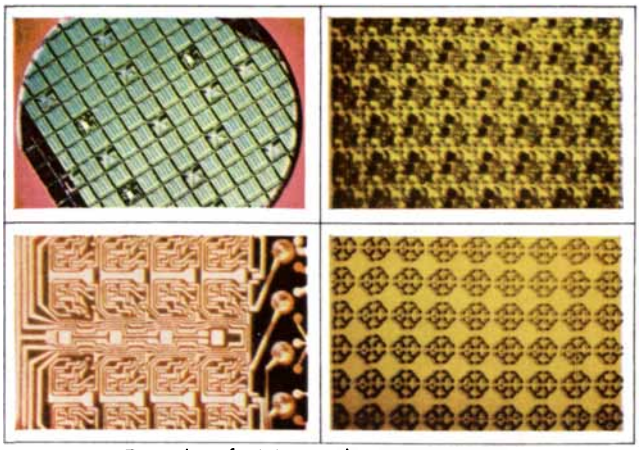
SCIENTIFIC AMERICAN

EXCAVATING MACHINE

SEVENTY-FIVE CENTS

November 1967



Examples of miniature electronic circuitry.

How First National City Bank helps electronics companies to get credit tailored to need, keep posted on world money markets, finance and lease computers...

...and get 8 other services that might give you some ideas for your company.

1. Get credit tailored to need

Fast growth, high R & D costs, sophisticated products, and volatile consumer, industrial, defense and space markets are the facts of life in electronics. To solve the complex financial problems they create, First National City Bank has established an Aerospace and Electronics Department.

These men know the industry cold, can judge such things as the market potential of exotic new electronics products, and the impact of product obsolescence on financing. Result: they can adapt short term credit, revolving credit and term loans to help these companies realize their full growth potential.

2. Keep posted on world money markets

Electronics executives call on Citibank's Economics Department and Overseas Division regularly for reviews of international economic, financial, political and social problems. They are also briefed on new developments affecting the speed and cost of foreign exchange in areas where their companies do business.

3. Finance and lease computers

Citibank buys computers from manufacturers and rents them to the manufacturers' customers. This technique lets some customers conserve capital, lets some get equipment they might not otherwise be able to buy.

The bank also supplies millions of dollars worth of credit to manufacturers of computers, peripheral equipment and software.

4. Set up businesses overseas

Citibank people both in New York and overseas help electronics companies set up plants and offices in new markets. The bank supplies information about local pay scales, employee benefits, regulations on loans, etc. Citibank helps company representatives find and finance homes, locate office space, set up banking services, and introduces them to key people in local business and government.

Note: Citibank simplifies overseas banking for electronics companies with uniform procedures at Citibank in New York and its branch network in 47 countries overseas.

5. Get credit checks

Electronics firms make many substantial one-time sales through their catalogs to unknown buyers. Citibank makes thousands of credit inquiries on these prospective buyers, as well as routine credit checks on regular customers.

Citibank's people overseas know what credit information U.S. businessmen need. They frequently report facts not readily available elsewhere.

6. Maintain special purpose accounts

Electronics firms maintain special accounts at Citibank in New York and overseas for cash mobilization, payrolls, deductions, accounts payable, etc.

7. Use world money markets

In the U.S., Citibank serves companies as adviser or principal in sales of government notes, commercial paper, C.D.'s and other short-term investments.

Companies use Citibank's overseas branches to invest proceeds of foreign underwritings until they are needed.

8. Locate and evaluate acquisitions

Citibank keeps an eye peeled for potential mergers and acquisitions, helps evaluate them, makes introductions, furnishes financial assistance.

9.-11. Other important services

First National City Bank protects and services securities for many electronics firms; supplies leads on qualified personnel; acts as trustee and paying agent for debentures and as registrar or transfer agent for company stock, etc.

We welcome inquiries about the many ways your company can use First National City Bank.

FIRST NATIONAL CITY BANK

399 PARK AVENUE, NEW YORK, N.Y. 10022 · MEMBER FEDERAL DEPOSIT INSURANCE CORPORATION

His airline spent millions to make sure his flight will be comfortable, and a few pennies more to put his mind at ease.

When a passenger on a tight schedule needs to know if his connecting flight in Rome will be on time, an airline should be able to answer, fast.

That's not always so easy when the place you have to ask is an ocean away from you.

Ordinarily, when a transoceanic query has to be relayed, it's done manually. If the operator has his hands full at the moment, query and passenger have to wait. And you know how long that can be sometimes.

But at ITT World Communications we have a computerized switching system called ARX. When a message comes in, ARX switches it to its destination electronically.

At the speed of light, not at the speed of people.

Some large companies have their own switching systems, but that's expensive. We let companies share ours for pennies a message—a lot less than the cost of a manual routing, or the price you'll eventually have to pay because of an unhappy customer.

Banks, oil companies, steamship lines and many other businesses can use our ARX.

We can't think of a better way to spend a few pennies—to keep a customer happy.

International Telephone and Telegraph Corporation, New York, New York 10022.

ITT

We figured out how to share a computer with anyone who needs it.

About five years ago, we developed the first software system allowing "remote multiple access" to one of the largest computer systems in the world. This computing utility, called REMOTRAN, operates in Richland, Washington as one of our service bureau facilities. Terminals in neighboring states and Canada—some as far away as 100 miles—tie into Richland via phone lines.

But this system, and most concepts like it, feature "remote batch" processing. Everything is pre-arranged. A program is tailor-written and stored in the computer memory. When a remote subscriber taps the computer to solve a problem, his program is called out and temporarily monopolizes the computing operation. Consequently, users get to the computer on a first-come, first-served basis. Although the problem may be solved in milli-seconds, getting to the computer and getting answers back can often take hours.

Swifter computers with big, safe-guarded memories have let us change all that. Now we're developing time-sharing software systems that furnish a reply almost as soon as the question is received. With the recent delivery of one of the largest third generation computers, our Richland facility is now being converted to a true time-sharing network using CSC developed and implemented software.

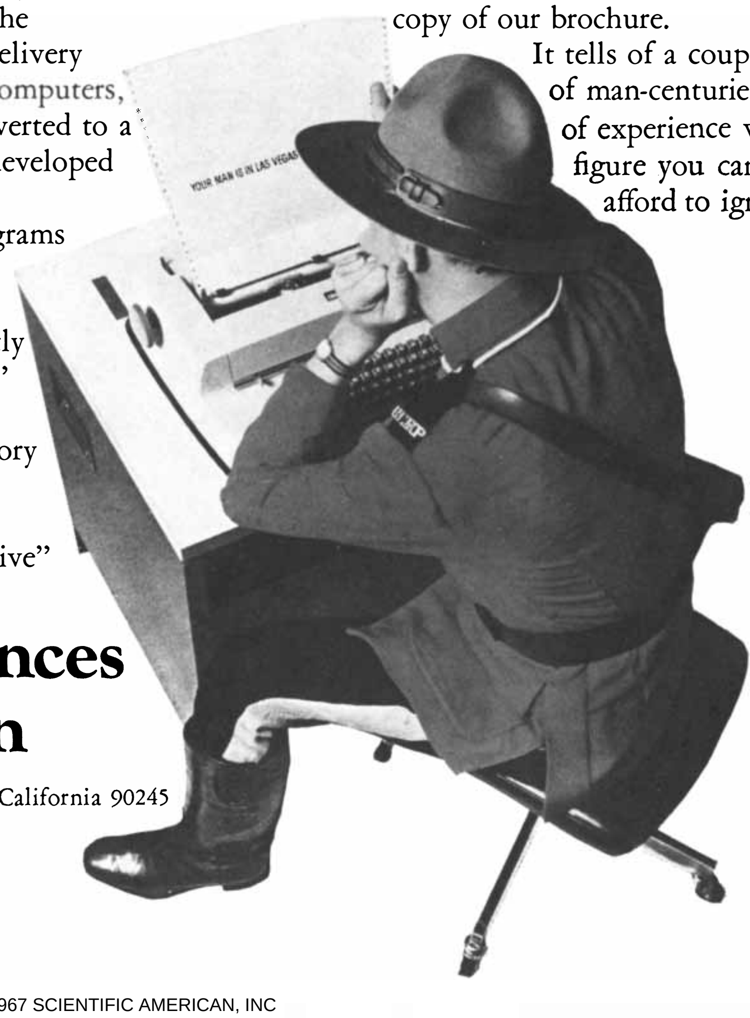
The danger of shoddy software programs was never more important than in time-sharing. If the thousands of inter-related program elements are inefficiently conceived and arranged, the "executive" program itself can become so complex that it would occupy most of the memory and consume much of the computer's calculating power.

Then, too, demands on the "executive" grow with the proficiency of the user. A subscriber soon discovers new ways of using the computer. With an inept "executive," these new applications, when multiplied by the number of users, could cause a saturation and slow the computer's response way down. The "key" is being ahead of the subscriber from the very beginning.

We've been working with this "key" for over 200 man-years. This includes both "executive" programs and all the other time-sharing software support. Among the latter are program checkout systems, control language systems, and conversational processors (e.g., FORTRAN, and PL/1). For instance, we recently designed a FORTRAN to compile 5000 cards a minute. (This is excellent speed for any computer system, time-sharing or otherwise.)

Currently we're involved in new time-sharing projects—ranging from modest systems for the near future to mammoth fourth generation systems for the next decade. If you or one of your customers has a time-sharing system in mind, write the President for a copy of our brochure.

It tells of a couple of man-centuries of experience we figure you can't afford to ignore.



Computer Sciences Corporation

650 North Sepulveda Boulevard, El Segundo, California 90245

Established 1845 **SCIENTIFIC AMERICAN** November 1967 Volume 217 Number 5

ARTICLES

DEPARTMENTS

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THE COVER

The painting on the cover shows part of the cutting face of a machine that bores tunnels (see "Rapid Excavation," page 74). The machine is a Jarva Mark 14, made by Jarva, Inc., of Solon, Ohio, with cutters made by the Reed Roller Bit Company of Houston. The studded cutters have teeth of tungsten carbide and are designed to enable the machine to bore through hard igneous formations. An array of such cutters is positioned on the face of the machine at various angles. In operation the entire face, which is 11 to 14 feet in diameter depending on the size of the bore, rotates; it is pressed against the face of the tunnel by hydraulic rams that are also part of the machine. Behind the rams are hydraulic legs that lock the machine in the tunnel during a boring cycle, which can continue for as much as two feet. At the end of a cycle the locking legs are retracted and rear support legs push the machine forward for another cycle. Material gouged from the face of the tunnel by the machine is passed along the top of the machine and discharged at the rear. A machine of this type used to bore 10.5-foot sewage tunnels in St. Louis had an average penetration rate of 3.62 feet per hour.

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Super stamp

It's just an ordinary airmail stamp. Until you put it under ultraviolet light. Then it turns into a glowing super stamp that lets the Post Office sort 30,000 letters an hour!

Sylvania phosphors did the trick. After seven years of research. Several thousand were tested before two were selected from Sylvania.

Now, the phosphors are simply added into the stamp ink. A red-orange for airmail, a green for the rest. When the letters come in, they are fed through special electronic equipment that cancels and sorts them automatically.

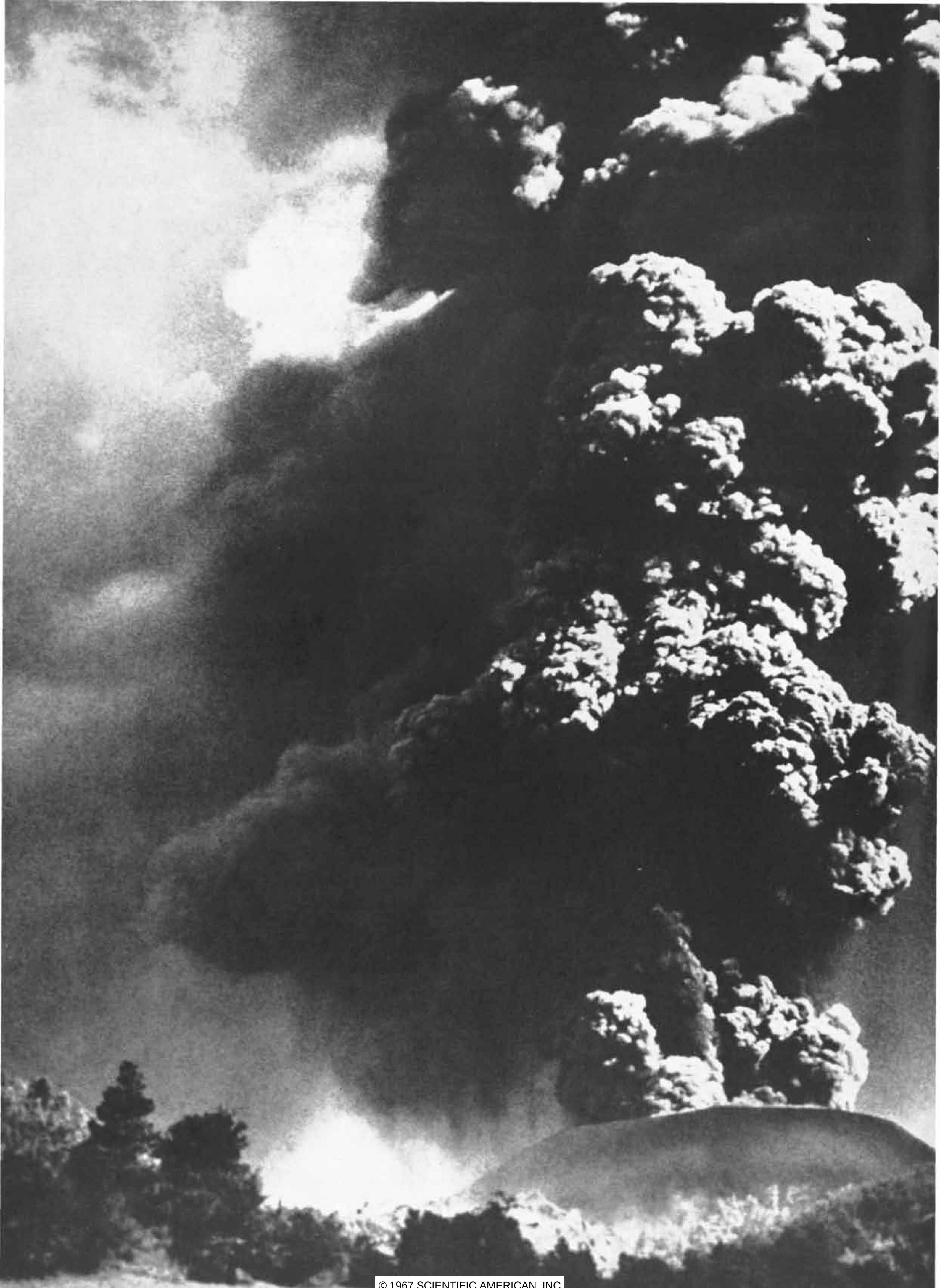
Sounds simple, but it took some doing. The phosphors not only had to luminesce brightly under ultraviolet, but had to be as fine as confectioner's sugar (normally antagonistic characteristics).

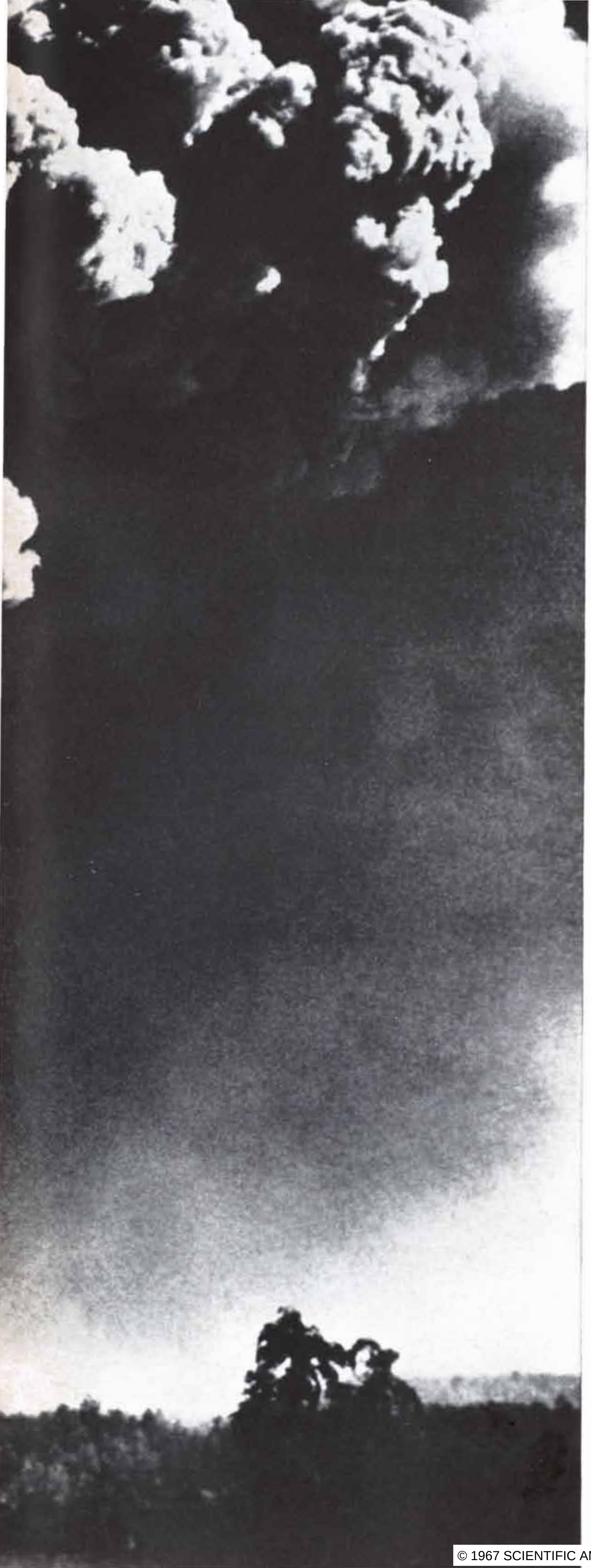
Altogether, we offer hundreds of different phosphors. Some detect counterfeiting, some illuminate safety devices, some coat fluorescent tubes, some trace air currents, some make plastics glow, some brighten your TV picture.

Maybe we can solve your materials problems too. After all, we've been a leading phosphor producer for over 25 years. We're also a leader in tungsten, molybdenum, specialty industrial inorganic chemicals, and semiconductors.

For information, write to Sylvania Electric Products Inc., Chemical & Metallurgical Division, Towanda, Pennsylvania 18848.

SYLVANIA
A SUBSIDIARY OF
GENERAL TELEPHONE & ELECTRONICS





Volcano vs. diamond. Diamond wins.

The fiery turbulence of a volcano produces lava, a hard, abrasive substance now being used in atomic reactors and related equipment.

The problem was machining the lava to various configurations. Atomics International, division of North American Aviation, Inc., at Canoga Park, Calif., looked around for tools to machine lava, on which carbide tools were first tried and found wanting.

They found the proper cutting edge in a shaped ½-carat diamond. First, they turned a cylinder of extremely hard and abrasive Grade A lava. Then the same diamond was used to achieve a close tolerance and fine finish on P5N graphite, which is not hard, but difficult to machine.

Despite the grueling test on the lava piece, the dimensional loss on the graphite cylinder was less than .001 inch, and the finish finer than any previously achieved by hand-polishing.

But you don't have to battle a volcano to take advantage of diamond tools. Natural and synthetic diamond tools are used in grinding wheels, dressing tools and lapping compounds for all sorts of abrading jobs in metalworking, optics and ceramics.

Are you frightened by the cost of diamond tools? Don't be. Because if you cut, sharpen, grind or smooth *anything* in your business, you can probably use diamonds profitably. Your tool and wheel maker can show you how.

De Beers

World's leading source of natural *and* synthetic diamonds for industry . . . backed by the Diamond Research Laboratory

Shannon, Ireland

LETTERS

Sirs:

Thank you for the article on tetrodotoxin in the August issue. The common puffer fish on the Natal coast of South Africa is *Amblyrhynchotes honckenii.* It is highly poisonous and well left alone by both fish and birds.

Your author, Frederick A. Fuhrman, may be interested to know that this "toby" is called *blaasop* in Afrikaans (compare *blaser* given for the name in Indonesian). The Zulu name is *isi-kukkuku.* The poisonous nature of this fish is well known to the local Congoid witch doctors and doubtless many a sudden death can be attributed to this item of the medicine bag. The famous South African ichthyologist J. L. B. Smith states in his magnificent work *The Sea Fishes of Southern Africa,* and I quote: "Eaten by cats with rapidly fatal consequences, is sometimes employed to end nocturnal disturbances"!

A fatal case of poisoning through the eating of these fish is reported in the *Daily News* of Durban for July 17, 1967. I quote: "An African youth who escaped from the Vuma Reformatory is dead and his accomplice is in a critical condition after eating fried tobys. They came upon a few small fish which they cooked as they headed down the coast."

G. Noel Jonsson

Natal
Republic of South Africa

Sirs:

We were naturally pleased that Clarence F. Kelly, in his article "Mechanical Harvesting" [Scientific American, August], credited International Harvester with a very significant investment of both time and money in development of the cotton picker.

However, this reference and the one following it tend to leave the erroneous impression that International Harvester's efforts were eclipsed when "success was finally achieved by the Rust brothers."

It is perfectly true that a number of people were involved concurrently in experimental work on cotton pickers for a number of years. International Harvester had attacked the problem of mechanized cotton harvest from several angles when, in 1924, it acquired the Price-Campbell patents for a spindle-type cotton picker.

Thereafter our engineers worked continuously—and completely independently of the efforts of others, including the Rust brothers—on developing a successful spindle-type cotton picker.

