What Beck proved is that *if* the acute corner opening is a win for White, then it can be shown that if Black plays adjacent to it on his first row, Black can win. Since that is a contradiction, it follows that the acute corner cell is a losing opening. The proof does not specify Black's winning response. Indeed, as Craige Schensted and others pointed out, playing adjacent to the corner cell on Black's first row actually loses for Black on boards of orders 3 through 6 and probably on all higher boards.

For the past five years Schensted, a research engineer in the radio astronomy department of the University of Michigan, and his friends have been exploring unusual variations of hex. In 1970 he and Charles J. Titus, a mathematician at the University of Michigan, published *Mudcrack Y,* a report on their work that also contained sheets for playing. A much revised second edition of 188 pages, *Mudcrack Y and Poly-Y,* has just been privately printed. Interested readers can obtain copies postpaid by sending $2.50 to NEO Press, Box 32, Peaks Island, Me. 04108.

David Fremlin and Dennis Rebertus independently wrote computer programs that verified the first player's win in order-3 dodgem, another game discussed in June. White wins only by first moving his piece at the corner. Order-4 dodgem is still unsolved.

John Beidler, who heads the computer science department at the University of Scranton, found by computer that Stanislaw Ulam's triplet game in standard play on a 6-by-6 field is a win for the first player only if his first move is on one of the four central cells. Beidler generalized the game to rectangular boards and obtained the results shown in the top illustration on the next page. The numbers give winning moves by row and column for the first player. The asterisks indicate a win for the second player. If the game is played in reverse form, Beidler found that the second player has the win on 3-by-3, 3-by-4, 3-by-5 and 4-by-4 boards. For 1-by-n reverse tromino cram, with n less than 19, Beidler proved first-player wins for $n = 4, 5, 7, 8, 11, 14, 15, 17$ and 18 and second-player wins for all other values.

The more difficult version of G. W. Lewthwaite's game, as I described it in June, was solved by David Elwell, who found by hand a winning but inelegant strategy for the second player. I had, however, misinterpreted Lewthwaite's own rules for this game. He meant that a player could move *any* number of adjacent counters (not just one or three) in a row or column, provided that his color is at both ends. Elwell conjectures that the second player has a win.

In the July column on tiling with convex pentagons I mistakenly said that the equilateral pentagonal tiler belonged to Type 1. It belongs to types 2 and 4. Describing the flower pattern of pentagons, I said it belonged to types 1, 5 and 6. I meant that the tile itself belongs to those types. As several readers pointed out, the pattern belongs only to Type 5.

A remarkable letter on the tessellations in July came from Richard E. James III, a computer scientist with the Control Data Corporation. He sent a strange tessellation [*see bottom illustration on next page*] along with a note describing the pentagon (in R. B. Kershner's notation) as $A = 90$ degrees, $C + D = 270$ degrees, $2D + E = 2C + B = 360$ degrees, and $a = b = c + e$. "Do you agree that Kershner missed this one?" he asked.

Kershner had indeed missed it. This means that the problem of classifying all convex pentagons that tile the plane is not solved, as Kershner had supposed. I must say that Kershner received the blow with grace and good humor. In a letter to him I mentioned that James's discovery illustrates the pragmatic side of mathematical proof, namely that proofs are not known to be proofs until there is a consensus among experts. Kershner replied as follows:

"In connection with your philosophical comments on the nature of a proof, you might be interested in an observation by that eminent authority, me. In *The Anatomy of Mathematics,* Kershner and L. R. Wilcox, Ronald Press, 1950, I wrote:

" 'Now it must be said that there is no simple test that can be applied to determine the validity of a proof, that is, to determine that an alleged proof really is a proof. Mathematical history contains rare instances of arguments that were generally accepted as proofs for hundreds of years, before being successfully challenged by a very ingenious mathematician, who pointed out a possibility that had been overlooked in the alleged proof. And more recently, every year there appear, in the mathematical journals of the world, a certain number of papers which point out that some statement, allegedly proved in a preceding paper, was not only erroneously proved (that is, not proved) but was, in fact, incorrect. These facts are mentioned for the benefit of those who feel that there is some magic formula for a proof which makes it immutable and unarguable henceforth and forevermore.'

"I must say that when I wrote this paragraph I did not at the time propose eventually to illustrate its validity so graphically myself."

James's tessellation can be varied in ways that have been analyzed in an unpublished paper by Doris Schattschneider of Moravian College in Bethlehem, Pa. It is a basic pattern that could have been discovered by the medieval Moors

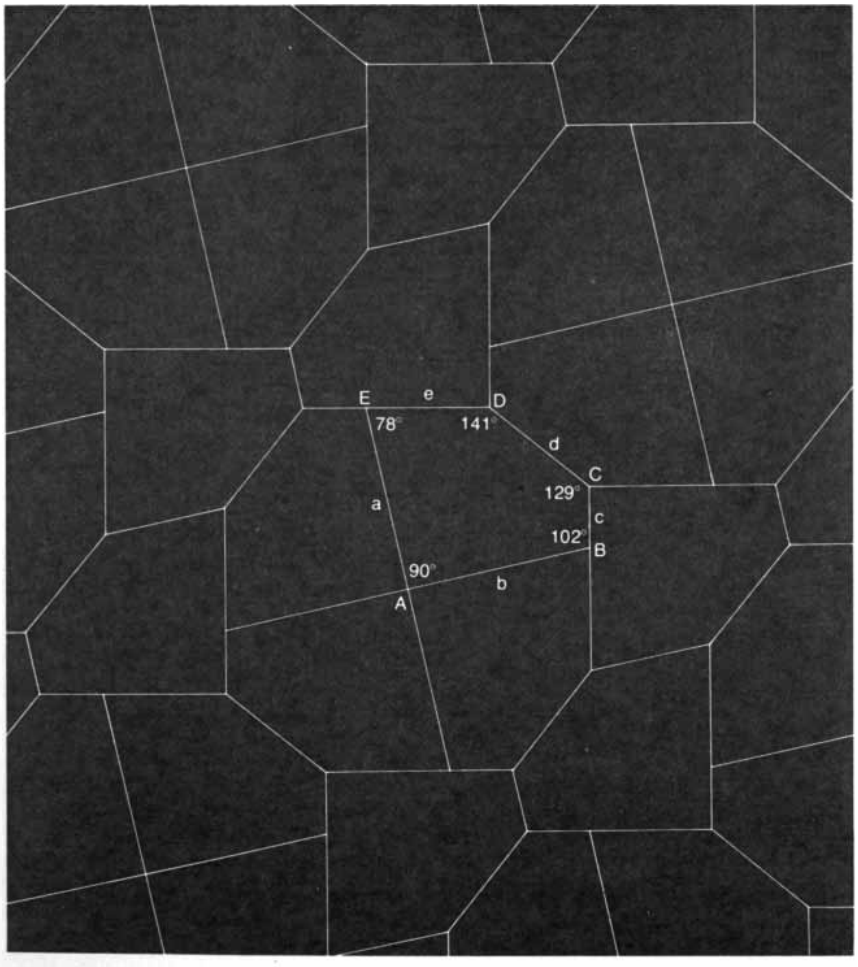
Where and what is the third man?

	3	4	5	6	7	8	9	10	11	12
3	2,2	*	2,3	*	2,4	2,5	2,5	*	2,6	3,3
4		3,3	*	3,4	4,1	*	*	3,8		
5			3,3	4,1	3,4	3,5	3,5			
6				4,4						

John Beidler's results for Stanislaw Ulam's triplet game

or even by the ancient Greeks or Romans, but it is probable that the pattern had never before been seen by human eyes until James first put it on paper!

Many readers found alternate ways of tiling for some of the tessellations discussed in August. Allan L. Sluizer discovered a third tiling (with its reflection) for heptomino 5. The tiling I gave in September for the heptomino combined with a 2-by-2 square is not unique. Alternate tilings were found by Robert Abes, Peter Gallin, Dan Gautau, William Heaps, Charles W. Karns, G. Wesley Pedlow, Jr., Lois Rogers, Jon Siegel, Jack K. Thompson, John M. Wilczek and no doubt others whose letters will arrive after this is written. Although the tiling pattern for Roger Penrose's wheelbarrow polyiamond is unique, there are many different ways a fundamental region can be outlined on the infinite plane. Several readers sent alternate ways of doing this.



A remarkable new tessellation with congruent convex pentagons by Richard E. James III

Dr. Matrix' Bible commentary in September brought an interesting explanation from Webb Simmons of why Mrs. E. G. White imagined she had seen the 144,000 translated saints in a perfect square. Perhaps the saints were in a trapezoidal formation of 375 ranks, starting with 197 in the first row, 198 in the second and so on to 571 in the back row. If such an array is viewed from above, it will appear to be square.

Harold F. Williams informed me that when Mrs. White wrote her most popular book, *The Great Controversy Between Christ and Satan,* she described the totality of the redeemed as standing in a "hollow square" with Christ in the center. If this statement is taken to mean a square array that is missing a central square with sides parallel to the sides of the array, and if it is applied to the subset of 144,000, Williams calculates that the number of possible solutions is itself a square as well as a factor of 144,000, namely 36. "The smallest possible number for a side of the array is 380," he writes. "In this case the saints would stand 380 to a side, leaving a central hollow of 20 by 20 whose center would contain their Redeeming King." Readers may enjoy verifying this result by finding the 36 solutions in positive integers of the Diophantine equation $A^2 - B^2 = 144{,}000$.

Ariel Fischer and Steven J. Cooper each found support for the view that Methusaleh did not perish in the Flood but died just before it in the works of Rashi, a French rabbinic commentator of the 11th century. Rashi argued that the passage "For yet seven days, and I will cause it to rain..." (Genesis 7:4) indicates that God waited for seven days of mourning for the righteous Methusaleh before starting the Flood. Cornelius Van S. Roosevelt disagreed with Dr. Matrix' assertion that Bildad the Shuhite is the smallest man mentioned in the Bible. He says it is Habakkuk, who stood on his watch (Habakkuk 2:1).

Wayne's cryptarithm in September has a second solution if we ignore the convention that numbers must not start with zero: $472 + 472 + 472 = 0708 + 0708$. Many readers sent both solutions. Terry Terman and Daniel S. Marcus each noted that the second solution, like the first, has a connection with π: $472 \times 3 = 1416$, thus providing the first five digits of π, the decimal point having been replaced by an equal sign and the final digit rounded. Herb Freedman added that $472 = 314 + 158$, the six

numbers on the right differing from the first six digits of π only in that the final digit is 8 instead of 9.

Enthusiasts of John Horton Conway's computer game, Life, will be interested in two excellent articles on Life in the September and October issues of a new monthly journal, *Byte,* devoted entirely to information on microcomputer systems. The articles are by the journal's editor, Carl T. Helmers, Jr. A year's subscription to this periodical is $12. The publisher is Green Publishing Company, Inc., Peterborough, N.H. 03458.

Readers who enjoyed the column last January on anamorphic art (distorted art that is restored to normal when it is viewed in perspective or when it is reflected in cylindrical or conical mirrors) will be pleased to know that a truly magnificent exhibition of anamorphic art, in all its many forms and gathered from all over the world, opened on November 7 at the Rijksmuseum in Amsterdam. It will continue through January 25. For *Scientific American* readers who would like to see the exhibition, Grand Metropolitan Hotels and KLM, the Dutch airline, have arranged a special program based on the exhibition.

The program begins January 17 and runs for seven nights. Participants will be flown to Amsterdam by KLM and accommodated at reduced rates at the American Hotel, which is near the Rijksmuseum. The week's schedule will include special lectures at the museum, shopping and sightseeing tours of Amsterdam, side trips to The Hague and Rotterdam, a boating excursion and other activities. The person to contact for information is Marilyn Newman, 119 West 57th Street, New York, N.Y. 10019. The telephone number is 212–586–7980. A book based on the exhibition is being prepared and will be published in Dutch and English editions.

Here are the answers to last month's map problems. A two-point equidistant map of the world, when the two points are any pair of antipodes, is a straight line. The next problem dealt with the distribution of continents around the world. If one, two or three nonoverlapping circular caps are randomly distributed around the globe, the probability that their centers lie on one hemisphere (any half sphere, not necessarily the Northern or the Southern Hemisphere) is 1.

The answers to the geographical questions are: 1. Pacific. 2. Canada. 3. California. 4. Venice. 5. Vladivostok. 6. Japan. 7. Arizona, Colorado, New Mexico, Utah. 8. East.

THE AMATEUR SCIENTIST

Diverse topics, starting with how to supply electric power to something that is turning

Conducted by C. L. Stong

How do you supply electric power to a rotating device through flexible wires? What prevents the wires from twisting up and breaking? The usual answer is to put into the circuit a pair of slip rings. They are annular conductors mounted on insulators that are attached to the rotating object. Current is supplied to the rims of the rings through a sliding contact with a pair of electrically conducting brushes.

The electrical resistance of the sliding contacts varies slightly. The variation is of no significance in circuits that carry a substantial amount of power, but in low-power circuits changing resistance can introduce unacceptable noise. D. A. Adams (Route 8, Box 316-0, Tucson, Ariz. 85730) has solved the noise problem by patenting a device for making a direct electrical connection with flexible conductors between the fixed source of power and the continuously rotating load. The load can rotate indefinitely without twisting the flexible connection in two.

Adams' scheme can best be explained by a series of diagrams [*see illustration on opposite page*]. Imagine a turntable that floats in air. A strip of paper tape is fastened to the center of the turntable at its top. The tape then arches over the edge of the turntable and extends downward in the general shape of a question mark to a fixed point directly under the center of the turntable.

Assume that the turntable rotates counterclockwise as viewed from above. Beginning at the upper left in the illustration and proceeding from left to right, note that as the turntable rotates 90 degrees the paper strip rotates around the turntable 45 degrees. When the turntable has rotated 180 degrees, the paper tape has rotated around the turntable only 90 degrees. In short, the turntable rotates at twice the speed of the tape.

Note also that when the turntable has made a full revolution and the tape a half revolution, the tape has turned through 180 degrees with respect to its starting position but has not twisted! You should find it even more remarkable to observe that the first diagram is identical with the last one even though the turntable has made two full revolutions while the tape has made only one. Yet the tape still remains straight.

However fascinating these diagrams may be, are they of practical interest? The scheme requires that the turntable float in midair, which is hardly a practical arrangement. Adams accomplishes the same effect, however, with a mechanism that enables the tape to rotate completely around the turntable on all sides [*see illustration on page 122*]. The base of the machine supports a fixed bearing in the form of a hollow shaft that terminates at its upper end in a spur gear. This unit functions as a bearing for a hollow shaft that terminates in a spur gear at its lower end. The spur gear meshes with the similar gear of an electric motor. The upper end of this rotating hollow shaft is rigidly fastened to one end of a closed cylinder. Hence the motor can rotate the cylinder through the spur gears. The weight of the cylinder is borne by a ball thrust bearing.

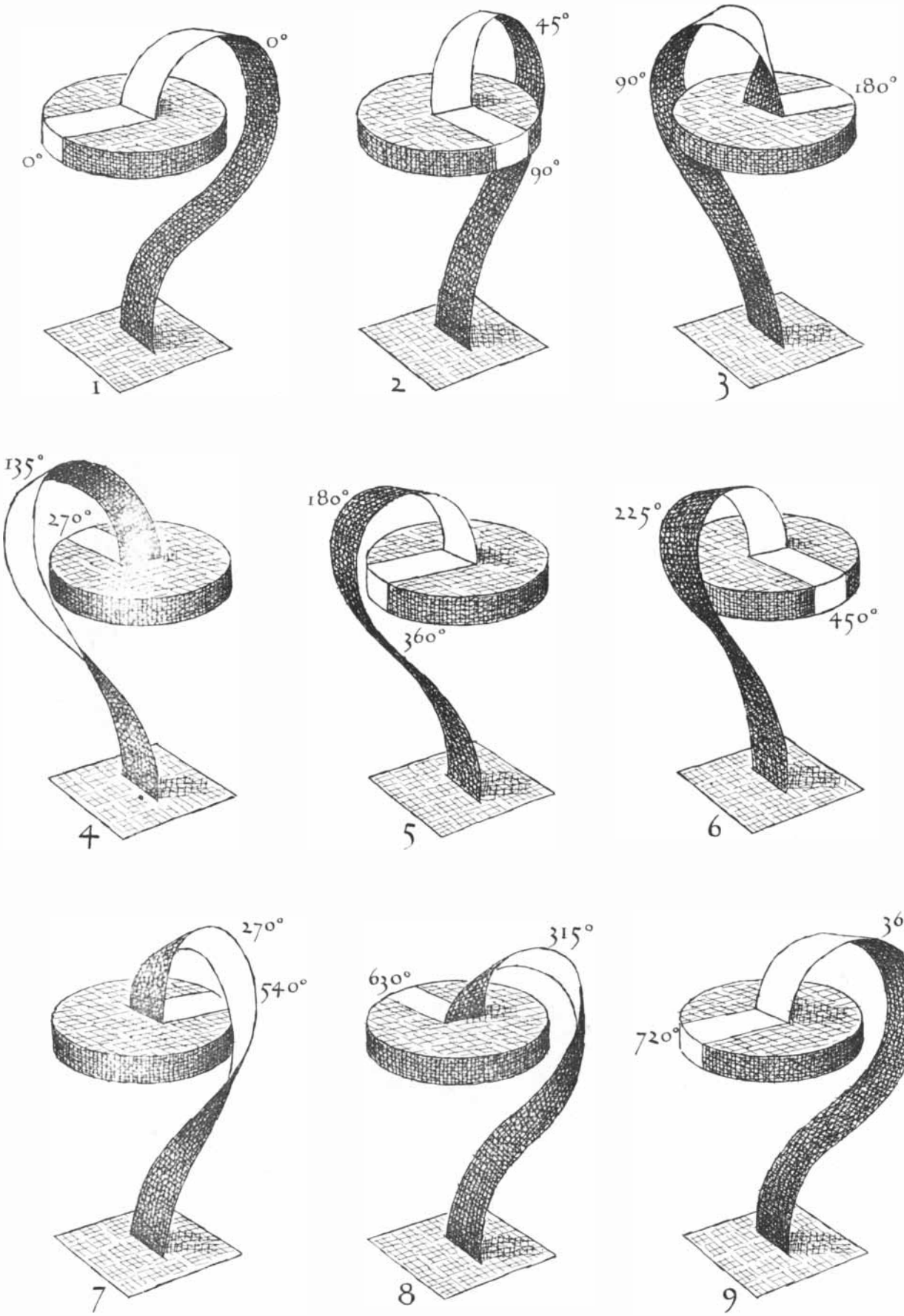
The spur gear that is part of the hollow shaft fixed to the base engages an idler gear supported by the bottom of the cylindrical container. The idler gear in turn engages a spur gear supported by a shaft that extends to the upper end of the cylinder, where it carries a second spur gear. When the motor drives the cylinder, the idler gear and its companion rotate as a planetary system around the sun gear that is fixed to the base. The upper end of the larger planetary gear engages a spur gear fixed to a turntable. The turntable is loosely supported by the upper end of the cylinder through a thrust bearing and hence is free to rotate.

An inspection of the system of gearing discloses that when the motor operates, the cylinder turns continuously. With the proper choice of gear ratios the turntable also rotates in the same direction but at exactly twice the speed of the cylinder. A pair of flexible conductors can be threaded up through the hollow pair of coaxial bearings at the base and then out of the cylinder through the small hole at the upper left. The conductors arch over the edge of the turntable and are attached to its upper center. The rig includes a rigid pipe for shielding the flexible conductors between the rotating cylinder and the top of the turntable. Thus the construction meets the requirements illustrated by the series of schematic diagrams but differs essentially in that a pair of flexible conductors have been substituted for the strip of tape.

It is apparent that uninterrupted connections of other kinds can be substituted for flexible electrical conductors. For example, hydraulic and pneumatic tubing without swivel joints or rotary valves can replace the wiring. So can channels for various gases, including air, chemicals and refrigerants. Moreover, a train of prisms can be arranged to transmit an image of all the movement (other than the rotary motion) of a specimen mounted on the turntable of a centrifuge. A biological specimen in a spinning centrifuge would appear to be motionless except for the distortions induced by the action of centrifugal force.

The scanning device would consist of four prisms rigidly mounted to the turntable through a framework that is in the form of a square-cornered *C*. Light rays from the prism configuration would be deflected through a right angle by a prism at the bottom. These rays, now fixed and horizontal, would fall on an eyepiece through which the spinning specimen would be observed [*see bottom illustration on page 123*]. The emerging rays would be constant, not intermittent as they are with the devices that now serve for examining specimens in centrifuges.

By omitting the idler gear at the bot-



Sequential models of D. A. Adams' antitwister mechanism

tom of the cylinder and altering the gear ratio it is possible to make the turntable stand still while it is being encircled by the conductors. If the turntable is then fitted with a capstan and a motor-driven spool, it is possible to pull two wires through the machine and simultaneously twist them into a pair. The wires would be supplied by a pair of spools supported on a nonrotating shaft that is external to the base of the machine. Mechanisms of this type, which are called high-speed twisters, have had wide application in the electrical manufacturing industry.

This department for January, 1974, carried a description by Eugene F. Ruperto (Box 166, R.F.D. 1, West Alexander, Pa. 15376) of a homemade apparatus for picking up images of cloud cover as photographed by weather satellites. The signals transmitted by these vehicles may be relatively weak while the satellite is rising above the horizon or when it is about to set. For this reason it is customary to use receiving antennas that favor signals from a given direction and that can be pointed toward the satellite much as one would point a telescope.

Ruperto has made a directional antenna of the helical type that in effect increases the strength of the received signal by 13 decibels, thereby producing some 20 times the output of an omnidirectional antenna. The assembly is supported by an altazimuth mounting so that it can be turned toward any region of the sky [*see top illustration on page 124*]. Ruperto describes his antenna.

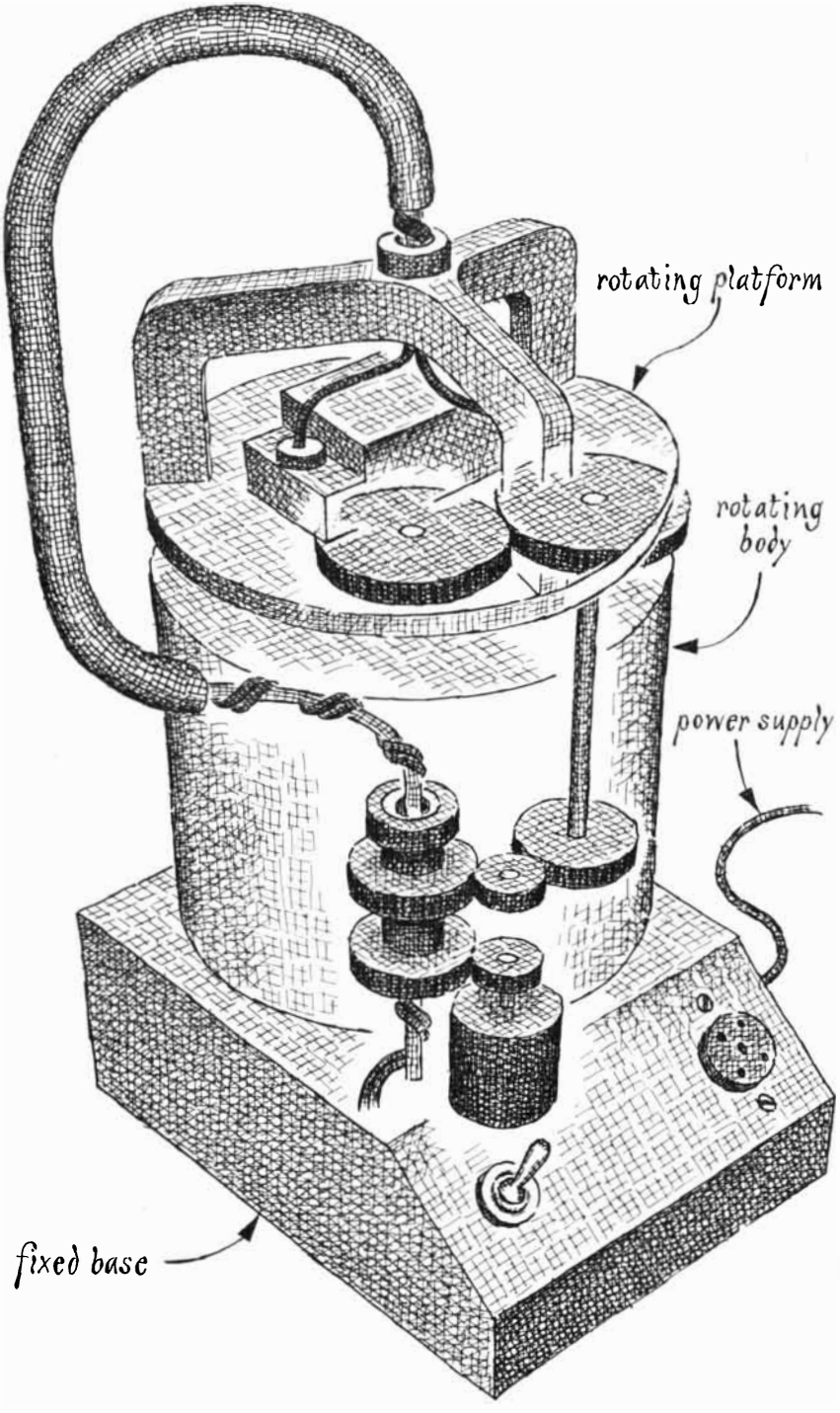
"Helical antennas have many attractive characteristics for observing a satellite. They are inexpensive and relatively light and can cover frequencies in the ratio of 1.7 : 1 megahertz. Their most pronounced disadvantage is their size.

"My antenna includes a wood boom that supports a helix of No. 6 hard-drawn copper wire through a system of radial wood struts; a ground plane of 1/4-inch aluminum tubing that resembles a spiderweb; an altazimuth mounting made of two wood blocks, and a counterweight in the form of a disk of concrete. The length of each turn of the helix is approximately equal to the wavelength of the signal. The wavelength is somewhat shorter in the metal than it is in free space because the energy is propagated through wire at a somewhat lower velocity than it is in free space.

"I determined the approximate wavelength in the helix with an old formula frequently employed by radio amateurs: Wavelength (in feet) equals 936 divided by the frequency (in megahertz). The frequency of the signal from the weather satellite is 137.6 megahertz. Hence the wavelength of the signal in the helix is 6.8 feet, or 81.63 inches, per turn.

"The No. 6 copper wire from which the helix was made was preformed by wrapping the wire around a 55-gallon wine barrel and then reducing the diameter by hand to a length equal to 81.63 inches multiplied by .31. The helix was then stretched so as to space its six turns a fourth of a wave apart, which amounted to about 21 inches between turns. The turns were bent by hand to a roughly circular shape about 26 inches in diameter. The inner end of the helix is bent in toward the center of the ground plane, where it enters an impedance-matching transformer.

"The ground plane consists of a square sheet of plywood, 18 inches on a



A machine embodying the antitwister principle

side, that supports the ground-plane assembly. A sheet of aluminum is screwed to one surface of the plywood. To the base thus made a set of 16 lengths of 1/4-inch aluminum tubing is attached as a uniformly spaced radial array. The attachment is done with self-tapping metal screws. The sheet aluminum bonds the radial members electrically.