By 1942 our development had progressed to the point where International Harvester publicly announced its cotton picker was ready for regular production.

Although wartime material allotments limited early production to a few hundred machines, International Harvester was the first firm to market a successful cotton picker. At war's end International Harvester began construction of its Memphis, Tenn., works and located cotton-picker production there when the plant was completed in 1948.

That year the plant produced more than 1,100 spindle-type pickers, and International Harvester machines represented all but a tiny percentage of cotton pickers then commercially available. By the fall of 1952 our production had passed the 8,000-unit mark.

Today there are more International Harvester cotton pickers in use than any other make, and the majority of those on the market operate under principles established by our designs.

W. F. Overman

International Harvester Company
Chicago, Ill.

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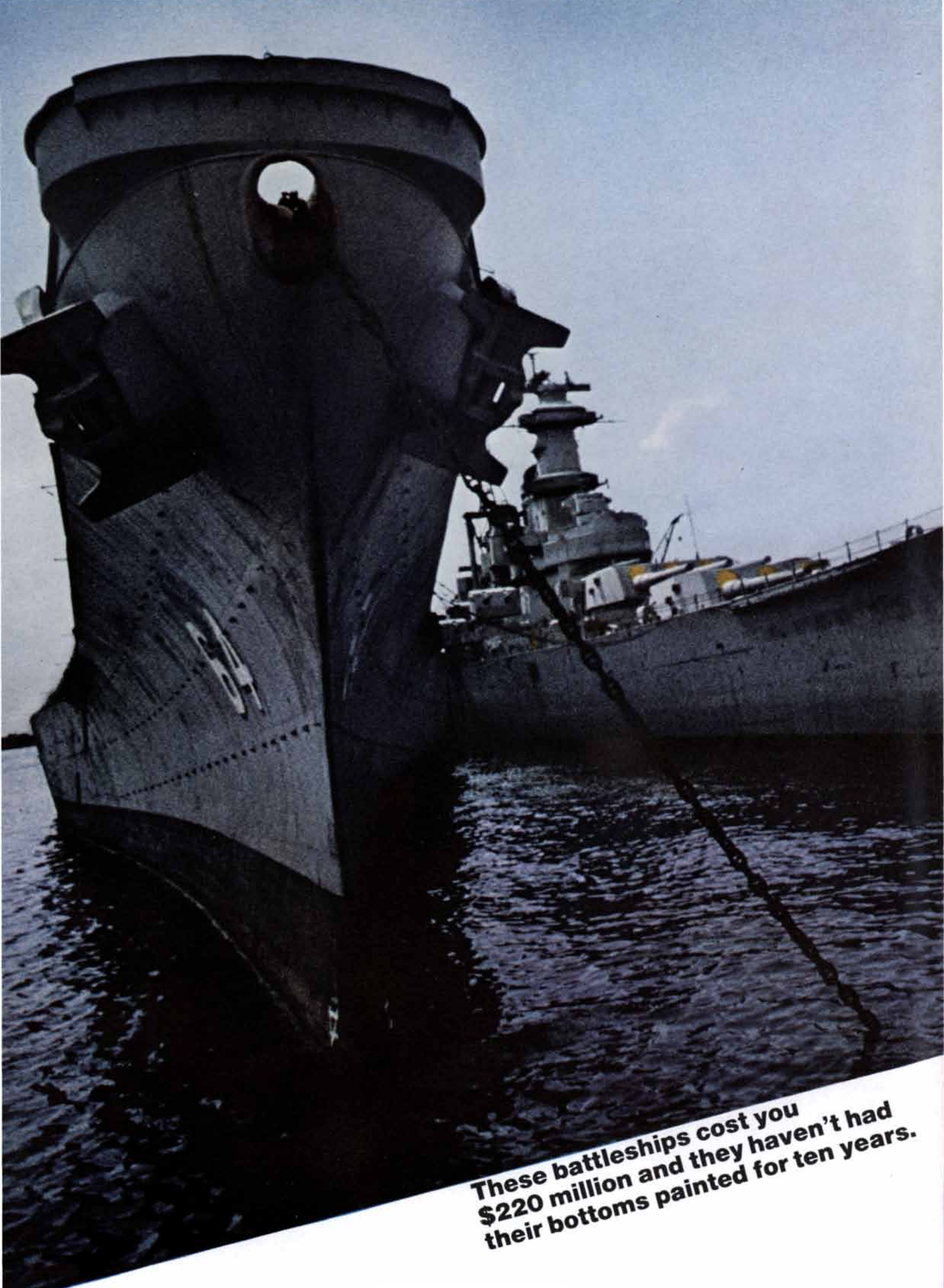
Look for the copper lining.
Next time you take some silver out of your pocket, check the copper.
Many of the new dimes and quarters contain an inside slab of a high-purity Anaconda alloy, Boron Deoxidized Copper, which bonds the nickel alloy faces so the coins can't come apart. Also it provides high electrical conductivity (this makes the coins work in vending machines). Further, it releases scarce silver for growing demands in photography, silverware, and electrical equipment.
But the usefulness of Boron Deoxidized Copper (a product of Anaconda American Brass Company research) goes beyond coins. It's helping beef up the reliability of electric and electronic equipment, from transistors to satellite communications and advanced radar.
Fact is, Anaconda is hard at work developing copper metals not only for standard industry needs, but also to meet the more critical demands of modern technologies. The Anaconda Company, 25 Broadway, New York, N.Y. 10004.
ANACONDA



Don't write your Congressman—they don't *need* painting yet. They have a vinyl coating below the waterline that's made with special resins from Union Carbide. It lasts a lot longer than ordinary paint. And that means it can save millions of dollars in repainting costs.

The same kind of coatings can give you savings much closer to home. Precoated house siding may go as long as 20 years with just an occasional hosing down. It can save you a small fortune in paint, brushes and ladders.

The synthetic plastics industry started 57 years ago with a Union Carbide plastic. Today our plastics are helping to explore the ocean floor and the surface of the moon. And we're working on some that may go farther than that. In fact there's very little we're not working on.

UNION CARBIDE

THE DISCOVERY COMPANY

50 AND 100 YEARS AGO

SCIENTIFIC AMERICAN

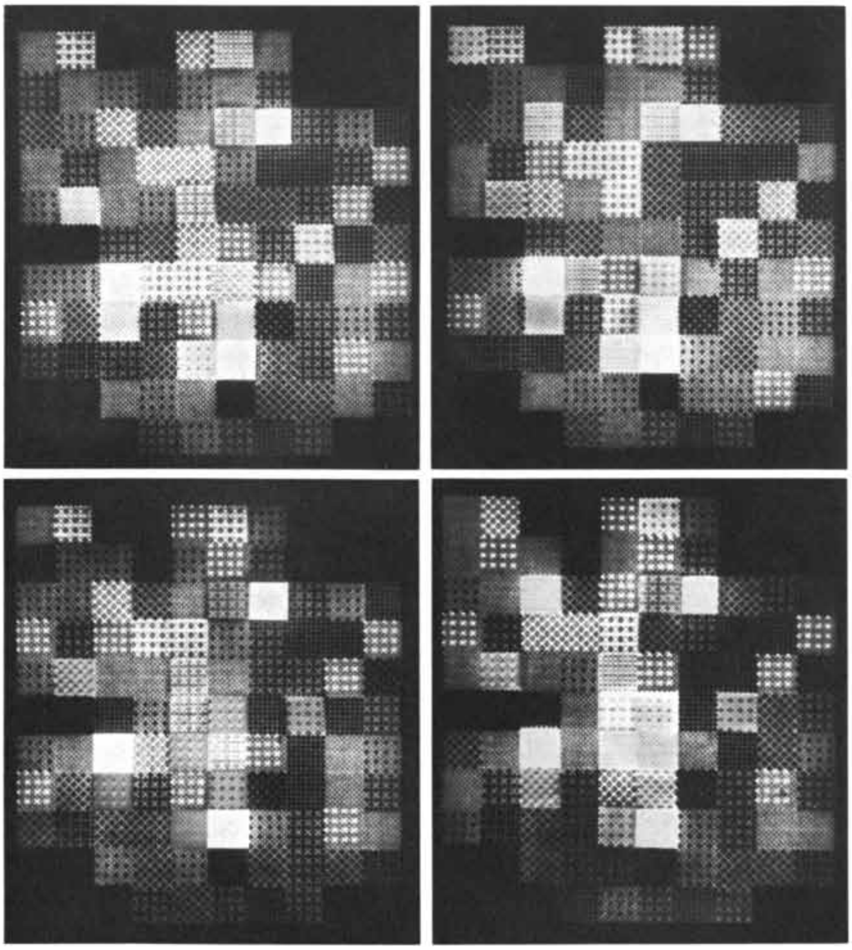
NOVEMBER, 1917: "Nothing short of a catastrophe of the first magnitude has descended upon Italy's armies. Of that there can be no doubt. At the time of writing the mountain heights on the Isonzo have been lost to the Italians, the important railroad center of Udine has been captured and the invasion of the northern Italian plains appears to be well under way by the Austro-German forces pouring in through the mountain defiles. Whether or not the Italians will be able to check the invader on the Tagliamento line, which takes its name from the river flowing more or less in a north and south direction, remains to be seen. At any rate, the Italians are fighting well, remarkably well; their cavalry and other light units are conducting an effective rear-guard action with the Austro-German vanguards, while the bulk of Cadorna's forces are retreating in an orderly and masterful manner."

"Before the ever changing kaleidoscope of Russian events as revealed from day to day, prediction must falter and grow pale. Never has a revolution been brought about under such circumstances or involved such possibilities of world-wide consequence. On these grounds alone the daily chronicle of Russia's conflict would possess extraordinary interest for all people of all nations. But today, with the world plunged in its greatest international struggle, the battles of Petrograd and Moscow claim our attention even more urgently for another reason. What effect will the Russian Revolution have upon the war is the question that rises instinctively to every lip of whatever nationality. When we attempt to consider the revolution from this point of view, the first thing we must realize is that we are at once separating ourselves from the revolutionists by a tremendous gap. The Russian regards the war as an incident of the revolution, rather than the other way about; he is interested in making sure that the war shall not interfere with his revolution rather than that his revolution shall not

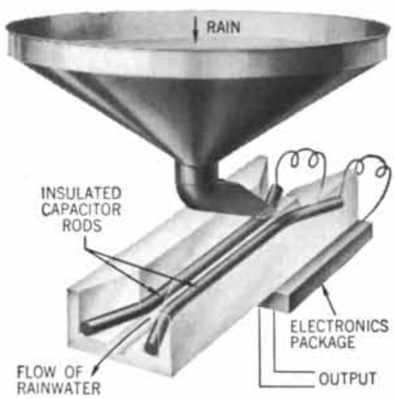
Report from

BELL LABORATORIES

Photos of a rainstorm



Sequence of computer-generated rainfall-rate patterns at 10-second intervals. (Order is upper left and right, then lower left and right.) Small "patches" correspond to geographic positions of 93 rain gauges. Each patch can have one of 48 computer representations of rain rate: dark for no rain, gradually brightening for increasing rainfall. Thus, each of the four frames "maps" a rainstorm in the area, and the sequence is like a motion picture. (Detailed data are recorded on magnetic tape for analysis and correlation with radio transmission characteristics, but the display gives a quick overall view.)

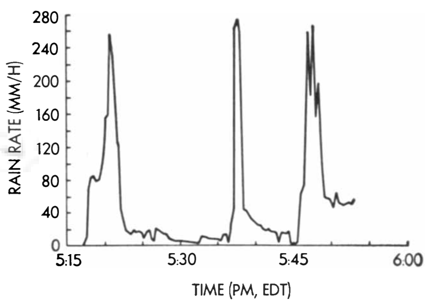


The new rain-rate gauge. Rain collected in funnel, top, flows along 45° incline between two insulated rods . . . the electrodes of a capacitor in an oscillator. Heavier rainfall lowers the oscillator frequency. The gauge can detect one raindrop, yet is accurate within five percent at rates of more than 10 inches per hour.

The pictures at the left represent rain on a 60-square-mile area in east-central New Jersey on November 28, 1966. Actually, they are four photos of a computer-generated display. The brightness of each little "patch" indicates the rainfall rate at each of 93 gauges spaced throughout the area.

We study rainfall because it impairs higher-frequency microwave radio transmission. But no one has had detailed data on its effects. All we had were relatively infrequent rainfall readings from a few gauges near radio paths. We needed—and now have—almost instantaneous readings of rainfall rate from closely spaced gauges over an area.

The result? We have learned a lot about rainfall—for example that heavy, small-area concentrations of rain occur and shift around within a wide-area storm. More important, we can now begin to relate rainfall patterns to specific transmission difficulties. With this information we are improving our strategies for establishing, despite the weather, more reliable radio relay paths at higher microwave frequencies.



Rainfall rate on one gauge during a storm on May 27, 1965. Note rapid response of gauge to changing intensity of rain.

Bell Telephone Laboratories
Research and Development Unit of the Bell System

compromise our war. Alike because of this and because of the physical condition of Russia, we must face the bald fact that this nation is out of the war so far as effective participation is concerned."

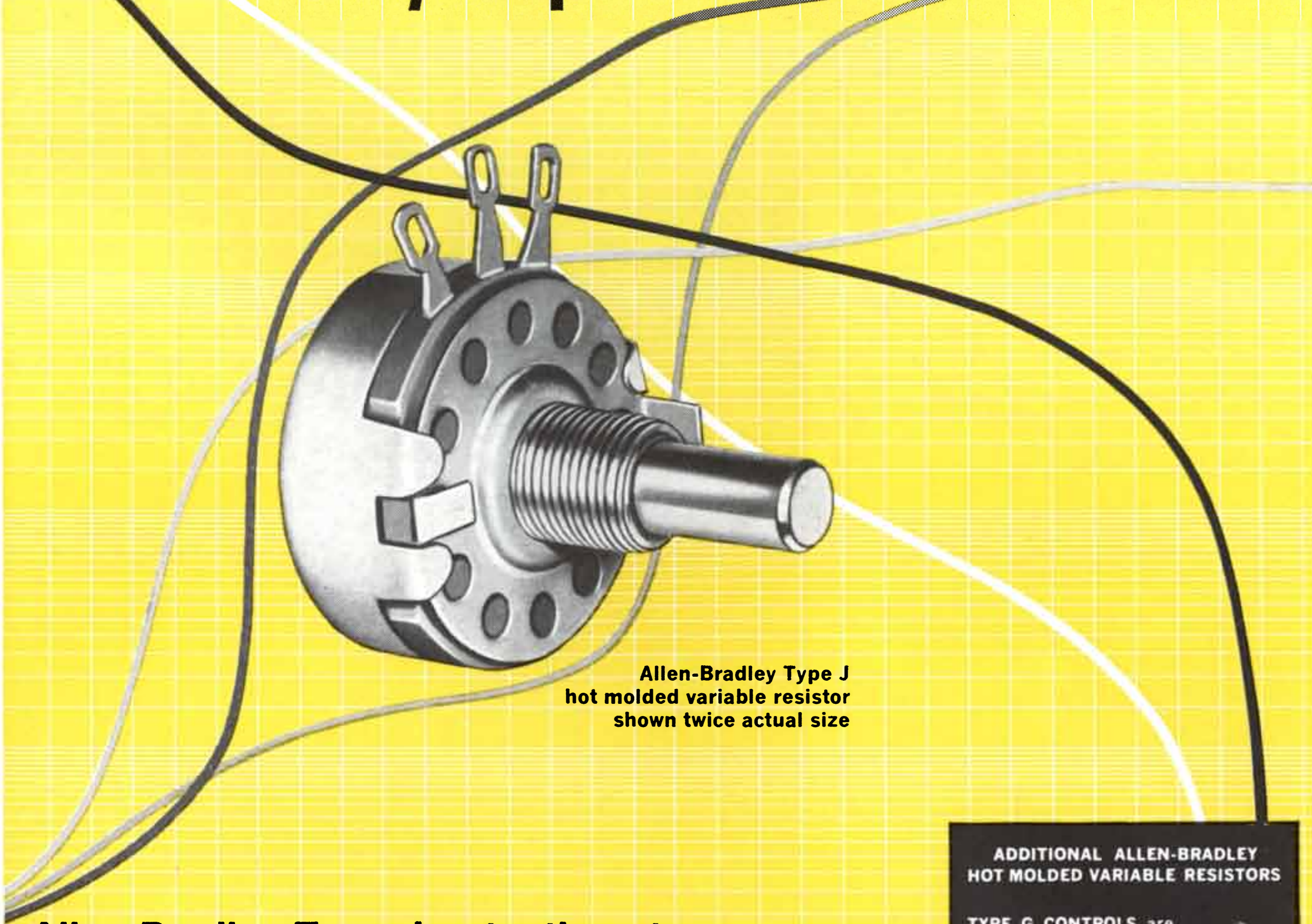
"In view of the recent measurements of the altitude of the aurora made by Carl Störmer and others, which indicated that the phenomenon was chiefly limited to a region 55 miles and upward above the earth, Camille Flammarion suggests that this location may be related to the fact that the atmosphere at such levels consists mainly or entirely of hydrogen. The auroral discharges would, he thinks, be due to the ionization of this gas by corpuscles emitted by the sun."

"According to a note in the *Journal of the Society of Chemical Industry,* it has been found that many tobaccos yield a smoke containing large quantities of free nicotine, which can be extracted by passing the smoke through a cotton-wool plug treated with tannin. In some cases as much as 12.3 per cent of the total nicotine can be recovered in this way. It is suggested that the use of such plugs by smokers would be of advantage from a health point of view."

"There now, unfortunately, seems little doubt that Captain Guynemer, the famous French airman, is dead. The Germans have announced in the *Gazette des Ardennes* that he was killed about 800 yards east of the cemetery of Poelcapelle. It is said that a German sergeant found there a one-seater with a wing broken and the pilot dead from a bullet wound in the head, and on him an identity disk with the name 'Georges Guynemer.' Captain Guynemer had brought down no fewer than 53 enemy machines and had been decorated by the French government with the Légion d'Honneur, the Médaille Militaire and the Croix de Guerre. A telegram to the *Cologne Gazette* states that the German officer who shot down Captain Guynemer was Flight Lieutenant Wissemann, who himself has since been killed. In his last letter to his parents, in which he described how he brought down the French 'Ace,' Lieutenant Wissemann wrote: 'Do not be anxious, as I can never have a more dangerous enemy.'"

"A new wood, apparently little known and called balsa wood, is exceedingly light and promises to have an extended field of usefulness in connection with cold-storage structures when heat in-

tricky tapers...



Allen-Bradley Type J hot molded variable resistor shown twice actual size

Allen-Bradley Type J potentiometers offer tapers designed to your special needs!

■ When standard tapers fail to provide the control you desire, Allen-Bradley Type J potentiometers have the unique capability to provide a virtually limitless variety of curves to meet your specialized requirements. While not a precision device that is continuously taper-trimmed to very close tolerances, Allen-Bradley's control of the resistance-rotation characteristics during production assures a high degree of conformity.

Allen-Bradley Type J potentiometers have a solid hot molded resistance track made by an exclusive process which was pioneered and perfected by A-B. This solid resistance track assures smooth adjustment at all times—with none of the discrete changes in resistance that are encountered in wire-wound units. And being essentially noninductive, Type J controls can be applied in high frequency circuits where wire-wound units are useless.

Furthermore, A-B's solid molded resistance track assures low noise and long life. On accelerated tests, Type J potentiometers exceed 100,000 complete operations with less than 10% change in resistance.

For more complete details, please write: Allen-Bradley Co., 1204 South Third St., Milwaukee, Wis. 53204. In Canada: Allen-Bradley Canada Limited. Export Office: 630 Third Ave., New York, N.Y., U.S.A. 10017.

ADDITIONAL ALLEN-BRADLEY HOT MOLDED VARIABLE RESISTORS

TYPE G CONTROLS are only ½" in diameter. Quiet, stepless operation. Rated ½ watt at 70°C. Values to 5 megohms. Type L are similar in construction but rated ½ watt at 100°C.

TYPE F TRIMMERS are for mounting directly on printed wiring boards by means of their terminals. Rated ¼ watt at 70°C. Values to 5 megohms. Type O are similar but rated 0.4 watt at 70°C.

TYPE R ADJUSTABLE RESISTORS for trimming applications are built to withstand environmental extremes. Only 1¼" in length. Have stepless adjustment. Watertight and can be encapsulated. Rated ¼ watt at 70°C. Values to 2.5 megohms. Type N for less severe environments are rated ⅓ watt at 50°C.

867-3AB

ALLEN-BRADLEY

QUALITY ELECTRONIC COMPONENTS

sulation is important. It is a tropical wood growing principally in the countries of South and Central America. The wood is remarkable, first, as to its lightness; second, as to its microscopic structure; third, for its absence of woody fiber; fourth, for its elasticity, and fifth, for its heat-insulating properties."

SCIENTIFIC AMERICAN

NOVEMBER, 1867: "M. O. Poulet read at a late meeting of the French Academy a paper on whooping cough, in which he stated that during an epidemic of whooping cough that prevailed in his neighborhood he found in the air expired by a number of children suffering under it a vast number of infusoria, identical in every case, which had the property of communicating the disease to persons inhaling them."

"A very curious observation, on the spectrum of a terrestrial flame closely resembling that of certain yellow and red stars, has been communicated to the Italian society called the Forty of Modena by M. Secchi. This flame is that which proceeds from a converter in which Bessemer steel is being made and at the time when the iron is completely decarbonized. The spectrum presents a series of very fine and very numerous lines, similar to those of certain stars, only reversed. This results from the great number of metals burning in the flame and is the only flame comparable with the colored stars."