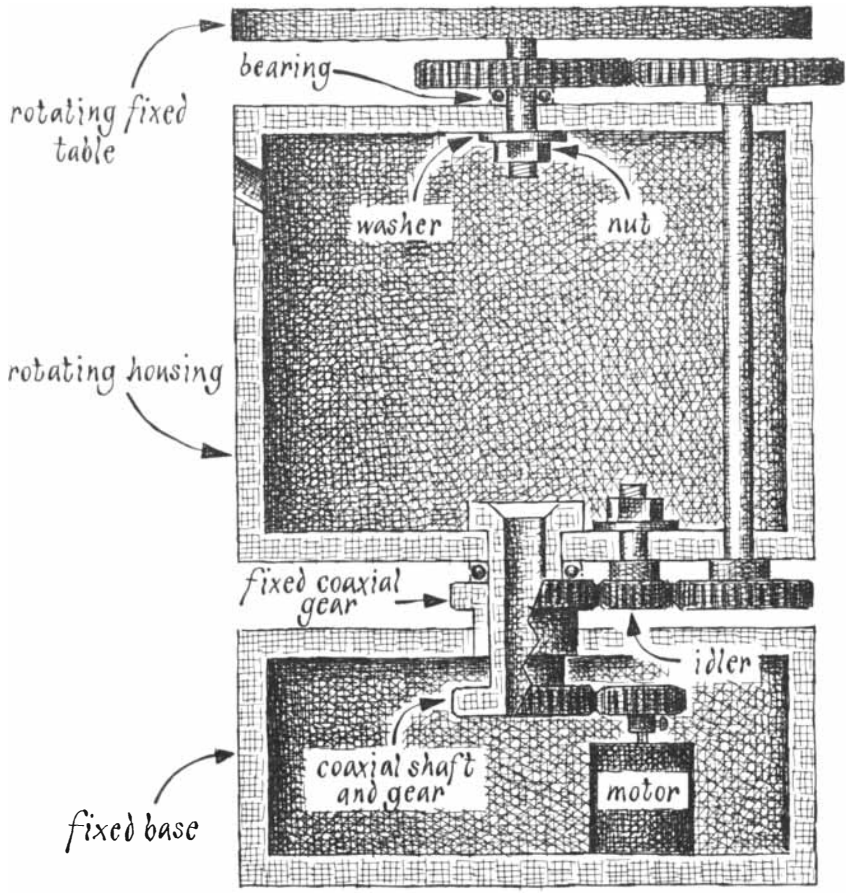
"In addition the radial members support a nested set of circular aluminum rings made of the same material. The output of the antenna is taken from the inner end of the helix and the ground plane. The electrical impedance across the output is approximately 140 ohms.

"This impedance must match the impedance of the transmission line that connects the antenna to the receiving apparatus. The commoner transmission lines are made of commercially available coaxial cable with an impedance of 50 ohms. An appropriate transformer for matching the 140-ohm impedance of the antenna to the 50-ohm impedance of the transmission line is a device that resembles a quarter-wave section of coaxial transmission line.

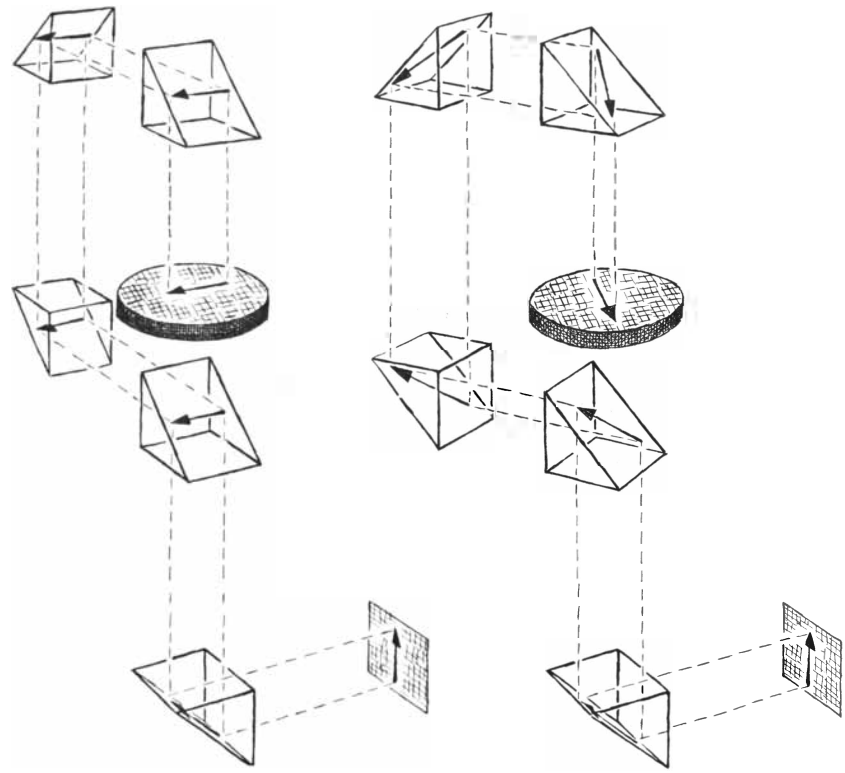
"My transformer is made with a copper pipe (inside diameter 3/4 inch) that encloses along its axis a coaxial length of the copper wire. The wire enters one end of the copper pipe through a Plexiglas washer. The inner end of the wire is soldered to the central terminal of a screw fitting that functions as a connector for joining the coaxial cable to the transformer.

"The impedance of the matching transformer must be equal to the geometric mean of the impedances of the transmission line and the coaxial cable. It is found by taking the square root of the product of the two: $(140 \times 50)^{1/2} = 7{,}000^{1/2} = 83.6$ ohms. The impedance of the transformer is equal to 138 log B/A, where B is the inside diameter of the outer conductor and A is the outside diameter of the inner conductor. The outside diameter of No. 6 ground wire is approximately .162 inch.

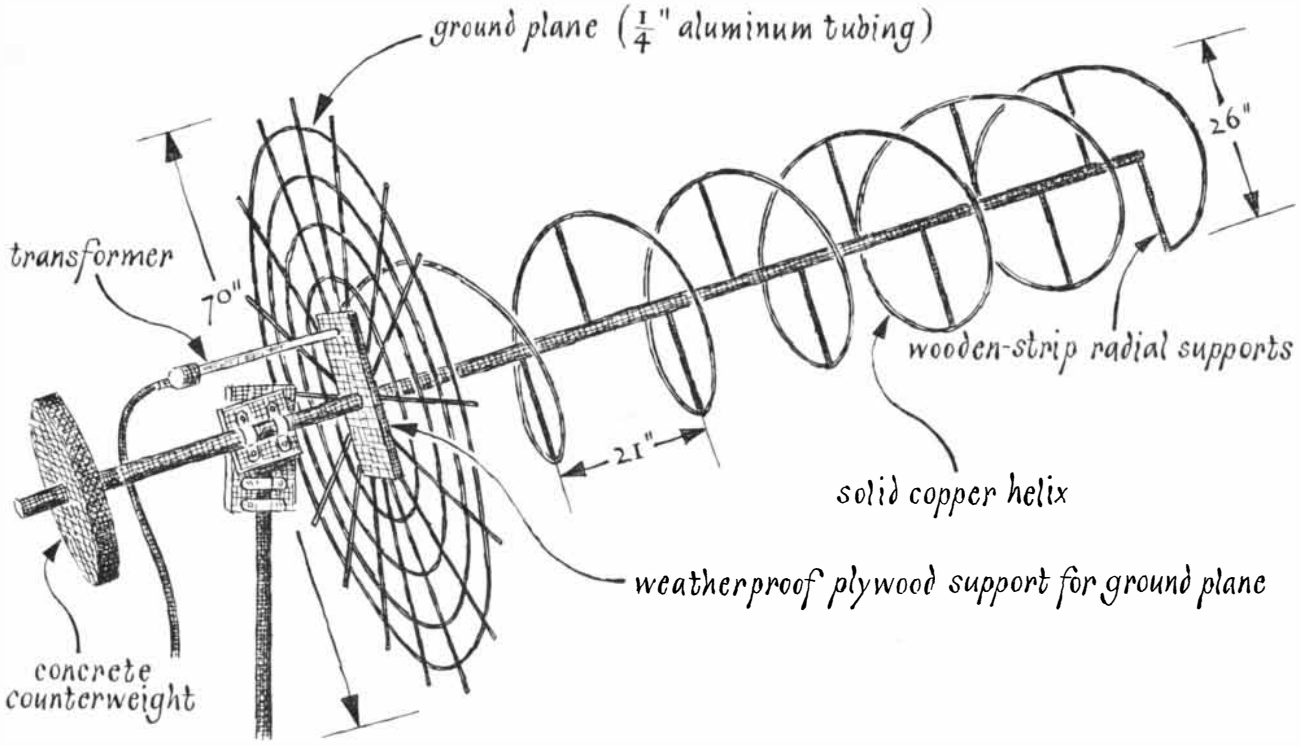
"Since the inside diameter of my copper tubing is .75 inch the calculation is $138 \log_{10} (.750 / .162) = 138 \times .666125 = 91.92$ ohms. The length of the transformer is equal to a fourth of the wavelength, or approximately 21 inches. The impedance of the structure is in error by about eight ohms. The error could be corrected by altering the diameter of the coaxial conductors, but the match is close enough for amateur work. A good electrical contact must be made between the copper pipe of the transformer and the ground plane of the antenna. I achieve it by mounting the coaxial fit-



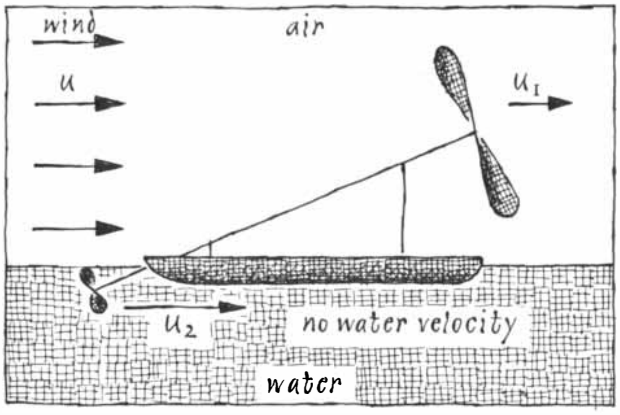
Cross section of the machine



Train of prisms for imparting antitwist to an optical beam



Eugene F. Ruperto's helical antenna



"Push-me-pull-you" boat designed by Peter Kauffman and Eric Lindahl

ting to a brass plate that I brazed to the outer end of the pipe.

"In practice the antenna appears to have a signal gain of between 10 and 13 decibels through an angle of approximately 25 degrees on each side of the target toward which it is pointed. In other words, the directivity of the antenna falls to half power at the edges of a beam 50 degrees wide. It is not necessary to continuously track the satellite with the antenna. I determine in advance the azimuth at which the satellite has been predicted to rise and aim the antenna in that direction at an elevation of approximately 20 degrees. Usually the signal strength is adequate for making a good picture of cloud cover throughout the pass."

Seelye Martin of the department of oceanography at the University of Washington writes about this department's recent article [March] on sailboats without hulls. "It seems appropriate in a festive season of playthings to follow up this concept with a description of a toy boat that sails directly into the eye of the wind. It is the invention of Peter Kauffman and Eric Lindahl here in Seattle. We call it the 'push-me-pull-you' after the Dr. Dolittle animal with two heads.

"The boat consists of a propeller in the air coupled by a straight shaft to a propeller in the water [*see bottom illustration on opposite page*]. To reduce drag the shaft housing is mounted on a simple frame on top of a pair of pontoons. When the boat is placed on water in a wind with the water propeller upwind, the wind turns the air propeller and thereby the water propeller, which drives the boat into the wind.

"We have tried the boat in both laboratory and field tests. In the laboratory test, where the boat was in a large tank of water and a room fan was the source of wind, we placed the boat in front of the fan with the air propeller motionless. The breeze blew the boat away from the fan and started the propeller turning. As the propeller came up to speed, the boat stopped moving away from the fan and began accelerating toward it until the boat reached the fan.

"We also conducted a field test between two piers on Lake Union on a gusty day in February. The boat moved upwind over a distance of about 50 feet at a speed of about two feet per second in a strong wind with gusts of up to 30 miles per hour. The response of the boat to gusts is to slow down at first, because of the increased wind drag, and then to accelerate as the air propeller speeds up.

"There are some problems with the boat. If it becomes tilted at a direction of about 20 degrees to the wind, the air drag on the frame and the propeller tends to maintain the tilt. Moreover, wave motion can cause the air propeller to strike the water occasionally, so that the water propeller surfaces. Another problem is that too large a propeller velocity can pull the front end of the boat under water. In general, however, the force couple between the propellers manages to keep the boat headed into the wind.

"Why does it work? In the boat that you described in March, J. G. Hagedoorn replaced the sail of a sailboat with a kite and the keel with a hydrofoil. In the push-me-pull-you we replace the sail with a rotating airfoil and the keel with a coupled rotating waterfoil. The boat works for two reasons. First, the air velocity is much greater than the water velocity. Second, the energy of a moving parcel of air or water is proportional to the square of the air velocity, whereas the momentum is proportional simply to the velocity.

"To expand on this idea the accompanying illustration includes a sketch of the push-me-pull-you with the relevant air and water velocities. For simplicity we assume that the boat is initially stationary. We then estimate the drag and thrust forces on the boat caused by a parcel of air moving past the air propeller. Working out the calculations properly involves messy algebraic equations; the following is an extremely simplified version.

"The air propeller extracts energy from the parcel of air by reducing the air velocity immediately downwind of the propeller. If the wind velocity is 5 (in some convenient unit) upwind of the propeller and 4 downwind, the energy extracted is proportional to the difference of the square of the two velocities ($25 - 16 = 9$), whereas the drag on the propeller is proportional to the momentum difference ($5 - 4 = 1$).

"If the shaft has no energy loss, the water upwind of the water propeller has zero velocity and the water propeller is perfectly efficient, the water energy or water velocity squared behind the propeller is $(U_2)^2 = 9$, so that $U_2 = 3$, and the water-propeller thrust is proportional to 3. From this oversimplified argument on energy and momentum the thrust is three times the drag, so that if we release the boat, it will accelerate into the wind. Because of the difference in the effects of momentum and energy, the faster the wind is, the better the push-me-pull-you works."

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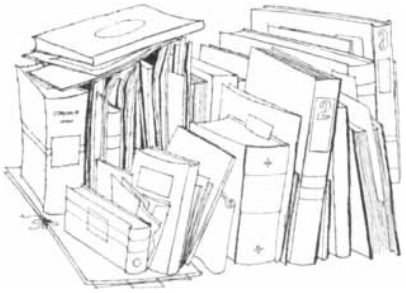

BOOKS

A Christmas collection of children's books on the many worlds of science

by Philip and Phylis Morrison

This year saw the publication of a great many books about a single species of animal. We were pleased by the quality they showed. There were as many science books for the youngest readers in 1975 as ever, but fewer for older children.

A Bestiary

AMONG THE ELEPHANTS, by Iain and Oria Douglas-Hamilton. Foreword by Niko Tinbergen. The Viking Press ($14.95). Who is among the elephants? Why, for one the beautiful Oria Rocco, "a girl with long, dark hair... Kenya born and bred," who had "a burning restlessness" through her Left Bank days and her finishing schools in Rome and Paris. Although she had learned five languages, she could not leave for good the great highlands farm where her father and mother grew vegetables for export. One evening she met a "rather shy," slender, blond Scots graduate student ("I do elephants," he said) who was a visitor from the bush. Iain was a marginal Oxford student of zoology, "just another face" to the noted ethologist who writes the foreword, a diffident fellow, plainly less concerned with zoology courses than with mountaineering. But one summer as a raw research assistant in the Serengeti had galvanized him; he passed his examinations, somewhat against the form book, and accepted the generous and farseeing offer of his old Serengeti boss to go among the elephants. He talked his way into a grant, learned to fly (the first time around his money ran out before he got his license), came to know a great many of the 400 to 500 elephants in the Manyara National Park by face and by age, bought his own Piper Pacer out of a small windfall of family money and became an original, daring and insightful researcher into the behavior, economy and social life of the African elephant.

The Sunday after they met Iain flew in, uninvited but plainly welcome, for lunch, "dressed in green, with no shoes on," landing in a pasture full of holes and long grass. "You're crazy," Oria shouted when she saw him, but he laughed at her. Now they and their children have left the elephants once and returned again, to film. "Saba now has no fear of wild elephants due to her early conditioning." Indeed, here is a two-page color spread (the photographs, mostly by the authors, are fascinating) showing Oria with daughter Saba, a babe in arms, offering a gardenia fruit to the most tolerant of the elephants, Virgo, the only one who would come into friendly body contact. "We both stood still for a long while, facing each other with our babies by our sides."

You recognize free-living elephants by carefully building up a file of photographs, so that you can learn their faces, particularly the tusk details and the tatters and holes of the edges of the big, floppy, heat-radiating ears. You age them by taking stereoscopic photographs—with a camera on a T bar of wood fitted with improvised mirrors—to be measured back home on the Oxford physicists' bubble-chamber equipment. The absolute shoulder height gives a good age value up to 15 years, based on the correlation between tooth-structure age and size of elephants that have been shot. (Compare Sylvia K. Sikes's *The Natural History of the African Elephant*, reviewed here in October, 1971). You learn that elephants such as the great matriarch Boadicea can stage a magnificent and terrifying charge, but that it is only a splendid bluff. (There she pounds in, caught in a snapshot on the back jacket.) You learn that other matriarchs are totally hostile, charge on sight and mean it: "She stabbed again and wrenched her embedded tusks upwards like a demented fork lift. Then digging her tusks in again she charged, and the Land-Rover was carried backwards at high speed for thirty-five yards."

The volume is first-rate science; it gives the initial popular account of the social structure of the African elephant, with family units of 10 or a dozen young under the big matriarchs, kinship groups formed of a handful of related families and the grumbling but not very violent club of full-grown bulls, steadily testing and adjusting their rankings in the near distance.

This is the most intimate book on elephants to appear. The authors will forgive a reviewer, one is sure, for the remark that it is also a human love story of real warmth and fascination. There is a heroic supporting cast too, with President Nyerere offstage establishing Tanzania's wise policy of trying to live in peace with its wildlife; Howard Baldwin, the American electronics man "fired by wild enthusiasms to do unusual things" with his radios on elephants and lions and hyenas, and John Owen, who saw what might be expected of a student whose qualities were not reflected in the examination scores. For teenaged readers and beyond who have any interest in wildlife, this book is the best adventure of the year.

JOURNEY OF THE GRAY WHALES, by Gladys Conklin. Illustrated by Leonard Everett Fisher. Holiday House ($5.50). WHEN THE WHALE CAME TO MY TOWN, by Jim Young. Photographs by Dan Bernstein. Alfred A. Knopf ($3.95). DOLPHINS, by Jacques-Yves Cousteau and Philippe Diolé. Translated from the French by J. F. Bernard. Doubleday & Company, Inc. ($12.95). Two thousand gray whales crowd into Scammon Lagoon, where they were born, to play, breed and give birth in their turn. The calf is set free into the world there, its mother and a "helper" whale together pushing the great newborn babe up toward its first breath. The deft, cool, clear text, easily read by young readers, tells the story of the annual coastal migration north of the much watched grays past the terrible killer whales, through the cold waters of a Northwestern river mouth where the whales first rid themselves of whale lice and then dance happily on their tails, at last to the Bering Sea. The story is so sharply and compactly told and the drawings in sea blue

and black and white so convincingly report the two worlds—air and sea—that are home to whales that the familiar story takes on perfected form.

Across the continent a whale died. "He died on the beach behind my house." The second book is a child's elegy, simple and eloquent. For three days the whale was stranded on the beach at Provincetown, while a small boy pondered life and death. He had found the whale: "A dead thing bigger than a bus." But it was not dead. Not yet; here is the look of its eye. Many people came to help, some to hinder. The man with a stethoscope "didn't come to make the whale well. He said he came to learn from the whale." The boy kept vigil for three days. The photographs show what he saw, the text reveals his private thoughts. The book is biology only in the grand sense in which life and death bind all us creatures, but it is a testimony for all ages.

The third of these books is of course the work of the captain of the *Calypso* and his colleagues. Some of that lengthy series of volumes are rather padded with matter that owes less to the divers and biologists of the *Calypso* than to scissors and paste. Not so here. The bulk of the beautifully illustrated volume recounts the dolphin experiences of Cousteau and the others over nearly 30 years: following, admiring, luring, capturing, feeding, training and swimming with dolphins of varied species in the several seas. The posthuman intelligence attributed by some to the dolphins gets little support here. Most original are accounts of human whistle speech, unfortunately only a few pages and photographs, and a long and detailed record of a visit with fisherfolk on the desert coast of Mauritania who have for a very long time regarded the local dolphins as their special allies. The dolphins in their season press great schools of mullet close to the shore, where the men can take them abundantly in their nets. It is probable that this is not the dolphins' purpose, but it would be "'very difficult to convince the Imragen" that their sacred dolphins are not benevolent. The book is so wide in its attention that it is more diffuse than one would like, but it remains a remarkable treatment all the same. A glossary, art reproductions, a species summary and a list of where one can encounter trained dolphins worldwide are valuable accessories to the narrative.

THE BLUE LOBSTER: A LIFE CYCLE, by Carol and Donald Carrick. The Dial Press ($4.95). THE LOBSTER: ITS LIFE CYCLE, by Herb Taylor. Sterling Publishing Co., Inc. ($5.95). When lobsters are clear blue, one almost expects shrimps to whistle. Blue they are. One is painted on the jacket of the little biography for which it furnished a heroine and a title; the other—just as blue—is taken from life in a convincing color photograph on the cover of the more general account. The Carricks—he does the drawings, in a wide range of scales—have told well in the third person the story of a single blue lobsterling from egg through many molts to "the rare ripe old lobster age of twenty." Once it is robbed of a fish morsel by a bigger lobster intruder, to whom it sacrifices a claw. But that morsel was bait and its rival was trapped. This makes an effective story for young coastal readers or the read-aloud-to set.

The second book is a compact, circumstantial, up-to-date treatment of lobster life, with drawings and many colorful photographs, mostly by the author. Lobster shells have three pigments, red, yellow and blue; with all present the normal shell is deep green with red touches. But mutants and their crosses can become fine lobsters: red, blue, yellow, even albino. There is a chapter with maps and photographs that clarifies the puzzles of lobsters around the world. Your true lobster lives in cool northern waters on both shores of the Atlantic; the *homard* is exactly like its Down East counterpart but darker in color.

SPRING PEEPERS, by Judy Hawes. Illustrated by Graham Booth. Thomas Y. Crowell Company ($4.50). If spring does not seem too far behind, the boy or girl lucky enough to live within earshot of some small freshwater pond will welcome this brief, simple and expertly written account of animals much more familiar by ear than by eye, and of how to find them. The drawings, some in pleasant wash tones, are striking. The little fellows clinging to the end of a pencil, or small in the open palm, or with the sounding-balloon throat swollen spherical, are not to be forgotten. It becomes clear how the peeper makes that noise without even opening its mouth, the air going from throat to sac and back again.

The family relations of our peepers are not neglected. There is real aptness in the name of the "best-loved frog anywhere," the *coqui* of Puerto Rico. Every night, all over the big island, they cry "ko-kee, ko-kee"—and here is the music for it too, in 4/4 time.

THAT WONDERFUL PELICAN, by Jack Denton Scott. Photographs by Ozzie Sweet. G. P. Putnam's Sons ($6.95). The brown pelican looks "as if it had some spare parts that don't quite fit." It is the largest American webfooted bird. The birds shown in these pages of big, vivid photographs are from the breeding ground on Pelican Island, off the Florida Gulf Coast. Some 20,000 pelicans live along both Florida coasts, the only place in America where the species is stable and "in no obvious danger."

The gawky, ill-jointed, snag-feathered birds are well pictured here. So is their action, which renders them beautiful and fit once they are seen in flight or dive, surf-skimming along the smooth trough, or neck outstretched, dropping as vertically as a stone to scoop up or stun the submerged fish they seek. That angular fall, one of the most dazzling sights of a Florida shore, is evoked here as well as any still picture can do it: three birds at once, dives straight and sudden, purposeful and elegant, three barbed W's just above the water. Any reader or onlooker who has seen one pelican will enjoy this book.

AUSTRALIAN MARSUPIALS AND OTHER NATIVE MAMMALS, by Michael Morcombe. Charles Scribner's Sons ($7.95). Larger than life, the feathertail glider slips down through the night air from the bright red flower it has been sampling; pink nose and claws fairly glow in the well-aimed flash. Such photographs crowd the slender book. A well-known naturalist has produced a virtuoso treatment of the singular beasts of his continent. He shows animals in action: a carnivore clawing a cockatoo, a platypus caught underwater, a joey at the pouch and the rest. Even better, his photographs are not single shots but frequently catch an animal in a set of significant positions, filling a page or two with revealing and often dramatic pictures. The art of visual presentation of such small fry is here at its highest level; then one recognizes that the animals themselves are those strange and appealing cousins from Down Under. The echidna, looking quite cactuslike, is a favorite of the author, and he has not forgotten the few placental mammals that made it across Wallace's Line. The captions are helpful, and there is a quite technical summary of forms and their distributions.

BEAVERS: THEIR EXTRAORDINARY LIVES AND CURIOUS HISTORY, by James Poling. Franklin Watts, Inc. ($3.90). Beavers are remarkable, and the credulous have made them more so. Once the bishops of Paris ruled that the beaver tail was fishy and could be eaten without sin

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From the Fundamentals to the Frontiers: Freeman Books in Biology

Introduction to Biophysical Plant Physiology

PARK S. NOBEL, University of California, Los Angeles

In this expansion of his earlier *Plant Cell Physiology*, the author relates biophysical models of cell interaction to the whole plant, discusses in some detail the physicochemical areas of thermodynamics and photochemistry, and includes an extensive chapter on environmental physiology. The mathematical arguments may be followed by readers who have had a brief exposure to elementary calculus. *An Introduction to Biophysical Plant Physiology* can serve as a text for advanced undergraduate and graduate courses in plant physiology as well as a reference for the professional.

"I plan to use this book along with three others to teach an advanced undergraduate-graduate course in plant physiology. . . . It is a required text as it brings plant physiology from a vague qualitative approach to a quantitative approach!"
—Govindjee, University of Illinois

1974, 488 pp., 68 illus., $15.00

The Strategy of Life

CLIFFORD GROBSTEIN, University of California, San Diego

The *Quarterly Review of Biology* said of the first edition: "The book is brief, and says much in little space. It is beautifully conceived and written. As an outstanding statement of what modern biology thinks about life, it is mandatory reading for all would-be and for practicing biologists, as well as for non-biologists who like to read wonderful books."

The second edition—revised to include greater emphasis on man—maintains these high standards. "It is," writes the author, "a statement about life—where it came from, what its nature is, and what premonition we have of its future. . . . Anyone contemplating the issues of our time needs to understand the strategy that life has followed to reach Man and his present state. Without that understanding, Man appears more fragile than he will prove to be in the terrible test of the coming century."