"Artificial rubies, not mere copies in glass but made veritably out of the same substance—alumina—of which the natural gems are composed, have been produced by M. Ebelsman of the Sèvres Porcelain Works near Paris. The process consists in employing a solvent, which dissolves the mineral or its constituents and may thus, either upon its renewal or by a diminution of its solvent powers, permit the mineral to aggregate in a crystalline state. Certain proportions of alumina, magnesia, oxide of chromium, or oxide of iron, and fused boracic acid are placed in a crucible made of refractory alumina enclosed in a second one, the whole being exposed to a high heat. The materials are first dissolved in the boracic acid; then as the heat continues the latter evaporates, the alumina and coloring matter combine, crystallize and present the exact appearance of the spinel ruby."

With RAX time-sharing, up to 63 people use one IBM SYSTEM/360 simultaneously.

RAX (Remote Access Computing System) is a time-sharing program designed for IBM SYSTEM/360 Models 30, 40, 50.

With RAX, the engineer, scientist or programmer—using a remote terminal—processes his problems on the central SYSTEM/360. Up to 62 of his colleagues can do the same thing simultaneously. Each one works without concern for the system's total processing load. Their typewriter consoles or visual display stations return results after a typical wait of only four to five seconds.

At the same time, operators at the computer center can batch process FORTRAN and Basic Assembler Language problems through SYSTEM/360.

The first RAX system was developed at Lockheed Aircraft in Marietta, Ga.

The one-man, one-console idea began to germinate at Lockheed about four years ago. It had become apparent to people like Dr. Warren Herron, Chief of Scientific Computing, that engineers need a highly accessible computing medium to work out small computational problems requiring quick turnaround.

Aided by systems engineers from the local IBM office, Lockheed developed a program suited to its particular needs that reduced turnaround time from two or three days to a matter of seconds in most cases.

From experience gained with this and other interactive systems, IBM has now generalized and expanded RAX, adding various operational features that allow SYSTEM/360 users to select from a variety of configurations to meet their specific requirements.

Textron's Bell Aerosystems Company, for example, has a RAX installation for its engineering design work at Wheatfield, New York.

"With RAX," says R. E. Carroll, Bell's Director of Data Processing, "an engineer is no longer faced with the problem of queuing for short jobs. Previously, if he had a job that was too complex for a desk calculator, he had to stack it with others and wait as long as two days for the computer output. In the meantime he would turn to other things—in effect, he learned to time-share his work. Now the computer does the time-sharing, not the engineer."

At LTV Aerospace Corp., Dallas based subsidiary of Ling-Temco-Vought, Inc., engineers use RAX to process data from wind tunnel experiments and to solve other aircraft design problems. One typewriter-like terminal, located in the office of a vice president, is used for financial analysis and forecasting. The LTV computer center has installed 18 terminals—nearly all of them miles from the central computer; the most distant is 200 miles away.

Illinois Bell Telephone Company headquartered in Chicago, has strategically located over 30 remote terminals throughout the company for shared-time operations. Over the next two years the number of terminals will more than double. The company uses the RAX system for a variety of jobs, such as telephone transmission and rate studies, analyzing sales performance, and identifying trends in telephone usage.

At the University of Rhode Island, visual display terminals help researchers study problems like fish population interaction. Such studies take into account mortality rates, growth rates, migration habits and other factors, and how the fishing industry and its markets are affected.

At the same time, students and faculty at other terminals elsewhere on the campus are using the central computer to find more efficient ways to transmit information electronically, to analyze urban housing characteristics and to solve other problems.

If you would like to know more about RAX and how it can help you solve your problems faster, write for a copy of the RAX brochure to: Director, Scientific Development, IBM Corporation, Department 805-054, 112 East Post Road, White Plains, New York 10601.

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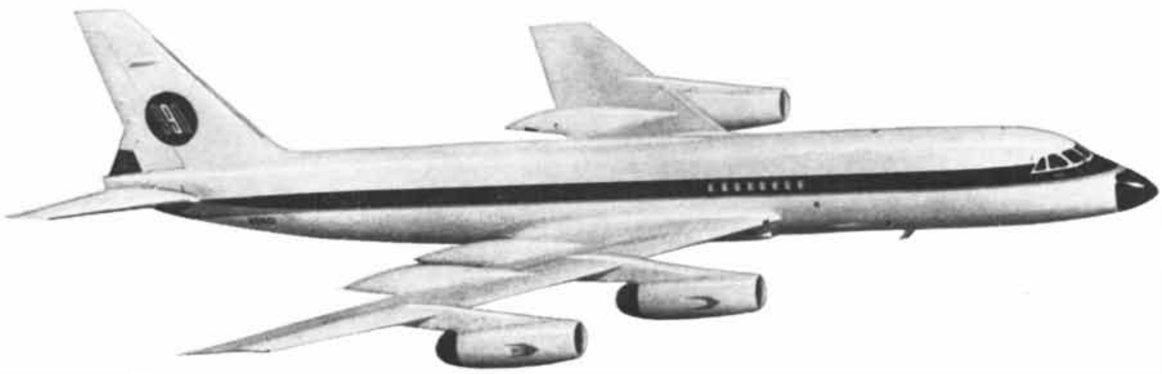
F-102. Now serving overseas. World's first all-weather supersonic interceptor. It was designed for the United States Air Forces to seek and destroy invading high-speed aircraft before they can reach their target.

F-106. Now operational with the Air Defense Command of the United States Air Force. A later, faster sister to the F-102. In 1959, it was clocked at 1,525.95 miles per hour—or 2.3 times the speed of sound.

CL-44. Now carrying freight around the world. It is the first aircraft designed specifically for airfreight. The swing tail reduces loading and unloading time because of unobstructed access to the fuselage, and permits carrying longer and larger objects than possible with conventional aircraft.



Convair 990. Now flying throughout the world. It is the world's fastest commercial jet liner. Carries 121, cruises at 640 miles per hour. The 990 can be distinguished from all other jet passenger liners by two "speed capsules" on the trailing edge of each wing. The capsules decrease drag by lessening shock waves.

CL-84. Now in development production. It combines features of the helicopter and fixed-wing plane. With wing, engine and propeller unit tilted straight up, it can take off or land vertically. With partial wing tilt, it can take off from short fields with heavy payload. With wings and engine positioned horizontally, it can fly as fast as 300 miles per hour.

CL-215. Now in production for France and the Province of Quebec. First new amphibian to be built in 30 years. Can be used for water bombing, search and rescue, patrol, cargo, crop dusting or spraying. It can scoop up about 5,500 liters of water as it taxis across a lake, take off, then drop water on fire area in an uninterrupted flight.

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THE AUTHORS

HARRIET ZUCKERMAN ("The Sociology of the Nobel Prizes") is assistant professor of sociology and a project director of the Bureau of Applied Social Research at Columbia University. She was graduated from Vassar College in 1958 and received a Ph.D. from Columbia in 1965. "My studies of the laureates," she writes, "are part of a more comprehensive comparison of the work patterns of scientific elites and rank-and-file investigators. After doing a small number of interviews, I found—and this is scarcely surprising—that the laureates were a remarkably fruitful source of information on the reward system in science and its relation to such matters as scientific collaboration, communication and the development of scientific ideas. It seemed sensible then (and it still does) to focus my efforts on this distinguished group of scientists." The studies on which the article is based are part of Columbia's Program in the Sociology of Science, which is supported by the National Science Foundation.

RONALD F. SCOTT ("The Feel of the Moon") is professor of civil engineering at the California Institute of Technology and also a consultant to the Jet Propulsion Laboratory of Cal Tech. He obtained a bachelor's degree in civil engineering from the University of Glasgow in 1951, a master's degree in civil engineering from the Massachusetts Institute of Technology in 1953 and an Sc.D. in soil mechanics from M.I.T. in 1955. For two years after leaving M.I.T. he was a soil engineer with the Arctic Construction and Frost Effects Laboratory of the U.S. Army Corps of Engineers. His activities there included directing a research project that involved building a road and a bridge on an ice cap in Greenland. Before going to Cal Tech in 1958 Scott spent a year and a half as a soil engineer with a Canadian firm.

EDWARD P. LANNING and THOMAS C. PATTERSON ("Early Man in South America") are respectively associate professor of anthropology at Columbia University and assistant professor of anthropology at Harvard University. Lanning, who received a Ph.D. from the University of California at Berkeley in 1960, has worked extensively in Peru. Patterson did his undergraduate work at the University of California at Riverside and obtained a Ph.D. from Berkeley in 1964. He was on the Berkeley faculty until he went to Harvard in 1965; at Harvard, in addition to his teaching, he is a research associate in South American archaeology.

ANTHONY ALLISON ("Lysosomes and Disease") has spent most of his professional career with the Medical Research Council of Great Britain. He is now head of the division of cell pathology at the council's Clinical Research Centre in London. Allison received a Ph.D. and a medical qualification from the University of Oxford. For several years he worked on human population genetics, traveling extensively in various parts of the world to get material. Recently he has been attempting to apply similar principles to populations of cells in single organisms, particularly in relation to the origin of cancer. Allison describes himself as "interested in far too many things." He adds that he is "a firm believer in the necessity for communicating scientific approaches and results to nonscientists, especially to children in high school."

THOMAS E. HOWARD ("Rapid Excavation") is director of mining research in the Bureau of Mines of the U.S. Department of the Interior. He was graduated from the Colorado School of Mines in 1941 and worked in both mining and the construction of tunnels before joining the Bureau of Mines in 1951. He writes: "The research program for which I am responsible covers the entire spectrum of mining technology and is concerned with all solid minerals. Studies we have under way on behalf of the National Aeronautics and Space Administration, concerned with extraction and utilization of extraterrestrial minerals, together with our own research in marine mineral technology in effect extend the scope of the program all the way from the moon to the bottom of the sea."

KIP S. THORNE ("Gravitational Collapse") is associate professor of theoretical physics at the California Institute of Technology. He was graduated from Cal Tech in 1962 and received master's and doctor's degrees from Princeton University in 1963 and 1965 respectively. In 1965–1966 he was a postdoctoral fellow in physics at Princeton; from then until he took up his present post this year he was a research fellow in physics at Cal Tech. Before beginning his current research, which he describes in his article, he made experimental studies of the structure of atomic nuclei, using a cyclotron at Princeton; did theoretical research on synchrotron radiation from stars and planets with dipole magnetic fields (he writes that "this work, when combined with astronomical observations, has yielded information about the Van Allen radiation belts of Jupiter"), and mathematical research in general relativity theory with the objective of discovering and describing new physical phenomena peculiar to that theory.

W. EHRENBERG ("Maxwell's Demon") is professor of experimental physics and head of the physics department at Birkbeck College of the University of London. He writes: "Apart from 10 years in industry I have held various academic posts since I was graduated in 1924. As a student I was almost equally interested in moral and social philosophy and in physics. In my early postgraduate years in Berlin the weekly colloquia, which were regularly and actively attended by such leading physicists as Planck, Einstein, von Laue, Nernst and Schrödinger, provided a unique education in the appreciation of scientific achievements." Of his present activities Ehrenberg says: "Naturally I spend much time talking to students, colleagues and administrators, probably more than in teaching and in research. Still, occasionally a little time or strength is left for other occupations. I like reading, mainly novels, history and philosophy. I do some gardening, carpentry and those crafts that keep a house together and that my wife and my teen-age daughter ask me to apply."

SUZANNE W. T. BATRA and LEKH R. BATRA ("The Fungus Gardens of Insects") are biologists at the University of Kansas; Mrs. Batra is a research associate in the department of entomology and her husband is associate professor of botany. Mrs. Batra was graduated from Swarthmore College in 1960 and obtained a Ph.D. from the University of Kansas in 1964. At Kansas she has been primarily studying the behavior and ecology of various social and solitary wild bees. Her husband, a native of India, received a Ph.D. from Cornell University in 1958 and then taught for two years at Swarthmore. At Kansas he teaches mycology and plant pathology. He is currently working at the National Fungus Collection of the U.S. Department of Agriculture in Beltsville, Md.

CHARLES F. HOCKETT, who in this issue reviews *Biological Foundations of Language,* by Eric H. Lenneberg, is professor of linguistics and anthropology at Cornell University.

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When UOP designs its Aerotherm® seats, you can bet we look out for All-Pro Chicago Bear linebacker Dick Butkus. For, after a tough day at the office—greeting the Detroit Lions or shaking hands with the delegates from Green Bay—Dick insists on comfort, and no annoyances. When he wants the seat to recline, it had better; and just right.

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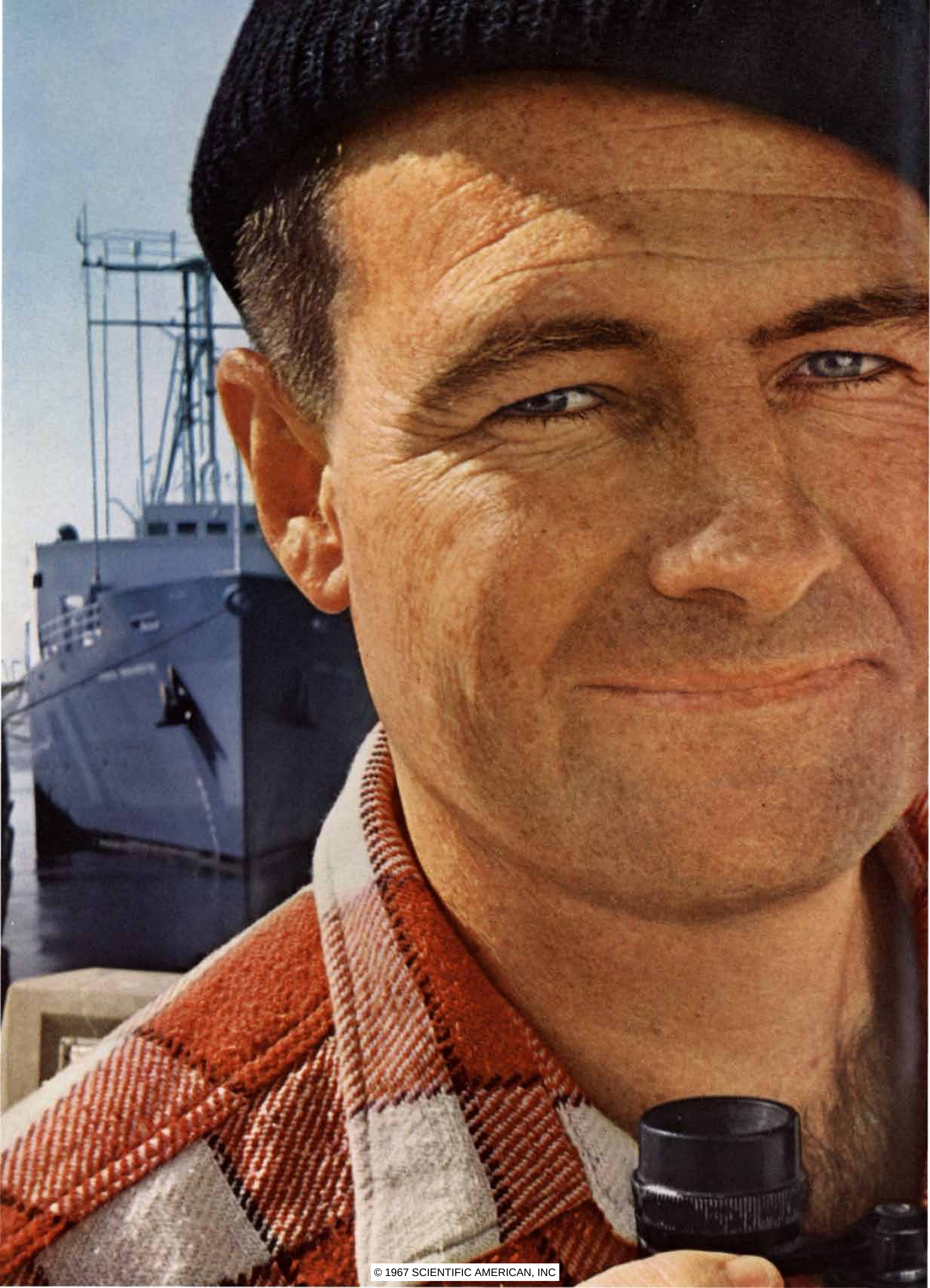

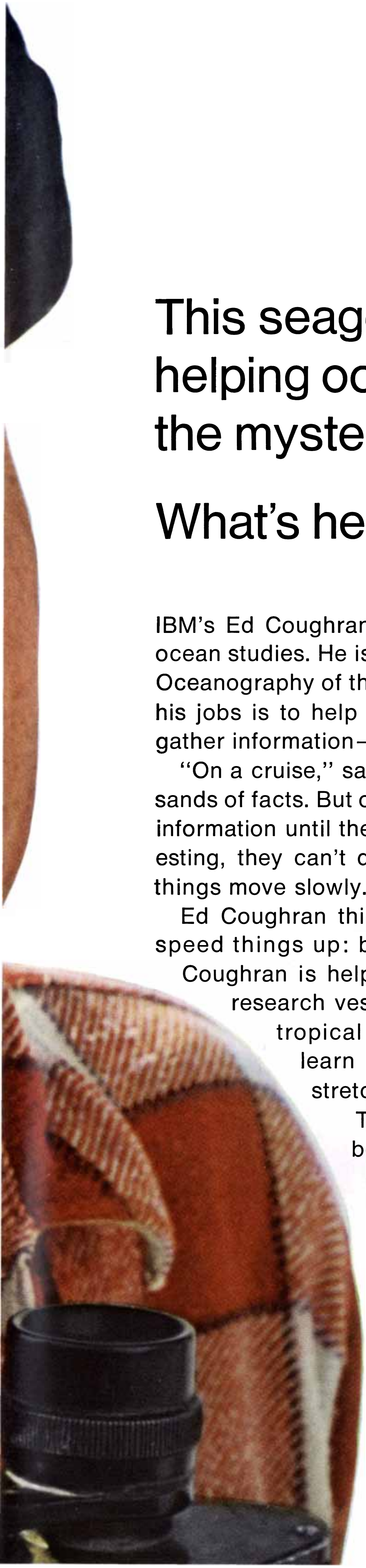

This seagoing scientist is helping oceanographers fathom the mysteries of the deep.

What's he doing at IBM?

IBM's Ed Coughran is a scientist who applies mathematics to ocean studies. He is assigned to work with Scripps Institution of Oceanography of the University of California, San Diego. One of his jobs is to help oceanographers at sea as they struggle to gather information—in fair weather or foul, 24 hours a day.

"On a cruise," says Coughran, "oceanographers collect thousands of facts. But ordinarily, they don't have time to analyze this information until they return to port. If they find something interesting, they can't do anything about it until next time out—so things move slowly."

Ed Coughran thinks he has a way to help oceanographers speed things up: by going down to the sea with computers.

Coughran is helping to install an IBM computer aboard the research vessel, Thomas Washington, for a trip into the tropical Pacific. Scripps' oceanographers want to learn more about this lonely, largely unexplored stretch of sea.

The computer, through sensing equipment, will be able to collect and store facts on water temperature, salinity and pressure. Then, analyze it immediately. This means oceanographers can formulate new theories and gather the facts to test them while still in the Pacific.

This and other information about the ocean can serve mankind in many ways—for example, in helping us exploit the food resources of the undersea world. And it's one more demonstration of how IBM experts—like Ed Coughran—are using computers to help solve information problems of all kinds, ashore or afloat.

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Tin Free Steel

Metallic chromium and a chemical passivation combine to produce a coating on steel strip that is extremely thin, highly corrosion resistant and likely to result in superior steel containers.

by E. J. Schneider, Research Supervisor

Tin cans, which are, of course, made from a sheet of steel covered by a thin layer of tin, are the most familiar of all metallic containers. In recent years, however, the container industry has been undergoing a revolution in materials, and the prominence of the tin can is now challenged by competitors such as the aluminum can and the latest entry into the field, the "tin free steel" (TFS) can.

Replacement of tin plate by a substitute material is not simple. Tin permits soldering the side seam of the can at high speeds and provides corrosion resistance. Therefore, the new product has required the development of alternate ways to join the side seam, such as with adhesives, and the use of other types of protective coatings, such as improved organic enamels. It has been shown that bare steel will not serve as an adequate base for the enamels, or provide corrosion protection in the area of a ruptured film. These requirements have led to the evolution of a new class of coated product, a chromium plated can stock.

During early phases of seeking a coating system for steels for application in the enameled, adhesive side seam container, researchers examined various metallic and non-metallic materials which could be deposited on steel strip at high strip line speeds (1,000 feet per minute or greater). It soon became evident that chromium-based systems offered both the required physical and chemical properties, plus ease of application.

Chemical passivation treatments involving chromium salts (such as CrO_3 or $Na_2Cr_2O_7$) have long been employed to provide increased corrosion resistance to steel, galvanized steel and tin plate. However, chemical passivation treatments did not by themselves provide the combination of corrosion resistance and enamel adhesion required. On the other hand, deposits of metallic chromium alone afforded more corrosion resistance, but tended to stain under the organic coating when made into cans and packed with certain foodstuffs. However, by applying metallic chromium plus a chemical passivation treatment the properties required by the can manufacturers were obtained. If we consider the amount of surface covered by rust on a steel sample after exposure to a laboratory corrosion test, we find a striking decrease in the rusting of a sample given the duplex (chromium plus passivation) treatment. This is shown in Table 1.

Treatment	% Rust
Chemical Passivation	90
Chromium Only	3
Chromium + Chemical Passivation	<1

Table 1—Rust after exposure

The chemical treatment permits reduction of the metallic chromium to very thin layers (.2 to .4 microinches, or 50 to 100 Ångstroms).