Second Edition, 1974, 174 pp., 90 illus., cloth $4.95, paper $2.95

Plant Science

An Introduction to World Crops

JULES JANICK, Purdue University,
ROBERT W. SCHERY, The Lawn Institute,
FRANK W. WOODS, The University of Tennessee,
and VERNON W. RUTTAN, Agricultural Development Council

"I am using the book as a required text for a course known as Plant Science 200—Ecology of Crop Production. The course is required by students majoring in Environmental Resource Management (renewable resources). The text provides sufficient depth about environmental factors and plant growth plus a very fine discussion of the technology of crop production for those students interested in land use from an environmental viewpoint."
—John W. Mastalerz, The Pennsylvania State University

"I used the book when I was developing our course, World Crops and Food Supply. . . . The book goes beyond what we need in this particular course, but it is so readable. I am sure it is our best choice for our course. I am pleased with the new chapters on pollution and the environment and on agricultural research."
—Neri A. Clark, University of Maryland

Second Edition, 1974, 740 pp., 355 illus., $14.50

DNA Synthesis

ARTHUR KORNBERG, Stanford University

". . . Genetics and DNA have become a branch of chemistry. Despite its chemical complexity, DNA is being modified, dissected, analyzed, and synthesized in the test tube. There are insights into a metabolic dynamism of DNA that had not been anticipated. DNA suffers lesions and is repaired. DNA molecules are specifically modified and degraded, twisted and relaxed, transcribed in reverse from RNA as well as directly into RNA. DNA functions not only in the nucleus but also in mitochondria and chloroplasts. There is now a stimulus to determine the total base sequence of DNA and to resynthesize it. There is also a confidence that the metabolic gyrations of DNA in the cell can be understood in as explicit detail as those of, say, glucose or glutamate."—from *DNA Synthesis*

Written by a Nobel Laureate in medicine, this is the first comprehensive treatment of DNA synthesis emphasizing its biochemical aspects and recent develoments.

1974, 399 pp., 194 illus., $19.00

Comparative Morphology of Vascular Plants

ADRIANCE S. FOSTER, late of University of California, Berkeley, and ERNEST M. GIFFORD, JR., University of California, Davis

"Since its introduction in 1959, this book has become a classic in its field. The new edition is excellent, truly outstanding, far better than the already excellent first edition. It has no rivals."
—Rudolf Schmid, University of California, Berkeley

"The revised edition is exactly the type of text needed for senior students in Plant Morphology since the authors have retained the excellent organization of the first edition and yet have updated the content without becoming verbose. The illustrations are excellent."
—R. L. Peterson, University of Guelph, Ontario

"I have used the first edition every year except one since its publication. I will be using the second edition this fall for my one-semester course in the morphology of vascular plants. . . . It is the clearest presentation of the subject on today's market."
—J. M. Herr, Jr., University of South Carolina

Second Edition, 1974, 751 pp., 440 illus., $18.00

The Vertebrate Retina

Principles of Structure and Function

R. W. RODIECK, The University of Sydney

"This book is an attempt to explain to myself what is known about how the vertebrate retina is organized and how it functions. What I have tried to present the reader with is a simple and straightforward account, which starts with the fundamentals and leads to the frontier."—R. W. Rodieck

The Vertebrate Retina—the most comprehensive volume now available on the subject—draws from a wide range of methodological approaches. The book contains 615 illustrations (plus a twelve-page full-color section) and includes extensive citations to key original literature. One of the appendixes is an English translation of Ramón y Cajal's classic monograph, *La Rétine des Vertébrés*.

1973, 1044 pp., 615 illus., $45.00

W. H. FREEMAN AND COMPANY
660 Market Street, San Francisco, California 94104
58 Kings Road, Reading, England RG1 3AA

on fast days. From the third century B.C. until the 18th century the clever engineer was ferociously hunted because it was held that its castor glands secreted a medicine of sovereign virtue for many ills. The reasons are "lost to history," but the beaver almost disappeared from Europe, nearly hunted out. The American beaver trade then thrived on the demand for felt hats, so that the 60 million beavers of our continent had dwindled to a handful by the turn of the century. No longer a pharmaceutical and with beaver hats long out of fashion, the animal has now come back. Its ponding, canals, lodges, dams, plunge holes and overall contracting give it a watery "private kingdom" for shelter against predators and for waterborne access to the "acre of dense trees" a beaver family may harvest each year. The underbark of the stored trees is their chief winter food; in the summer they enjoy other aquatic greenery.

Beavers loaf by summer but are eager enough in season. There is one fine tale of a Maine colony that doggedly refused all notices of eviction. "The warden, steeped in beaver lore, crept out one night and draped a gasoline-soaked burlap bag over the dam. (Any beaver expert will tell you the creatures just can't abide gasoline fumes.) In the morning the bag was found artistically woven into the dam. The warden set out three steel traps that night. In the morning one was empty. The other two had been stolen by the beavers and used to buttress the dam."

We still have a lot to learn about beaver behavior; some of the uncertainties are treated here. One thing seems sure: although beavers may make local trouble, in the long run there is no doubt that their land-building work of damming streams and their wildlife support are so great that we "owe more to the beaver than [to] any other wild animal." Our country now leads the world in beavers; we have about the right number. Readers of this book, in upper school grades, will surely help to maintain the steady state.

TURTLES: EXTINCTION OR SURVIVAL?, by Sarah R. Riedman and Ross Witham. Abelard-Schuman ($6.95). Photographs of an albino turtle, a big seagoing turtle bearing a small radio transmitter and a long antenna and a set of hungry little turtles feeding on small Portuguese man-of-war jellyfish sample the range of turtle lore described here in a very satisfying way for readers in the upper grades. The conservation note struck in the subtitle is real but not limiting. Rather, the book takes a close look at the order, from modern-day turtle watchers on the Florida beaches to Hindu myth and reptilian physiology. Many such surveys are attractive enough but overdidactic: experts tell you what to believe. These authors (Sarah Riedman is an experienced college teacher and productive writer for children, Ross Witham a sea-turtle research biologist) have done much better, using an approach that often subsumes the main lines of evidence they use. "Does the turtle live more slowly by holding on more tightly to [the] oxygen in the blood and releasing it more gradually in the tissues than a warm-blooded dog or human does? This is, at least, one way of thinking about it." Turtles make good pets, although they are often mistreated. The book will enrich a young turtle owner's view a great deal; it is good biology widely seen.

EMPEROR PENGUIN: BIRD OF THE ANTARCTIC, by Jean-Claude Deguine. The Stephen Greene Press ($6.50). At the close of summer the bright red ship leaves supplies for the men at the base. A year later she comes again into the blue-and-white loneliness of the polar ice cap to replenish the base. In evocative color photographs we have meanwhile seen some 12,000 great emperor penguins crowded in their rookery, the only land creatures to winter ashore in the Antarctic except for the men in their alien heated red huts. This slender, straightforward book, with a brief text to go with the strangely dignified pictures, is the work of a member of a recent French expedition to the loneliest continent. The emperors somehow make it look more homelike than one expects: the "stately lines" of grave and formal birds coming together to cluster in a great throng, the male and female facing each other in courtship and decision, the fuzzy young at last floating north in spring on the ice-floe raft that alone can carry them into the cycle of emperor-penguin life. Special, almost bizarre, the picture story documents a way of animal life few have ever witnessed. Young readers can master the book easily, although it is not slanted toward them in any way except through its brevity.

Other Living Things

CHAINS, WEBS & PYRAMIDS: THE FLOW OF ENERGY IN NATURE, by Laurence Pringle. Illustrated by Jan Adkins. Thomas Y. Crowell Company ($5.50). A flood of books on ecology for grade-school readers continues season after season. Here is one that has managed conviction without clamor and carries argument more than mere conclusion.

It is of course a discussion of the flow of usable energy from the sun down the food chain or the web of interlacing food chains that make up the community of a salt marsh or of a grassy field. The author does not begin with a glib and meaningless definition of energy—what makes things go or the like—but treats it as the abstraction it is and makes it honestly clear by tracing examples. He knows that free energy is lost to the living world as heat and says so. A few key numerical examples appear; he ends with the recognition of human involvement in the flow and of the importance of our food web. The drawings lend concreteness and geometric form to the simple arguments. This is a quiet book, an honest and instructive one that confronts readers without exploiting them.

DOCTOR IN THE ZOO, by Bruce Buchenholz. Introduction by Cleveland Amory. The Viking Press ($10.95). With big photographs of the highest quality, bled out to the margin, one looks through the strong wire mesh right into the eye of the siamang (a gibbon) or past the glass at two white babies riding the back of their scorpion mother. The scene is the Bronx Zoo, a strange and wonderful place. But the book is really a study in feeling, in human feelings for the animals whose nature we share and for our own kind. "You may not have daily responsibility for life or death, yet this book is about you." The vehicle for the study is a remarkable man, the chief veterinarian, Emil Dolensek. Here are surgery, medicine, management, reception, for animals large and small in great variety. Tranquilize a wolf? Pelvic examination of a possibly pregnant whale? Anesthesia for a sick and venomous Gaboon viper? The work becomes a genuine if implicit study of the human issues of medicine as a whole, seen from the oblique viewpoint of an extraordinary practice among animals. "The hardest thing is the responsibility. Every time I handle an animal I'm causing him distress—discomfort, fright, pain, perhaps even death. I always hope I'm right to do it, but sometimes I'm wrong." Good for any age able to handle the weight of the presence of death in life, even a newborn guanaco's.

CHRISTMAS TREE FARM, by David Budbill. Illustrated by Donald Carrick. Macmillan Publishing Co., Inc. ($5.95). THE WORLD OF THE WOODLOT,

by Thomas D. Fegely. Dodd, Mead & Company ($5.50). The forest once spread all but unbroken from Tennessee north into Quebec. Now the plow has cleared most of the lowland. A multitude of island woodlots remain, having been spared by the farmer for his own use or having returned after the men who once cleared the land abandoned the farm for the city or the West. At the edge of a forested mountain lies the land of Marcel, who with his crew raises Christmas trees for sale. The first book is a series of soft color paintings of men and the land, as evocative of the toil and the quiet of northern Vermont as they are lovely. Each page or spread bears only a sentence or two of text. We follow over the year, in a strangely loving way, the hard work of the tree farmer, from taking seedlings out of the forest floor to loading cut trees onto the big truck in the December snow and finally coming home to stove-heated living room, frolicking dog and a happy small daughter with a new Christmas tree of her own. Chain saws and tractors are tools of the trade, but snowmobiles, no!

The second book is another look at the woodlot. The archipelago of such small stands is the home of may apple and salamander, red fox and sugar maple. The author has watched the woodlot closely and unfolds its living year in a clear, knowing naturalist's text for fourth-grade and older readers. Forests can be seen as being uniform, but each woodlot survivor and its boundary are in a way unique. We need them, and the readers of this book will begin to understand why and will gain much more from the visits they are bound to make, in every season. The index is a list of woodlot forms with their photographs; the final chapter describes the principal trees of the Eastern woodlots.

THE BLOSSOM ON THE BOUGH: A BOOK OF TREES, by Anne Ophelia Dowden. Thomas Y. Crowell Company ($7.50). In this book a distinguished botanical illustrator has turned her eye and hand to trees. The striking paintings of leaf, flower and fruit exactly scaled at three-fifths natural size are as detailed and precise as they are glowingly attractive. There are about 30 here in full color (the bouquets of fall leaves and of spring buds are particularly happy), dogwood and horse chestnut, blue paloverde and Douglas fir, live oak, plains cottonwood and eucalyptus. There is something for Americans in every region. The text is simple and clear; its main burden is the story of the cycle of the tree, the unfolding and maturity of leaf, flower and fruit. There is a good list of common trees and a map of the regions of the country. Southern Florida trees are alone unpictured: beautiful, but a piece of the Tropics.

This artist requires and takes a close look; that is not easy when the tree arches 20 meters above your head. Many people helped her to collect; her husband "sometimes in exasperation titled the book 'Go Climb a Tree.'" He did climb, and it was worth the effort.

Technologies

PAPER MOVIE MACHINES, by Budd Wentz. Troubador Press, 126 Folsom Street, San Francisco ($2). ANIMATING FILMS WITHOUT A CAMERA, by Jacques Bourgeois. Sterling Publishing Co., Inc. ($3.50). Let Charlie Chaplin dance a staccato tango in your hands! The miracle is worked by a flip-book of 34 small sequential photographs from 1914. The device was patented in 1868, although surely it is much older. It bears the proud and pretentious name of kineograph, a Greek neologism like the names given to almost all the 11 devices presented here, mainly 19th-century schemes for exploiting the persistence of vision—precursors, of course, of the cinema. This big 32-page brochure is brilliant. It is excellent in layout, in pedagogy, in its mix of authentic period illustrations and those made specially for the book. What you get are outlines and black-and-white images on heavy paper, ready to cut out and make up into a zoetrope or a praxinoscope. The variety ensures that you can get to work at once; if spools and shiny plastic are not at hand, make the simpler devices that require only the cutouts and thread, a paper clip or a rubber band. The range of difficulty is large. The earlier devices are really easy—less than five minutes' work; the later ones are more demanding, but in all justice they perform better. Throughout the book there are suggestions for further variations to be attempted independently. There is a capsule history and a fine, learned bibliography. Be sure to seek bright light; the light must spread over a much larger area than you expect. This book is the best buy of the year.

The passage to the cinema is not easy. But given a real motion-picture projector of any kind, the second book explains in step-by-step detail from inks to story board and splices how to prepare simple animated cartoons without photography. You draw on clear film (commercial leader or film that has been unrolled in sunlight and sent off for processing) or you can scratch images into unexposed but processed film. Representational cartoons require a great many drawings—nearly 1,500 per minute—and are suited for a club or classroom, where you can organize the division of all that labor. More abstract images can be made relatively easily, without reference to frame-by-frame sequence. You can try a hand at synthetic sound too. The book is technical and laconic; it is intended for teachers and other adult leaders. High school students could make use of it directly. The text is a smooth translation from the French by Anne E. Kallem.