Some of the more interesting information on these coatings arises from attempts to characterize the films. Problems are encountered because of the very thinness of the films (a .2 microinch coating of chromium, if distributed evenly, would be only on the order of 20 atoms thick). Several techniques are used to evaluate the thickness and nature of the films. For example, the direct measurement of extremely thin chromium layers in the tin free steels is very difficult by even advanced metallographic techniques. However, if a sample is placed in an electrolytic cell and made the anode, the films are dissolved as current flows through the cell. This is the reverse of the electroplating process. When the potential of the sample is measured against some standard electrode, a plot of potential vs. time will reveal the thickness of the chromium layer, since the time required to remove a uniform coating is proportional to the amount of material in the coating.

Electrolytic techniques which determine thickness, however, give us only part of the story.

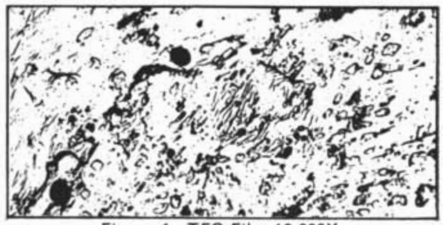

Figure 1—TFS Film 10,000X

Figure 1 shows an electron micrograph of a composite surface coating removed from a sample. By electron diffraction, the presence of metallic chromium and Cr_2O_3 has been verified in this film. The integrity of the film, i.e., its relative freedom from cracks or voids as might be anticipated in chromium electro-deposits, is undoubtedly due to the extreme thinness of the deposit, and plays an important part in the corrosion protection which it provides.

These characterizations are, by themselves, only of limited interest. Simultaneous programs involving research on the plating process and evaluation of the coated steels in both laboratory tests and actual use (pack) tests are also under way. In this way, research correlates all phases of the container material investigation. By gaining insight into the structure and properties of coatings like the one described above, steel researchers can develop superior products which can be effectively produced.

The work on TFS and other coatings for steel is only a small part of the continuing investigations being conducted at Youngstown's Research Center on steel as a basic material. If you believe that Youngstown Research could help you as a user of steel, call us or write Department 251B8.

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Established 1845 SCIENTIFIC AMERICAN November 1967 Volume 217 Number 5

The Sociology of the Nobel Prizes

The prizes in science have such prestige that they affect institutions as well as the individuals who win them. An analysis of the American prizewinners, with special reference to their origins and their fate

by Harriet Zuckerman

For a few weeks each winter the city of Stockholm becomes the capital of the international community of science. The bestowal at this season of the Nobel prizes—in physics and in chemistry by the Swedish Royal Academy of Science and in physiology and medicine by the Royal Caroline Institute—confers on their winners the ultimate accolade. No other award brings comparable prestige. The Nobel Prize is regarded not only by laymen but also by scientists as the most honorific recognition of scientific achievement. For example, nearly all of some 1,300 American physicists ranked it in a survey ahead of such older or richer prizes as the Rumford Premium, the Enrico Fermi Award or the Albert Einstein Medal.

The prestige of the Nobel Prize is so great that it enhances the standing of nations and institutions as well as the reputation of its "laureates." The fall of Germany from preeminence in science and

GROUP PICTURE OF NOBEL PRIZEWINNERS made at a White House dinner in 1962 includes a substantial fraction of the 71 American "laureates" in science discussed in this article. Seated in the front row are Georg von Bekesy, Pearl Buck, Rudolf L. Mössbauer, Mrs. Ernest Hemingway, President Kennedy, Mrs. George C. Marshall, Melvin Calvin, Mrs. Kennedy and Robert Hofstadter. Standing are William Shockley, Lester Pearson, E.C. Kendall, Joseph Erlanger, W. P. Murphy, Peter J. W. Debye, Philip S. Hench, Victor F. Hess, C. N. Yang (*rear*), Arthur Kornberg, Owen Chamberlain (*rear*), Carl D. Anderson, I. I. Rabi, Thomas H. Weller, Fritz Lipmann, Albert Szent-Györgyi, E. A. Doisy, John Bardeen (*rear*), C. F. Cori, H. J. Muller, W. F. Giauque (*rear*), Selman A. Waksman, Harold C. Urey, F. C. Robbins, W. M. Stanley and Edwin M. McMillan. Eight others in the photograph are obscured.

YEAR	PHYSICS	CHEMISTRY	PHYSIOLOGY AND MEDICINE
1901	Röntgen, W. K.	van't Hoff, J. H.	von Behring, Emil
1902	Lorentz, H. A. Zeeman, Pieter	Fischer, Emil	Ross, Ronald
1903	Becquerel, Henri Curie, Pierre Curie, Marie	Arrhenius, Svante	Finsen, N. R.
1904	Rayleigh, Lord	Ramsay, Sir William	Pavlov, I. P.
1905	von Lenard, Philipp	von Baeyer, Adolf	Koch, Robert
1906	Thomson, J. J.	Moissan, Henri	Golgi, Camillo Ramon y Cajal, Santiago
1907	**Michelson, A. A.**	Buchner, Eduard	Laveran, C. L. A.
1908	Lippmann, Gabriel	Rutherford, Ernest	Metchnikoff, Elie Ehrlich, Paul
1909	Marconi, Guglielmo Braun, Ferdinand	Ostwald, Wilhelm	Kocher, Theodor
1910	van der Waals, J. D.	Wallach, Otto	Kossel, Albrecht
1911	Wien, Wilhelm	Curie, Marie	Gullstrand, Allvar
1912	Dalén, Gustaf	Grignard, Victor Sabatier, Paul	**Carrel, Alexis**
1913	Kamerlingh Onnes, Heike	Werner, Alfred	Richet, Charles
1914	von Laue, Max	**Richards, T. W.**	Bárány, Robert
1915	Bragg, W. H. Bragg, W. L.	Willstätter, Richard	
1916			
1917	Barkla, C. G.		
1918	Planck, Max	Haber, Fritz	
1919	Stark, Johannes		Bordet, Jules
1920	Guillaume, C. E.	Nernst, Walther	Krogh, August
1921	Einstein, Albert	Soddy, Frederick	
1922	Bohr, Niels	Aston, F. W	Hill, A. V. Meyerhof, Otto
1923	**Millikan, R. A.**	Pregl, Fritz	Banting, F. G. Macleod, J. J. R.
1924	Siegbahn, Manne		Einthoven, Willem
1925	Franck, James Hertz, Gustav	Zsigmondy, Richard	

ALL THE NOBEL PRIZEWINNERS in science are given in the list on these two pages and the following one. The prizewinners who are credited to the U.S. are indicated in heavier type. The criterion for so crediting them is whether or not the work for which

the ascendance of the U.S. is sometimes reckoned by the number of Nobel prizes won by the nationals of the two countries. In the U.S., as this country has moved up to first place in the cumulative total of prizes bestowed, the claiming and counting of prizewinners has come to serve as a mode of competition for prestige among the country's universities, colleges and research organizations, including even the most prestigious of them.

Although such competition seems trivial, it is serious business. All manner of organizations need to appraise their performance. Business enterprises seize on percentage of profit and growth of sales and assets. For academic and scientific institutions there are no comparably objective and precise measures of accomplishment. When it comes to the training of scientists and the support of their work, the Nobel prizes are assumed to be one relatively objective measure of how well institutions are doing. To put the matter quite simply, therefore, what does the counting of Nobel prizes tell about the performance of the institutions of higher learning that claim their winners? The inquiry described here undertakes to answer this question from a survey of the self-appraising official publications of the universities, from biographical data on the laureates living in the U.S. and from interviews with 41 of them.

All the 24 American institutions with which 57 Nobel prizewinners are now (or, more precisely, as of the academic year 1966–1967) affiliated derive honor from these men. The University of California at Berkeley takes pride in the presence on its faculty of 10 prizewinners (including professors emeritus), Harvard University in having nine. Columbia University and Stanford University each have five.

The spread of glory does not, however, stop at present affiliation. Every institution with which the prizewinners have been affiliated at any time and in any way can and does take pride in the fact. A survey of official documents of these institutions shows there are at least 10 kinds of affiliation that serve as grounds for public claim to a Nobel prizewinner. He can be claimed by the institution at which he did his undergraduate work and by the one from which he got his doctoral degree. Some institutions claim him if he studied there without getting a degree. A postdoctoral year or two may also suffice for a claim. Membership on a faculty in any rank, from research assistant to full professor, establishes a legitimate connection, whether the scientist held his appointment before, during or after he did his prizewinning work. Presence at an institution at the time the award is made, or after that, also justifies a claim. At the end of the prizewinner's career, when he takes a visiting professorship after his official retirement, he brings honor to his new employer. The prestige of the Nobel Prize is such that 80 percent of the institutions that can lay claim to a prizewinner on the basis of any one of these ties do so.

Reckoning of this kind has several intriguing consequences. In the first place it multiplies the presence of the prizewinner and brings honor to a number of institutions much larger than the number of prizewinners. The 409 different affiliations of the 76 men who were in the U.S. at the time they won the prize (the basis on which national claims are usually grounded) allows them to be claimed by 141 institutions. Academic mobility thus expands the pool of institutional

1926	Perrin, Jean	Svedberg, The	Fibiger, Johannes
1927	**Compton, A. H.** Wilson, C. T. R.	Wieland, Heinrich	Wagner Jauregg, Julius
1928	Richardson, O. W.	Windaus, Adolf	Nicolle, C. J. H.
1929	de Broglie, Louis	Harden, Arthur von Euler Chelpin, H. K. A. S.	Eijkman, Christiaan Hopkins, Sir Frederick Gowland
1930	Raman, Sir C. V.	Fischer, Hans	Landsteiner, Karl
1931		Bosch, Carl Bergius, Friedrich	Warburg, Otto
1932	Heisenberg, Werner	**Langmuir, Irving**	Sherrington, Sir Charles Adrian, E. D.
1933	Schrodinger, Erwin Dirac, P. A. M.		**Morgan, T. H.**
1934		**Urey, Harold C.**	**Whipple, G. H.** **Minot, G. R.** **Murphy, W. P.**
1935	Chadwick, James	Joliot, Frédéric Joliot Curie, Irène	Spemann, Hans
1936	Hess, Victor F. **Anderson, Carl D.**	Debye, Peter J. W.	Dale, Sir Henry Loewi, Otto
1937	**Davisson, C. J.** Thomson, G. P.	Haworth, W. N. Karrer, Paul	Szent-Györgyi, Albert
1938	Fermi, Enrico	Kuhn, Richard	Heymans, C. J. F.
1939	**Lawrence, Ernest O.**	Butenandt, Adolf Ružicka, Leopold	Domagk, Gerhard
1940			
1941			
1942			
1943	Stern, Otto	de Hevesy, George	Dam, Henrik **Doisy, E. A.**
1944	**Rabi, I. I.**	Hahn, Otto	**Erlanger, Joseph** **Gasser, H. S.**
1945	Pauli, Wolfgang	Virtanen, A. I.	Fleming, Sir Alexander Chain, E. B. Florey, Sir Howard
1946	**Bridgman, P. W.**	**Sumner, J. B.** **Northrop, J. H.** **Stanley, W. M.**	**Muller, H. J.**
1947	Appleton, Sir Edward	Robinson, Sir Robert	**Cori, C. F.** **Cori, Gerty T.** Houssay, B. A.
1948	Blackett, P. M. S.	Tiselius, Arne	Müller, P. H.
1949	Yukawa, Hideki	**Giauque, W. F.**	Hess, W. R. Mon[illegible] A. F

they received the prize was done in this country. For example, James D. Watson (*see continuation of this list on next page*) is an American, but because his main work on the structure of nucleic acids was done while he was in Britain it is not credited to the U.S.

prestige. At one extreme, the biochemist Fritz Lipmann can be claimed by 11 institutions and the chemist Harold C. Urey by 10. On the other hand, there are three prizewinners who can be counted only once because each spent his entire career at a single university: the physicist Carl D. Anderson (the California Institute of Technology), the physicist P. W. Bridgman (Harvard) and the physical chemist W. F. Giauque (the University of California at Berkeley).

The present inquiry has not attempted to determine whether the claims laid to prizewinners in all the diverse capacities mentioned carry equal weight with the audiences to which they are directed, nor even whether close ties to a single laureate throughout his career brings greater advantage to an institution than more tenuous ties to a large number of men associated for shorter periods. The claims themselves, however, and the manner in which they are put forward tell much about the relative standing of institutions.

For the most part institutions are remarkably precise in characterizing a prizewinner's affiliation with them. Washington University counts the biochemist E. A. Doisy in its roster of prizewinners with the qualification that he "did most of his work at St. Louis University [but] served for a time on the Washington Medical School faculty." The University of California at Berkeley shows the same care in claiming the biochemist J. H. Northrop: "[He] has been a member of the Rockefeller Institute since 1916, contributing the major part of his numerous research accomplishments at the Institute's former laboratory in Princeton. He came to the University of California in 1949, but has continued to serve as a member of the Rockefeller Institute." By such precision institutions concede the legitimacy of competing claims and avoid embarrassing accusations of encroachment by others. By the same token they are able to extend their claims to men whose association may have been slight, to say the least; implicit in the careful specification of claims is the assumption that any claim is justified as long as it is spelled out. As a result the geneticist H. J. Muller appears on the Cornell University list on the ground that he spent a year there as a student; the physicist Ernest O. Lawrence, on the University of Chicago list because he began his doctoral work there under the Nobel prizewinner R. A. Millikan, and the Swedish chemist Arne Tiselius, on the Princeton University list because he spent a postdoctoral year at the Frick Chemical Laboratory. The Princeton list also includes the physicists P. A. M. Dirac and Wolfgang Pauli on the basis of visiting professorships. The short career of Rudolf L. Mössbauer at Cal Tech and of Hideki Yukawa at Columbia qualify them for inclusion on the lists of those universities because they happened to be there at the time the award was made. Chicago stakes a claim to Eugene P. Wigner and Glenn T. Seaborg on the basis of their wartime work in the Metallurgical Laboratory of the Manhattan project, which was housed on the Chicago campus.

These claims are the principal but not the only means used by institutions to assert publicly their association with Nobel laureates. The Case Institute of Technology, for example, has established the Michelson Prize to honor its first professor of physics and America's first Nobel laureate in any science. And City College of the City of New York has

YEAR	PHYSICS	CHEMISTRY	PHYSIOLOGY AND MEDICINE
1950	Powell, C. F.	Diels, Otto; Alder, Kurt	Kendall, E. C.; Reichstein, Tadeus; Hench, Philip S.
1951	Cockcroft, Sir John; Walton, E. T. S.	McMillan, Edwin M.; Seaborg, Glenn T.	Theiler, Max
1952	Bloch, Felix; Purcell, Edward M.	Martin, A. J. P.; Synge, R. L. M.	Waksman, Selman A.
1953	Zernike, Frits	Staudinger, Hermann	Krebs, H. A.; Lipmann, Fritz
1954	Born, Max; Bothe, Walther	Pauling, Linus	Enders, John F.; Weller, Thomas H.; Robbins, F. C.
1955	Lamb, Willis E.; Kusch, Polykarp	du Vigneaud, Vincent	Theorell, Hugo
1956	Shockley, William; Bardeen, John; Brattain, Walter H.	Hinshelwood, Sir Cyril; Semenov, N. N.	Cournand, André F.; Forssmann, Werner; Richards, Jr., Dickinson W.
1957	Yang, C. N.; Lee, T. D.	Todd, Sir Alexander	Bovet, Daniel
1958	Čerenkov, Pavel A.; Frank, Ilya M.; Tamm, Igor J.	Sanger, Frederick	Beadle, George W.; Tatum, Edward L.; Lederberg, Joshua
1959	Segrè, Emilio; Chamberlain, Owen	Heyrovský, Jaroslav	Ochoa, Severo; Kornberg, Arthur
1960	Glaser, Donald A.	Libby, Willard F.	Burnet, Sir Macfarlane; Medawar, P. B.
1961	Hofstadter, Robert; Mossbauer, Rudolf L.	Calvin, Melvin	von Bekesy, Georg
1962	Landau, L. D.	Perutz, M. F.; Kendrew, John C.	Crick, Francis H. C.; Watson, James D.; Wilkins, Maurice H. F.
1963	Wigner, Eugene P.; Goeppert-Mayer, Maria; Jensen, J. H. D.	Ziegler, Karl; Natta, Giulio	Eccles, Sir John; Hodgkin, A. L.; Huxley, A. F.
1964	Townes, Charles H.; Basov, N. G.; Prokhorov, A. M.	Crowfoot Hodgkin, Dorothy	Bloch, Konrad; Lynen, Feodor
1965	Tomonaga, S. I.; Schwinger, Julian; Feynman, Richard P.	Woodward, Robert B.	Jacob, François; Lwoff, André; Monod, Jacques
1966	Kastler, Alfred	Mulliken, Robert S.	Rous, Peyton; Huggins, Charles B.

LIST IS CONTINUED from the preceding two pages. Where there are blanks in the list no prize was awarded in that category that year; this is notably true of the war years 1916, 1940, 1941 and 1942. Three of the German prizewinners (Kuhn, Butenandt and Domagk) were not allowed to accept the prize during the Nazi period. After the war they were given the prize without the cash award.

given a prize to Arthur Kornberg, its first alumnus to win "the prize"—possibly the first time a man has won an award for having won an award.

Certain institutions observe self-denying ordinances that limit their claims to laureates. Harvard does not list its laureate-alumni, nor does it count men who were on its faculty at some time or another before or after winning the prize. It claims only those who did their prize-winning research at Harvard and those who were on its faculty when the award was made. The University of California at Berkeley observes the same restraints but counts its alumni as well. Rockefeller University, listing the names of six laureates in its catalogue, gains prestige by the inverse strategy of making no published claims at all.

A kind of stratification can thus be observed in the style with which institutions wrap themselves in the Nobel mantle. The same stratification appears in the way they invoke other indicators of their standing and performance. Higher-ranking universities confine themselves to mentioning winners of major scientific awards; those at the second and third levels of prestige do not neglect what award winners they have but will also indicate, for example, which faculty members hold office in scientific societies. Those at the lowest level are confined to using such indicators as the number of papers published by their faculty members, which are the best they can muster. This pattern reflects the fact that the choice of measures of performance available becomes increasingly limited at successively lower ranks. Top-ranking universities could use most of the indicators mentioned by those ranked below them; they do not choose to do so. Whatever form the "publish or perish" syndrome takes at Berkeley or Harvard, it does not take the form of toting up the number of faculty publications. Their laureates and academicians provide them with much loftier measures of institutional accomplishment.

It should be noted, by the way, that universities are not the only institutions to seek in the counting of Nobel prizes an objective measurement and affirmation of their performance. The Guggenheim Foundation, with its modest stipends covering all fields of learning and the arts, takes understandable pride in the finding that it supported the work of 12 Nobel prizewinners in the sciences before they won the prize. The Rockefeller Foundation, with much larger programs of support for science, can claim to have sponsored nearly 100 laureates, "almost always before [they] received their prizes." Even the National Academy of Sciences must stand scrutiny on this standard of performance. The Academy itself has not, of course, publicly assessed its own prescience. Writing in *Science*, however, D. S. Greenberg reports the finding that the Academy had elected, before they won the prize, 36 out of the 45 U.S. scientists who have won the prize since 1950. Finally, it can be said of *Scientific American* that it has, in its coverage of a much greater diversity of science than that recognized by the Nobel prizes, published the work of 17 prizewinners before that work won them the prize.

The grand total of "American" Nobel prizewinners in the sciences can be counted in various ways. If it is taken to include those who emigrated to this country after they won the prize, as Enrico Fermi and Albert Einstein did, then the number is 82. If one restricts the count to those who were in this country when they received the award, the total is 76; if to those who were here when they did their prizewinning work, then the total is 71. A stricter measure of the performance of the country's universities in identifying and nurturing scientific talent is the number of prizewinners who got their doctoral training at these universities; that number is 58. In all, they received their degrees from 16 institutions. Half of them were trained at only four: Harvard, Columbia, Berkeley and Princeton. The concentration of laureates-to-be in this small number of universities reflects to some extent the concentration of doctoral training. Only four universities have trained 20 percent of all the Ph.D.'s in physics, chemistry and the biological sciences since 1920. These four are Chicago, the University of Illinois, Berkeley and the University of Minnesota—not the same four that produced half of the laureates. The latter four bestowed only 14 percent of the doctorates and therefore trained far more than their proportionate share of these distinguished scientists.

That does not necessarily mean that these universities are superior. Nor does it mean the opposite: that one university is as good as another. What the figures do show, at the very least, is that the future laureates were more apt to seek admission to certain graduate schools and to be accepted by them. There is evidence of a high degree of discrimination on both sides of these transactions. A physicist laureate, comparing his approach to the choice of his "master" and graduate school with that of his contemporaries, declared: "Many students are just silly [about] the way they go for professors. They just don't know; they are very innocent. I was far from innocent . . . I made my own judgment." In the same vein another physicist laureate remarked: "I was attracted by [his] name . . . I know enough about physics to appreciate him, to appreciate his style." It so happens that both of these men were discussing Enrico Fermi. The record suggests that Fermi, for his part, had quite a talent for identifying young men of promise; no fewer than four of his graduate students and junior collaborators went on to win the Nobel Prize. Although few laureates claim a talent equal to Fermi's, most of them believe they can recognize a promising student when they come across him. They are what the sociologists Paul Lazarsfeld and Robert Merton of Columbia call "scientific truffle dogs." One laureate responds to questioning on this subject with exuberance: "Oh, I'm wonderful!" Such a combination of self-selection and eagerly selective recruitment would indeed tend to concentrate the talented students in a small number of graduate schools.

It is also possible that these concentrations of future laureates in a few universities result in part from differential visibility. Young men who take their degrees under distinguished scientists who themselves are concentrated at a few institutions are inevitably more visible to senior scientists who count, that is, the men who allocate research funds and facilities and who, indeed, participate in the selection of Nobel prizewinners. This hypothesis is consistent with the fact that the laureates who trained at the most prestigious institutions received the prize, on the average, at the age of 47, more than 10 years earlier than men trained elsewhere; this difference holds within each field.

The presence of great teachers accounts in part for the differential distribution of prizewinners among universities by field of work. Thus the prominence of Berkeley in chemistry can be traced to the fact that every one of its laureates in chemistry studied under G. N. Lewis—one of the several truly great scientists overlooked in the award of the Nobel Prize. The attraction of Fermi brought C. N. Yang and T. D. Lee from China to Chicago. On the other hand, no single teacher accounts for the appearance of Princeton in first place in the training of laureates in physics. Princeton produced its five prizewinners over the long period from 1911, when C. J. Davisson got his degree, to 1942, when Richard P. Feynman received his.

The universities that rank first in the production of prizewinners also rank first when it comes to the retention and recruitment of future prizewinners on their faculties. Although most of these men were "early bloomers," few were truly eminent before beginning their prizewinning research. One measure of the performance of a university is its record in the recognition of such promise. It is significant, therefore, that the 12 leading universities managed to identify and to retain these scientists of exceptional talent; they kept 70 percent of the future laureates on their faculties after they had received their doctoral degrees, compared with only 28 percent of other Ph.D.'s they trained. The same 12 universities recruited to their faculties half of the laureates-to-be who trained elsewhere, these men being among the 6 percent of the graduates of lesser schools who found appointments in the elite universities.

Again, it can be argued that visibility works in favor of the scientist thus selected. A crude test of this hypothesis is provided by consideration of the time lag between accomplishment of the prizewinning work and the award of the prize. It turns out that men who did their work at the top 12 universities waited on the average 8.6 years for the prize, whereas men who did their work elsewhere waited 10.7 years. The difference is not great, but it holds for each field. An appointment outside the top 12 universities thus delays but scarcely precludes the winning of the prize.

With their commanding lead in the training, retention and recruitment of laureates-to-be, the same group of universities naturally provide the setting for prizewinning research. The number of prizes now to be accounted for totals 71, won by 57 American-trained scien-

MEDALS that accompany the Nobel science awards show, in the case of the physics and chemistry prizes (*left*), the allegorical figure of Nature being unveiled by Knowledge and, for the prize in physiology and medicine (*right*), Healing in the act of comforting the sick.

tists, 12 Europeans and two Americans who got their doctorates abroad. Harvard, Columbia and Berkeley in that order were the sites for the work of 40 percent of the laureates; in all, prizewinning work was done at 22 institutions, among them the Bell Telephone Laboratories and the General Electric Research Laboratory. Harvard and Berkeley again appear in first place in the life sciences and chemistry respectively, whereas Columbia replaces Princeton in physics.

With this background we can better understand how it is that 33 laureates-to-be had taken their doctorates or worked, as young men, with 38 prior prizewinners. The prizes again follow two patterns of distribution. On the one hand, there is the clustering of prizes around one line of work. All but one of Berkeley's seven physicists and chemists did much of their work in the laboratory of Ernest O. Lawrence. I. I. Rabi, whose work on the magnetic properties of nuclei won him the Nobel Prize, attracted three future prizewinners, Willis E. Lamb, Polykarp Kusch and Charles H. Townes, to Columbia's Radiation Laboratory. On the other hand, the work at Harvard that won prizes for eight life scientists was spread over many years and a great diversity of specialties, from virology to psychoacoustics.

In view of the time lag between the doing of the work and the awarding of the prize, it is something of a test for a university to hold on to a laureate-to-be whose light has begun to shine—at least among the colleagues in his own field. In the face of presumably frequent and tempting offers from outside, however, 73 percent of the winners were at the universities where they had done their work when the word came from Stockholm. Of the 19 men who did migrate during this interval, four stayed within the top 12 universities and six came in from outside. Harvard and Berkeley each retained all their future prizewinners, 12 and seven of them respectively.

COUNTRY	PHYSICS	CHEMISTRY	PHYSIOLOGY AND MEDICINE
Argentina			1
Australia			2
Austria	3	1	3
Belgium			2
Canada			2
China	2		
Czechoslovakia		1	
Denmark	1		4
Finland		1	
France	8	6	6
Germany	14	21	10
Great Britain	15	15	15
Hungary		1	2
India	1		
Ireland	1		
Italy	2	1	2
Japan	2		
The Netherlands	5	2	2
Portugal			1
Spain			1
Sweden	2	4	2
Switzerland		3	4
Republic of South Africa			1
U.S.	26	15	30
U.S.S.R.	6	1	2
Total	88	71	92

CITIZENS OF 25 NATIONS have received Nobel science awards. In this table the Republic of South Africa is included because Max Theiler, prizewinner in medicine in 1951 for his studies of yellow fever at the Rockefeller Foundation, is a citizen both of that country, his birthplace, and of Switzerland. The number of French laureates includes Marie Curie under both physics (shared with her husband in 1903) and chemistry (hers alone in 1911).

As some three to nine additional scientists will discover in the 1967 Nobel season, winning the prize is an unsettling experience. That is the testimony of all the prizewinners interviewed in the course of the present inquiry. A physicist declared: "Very few people have survived it with a whole skin." A new laureate finds himself subjected to a variety of demands and obligations laid on him by his colleagues, his university, the government, the press and the public at large. André Lwoff of the Pasteur Institute in Paris, who shared the 1965 prize in physiology and medicine with his colleagues Jacques Monod and François Jacob, described the experience:

"We have gone from zero to the condition of movie stars. We have been subjected to what may be called an ordeal. We are not used to this sort of public life, which has made it impossible for us to go on with our work.... Our lives are completely upset.... When you have organized your life for your work and then such a thing happens to you, you discover you are faced with fantastic new responsibilities, new duties."

Some laureates are better prepared for this ordeal than others. For those who have already won eminence the prize is only a capstone. Thus Eugene Wigner, recognized by his colleagues for years as an uncrowned laureate, had already won many awards, including the $50,000 Enrico Fermi Award, and was a member of two national academies. A man of similar eminence has said: "I've not found the Prize a burden.... It can be one very easily if you start accepting all the invitations.... But I've never done that. I've tried to limit this business...

INSTITUTION	LAUREATES AFFILIATED AS RECIPIENTS OF DOCTORAL DEGREE	LAUREATES DOING PRIZE-WINNING WORK AT INSTITUTION	LAUREATES AFFILIATED AT TIME OF AWARD	LAUREATES CURRENTLY ACTIVE ON STAFF
Harvard University	11	13	13	7
Columbia University	8	9	7	2
University of California at Berkeley	6	7	8	8
University of Chicago	4	6	4	2
California Institute of Technology	4	3	7	3
Princeton University	6	1	1	1
Washington University		6	3	1
Johns Hopkins University	5			
Bell Telephone Laboratories		4	2	1
Stanford University		4	4	5
Cornell University	1	2	2	1
University of Rochester	2	1	1	
Rockefeller University		3	7	2
University of Illinois	2		1	1
Massachusetts Institute of Technology	2		1	
Mayo Clinic		2	2	
University of Minnesota	2			
University of Wisconsin	1	1	1	
Yale University	2			2
Case Institute of Technology		1		
General Electric Research Laboratory		1	1	
University of Indiana	1		1	
Institute for Advanced Study		1	1	
University of Michigan		1		
New York University		1	1	1
University of Pittsburgh	1			
Rockefeller Foundation		1		
Rutgers University		1	1	
St. Louis University		1	1	
University of Texas		1		
University of California at Los Angeles			1	1
University of California at San Diego			1	1
Western Reserve University			1	1
Beckman Instruments			1	
Carnegie Institution of Washington			1	
State University of New York at Stony Brook				1

AMERICAN LAUREATES' CAREERS, from the time of their graduate work through the academic year 1966–1967, have seen them affiliated at one time or another with 29 universities, three industrial laboratories, two institutes, one clinic and one foundation. The top five organizations, among them, have educated or employed more laureates-to-be and laureates than the other 31 combined. Charles H. Townes, professor-at-large of the University of California, is numbered among the eight Berkeley prizewinners.

only to those cases where I have a special interest or a special friendship. So I haven't let it be a burden." For other laureates, otherwise unrecognized at the time of the award, the prize makes for an abrupt change of status. One laureate, who had been thrust into sudden eminence, complained: "I want to get rid of a lot of the honors and get back to work. But how do you do it? You have to discharge a certain number of obligations and fight off new ones. . . . At the present time it's difficult for me to keep going because of all this extraneous honor."

The difference in the character of the experience for laureates thus roughly classified in two groups is evident in their rate of publication, a commonly accepted index of productivity. Although the prize was conceived of as a stimulus to further achievement, it often has the opposite effect. The productivity of the American prizewinners falls by a third, from an average of 6.2 papers in the five

INSTITUTION	PHYSICS		CHEMISTRY		PHYSIOLOGY AND MEDICINE	
	RECEIVED DEGREE FROM	DID WORK AT	RECEIVED DEGREE FROM	DID WORK AT	RECEIVED DEGREE FROM	DID WORK AT
Harvard University	2	3	2	2	7	8
Columbia University	3	5	1	1	4	3
University of California at Berkeley	1	3	4	4	1	
University of Chicago	3	2	1	2		2
California Institute of Technology	3	2	1	1		
Princeton University	5	1	1			
Washington University		1				5
Johns Hopkins University					5	
Bell Telephone Laboratories		4				
Stanford University		2				2
Cornell University				2	1	
University of Rochester			1		1	1
Rockefeller University				2		1
University of Illinois	1		1			
Massachusetts Institute of Technology	1		1			
Mayo Clinic						2
University of Minnesota	1		1			
University of Wisconsin					1	1
Yale University	1				1	
Case Institute of Technology		1				
General Electric Research Laboratory				1		
University of Indiana					1	
Institute for Advanced Study		1				
University of Michigan		1				
New York University						1
University of Pittsburgh					1	
Rockefeller Foundation						1
Rutgers University						1
St. Louis University						1
University of Texas						1

LAUREATES-TO-BE received their graduate degrees from 15 U.S. universities and did their prizewinning work either at nine of the same 15 or at one of 15 additional universities and institutions. The same five universities continue to occupy the five top positions.

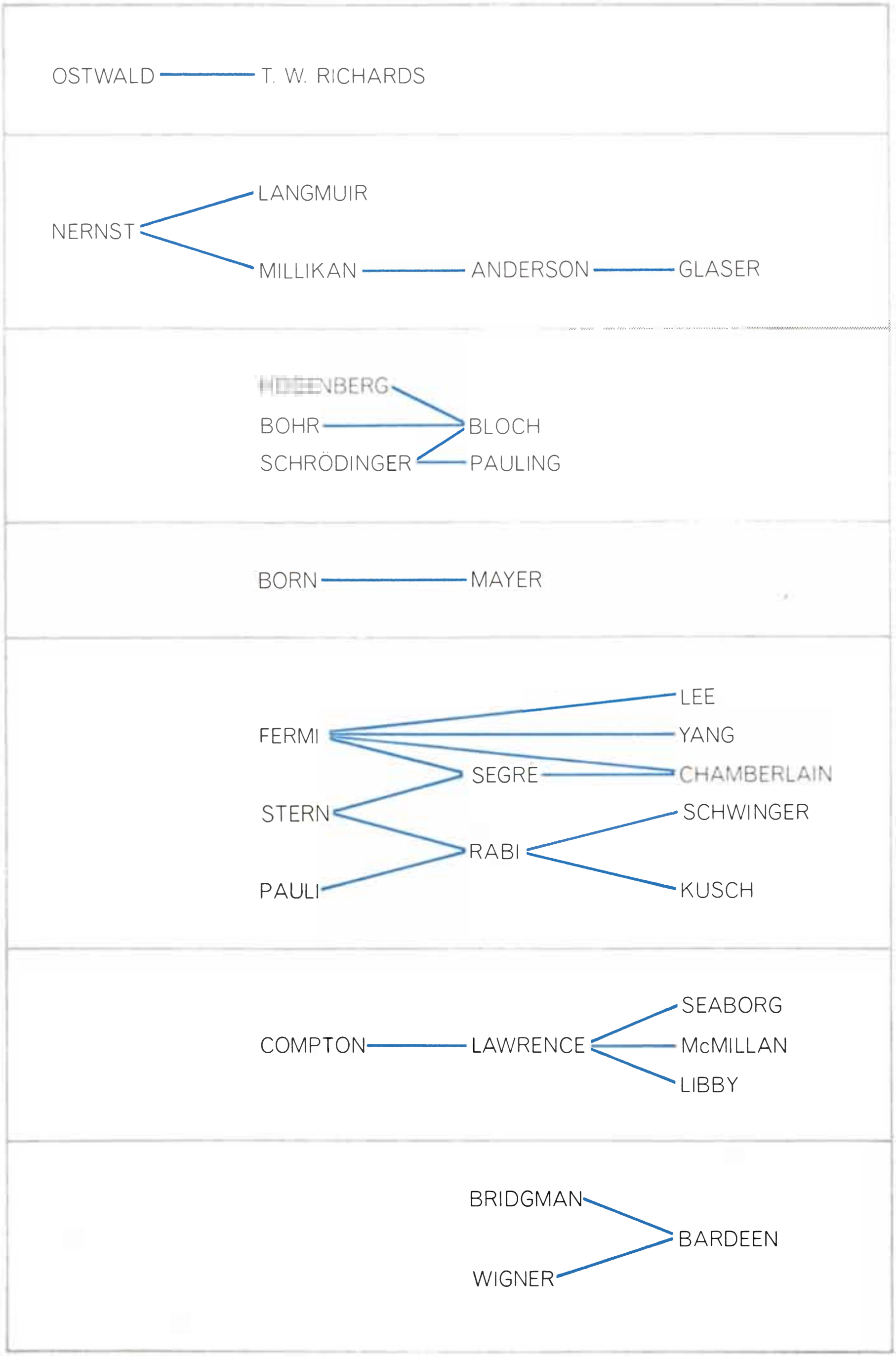
years preceding the prize to an average of 4.2 papers in the five years that follow. The greater the increment of prestige brought by the prize to the individual scientist, the greater the immediate decline in productivity. Among the men honored before they were 50 years old, the productivity of the already eminent dropped off only 9 percent, compared with a decline of 24 percent for those whom the prize catapulted into celebrity. Older laureates understandably show greater decreases in productivity, and the differential between the more and the less eminent is still greater, 28 percent compared with 49 percent. This finding is consistent with the observations of the great 19th-century French sociologist Émile Durkheim concerning the disruptive consequences of rapid change in social rank—including even a high incidence of suicide among the suddenly *nouveau riche*.

For many the award has the effect of erecting barriers between them and their colleagues. Collaborations, sustained for some years before the award, tend to terminate. A physicist who shared the prize tersely put it: "Questions of credit and who did what started coming up." So it turns out that collaborations of single winners and their principal colleagues break up sooner, an average of 3.6 years after the award, than the collaborations of pairs of winners, which persist for an average of 5.4 years—and two such collaborations are still continuing beyond this period.

A happier reflection of the change of status following the award is the *noblesse oblige* exhibited by the laureate in the allocation of first-authorship on collaborative papers. Working with laureates, as many of them did, the laureates-to-be had first-authorship on 60 percent of these jointly authored papers, and their masters took first place on only 16 percent of them. Then, as they themselves became more secure in higher rank, they in turn yielded first place to their juniors. The more eminent future laureates were twice as generous in this regard than the less eminent, taking first-authorship on only 17 percent of their papers, compared with 34 percent for the others. After the award the practice of the two groups becomes much the same: their names appear first on only 13 percent of all collaborative papers. In a crude sense the Nobel Prize serves to bring the standing of the two groups into parity.

There is a widespread impression that the award of the prize and the competitive bidding for "stars" brings an increase in the mobility of the laureates after the award. In reality they are more sessile afterward than before: 82 percent remain at the institutions with which they were affiliated at the time of the award. The opposite impression is perhaps created by the postretirement appointments by which Princeton, the University of Virginia, the new campus of the University of California at San Diego and the University of Hawaii have acquired laureates.

At this writing, prior to the announcement of the 1967 awards, there are a total of 57 laureates in science living in the U.S.; 41 of them hold regular appointments at universities and research institutions. As in all other enumerations in this inquiry, half of them are affiliated with just four institutions. Two of these institutions, Berkeley and Harvard, appear among the top four in all the other enumerations. The processes of training, evaluating and allocating scientific talent appear to operate with some degree of consistency and effectiveness, at least for the upper ranges of scientific talent.



CONTAGIOUS NATURE of laureateship is particularly evident in the physical sciences, where laureates have been the mentors of laureates-to-be for as many as three successive "generations." The chart outlines 26 such relationships, from the time of Wilhelm Ostwald (1909: chemistry) to 1965, when I. I. Rabi's student Julian Schwinger won the physics prize.

The Feel of the Moon

In September Surveyor V *showed that the moon's surface is not unlike the earth's in composition. Six months earlier* Surveyor III *had found that its consistency was also much like a granular terrestrial soil*

by Ronald F. Scott

When men first set foot on the moon, what will the ground be like? Will it perhaps be soft and powdery, as some have suggested, or hard and crusty, as has been proposed by others? Such questions have not been answered definitively by the many photographs of the moon returned to the earth from various spacecraft, although the photographs have certainly narrowed the range of speculation. The most specific evidence has come from *Surveyor III,* which was equipped with a device that could dig into the surface of the moon and place samples of lunar material in front of a television camera for close examination. The area in which the device operated was small, and one cannot assume that it was representative of the entire lunar surface. On the other hand, it is most unlikely that the 24 square feet over which the device probed has properties found only in that particular place. Therefore it is reasonable to say that the samples indicate what kind of surface will be found at least in the general area where *Surveyor III* landed—an area that is under consideration as a landing place for the first American astronauts to go to the moon. The samples tested by *Surveyor III* showed a surface material that in some respects is not quite like what anyone had expected: it is granular and rather like loose soil.

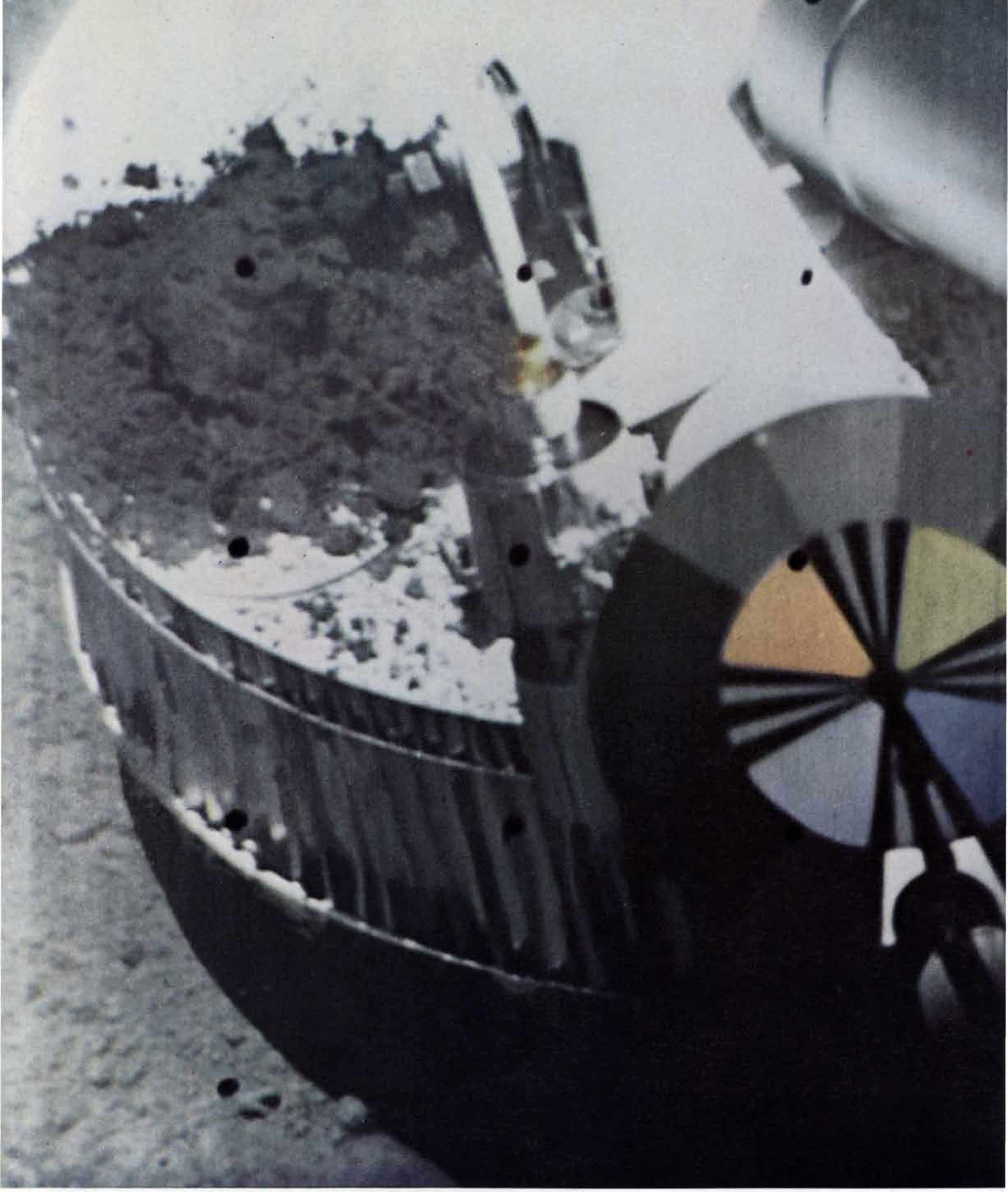
Surveyor III was one of the more recent space vehicles the U.S. has sent to or around the moon in preparation for the Apollo flights that will take men there. The series began with the Ranger vehicles, which made closeup photographs before crash-landing on the moon. In the second phase, now in progress, Lunar Orbiter vehicles make photographs from orbits around the moon and Surveyor vehicles land softly on the moon with cameras and a variety of instruments. By the end of October five Surveyors had been launched. The second and fourth were unsuccessful. The first, which landed in the crater Flamsteed on June 2, 1966, sent back thousands of photographs. The third, launched in April of this year, also sent photographs in addition to performing the digging operation. The fifth, which landed two months ago, provided photographs and also carried a device designed to assess the chemical constituents of the surface to a depth of a few microns by bombarding the surface with alpha particles. In this article I shall concentrate on *Surveyor III,* since it is the only spacecraft that has actually "felt" the lunar surface.