THE FORMULA BOOK, by Norman Stark. Sheed and Ward, Inc. ($5.95). The young chemist is a well-known type, eager for new chemicals, generally seeking the excitement of bright color or unusual gas or even a good-size bang. Eventually the aim may be a difficult preparation. The challenge is the ability to create novelty in matter. This book is entirely different in its aim, although it is closely related in activity. In a way the two styles mirror the relation of scientific research to technology. Here are collected what amount to some 200 "recipes" for an entire range of household preparations that can be realized in an ordinary kitchen, given a number of containers for the product. What you make is not particularly novel. Rather, it is useful. By your own understanding purchase of materials, by skill and careful work, you can produce what you might buy at the hardware store or supermarket. (You will not understand it much better, however; this book has two excellent pages on alcohol and its denaturing but almost no other background material beyond the how-to level. We would have welcomed even a few pages more.) Here are formulations for nonslip floor wax, contact-lens fluid, antiknock additive (benzene, a little doubtful), horse-hoof grease and tennis-net preservative. The tasks are often finicky and sometimes tedious, but they are first-class family activities, safe under supervision; they could pay for themselves, with the time spent charged to recreation. They might in some cases form a new way to make contact between parents and basement chemist.

COMMUNICATIONS SATELLITES: MESSAGE CENTERS IN SPACE, by Bernice Kohn. Illustrated by Jerome Kühl. Four Winds Press ($5.95). The man stands there, his figure nearly filling the small page. His gun is aimed; at the end of the barrel is a big arrow marked "Force," at his shoulder a similar opposite arrow,

"Reaction." The text tells how to see the same phenomenon as you jump from a skateboard. Rockets from V-2 to Saturn V are lined up in another drawing, all to scale, and a two-page spread shows a much simplified section of a liquid-fuel rocket, with only nine labeled parts from payload to nozzle. Satellites too grow across a marginal drawing, from little *Intelsat I* to *Intelsat IV*. The history is remarkably complete for such a brief and introductory text, managing to include without breathlessness Jules Verne, Arthur Clarke, Newton himself, Goddard, Tsiolkovsky and Oberth, plus Echo, Telstar and Syncom. Acronyms and technical words are explained in a little illustrated glossary.

For small readers in the lower grades here is a manageable entry into space by way of the television relays that must now be the closest direct nonfictional connection between children and space. The drawings are visually attractive: serious but simplified presentations in a cross-hatching technique that brings solidity to the careful ink line.

POWERED VEHICLES, by Reginald Carpenter, Peter Kalla-Bishop, Kenneth Munson and Robert Wyatt. Crown Publishers, Inc. ($14.95). Bulky and handsome, the volumes of this familiar series of topical Swedish visual encyclopedias are marked by careful corporate production, well-informed brief texts and rich illustrations: intricately detailed line drawings and showy, hard-edged, colorful profiles. Here related subjects have been treated together. The four authors divided the work: ships, trains, cars and aircraft. Among the major paintings one sees the *Wyoming*, the "largest wooden sailing ship ever built," sail by (on a plain buff page) with her six gaff-rigged masts; pages later she is followed by the *United States* and a Channel-crossing Hovercraft. The trains go from Stephenson's *Rocket* to the latest express locomotives of the French National Railways. The car pages show Trevithick's steam carriage of 1803 (which ran very well but attracted no investors), the Chevalier René de Knytt in his magnificent goatskin driving coat of Edwardian days, an imposing 1927 Bentley 4½-liter (the painting is apparently a reworked photograph) and a page on the evolution of the Volkswagen Beetle. The aircraft (the story includes unpowered balloons, as the ships include sail power) span from the Wright *Flyer* to the DC-10 and the "grotesque" Guppy. The entire tale is of civil craft. There is a lavish glossed index, illustrated with line drawings and thumbnail photographs of everything from radar to gaskets—both the cylinder-head kind and lines for tying up furled sails. This technical catholicity makes the volume a particularly good buy for libraries, as it is for motion fans of any literate age. The histories are careful (the hot-air balloon is correctly credited to Father Gusmão at the court in Lisbon, some 75 years before the Montgolfiers), although there are a few confusing captions.

Earth, Sky and Physical Sciences

ICEBERGS AND THEIR VOYAGES, by Gwen Schultz. William Morrow and Company ($5.95). SNOW SCULPTURE AND ICE CARVING, by Jim Haskins. Macmillan Publishing Co., Inc. ($8.95). Ice is the most plastic of minerals. Nature works it in the large; wherever the frozen river we call a glacier meets the sea, an ice cliff is likely to float in the heaving water. Sooner or later the cracks opened by bending stresses loosen and give way: the glacier has calved a berg. Sometimes a chunk of ice is detached unseen from the underwater face of the ice, to explode buoyantly upward. Most of the sizable bergs in the world's oceans arise either on the western shore of Greenland or far to the south on the ice shelves of the Antarctic margin. Here they are displayed in extraordinary photographs: an iceberg as tall above the water as the Washington Monument; the sinister ridge that "was the only one at the scene when the first rescue ships arrived" to seek the survivors of the *Titanic;* a tabular sheet of ice as big as Central Park, a floating ice arch framing a Coast Guard icebreaker in the near distance. The compact, lively account by a Wisconsin geographer tells the entire story, "from snowflakes to the sea." In the North Atlantic icebergs are shadowed as they float south to the shipping lanes. The Greenlanders tow small bergs to Jakobshavn harbor, chop them into ice cubes and export the cubes—fresh, extremely cold and full of bubbles that "sing" as the ice melts—around the world. The fantastic tale of the World War II plan to make aircraft carriers of flat bergs is recalled, along with equally original but more plausible present plans to tow tabular bergs from the Antarctic to be anchored outside our cities as offshore reservoirs of fresh water. Good maps are offered; the entire book, written to be understood by readers in the upper grades, is a coherent look at an unusual topic. "Whatever exotic sights there be in the universe," the author closes, "surely none can surpass the mystic beauty and allure of icebergs asail upon the seas of Earth." This is Gwen Schultz's third book about the ice.

Ice and snow are brought airborne to many of us. The second book, meant for energetic family groups and for those who might organize community projects, treats ice and snow as materials for the craftsman's hand. There are hints, examples, key points of design and technique for making snow figures on a human scale or—using armatures of wood and even steel piping—up to colossal size. In Sapporo the snow figures yearly include such tours de force as Bodhisattvas 35 feet high, and the book opens with an account of the 1939 Dartmouth Winter Carnival, when a heroic figure of Eleazar Wheelock himself 38 feet high was erected. (The mug of New England rum he held high in his right hand was made around a full-size flour barrel.) Armature, scaffold, center of gravity and three-dimensional planning are important at almost every scale. Ice sculpture takes advantage of the outdoor temperature but generally begins with man-made blocks of clear ice. Ice and snow are free, or anyway cheap. You can always knock down your mistakes and start over. The book gives few step-by-step recipes; rather, it is a logical development of methods and approaches, with tips from experience and supporting lore. Color, lighting and various inclusions are all treated. One hopes to see a great Olmec head glowing in some public space before the season closes.

CAVES, by Tony Waltham. Crown Publishers, Inc. ($12.50). A geologist and himself a leading caver, the English author has produced a book of catholic scope and splendid illustrations in color and in black and white; it is the richest book on this popular topic for several years. Not a how-to manual, it mixes the larger vistas of geology with the particularities and the romance of cave exploration. "Cavers tend to judge a system more on its depth than its length," and Europe boasts 44 of the world's 50 deepest caves. There is a reason: cavern systems can possess connected horizontal passages reaching cross-country for as much as 140 miles, as in the Flint Ridge–Mammoth caves of Kentucky. These are dissolved out of flat limestone countrysides. The limestone layers of Europe are heavily folded around the young Alps, however, and so there is room for limy depths. Of course Europe's caves may be the best known, but the Zagros Range in Iran and the Star Mountains in New Guinea hold deep promise. In the margin a section of the vertical chasm of Epos in Greece bears witness: the lake

lies 1,454 feet below the surface, access dropping almost straight down in three dizzying shafts, one after another. There are simple accounts of the forms of caverns, and of the growth of the varied calcite structures that mark active solution caves. Here one sees the remarkable forests of straws, each a hollow tube of calcite the diameter of a drop of water, that hangs from the ceiling of a room in a cave of the French Vercours. They were first found by a brave diver and have been partly drained to allow easier access. Cave chemistry, economics, prehistory and biology are all touched on informatively yet simply in this well-written survey and guide. It is modest in length and technicality and should find readers anywhere above the early grades.

HIGHLIGHTS IN ASTRONOMY, by Fred Hoyle. W. H. Freeman and Company ($10). No one in astronomy today combines an articulate prose and an original mind better than Fred Hoyle. This book is really a series of personal lectures amounting to a survey of astronomy, from the earth to life elsewhere to cosmology, in eight compact chapters of some six text pages each. It is a pleasure to see and to read. Most of the page area—there are some 180 pages in all—is given over to excellent photographs and diagrams in color and line. One or two from each chapter can be listed to catch the flavor: the earth in color from space, full and half; the simplest system of Copernicus, in the diagram from his manuscript; the craters of Mercury and Jupiter's Great Red Spot; the sun imaged by X rays; the entangled orbits of short-period comets; a sky map; a painting of the Milky Way (called a photomosaic, in error it seems); a dozen moving-picture frames of the Crab pulsar; a rendering of the proposed Cyclops radiotelescope array, and a good number of galaxies, radio galaxies and quasars. These are not so much novel individually as they are fresh, helpful and attractive as a collection.

There are plenty of personal and novel arguments—from the notion that birds would dominate the world were gravity a little weaker, to the idea that the great Mars volcano is an ice dome, to a symmetrical cosmology in which the universe is made very much larger, a mixture of positive-mass and negative-mass regions, with all that we sense now a minor sample! The commonplace popular talks on astronomy are going to have to gain sophistication to meet Hoyle's challenge. It is a little unexpected to see Hoyle growing almost mellow. He mistrusts the future—all those people—but hopes for a slow, easy downtrend to a mere half-billion humans with a long, tranquil future.

A CHOICE OF SUNDIALS, by Winthrop W. Dolan. The Stephen Greene Press ($10). Written with a gentle touch in a singularly honest and personal style, this attractively illustrated volume by an Oregon college mathematics teacher and sundial amateur is just right for any reader who knows what is meant by sine and cosine. Its easy view of sundial history is particularly strong for the consequences it suggests: the ancient hemispheric dial is the sky sphere itself; the vertical gnomon traces hyperbolic tip shadows on a horizontal plane, perhaps the origin of the Greek mastery of conic sections; the polar dial depends for its wit on willingness to use equal and not seasonal hours, so that its epoch is the 14th century; those Aussie dials, down under, must mark the hours counterclockwise. (There is a photograph to prove it.) The how-to-do-it chapter is genuinely helpful without overdoing the mathematics and the special cases, and the mottoes-and-nostalgia chapter is agreeable, yet not buried in sentiment. There are plenty of fine examples shown, mainly but not exclusively American. School clubs and libraries will find this a readable and instructive reference.

FRISBEE: A PRACTITIONER'S MANUAL AND DEFINITIVE TREATISE, by Stancil E. D. Johnson, M.D. Workman Publishing Company ($4.95). Take note of that M.D. The author is a California psychiatrist, and his training shows. Careful anatomical sketches of the plastic saucer in its principal models (note that the name is a proprietary one, owned by the Wham-O Manufacturing Company out on the Coast) are labeled with mock-heroic nomenclature in the manner of the baroque anatomists (the Minute Mound of Malafronte and Nachazel's Ring). There are history, detailed instruction, care and repair, a close, droll account of the culture (collectors, variants, officials, prizes, teams, tournaments) and a wonderful piece on the dog and the Frisbee. (The top Frisbee dog is a whippet named Ashley.) There are plenty of action photographs, with dogs, tyros and champions (Jo Cahow, the world's best woman player, in strenuous motion), and much more. It is all written archly in the medical tone, with words such as "hypersupine" and "clinical" worked heavily. It appears clear that the name Frisbee came from a certain Frisbie Pie Company with pie tins and cookie-can lids that, by way of the Yale campus, became the circular prototype of the real thing. The plastic model was the invention of one Fred Morrison in Los Angeles about 1948. He made and sold them in various styles until 1955, when the rights to the device were bought by partners who had just founded the now famous toy company. By now more than 100 million Frisbees have skimmed through the air. Military Frisbees were developed by the Navy in 1969, as spinning flares. But "the Frisbee refused to be drafted. When ignited, it flew up and away, AWOL forever!"

Jay Shelton of Williams College provides a neat, if too brief, chapter on Frisbee physics. The form of the spinning disk is optimal for stable flight with good lift. That interaction of spin stabilization and aerodynamic lift lies at the root of Frisbee performance.

ASIMOV ON CHEMISTRY, by Isaac Asimov. Doubleday & Company, Inc. ($8.95). Once a Boston biochemist, now label and linchpin of a New York corporate authorship, this writer is properly famed for his prolific output of readable exposition in science, and once upon a time also for science fiction of coherence and imagination. This well-made book collects 17 essays on chemical topics, all of which were published in the years from 1959 to 1966 in a science-fiction magazine. They are gathered here, slightly revised to be up to date and fitted with a nice set of portraits of worthies of the past, each bearing a biographical legend written by Asimov. The volume is a nifty way to sample Asimov.