The principal aim of the Surveyor series was to accumulate data that would be helpful in landing men on the moon. During the formative stages of the project an ambitious range of scientific devices had been proposed and carefully considered in terms of their complexity, reliability and weight, together with the character of the information they would provide about the moon. By the end of 1965 the field of prospects had been narrowed to six: a television camera to give information on the topography and geology of the lunar surface; a micrometeorite detector to measure the flux of small particles falling on the moon; a seismometer to record "moonquakes"; the device to assess the chemical nature of the surface by bombarding it with alpha particles; a "touchdown dynamics" system to keep track of the movements of the spacecraft on landing, and the digger, which bore the official designation "soil mechanics surface sampler" and was designed to provide information about the mechanical properties of the moon's surface material.

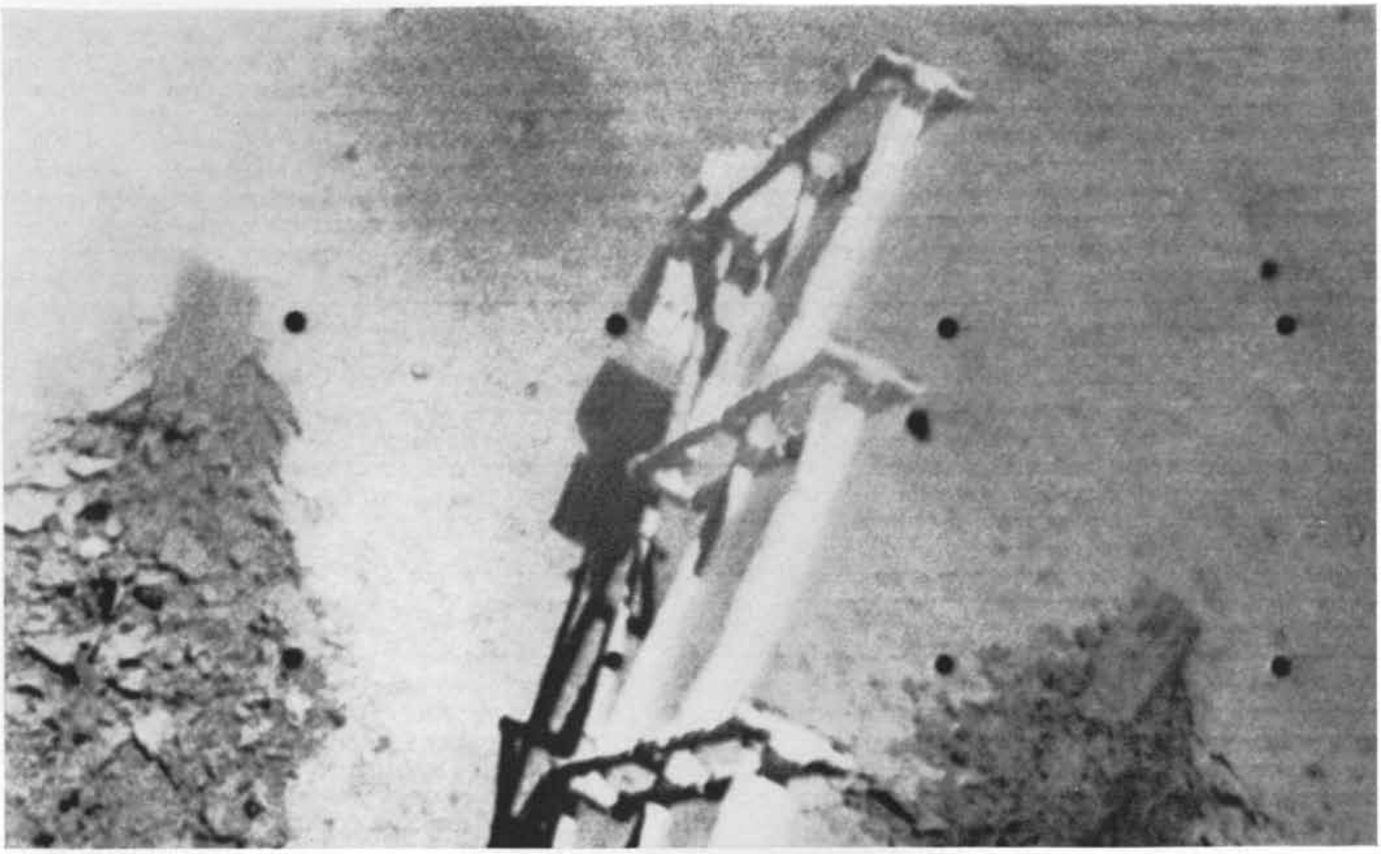
Before the flights that would carry these scientific instruments, however, seven launchings of engineering spacecraft were scheduled. An engineering flight is in effect an extension of the series of tests to which all spacecraft are subjected on the earth. In these tests each component of a spacecraft is tested individually. Then systems of components are tested, followed by work with combinations of systems. Finally all the systems are put in operation together as a spacecraft is flown to the moon. The performance of earlier spacecraft of various types sent aloft by both the U.S. and the U.S.S.R. had indicated that several spacecraft must usually be launched before all the engineering defects of the combined systems can be corrected. The performance of Surveyors is highly complex, and so it was decided that seven engineering flights might be needed to obtain a reasonable probability of a successful landing.

Because the first seven Surveyors were to be engineering vehicles, they were designed to carry no explicitly scientific experiments except for television cameras. The only instruments designated for the vehicles were those intended to yield information on engineering performance. Among them were instruments measuring temperature and acceleration at various points in the spacecraft to check preflight calculations. In addition the craft would carry strain gauges on the shock absorbers of its three landing legs to record the loads put on the legs during landing.

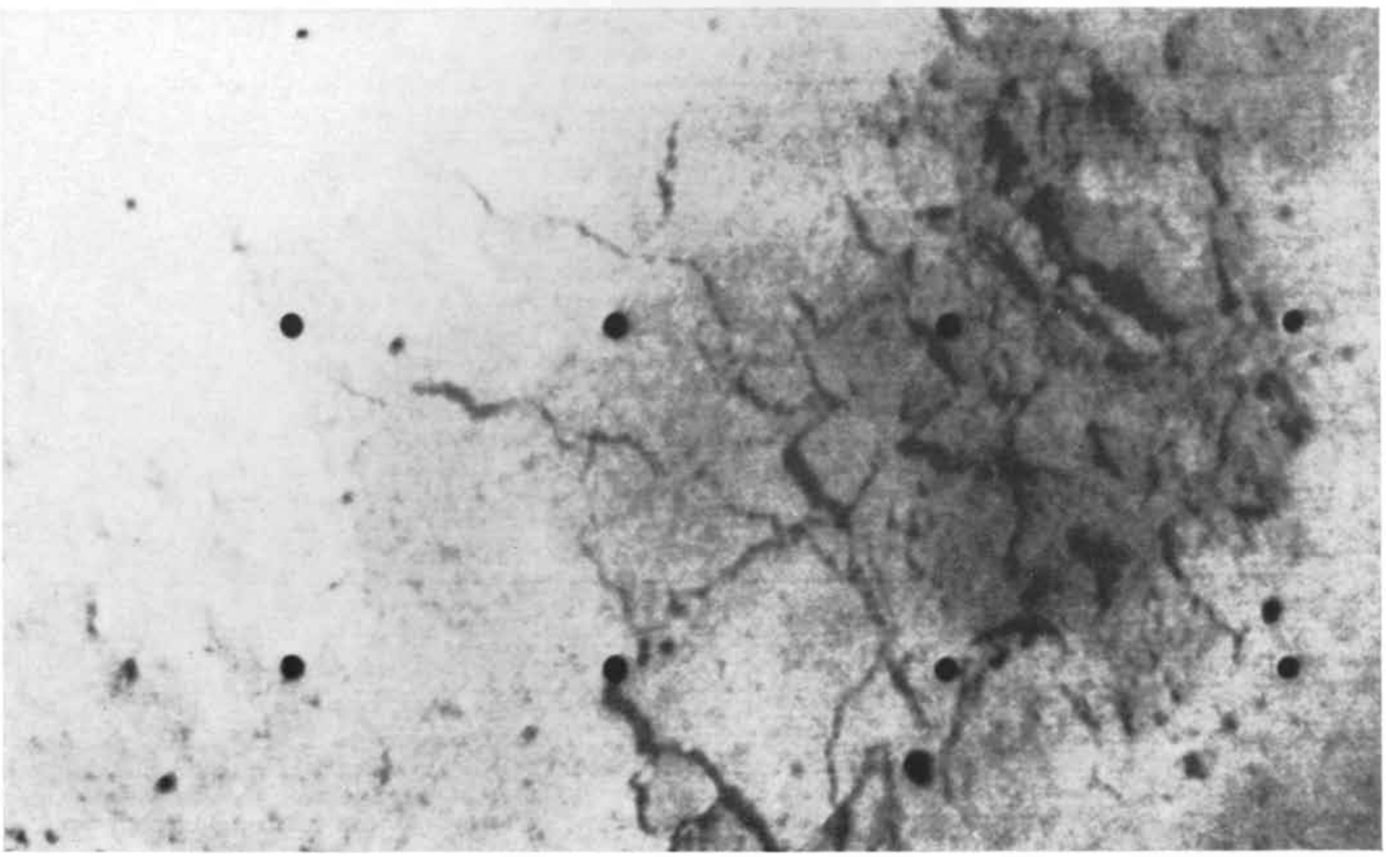
The distinction between an engineering measurement and a scientific experiment, however, is not always a sharp one. Obviously the signals from some of the engineering instruments can be used in scientific interpretations of the nature



LUNAR SURFACE MATERIAL is deposited on a footpad of the *Surveyor III* spacecraft for close examination under the spacecraft's television camera. Scoop carried by *Surveyor III* dug the material from the top few inches of the inside wall of a crater in which the spacecraft landed. The material was successively photographed through red, green and blue filters. A computer on the earth superposed the colors according to values transmitted by the spacecraft. J. J. Rennilson of the Jet Propulsion Laboratory supervised the color assembly. Spacecraft's color wheel (*right*), with pale colors matching spectrum of rocks found on earth, gave check of values.



TWO TRENCHES dug in the surface of the moon by the surface-sampling device of *Surveyor III* appear in this photograph returned to earth by the spacecraft's television camera. The digging was done by the small scoop at the end of the "trellis" at center; the shadow of the scoop is sharply outlined on the lunar surface. The trellis was used for extending and retracting the sampling apparatus.

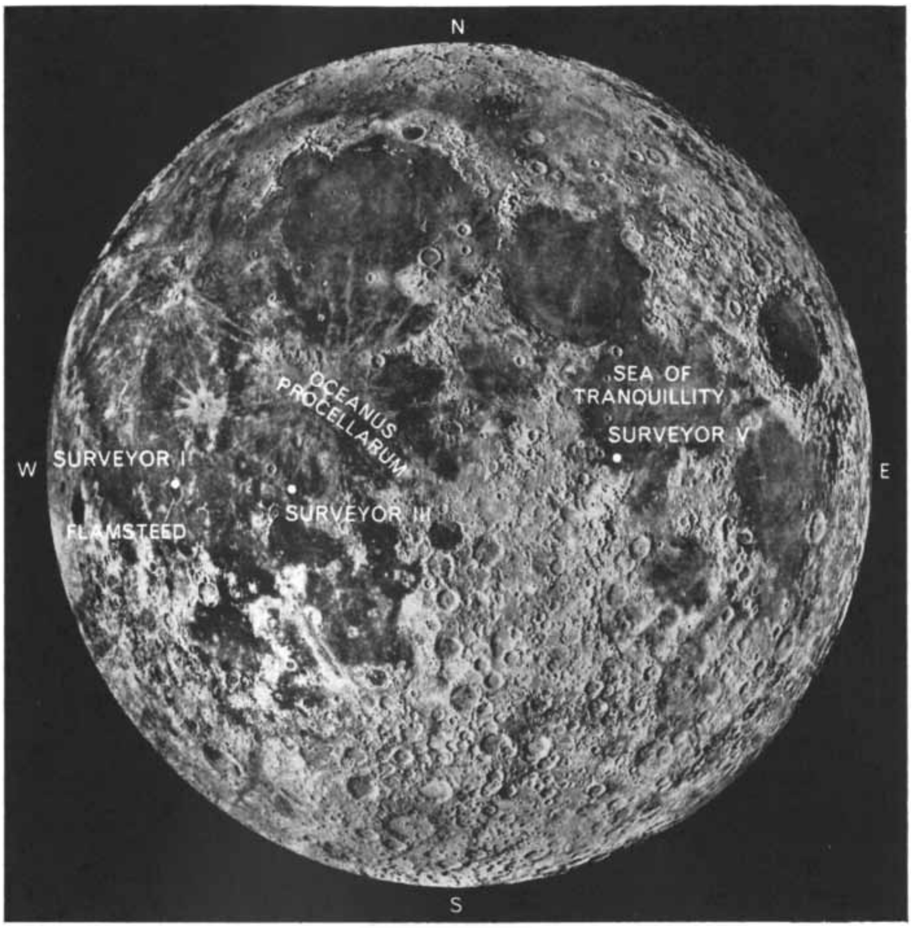


SANDY CONSISTENCY of the material sampled by *Surveyor III* is evident in this photograph of the lunar surface made after the sampling apparatus had carried out a bearing test. In a bearing test the sampler was brought into contact with the lunar surface and pushed downward until the electric motor operating the sampler stalled. The test gauged the mechanical properties of the material.

of the lunar surface. For example, the reflectivity of the lunar surface as seen by the spacecraft's radar at high resolution can be compared with the reflectivity observed at low resolution from the earth, so that variations from area to area can be studied. Moreover, the temperatures recorded by some of the sensing devices in a spacecraft sitting on the lunar surface depend on the radiation coming from the surface, so that the temperature of the surface can be calculated. The loads recorded by the strain gauges on the shock absorbers can be interpreted in terms of a soft surface or a hard one, and so on.

For the purpose of making such scientific evaluations from the engineering performance of the spacecraft a Surveyor Scientific Evaluation and Advisory Team was established. It consisted of a scientist from the National Aeronautics and Space Administration, a scientist from the California Institute of Technology's Jet Propulsion Laboratory, which conducted the Surveyor flights for NASA, and the six individuals who had proposed the six scientific experiments I have mentioned. The team met many times before the flight of *Surveyor I* and was together for the flight itself.

After the success of *Surveyor I* it was obvious that the accomplishment of all the engineering objectives on the first flight compelled a reconsideration of the plan to have six more engineering flights. NASA decided to begin the scientific experiments as soon as possible and gave first priority to the surface sampler. The reasons were that the photographs from *Surveyor I* had indicated a granular surface, in which the digger would be particularly useful, and that it was desirable to obtain early information on the mechanical properties of the surface in order to advance the Apollo program.



LANDING AREAS of the three successful Surveyor spacecraft are shown. Each area is under consideration as a landing place for the Apollo vehicles that will take men to the moon.

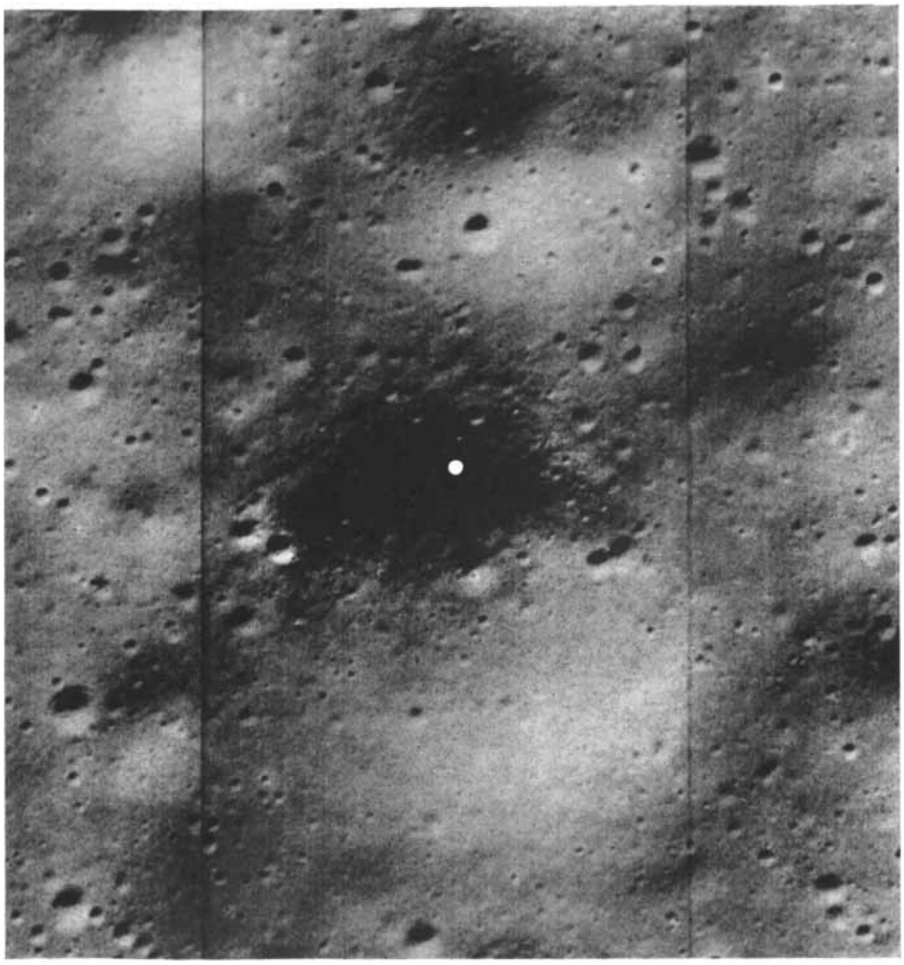
The surface sampler [*see bottom illustration on page 39*] was a piece of apparatus left over from a more ambitious experiment that had been planned and then abandoned for a variety of reasons. In 1963 I had proposed to NASA some simpler experiments on the mechanical properties of the lunar surface, and it seemed probable that they could be carried out if certain adaptations of the surface sampler were made. The adaptations included adding devices that would measure the position of the surface sampler and the amount of force it would apply to the surface in its movements. The plan was adopted, and I was designated the principal investigator for the surface-sampling experiment.

Essentially the surface sampler consists of a small bucket with a door; it is a miniature version of the scoop on a power shovel. The bucket is mounted at the end of an extensible "trellis." Four electric motors control the operation of the sampler. One moves it left and right; another moves it up and down; a third extends it and retracts it, and the fourth opens and closes the door of the bucket. Each motor will operate, on command from the earth, for either .1 second at a time or two seconds. The sampler can be pushed into the lunar surface with the door either open or closed. By means of a clutch in the elevation mechanism the scoop can be lifted and dropped to the surface from any height up to 30 inches. With the door closed a rectangular area measuring one inch by two inches is presented to the surface.

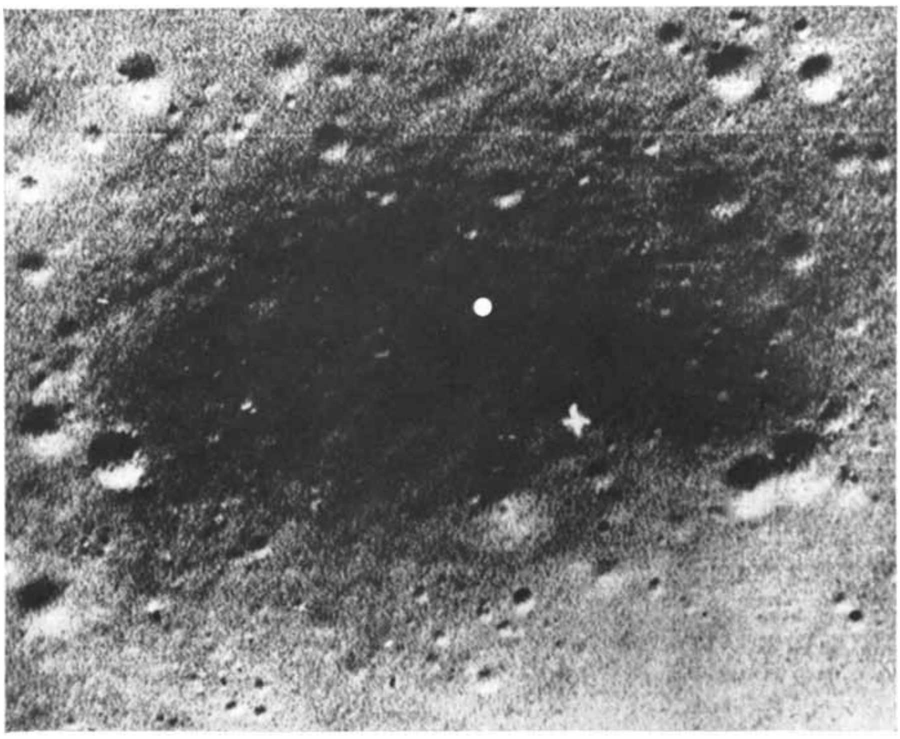
The tests devised for the sampler were in three categories: bearing, impact and trenching. In a bearing test the sampler is driven down until it is in contact with the lunar surface. This position is identified, and the sampler is then driven farther down by a series of two-second commands until no more motion is observed. An impact test involves lifting the scoop to various heights and dropping it onto the surface. In a trenching operation the door of the scoop is opened and the surface sampler is commanded to move down into the lunar surface and then to pull back toward the spacecraft. The trench can be deepened, widened or extended by successive passes.

During all these operations telephoto-lens pictures can be made of the surface sampler with the spacecraft's television camera. The pictures provide qualitative information about the mechanical properties of the lunar surface. If the material is soft, the depth to which the scoop penetrates and the manner in which the soil deforms give a basis for interpretations of the nature of the surface. If the material is hard, the way in which it cracks or breaks when it is hit by the bucket is informative.

In the original plan for the sampler some instruments would have been included to give quantitative information. Two strain gauges would have measured the vertical force imposed on the surface in a bearing test and the horizontal force required in a trenching test. An accelerometer attached to the



LANDING SITE of *Surveyor III* was the shallow crater that appears in the center of this photograph from *Lunar Orbiter II*. The crater is about 650 feet in diameter and 60 feet deep.



CLOSE VIEW of the landing site of *Surveyor III* is provided in another photograph from *Lunar Orbiter II*. East is at top; the approximate position of *Surveyor III* is marked by the white dot. Crosslike mark nearby is one of the reference marks on the photograph.

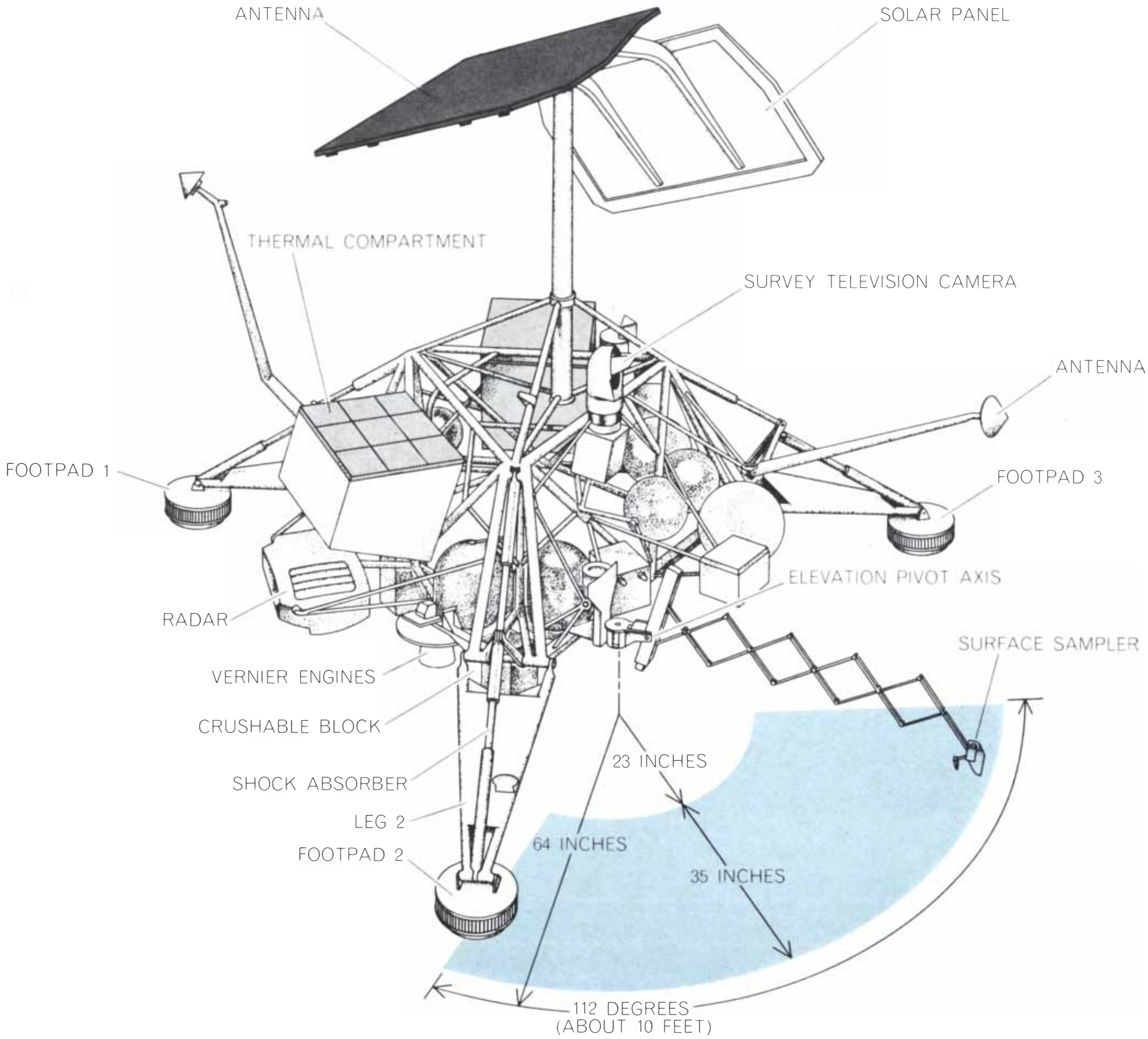
bucket would have recorded the decelerations undergone by the bucket in an impact test. All these measurements could have been correlated with the many tests previously made on the earth with various types of surfaces and materials.

After the success of *Surveyor I*, however, the instruments had to be left off in order to have a surface sampler ready for *Surveyor III*. The spacecraft is too complex to accommodate major additions on short notice, and the engineering models of Surveyor had no provisions such as special mounting brackets, wiring harnesses and electronic equipment for scientific experiments. Moreover, there was not enough time to make all the preflight tests that would have been necessary to establish the reliability of the instrumented sampler.

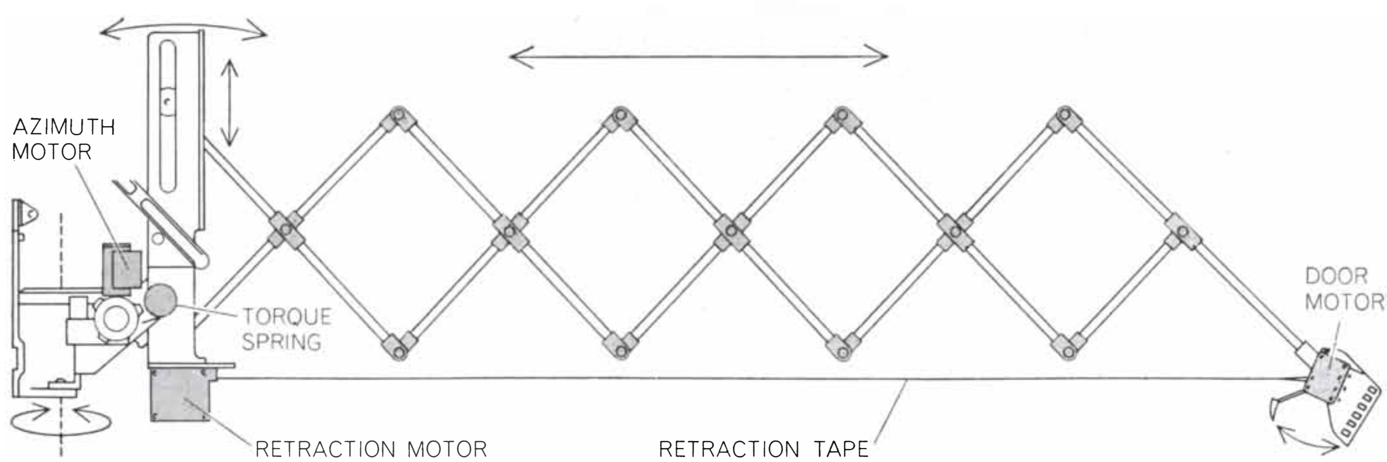
The engineering spacecraft did have, however, a place for a second television camera to look down on the moon during the approach of the spacecraft in order to identify the landing site. Since the Lunar Orbiter series had already provided excellent high-resolution photographs of the moon, the approach television camera was not needed on the Surveyors. Therefore the camera's mounting bracket, wiring harness and electronic controls could be used for the surface sampler, provided that the sampler could be adapted mechanically and electrically to use them.

The major problem was that the television camera required only four commands whereas the surface sampler needed 16. A special auxiliary electronic device that would use various combinations of the four commands to generate the 16 was therefore designed and built. Beyond that the existing equipment could provide temperature readings at any one location and measurements of the current used by whichever motor was operating at a given time. In coping with the problem of providing some kind of quantitative measurement we decided that quite a good indication of the forces applied to the lunar surface could be obtained by measuring the current drawn by the motors. In addition the maximum forces produced at the bucket could be estimated by operating the motors until they stalled.

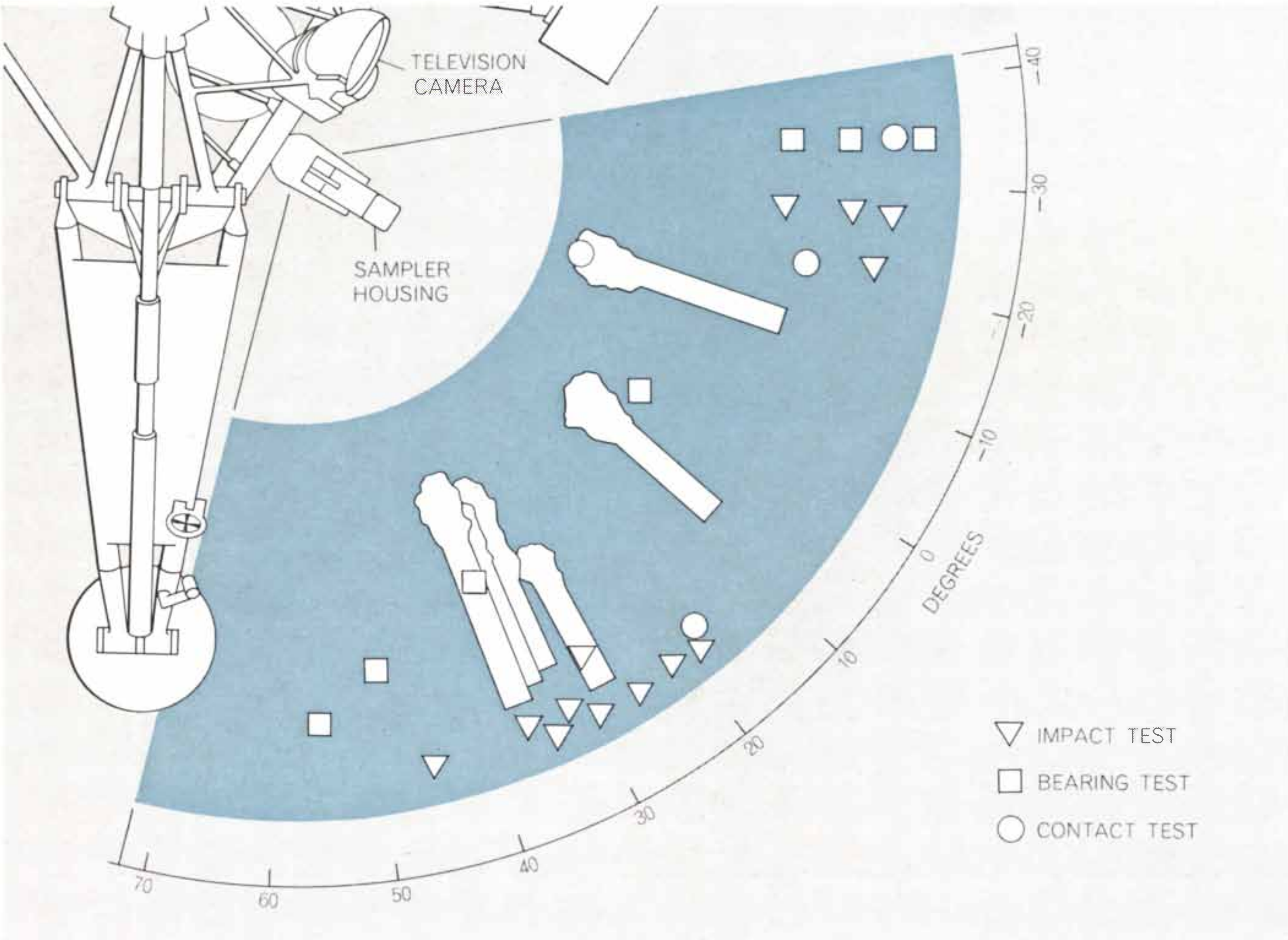
By the end of 1966 it was apparent that a sampler experiment thus adapted could be included on *Surveyor III*. We had also established a sequence of experiments to be carried out by the sampler on the moon. Many practice sessions had been held so that Floyd Roberson, who was the member of the Jet Propul-



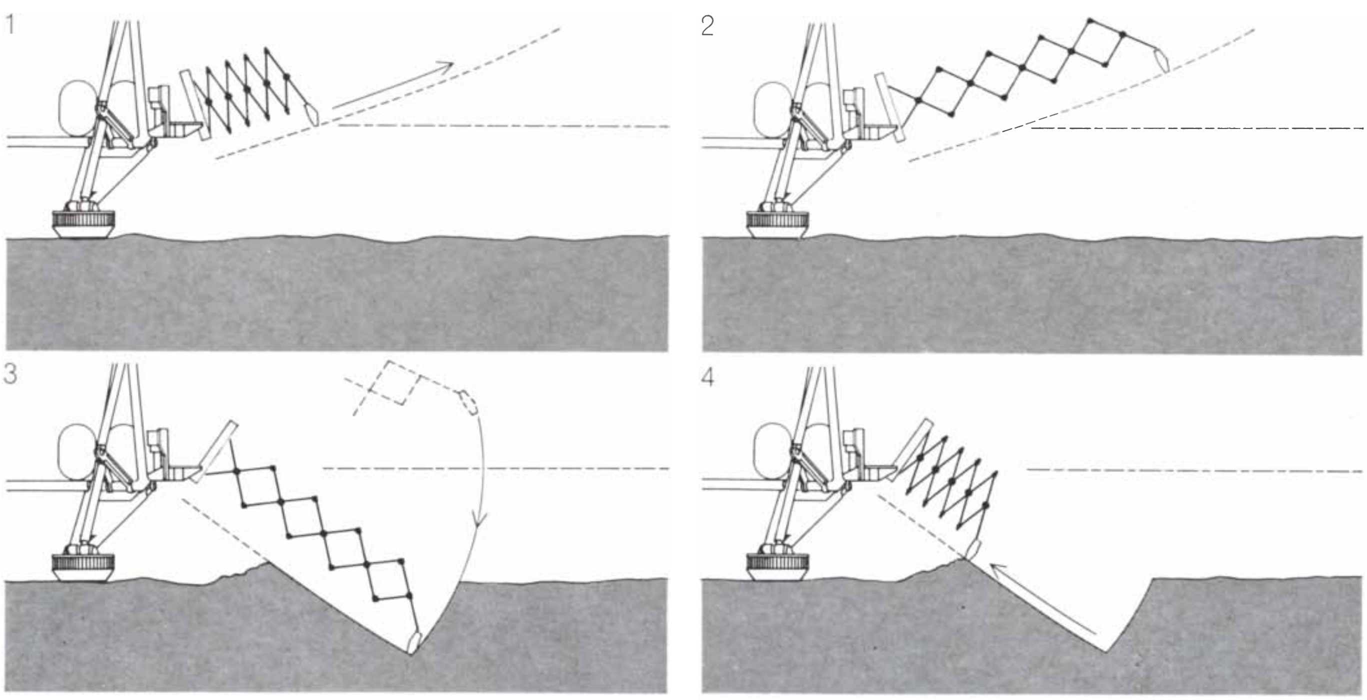
SURVEYOR III **SPACECRAFT had this appearance when it was in operation on the moon. The band of color shows the area, amounting to about 24 square feet, in which the surface sampler was able to function. The sampler was contained in its housing during the spacecraft's flight from the earth to the moon and was extended and put through its sampling operations by radio command from earth.**



SURFACE SAMPLER of *Surveyor III* consisted of a small bucket, which could be operated with its door either open or closed, and a "trellis" by means of which the bucket was moved. One of the sampler's four motors operated the door; the others respectively moved the bucket back and forth, up and down and left and right. Tape at bottom pulled bucket toward spacecraft during trenching.



VARIETY OF TESTS performed by the surface sampler of *Surveyor III* is summarized. In all the device made seven bearing tests and 13 impact tests and carried out six trenching operations, two of which consisted of widening the third trench the apparatus dug. The four symbols indicating contact represent occasions when the sampler bucket located the surface or picked up rock fragments.



SEQUENCE OF OPERATIONS performed by the surface sampler in a trenching operation is shown in somewhat exaggerated form to convey the extent of the device's vertical maneuvers. The bucket of the sampler could be raised a maximum of 40 inches above the lunar surface and driven into the surface to a maximum depth of 18 inches. It could dig a trench approximately 35 inches in length.

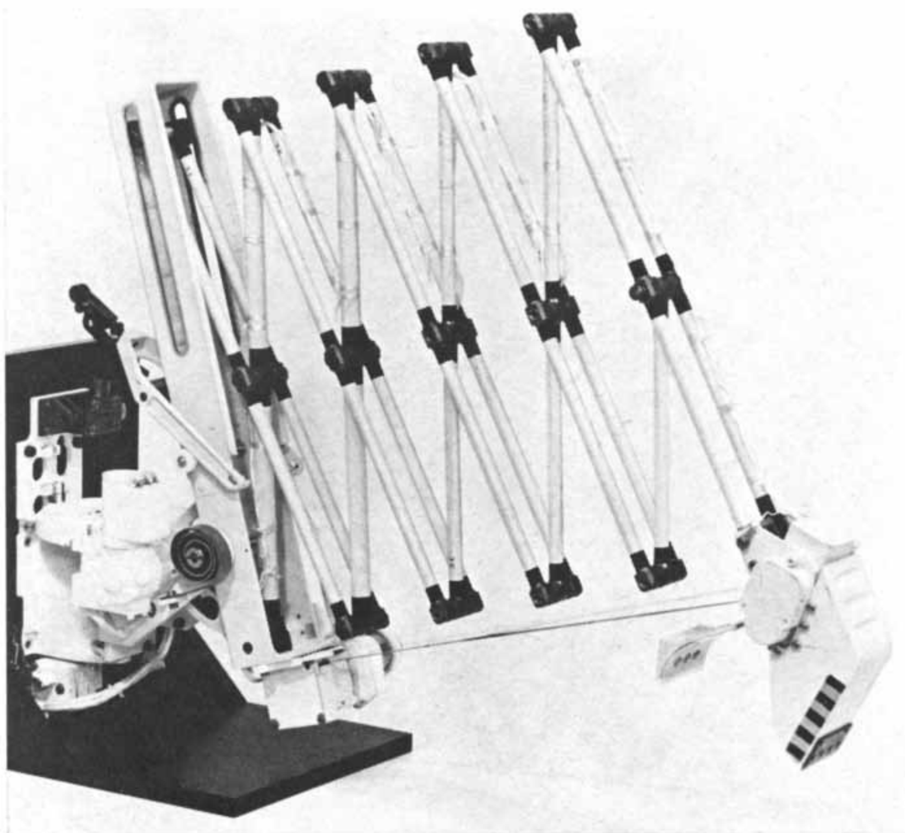
sion Laboratory staff primarily involved with the sampler experiment, and I would be familiar with the various positions of the surface sampler as seen through the survey television camera of the spacecraft.

Surveyor III was launched from Cape Kennedy at 2:05 A.M. Eastern Standard Time on April 17. It landed on the moon in Oceanus Procellarum at 7:04 P.M. E.S.T. on April 19. It was not known then, but it became apparent later from examination of the data recording the loads received by the shock absorbers on the legs of the spacecraft, that *Surveyor III* had actually landed three times because its vernier rocket engines (designed to stabilize the vehicle as it lands) failed to turn off at the right time. As a result the spacecraft had landed once, bounced to a height of 35 feet during a second flight lasting 24 seconds and then rebounded for a 12-second flight. Near the end of the second bounce the vernier engines did turn off and the spacecraft was able to settle gently on the lunar surface.

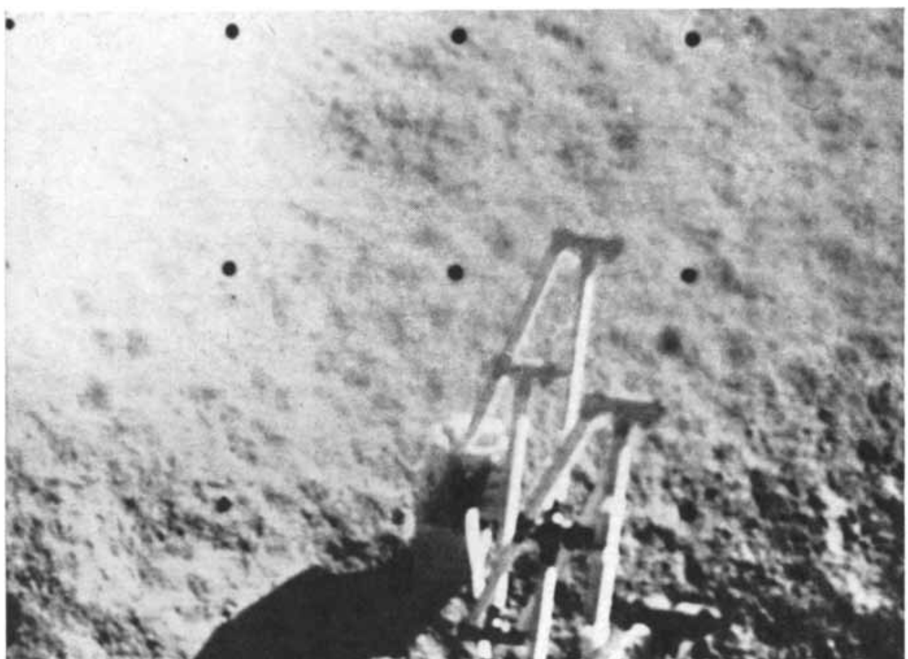
The erratic landing gave rise to some problems. One involved the electronic system that controlled the last stages of flight and touchdown. It draws a high current from the batteries of the spacecraft, and so as soon as the vehicle had landed a command was sent from the earth to turn off the system. The telemeter signal coming in from *Surveyor III* gave no indication, however, that the spacecraft had responded to the command.