Here are three subsamples. "To Tell a Chemist": first ask him to pronounce u-n-i-o-n-i-z-e-d and then what a mole is. There follow a whimsical, imaginative, self-appraising few pages about the right kind of mole (the chemist's dozen) in a miscellany of related chemistry, with a picture of Mendeleev thrown in. The funniest piece is "You, Too, Can Speak Gaelic," about the origins and meaning of the nontrivial names of organic compounds. (The title arose from the circumstance that paradimethylaminobenzaldehyde is stressed in dactylic and can therefore be sung to the jig tune "The Irish Washerwoman." This led to an amusing encounter.) "Not as We Know It" discusses and extends the old cliché about life based on ammonia as a solvent rather than water, to include hot-world fluorosilicones and cold-world lipids in liquid hydrogen.

FIRE, by Gail Kay Haines. Pictures by Jacqueline Chwast. William Morrow and Company ($4.95). Striking black

cutout forms and jagged-edged areas of fiery red are all there is to the strong and splendidly appropriate illustrations that dramatize this simple text for early readers. Black locomotive and black teakettle face each other across the fold, little red flame in the range burner, big red flame in the firebox and the water-tube boiler. The history is acceptable, concerning fire from cave to car engine. Emphasis is on the joint requirement of fuel, oxygen and heat. Carbon dioxide receives mention. The simple text is a bit too simple: flint makes sparks not against "metal" but against some metals. Worse, the candle in the glass goes out, but not because it uses up "all the oxygen." This facile conclusion, dear to textbook writers, is unsupported by any experimental controls. In a large container the oxygen may prove limiting; that was the classical origin of this bad old tradition. In a glass jar such as the one drawn here, however, you can bet that impeded convection will quench the candle long before the oxygen content drops low enough even to cause distress to mice living in the jar (which may happily try to eat the self-extinguished candle). The chemist-author ought to have known better. The book is beautiful but a qualified success.

Language and Mathematics

ANNO'S ALPHABET: AN ADVENTURE IN IMAGINATION, by Mitsumasa Anno. Thomas Y. Crowell Company ($6.95). BILLIONS OF BUGS, by Haris Petie. Prentice-Hall, Inc. ($5.95). It is the essence of an abstract symbol that it can be related to a large variety of real entities. The alphabet and the simple integers express all our words and count all the world's finite sets. In the best spirit of this depth of meaning two gifted illustrators have made these two books for very young readers or the read-to. With minimal text and plenty of bright, intricate pictures, they are entirely fresh exemplars of the venerable class of alphabet and counting books.

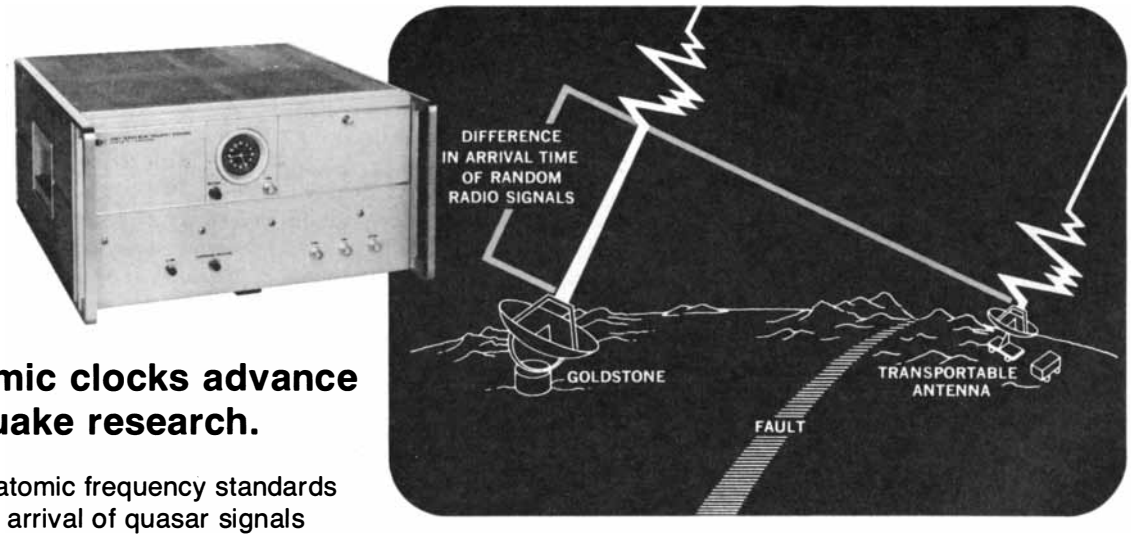
Anno presents us with a fine large letter painted on one page, and on the opposite page an object whose name begins with that letter. So far, old convention. But his *A*, so carefully painted, is really made of grainy yellow wood in an impossible form, the visual pun made famous by M. C. Escher and the impossible fork. The opposite page shows a real hardened gray iron anvil; an iron hammer beats the work, held on the anvil in a strong pair of iron tongs. The workpiece is a red-hot glowing bar—of wood! Framing each page is an intricate tracery of line concealing the clear forms of acanthus, anemone, ant and aster. And so we go, on to a joined Z. (There is a partial guide to the tracery figures at the end of the book.) The *M* is mirrored, and the zebra is only a black horse standing behind white bars—or is it? Young reader and parent can pore over this witty book for a long time and not exhaust its wry surprises and paradoxes.

Begin to count, you say? It is convention, again, to show sets of colorful objects arranged in the order of the natural integers: one, then a pair, then three and so on. Fine. But in this number book the author-artist starts with one rather fierce mantis eating a grub while standing on a bright red flower against a yellow ground. Turn the page and count not two but "10 Walking sticks [hiding] in a shrub." Pretty soon 300 fleas leap across the forest floor and 400 flies collect on the screen door! It is very perceptive that the count can proceed first by tens and then by hundreds up to 1,000 using real creatures—if they are insects. Little else animate can be drawn convincingly in such great number. As a consumer's check the reviewers tried to count the claimed 700 head of ladybugs. We got 704 ± 6 in several tries, and we announce our belief that Ms. Petie has given her young readers honest counts. It will be fun—and excellent practice—for them to check up on her.

THE CALCULATING BOOK: FUN & GAMES WITH YOUR POCKET CALCULATOR, by James T. Rogers. Random House ($2.95). This simple paperback guide is based on the wide distribution of those standard pocket calculators with four operations, which spread not mere numerical competence but true arithmetical fluency. They even make words, since the linear forms of the digital display strongly resemble specific letters when they are viewed upside down or in a mirror. The author is an experienced scientific journalist of taste and wit who writes as he computes, without confusion or pretense. His small book is in two sections. The first begins with the entry 107734, an upside-down greeting, and ends with $11934 \div 51$, to be viewed in a mirror. In between lie a wide variety of arithmetical games, patterns of digits, clever tricks for operating on ages and so on to extract the predicted result after what seem like impossibly mixed operations, for computing the name of a battle, for finding key dates in history and even for working at semiserious mathematics, such as forming $n!$, guaranteed soon to overflow an eight-figure display. It is all quite elementary, but swift, varied and ingenious. The second, briefer section demands a little higher degree of mathematical appreciation: it considers matters such as squares, primes and repetitive loops. Take an odd integer, multiply it by 3 and add 1. Then halve it. Iterate, halving all even numbers. Eventually you will have the unending loop 4, 2, 1, 4, 2, 1.... If you start with 27, however, you will loop only after 109 steps! There is bound to be much more recreational mathematics coming along in the near future; it is in the chips. Here is a pleasant pioneer effort.

A VISIT FROM A TURTLE, by Gene Deitch. Pictures by Vratislav Hlavatý. Franklin Watts, Inc. ($4.90). HIEROGLYPHS FOR FUN: YOUR OWN SECRET CODE LANGUAGE, by Joseph and Lenore Scott. Van Nostrand Reinhold Company ($6.95). The visit is described in about 15 gaudily colorful and exciting poster-like paintings, with a sentence or two of text for each scene, admirable for reading out loud to someone who can see the pictures. The out-of-the-way place is clear enough, a red-roofed village nestled among large, steep, green-brown hills as the pink sun sets. A rather large mouse lives there, but he is pictured unmistakably as a glowing blue elephant. He inhabits a flowerpot, which is drawn as an empty yellow-tiled swimming pool, and he rides to work each day through the clouds, headphones on his ears, in his red, two-engined, bubble-canopied rowboat. So we go through the book; the nouns are plainly redefined. The turtle shows up, curly-haired and grinning, and tries to convince his hosts that he is a boy. What a strange name for a turtle! He went home wondering, and we wonder with him, about the arbitrary nature of language. A half-page of moral was hardly needed; the book is whimsical and yet full of meaning. The talented pair who made it are collaborators in the busy Czech animated-film world.

The second book continues the substitution game, but for children old enough to take pleasure in writing. About half of the pages explain in the simplest of line drawings the use of the 24 Egyptian hieroglyphs as a substitution alphabet, adequate for spelling out English words given a little phonetic imagination. A real cartouche is drawn and decoded into *Kriowpadra*. The authors, amateur Egyptologists, go on to discuss and list some of the silent ideographic determinatives of ancient Egyptian, ending with a potpourri including Egyptian numbers, a little history, a simple map of the Nile, a paragraph on



HP atomic clocks advance earthquake research.

Using HP atomic frequency standards to time the arrival of quasar signals within 0.1 nanosecond, a JPL-Caltech research team is beginning a project aimed at measuring distortions in the earth's crust surrounding fault systems. Potentially, the technique could play a key role in predicting quakes.

On either side of an active geological fault, two crustal plates slowly but inexorably collide. With each increment of this collision, stress accumulates within the rocks along the fault, increasing until stored energy ruptures them.

The San Francisco earthquake of 1906, for example, was caused by a sudden 4-meter slip along the San Andreas fault. Since then, the rate of distortion has been variously estimated between 2 and 6 centimeters a year.

The issue seems simple enough. At a crustal deformation rate of only 2 centimeters a year, the fault will not reach the 1906 level of stress until 2100; at 6 centimeters a year, that level is already exceeded and a major quake could happen at any time.

Not so simple is the solution of the scientific problem that underlies the uncertainty about the true crustal deformation rate: how to measure accurately a distortion of only a few centimeters in a rather wide zone along the 800-kilometer length of the fault. A new extraterrestrial surveying method developed by Caltech's Jet Propulsion Laboratory for the NASA Office of Application may soon provide an answer.

Called ARIES—for Astronomical Radio Interferometric Earth Surveying—the new method employs signals from quasars and radio galaxies billions and billions of light years away, because they are extremely stable angular points of reference for measurements on earth. Using a transportable ARIES antenna and a fixed Deep Space Station at Goldstone, California, it has been possible to survey a portion of the San Andreas fault. During the past three years, the ARIES project team, using Hewlett-Packard atomic clocks, has developed methods for timing the difference of arrival of identical random quasar signals between two antennas with accuracies of about a tenth of a billionth of a second. With such accurate measurements from several quasars, it is possible to calculate the relative three-dimensional positions of antennas several hundred kilometers apart with accuracies of better than 10 centimeters. With further improvements, 1-centimeter accuracy will be possible.

With repeated measurements of a set of reference locations developed on advice from Caltech's Seismological Laboratory, ARIES will be able to measure the actual crustal deformation rate over the next three to five years with an accuracy of 2 centimeters per year along the San Andreas fault; so, they will identify the regions storing stress to be later released as earthquakes. They may also find the telltale crustal uplifting thought by some geophysicists to occur prior to earthquakes. ARIES may move mankind closer to reliable predictions of the place, time, and magnitude of future quakes, with enough warning time for effective planning.

The early achievements of ARIES have gained the interest of federal and local government agencies and private industry with surveying problems, because of ARIES' potential for extremely accurate, all-weather operation. Consideration is already being given to developing the ARIES techniques for routine land surveying use in the 1980's.

HP atomic clocks, by virtue of their extreme accuracy (to $\pm 7 \times 10^{-12}$) play key roles in many countries. Model 5061A cesium beam primary frequency standards and 5065A rubidium secondary standards are used to maintain national time standards throughout the world; and a number of worldwide navigation, communications and tracking systems depend on them for the precise timing that is essential to success. Basic price for the 5061A is $18,950*; for the 5065A, $8100*.

30 minutes vs. a week: new levels of speed and accuracy in automatic check of multiplex phone systems.

From permanently stored FDM plans, a built-in microprocessor automatically tunes to all system frequencies, measures true RMS power levels at each group and channel, and displays the measurements digitally.

At the same time and on the same coaxial cable, several thousand voice and data messages may be moving to their destinations, each one kept distinct from all others. Through a technique called Frequency Division Multiplexing (FDM), each message is assigned a specific 4-kHz channel within the overall system frequency range, according to an internationally-agreed convention (Bell in North America, CCITT elsewhere). The system works extremely well—provided each message remains at the exact frequency and power level specified by the FDM plan.

Consider for a moment the monumental effort required of a maintenance person assigned the task of overseeing a single 2700-channel FDM system, using the traditional manually-operated SLMS (Selective Level Measuring Set). From voluminous charts and tables, he must find the correct frequency for each channel and pilot, accurately tune his set, determine the locally-specified power level and select the appropriate attenuation, read the level measurement—and repeat the process for each channel, group, supergroup and master group in the FDM Plan. Assuming no system failures or emergencies, it takes him the better part of a week to complete a routine surveillance of the system.

Now, a new, HP-developed, microprocessor-based instrument capable of automatic computed measurements has changed things radically for the better. Using the new 3745 SLMS, a craftsman can do the entire job in less than 30 minutes, more accurately than with a manual set.

The central feature of the 3745 is its built-in microprocessor in whose ROM's are permanently stored all FDM plans. Operation is extremely simple: the craftsman need merely enter the appropriate FDM location numbers on the keyboard, and the 3745 does the rest. It tunes itself to the correct frequency within one part in 10^7; selects the appropriate filter and measures the true RMS power level measurement; displays the measurement digitally with a resolution of 0.1 or 0.01 dB—and automatically repeats the process for each channel or pilot. It can also automatically measure channel test-tone and signalling frequencies, virtual carriers and inter-supergroup test slots.

Two models are available: the 3745A for CCITT and 3745B for Bell system FDM plans. Both are priced at $23,625*.

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Aïda (and the hieroglyphic form of that name) and even the probable rules for an ancient board game, Senet. (The sign for "remain" was a drawing of the board, where capture is part of a winning game.)

People

THE GREAT CHESS AUTOMATON, by Charles Michael Carroll. Dover Publications, Inc. ($2). The Empress Maria Theresa was intrigued and puzzled by a French illusionist, and so she summoned from Hungary to her court in Vienna to watch the performances one Wolfgang von Kempelen, an engineer and civil servant with a deserved reputation for mechanical ingenuity. Instead of a mere explanation of the tricks, von Kempelen offered something more. He undertook to construct a still more astonishing illusion than any they had seen. He was as good as his word. Six months later he returned with a fascinating device, an automaton chess player, which he passed off as the supreme feat of clockwork before a public still amazed by machinery. It seized the imagination of audiences in Europe and America almost constantly from its construction in 1769 until the death of its second principal exhibitor, Beethoven's friend Johann Maelzel, metronome inventor and "Professor of Music and Mechanics," in 1838. The wonderful machine, forgotten in a crate, perished at last in the notable fire that destroyed Peale's Museum in Philadelphia in 1854.

But it remains immortal. Edgar Allan Poe (whose essay owed much to his uncredited sources) and E. T. A. Hoffmann wrote of it, and folklore has matched the machine against Prince Metternich, Andrew Jackson and George III. There is documentation for a real game against Charles Carroll of Carrollton, the last survivor of the signers of the Declaration of Independence. That stalwart beat the (generous?) machine in Baltimore when he was 89. The automaton was always first-rate at chess, although strong players would win a match from time to time.

The automaton appeared as a full-size figure of a moustached man. Costumed in Eastern fashion in a rich furred robe and a turban (it was popularly called the Turk), it was seated at a hardwood chest about four feet wide, two feet deep and three feet long that was mounted on casters. From the front the seated figure was lifelike, with head motion and rolling eyes; from behind it trailed off below the waist into a clockwork-filled box and bench. It moved the pieces with its left hand and its right held a long clay pipe. (The left-handedness was in no way relevant; it was either an oversight of design or clever misdirection.) The whole thing could be wheeled around the room freely; it seemed beyond any outside control by wires or rods. The exhibitor was not nearby during the performance. A ritual of opening doors to allow the audience to see within the entire chest, hastily disclosing only the clockwork and spaces clearly too small to hold a concealed player, was the start and the end of many shows.

In 1827 two Baltimore youths watching secretly after the noon show from a rooftop saw a "well-built man in shirtsleeves" climb out of the Turk's chest. The secret had lasted nearly 60 years. The boys' revelation did not end the attraction, but its days were numbered. A competitor even appeared. Yet at least three times since the 1780's careful analysts had published essentially correct accounts of how the machine worked, plus the unlikely fiction, concocted later by the great magician Robert-Houdin, that a certain chess master who was a double amputee was hidden inside. There was plenty of room for a man, but the director within (there were a dozen of them over the years, one perhaps a woman) had to change from position to position as several doors were opened in a special order. He followed the moves by watching magnetic needles, set under each square, that were tipped by the magnetized chessmen moved above, and he controlled the arm of the Turk through a pantograph device as he followed the game on a small board inside his tight cabinet. All of this was inferred from the evidence by several keen observers, the best being perhaps the 20-year-old Robert Willis in 1820. (Willis was to become a distinguished professor of mechanisms.)

Every contemporary drawing (the fine period engravings are reproduced here) omits one essential part of the whole clever scheme: two lighted candelabra were put casually on the chest before each session, no matter how bright the light in the room. The concealed director needed a candle to see his boards, and although the scanty ventilation was provided by openings well concealed to prevent a light leak, the scent of burning wax was sure to be detectable. Clockwork would not need candles; hence the ostentatious candelabra. That clue was picked up and worked into a fairly complete explanation as early as 1789.

An original piece of lighthearted historical research by an enthusiast of chess and of ideas, the story is full of meaning. Here are Carroll's closing phrases: "Half-a-dozen times... the Turk's secret was decisively revealed to all... but they refused to look or to think.... Kempelen and Maelzel... satisfied a deep-seated need to believe. In our scientific age it has not disappeared. *De nobis fabula narrabitur.*" The tale will be told of us.

This little book is a delight and a bargain for any reader, young or old, interested in chess or in magic, or indeed in human credulousness.

PEKING MAN, by Harry L. Shapiro. Simon and Schuster ($7.95). THE SEARCH FOR PEKING MAN, by Christopher G. Janus with William Brashler. Macmillan Publishing Co., Inc. ($8.95). The pharmacists of old China have for a long time sold "dragon bones," fossil bones recovered from the soil by some sharp-eyed peasant and prized for their traditional medical value. In 1921 such apothecaries' wares led to the discovery —the local people pointed out the site knowingly—of a bone-rich fissure in the limestone caves at Chou Kou Tien, a few tens of miles from Peking. By 1937 an international group of physical anthropologists had excavated there the bones not of dragons but of ancient humans, fragments of some 40 individual skeletons of *Homo erectus* half a million years old. Other finds of early hominids of that age are known, but this one remains the richest.

Found after all that time, the bones were lost again after only 14 years. The last fieldwork was done in 1937; Japanese military occupation made more work unwise. By 1941 neither Teilhard de Chardin nor Franz Weidenreich could work in Peking any longer. A plan was formed to send the precious bones to the U.S. until Chinese sovereignty might be restored. Weidenreich went off with excellent casts and photographs to finish his studies in New York. The precious originals were devotedly and carefully packed, but time had run out; it was early in December, 1941. Two crates were taken to the local headquarters of the U.S. Marine embassy guard as the Marines were leaving to board ship at Tientsin; they would certainly safeguard the marked boxes. Then war intervened; the Marines and their baggage went not to another U.S. base but to Japanese internment prison in Shanghai. No one knows just what happened to the particular regulation footlockers to which the bones, so valuable both as symbols and as documents for science, had been transferred.

Or at least no one is saying. These

SCIENCE/SCOPE

The first in a series of six new satellites Hughes is building for the 91-nation International Telecommunications Satellite Organization was launched September 25 and has passed all tests successfully. Intelsat IV-A, which has two-thirds more capacity than the present Intelsat IVs, provides 6,250 telephone circuits, plus two television channels, and serves more than 40 earth stations as the Atlantic primary satellite. Its new spot-beam antenna concentrates its signals on major business centers and makes more efficient use of the frequency spectrum allotted for satellites.

The U.S. Marine Corps has a new position locator system which pinpoints individual men, units, and vehicles. The Hughes-built engineering development model of the PLRS (Position Location Reporting System) includes a commander's mobile master unit and 17 user units, which can be man-packed or mounted in vehicles and aircraft. PLRS uses "time of arrival", burst-transmission, and spread-spectrum techniques. It does its job faster, more accurately, and in greater volume than older methods such as sight and sound reporting, radio triangulation, or even radar.

A high-speed, 16-bit microcomputer that can operate throughout the military-applications temperature range is being tested at Hughes. The AN/UYK(XN-1) has a capability of up to 500,000 operations per second -- 10 times greater than top state-of-the-art compact systems just months ago. Speed and flexibility were achieved at low cost through use of commercially available LSI microprocessor chips. The AN/UYK was developed for a Naval Air Systems Command digital missile autopilot R&D program. Other potential applications include mobile ground and helicopter fire-control systems, digital scan converters, and various distributed processor systems.

Hughes' Conographic™ graphic display terminal, which displays curvilinear information by conic curve generation rather than by x-y plotting, is now available in a low-cost version, the Conographic-9 terminal. With a package price of $9,750, the new fully interactive unit offers high resolution, selective erase, high light output, built-in serial interface, and other features of higher-priced terminals without requiring additional hardware options. Conographic process generates smooth curves with considerable reduction in data required, resulting in more cost-effective telecommunications.

Hughes needs manufacturing and equipment design engineers. Responsibilities include designing specialized manufacturing equipment and fixtures, efficiency analysis, implementation of reductions. Requirements: BS in ME or Industrial Manufacturing and five years' related experience, preferably in hybrid circuit assembly. Forward your resume and salary history to: Pat Schneider, Hughes Aircraft Company, 500 Superior Avenue, Newport Beach, CA 92663. An equal opportunity M/F employer.

A lightweight amplifier for satellite earth terminal transmitters, developed by Hughes, provides 35 watts minimum RF output power in the 6 GHz satellite uplink frequency band. It has solid-state circuitry for low power consumption and a rugged metal-ceramic traveling wave tube derived from the space-qualified TWTs Hughes builds for communications satellites. It operates from 115- or 230-volt AC or 48- or 24-volt DC input power. The unit measures 3½" x 19" x 16" and weighs 20 lbs. For information, write: Hughes Electron Dynamics Division, 3100 West Lomita Blvd., Torrance, CA 90509.

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two books elaborate the exciting story. Shapiro, a well-known anthropologist, tells his tale in an interesting context of evoking the nature and the life of Peking man as we surmise it. Janus, a romantic and energetic entrepreneur, tells—with writing help of a very skillful and readable kind—mainly his part of the modern melodrama of the puzzling search for Peking man, in which he has been caught up since early in 1972. He went to China, became struck by the enigma and has since put his money and his energies into the search.

There is a mysterious woman who delivered a photograph that the best experts seem to think shows an authentic missing skull part—not a cast—among a pile of irrelevant bones. There is more than one tipster who purports to know that the bones are in the possession of drug-trading warlords or obscure old Nationalist generals or even less plausible collectors. There is the Marine physician now in New York, the best-informed of the Peking military party, who recalls distributing some footlockers—maybe not the key ones—among unnamed friends in Peking before his arrest.

One hopes that indeed most or all of the bones were reburied for safekeeping. China has been skilled at that for millenniums. It may be that no one alive really knows where they are now. Still, a trail exists, tangled and cold though it is. The bones are likely to appear again before they can be called much older, since decades or even centuries of delay mean very little to such an archaic burial. Here is the most romantic scientific mystery tale in years.

THE BOOK OF FIRSTS, by Patrick Robinson. Clarkson N. Potter, Inc. ($10). Painstaking scholarship lies behind this slightly whimsical work, which lists alphabetically, from "Abortion clinic" to "Zip-fastener," the first record (within the modern world; antiquity is not examined) of some 1,200 innovations that have "contributed to life as it is lived today." A wide and fresh appeal is the aim, not the mere reproduction of familiar stories, so that beauty contests, motels and film reviews are included, whereas the steam engine and state education are omitted. The book is formally international but British in emphasis.

The first professional woman photographer? The Parisienne Antoinette de Correvont, who opened a studio for daguerreotypes in Munich in 1843. The first telephone? Maybe one made in Havana by the Florentine Antonio Meucci in 1849. He filed his patent claim only in 1871, too poor to apply earlier. The first income tax? The *catastro*, introduced under Lorenzo de' Medici in 1451. (The public works of his time may have been costly, but they were mighty well executed.) There is a chronology and an index that contain about 6,000 "firsts" by name; the main text devotes a paragraph or two—sometimes more—to each of its entries, often with illustrations. Here are reproduced two motion-picture frames, which show "Britain's first film actor performing Britain's first screen kiss—Fred Storey in *The Soldier's Courtship*, 1896." A Broadway comedy sequence made in West Orange, N.J., initiated that genre worldwide in the same month as Storey's slightly later achievement. The primal pair were John Rice and May Irwin.

THE PROUD MAIDEN, TUNGAK, AND THE SUN: A RUSSIAN ESKIMO TALE, retold by Mirra Ginsburg. Illustrated by Igor Galanin. Macmillan Publishing Co., Inc. ($4.95). FOLK TALES FROM ASIA FOR CHILDREN EVERYWHERE: BOOK ONE. Sponsored by the Asian Cultural Centre for UNESCO. John Weatherill, Inc. ($4.95). Once the tundra was always dark. In this fresh tale from the Russian Arctic we meet a new Persephone who brought the light and did not take it away. This lovely maiden is sought by a gross and harsh suitor, the evil spirit Tungak, all mask and sharp teeth. She flees to a strange tent, bright and warm from a great lard-burner. Fat Tungak is melted to nothing and the dogs chew up his bones. Her hosts turn out to be the family of the Sun; nowadays there is half a year of brightness because the Sun and his new wife come annually to visit her parents. The moon, too, is accounted for in this delightful myth from a dark and cold land. Fine drawings—perhaps etchings—reproduced in a clear blue monochrome complement the text very aptly.

The second book is a compilation of tales from eight lands, from Iran east to Korea. The tellers and the illustrators differ from country to country; the pictures are all colorful, from calligraphic Iranian drawings to free, folklike bright wash paintings from India. The Laotian tale of the small boy who could flick pellets of mud off his finger with precision to stop the idle talk of a courtier is remarkable. ("Every time I tried to speak, some kind of insect flew into my mouth.") A tragic little story of love and remorse comes from Vietnam, complex enough to explain why people at weddings to this very day chew areca nuts wrapped in betel leaves with a bit of lime paste. There is a lot to learn and enjoy in these unexpected stories.

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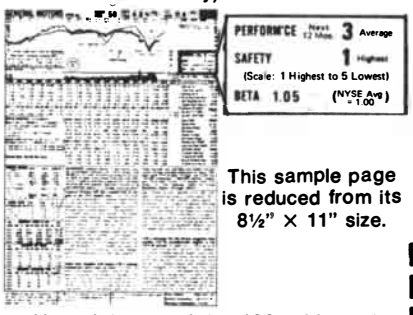
Rank 2. Expect less than av'ge volatility.
Rank 3. Expect both volatility and stability to be average.
Rank 4. Expect greater than average volatility (below average stability).
Rank 5. Expect the greatest volatility (the least stability).



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