Evaluation of the spacecraft's condition during the hour or so after the landing indicated that the problem lay in the telemetry and that otherwise everything was operating normally. *Surveyor III* was put to work making its first photographs. From the early pictures Eugene M. Shoemaker of the U.S. Geological Survey's Branch of Astrogeology, who was the principal investigator for the television experiment, concluded that the spacecraft was sitting on the inside slope of a crater and that everything the camera could observe was inside the crater.

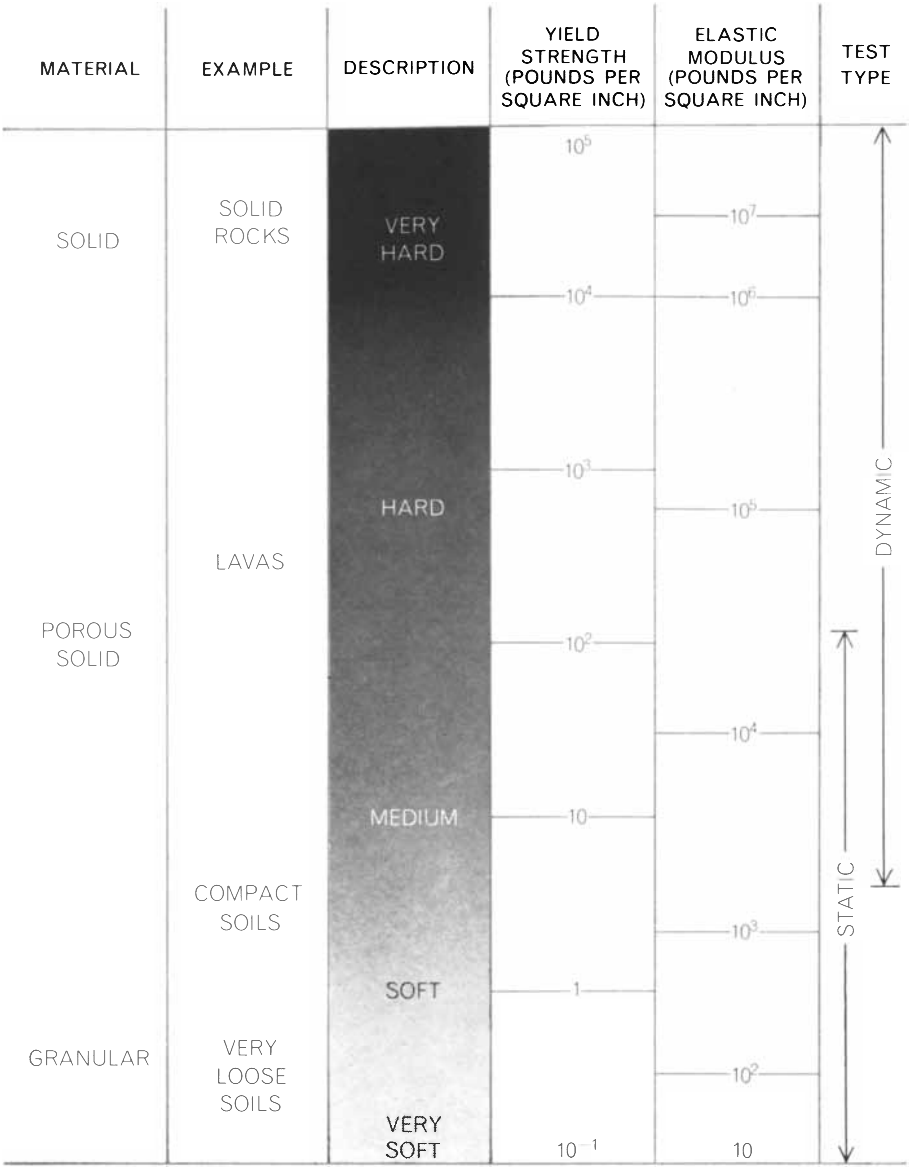
Later a comparison of features seen in the *Surveyor III* photographs and in high-resolution photographs from *Lunar Orbiter II* enabled Ewen Whitaker of the University of Arizona to identify the crater and to ascertain within a foot or two the location of the spacecraft [*see bottom illustration on page 38*]. The crater is about 650 feet in diameter and 60 feet deep. *Surveyor III* is on the eastern



SAMPLING DEVICE of *Surveyor III* is shown as it appeared during a preflight test of the spacecraft at the Jet Propulsion Laboratory of the California Institute of Technology, which conducted the flight for the National Aeronautics and Space Administration. The motor that operates the bucket door is at the top of the bucket; retracting tape is also visible.



FIRST BEARING TEST made by *Surveyor III* was seen by observers on earth in this photograph transmitted by the spacecraft. Testing began April 21 and continued for several days.



SURFACE PROPERTIES that the sampler device of *Surveyor III* was designed to investigate ranged from rock to loose soils. A static test entailed merely pushing on the lunar surface; a dynamic test involved striking the surface with the spacecraft's sampling device.

inside wall, tilted about 14 degrees to the west.

We began operating the surface sampler on April 21, after television photographs had showed that the surface around *Surveyor III,* like the surface around *Surveyor I,* resembled soil. Work with the sampler encountered certain difficulties. For one thing, the trouble with the spacecraft's telemetry included the measurements we had intended to make of the current used by the sampler's motors. Moreover, the force exerted by the scoop in trenching was only about a third of normal, probably because of binding or friction in the shaft or gears of the retraction motor, and so digging operations took longer than we had expected. In spite of these difficulties we were able to carry out a number of tests with the sampler over a period of several days [*see top illustration on page 40*]. Several of the photographs accompanying this article are representative of what the television camera recorded during the bearing, impact and trenching operations. The tests continued until the sun set on *Surveyor III*. We had hoped to make more tests during the second lunar day, but communication with the spacecraft could not be reestablished.

On the basis of the tests conducted with the surface sampler we have come to the following conclusions about the nature of the lunar surface:

1. The surface consists of a fine granular material with a wide range of grain sizes. A mark made by one of the spacecraft's footpads during its two-bounce landing provides a basis for estimating that a substantial proportion of the grains have a diameter of less than 30 microns (roughly a thousandth of an inch). The bottom of each footpad has a honeycomb pattern in which each hexagonal element is one centimeter across and 40 to 80 microns deep; the size of the grains of lunar material can be estimated from the observation of a distinct hexagonal pattern in the imprint on the soil. Studies of the form of small craters adjacent to *Surveyor III* by the Branch of Astrogeology indicate that the soil overlies a harder material at a depth of several feet. The surface is slightly lighter in color than the underlying material; the difference appears to be established in the uppermost fraction of an inch.

2. In the region accessible to the surface sampler the soil has essentially the same characteristics at any one level, but it increases in strength with depth in the top few inches. It is not known whether the increase is due to a change in the nature of the material or simply to an increase in its density.

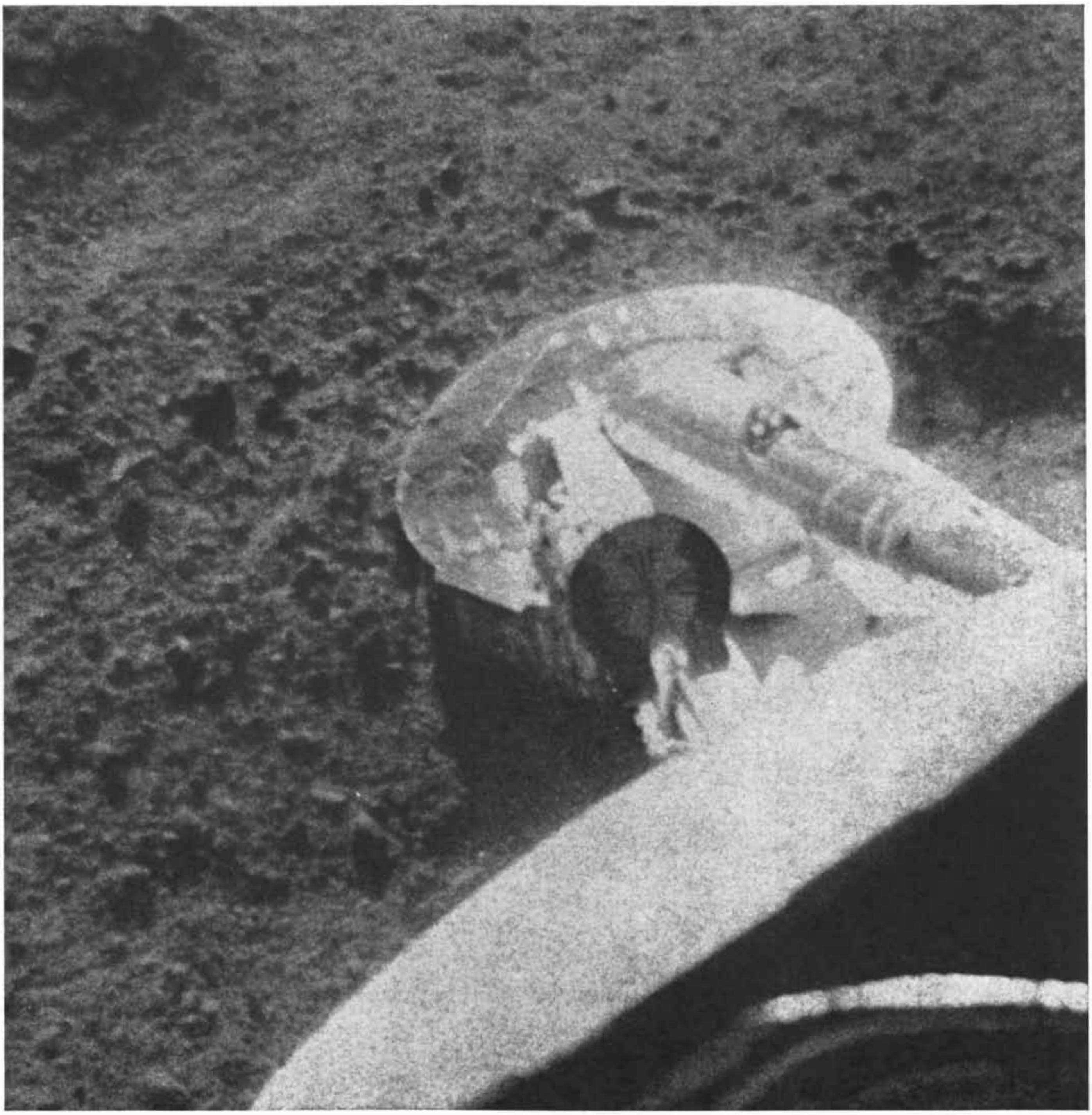
3. The soil is weakly cohesive; in general it behaves like a fine, damp sand on the earth. It is not damp, of course, but derives its cohesiveness from bonding forces. We had thought that in the very high vacuum at the surface of the moon the particles of soil would be extremely clean, so that because of primary chemical bonding forces the particles would adhere strongly to one another and possibly to components of the spacecraft. The particles did adhere to one another and also to the inside of the sampler bucket, but the amount of cohesion we measured was less than we had expected. Evidently, then, the particles are not extremely clean, and the forces acting between them are not the primary bonding forces but the weaker van der Waals forces.

4. The soil does not seem to be very porous or open-structured. When it was subjected to a penetration test, it was displaced in a manner similar to that of a relatively densely packed soil on the earth. Although the density of the lunar soil was not measured directly, the value that most plausibly explains the resistance of the material to penetration and trenching is about 1.5 grams per cubic centimeter. Earlier estimates—one based on a measurement of lunar soil density that the Russians made with one of their Luna vehicles and others based on observations made from the earth—indicated a fluffier material with a density of less than one gram per cubic centi-

meter. Material with the strength and higher density indicated by *Surveyor III* would be unlikely to offer much hindrance to the movement of astronauts.

5. Some of the objects observed on the lunar surface were clodlike clumps of soil. They disintegrated when the sampler pressed on them. Other objects are undoubtedly fragments of rock. One fragment the sampler picked up was subjected to a pressure of several hundred pounds per square inch by the bucket's door and did not break.

In sum, the sampler performed with remarkable efficiency, considering that it had to be operated by remote control over a distance of some 250,000 miles. We encountered no difficulty in picking up an object half an inch in diameter or in placing soil within a quarter-inch of its intended location on a footpad, even though the only assistance we had was practice and the view provided by the television camera. With the addition of suitable instrumentation the measurements could be made as sensitive as desired. It is not difficult to conceive of the use of more complicated material-handling devices or vehicles. If Surveyor craft are used for their original purpose as robot scientific probes, devices patterned on the *Surveyor III* sampler would be able to deliver material from the surface to instruments that could perform such informative tasks as weighing the lunar soil, looking at it under the microscope and subjecting it to X-ray-diffraction tests to determine its atomic structure.



LUNAR SURFACE around *Surveyor V*, which landed 850 miles east of *Surveyor III* on September 10, also resembles soil. The photograph was returned to earth by *Surveyor V*, which also carried a radiation device to test the chemical composition of the surface.

Early Man in South America

Stone tools indicate that men lived in South America no less than 14,000 years ago. The oldest clearly dated tools in North America are 2,000 years younger, suggesting that other tools may be older

by Edward P. Lanning and Thomas C. Patterson

Archaeological investigations over the past 40 years have greatly extended the known span of man's presence in the New World. Once regarded as latecomers who scarcely predated 1000 B.C., the immigrant hunters from Asia who first populated both continents of the Western Hemisphere now appear to have arrived no less than 14,000 years ago, at a time when the last Pleistocene ice sheet still covered much of the land. Firm evidence pointing in this direction came to light in 1926, when expertly made flint projectile points were discovered near Folsom, N.M., in association with the bones of an extinct species of bison. Ten years later, when stone tools of equally fine workmanship were unearthed along with the dung of extinct ground sloths in caves near the southern tip of South America, it became increasingly clear that man not only had reached the New World earlier than had been thought but also had spread swiftly throughout the hemisphere. A little more than a decade later the development of carbon-14 dating proved that the South American cave discoveries were at least 8,000 years old and perhaps as much as 3,000 years older. Work at a variety of archaeological sites in South America since then strongly suggests an even greater antiquity for man in the New World.

Apart from specialists in South American archaeology, few have been aware of this trend. One reason is that the new findings contradict the accepted view of man as a post-Pleistocene newcomer to the Western Hemisphere. To understand how this view developed it is necessary to go back briefly to the mid-19th century. In 1842 the Danish naturalist Peter Wilhelm Lund found human bones mixed with the remains of both ancient and contemporary animals in a cave near the town of Lagoa Santa in Brazil. He concluded that men much like the Indians of historic times might have arrived in eastern South America while ground sloths, horses and camels—all later extinct—still roamed the area. Lund was cautious about his conclusion. He made it clear that the association of human and animal remains at Lagoa Santa might have been due to a mixing of bones of various ages by natural causes.

Lund's work went largely unnoticed until late in the 19th century, when the Argentine paleontologists Florentino and Carlos Ameghino called attention to South America by their claim of having found the remains of early man on the pampas. The Ameghinos reported site after site in Argentina at which human bones and man-made objects were discovered in apparent association with ground sloths and other extinct South American mammals such as glyptodonts and toxodonts. Obsessed with these finds, Florentino Ameghino went on to claim the Argentine pampas as the original birthplace of the human species.

In 1910 the American physical anthropologist Aleš Hrdlička and his colleague Bailey Willis went to South America to review Ameghino's evidence. They rejected his claims—and Lund's as well—on two grounds. The first was that the associations had not been well established. The second was that the human bones were all "modern" and hence could not be very old. Today the latter argument is known to be wrong; "modern" man has existed in the Old World for at least 30,000 years. Hrdlička and Willis' criticism of the field evidence, however, was generally sound. For example, human remains had been removed from their original location without any effort to determine whether they were genuinely contemporaneous with the remains of Pleistocene animals or whether they had come from graves dug at a later time.

Having done a service by showing that Lund's and Ameghino's claims were unsupported by the existing evidence, Hrdlička and Willis unfortunately did not leave well enough alone. They went on to reach the conclusion that man could not have arrived in South America until quite recently. Essentially their reasoning was that, because the evidence for great antiquity was not conclusive, the possibility of any antiquity had to be dismissed. This *non sequitur* was accepted as the final word and for nearly three decades thereafter no reputable archaeologist undertook to study early man in South America.

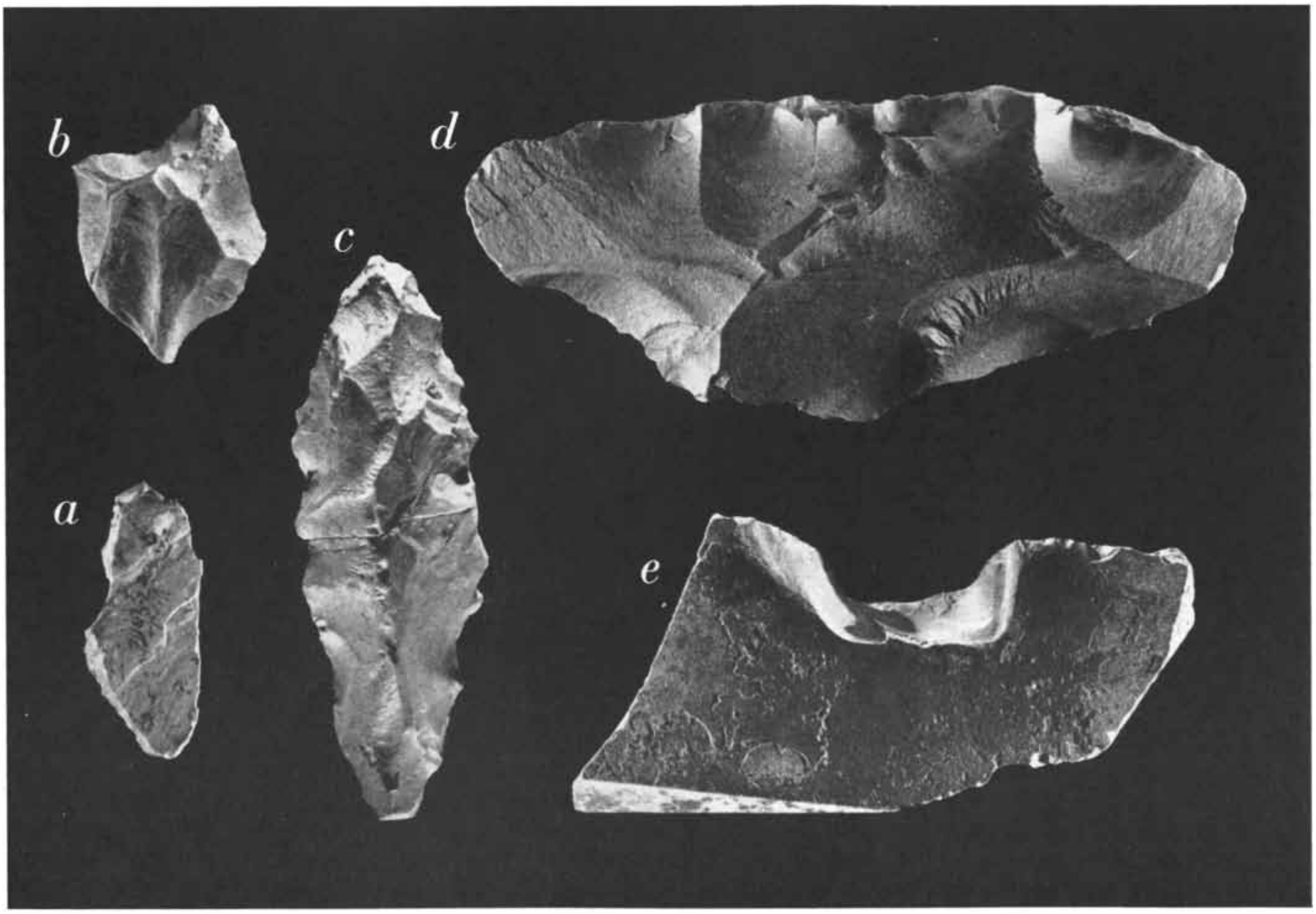
It was not until 1937 that Junius B. Bird of the American Museum of Natural History firmly established the contemporaneity of man and Pleistocene animals in South America. That year Bird excavated ancient refuse deposits near the Strait of Magellan. In two cave sites—Fell's Cave and Palli Aike—the deepest strata contained the bones of extinct mammals that had been killed and eaten by men. Fell's Cave was particularly important, because the animal bones, artifacts and human skeletons there had been sealed off by fallen rocks. This circumstance guaranteed that the association between animals and humans was not due to the later intrusion of human remains.

With the development of carbon-14 dating in the 1950's dates were obtained for the bottom strata of Bird's caves. These are respectively 6689 ± 450 B.C. for Palli Aike and 8760 ± 300 B.C. for Fell's Cave. The Fell's Cave date appears to us to be somewhat too early when it is compared with evidence secured elsewhere near the Strait of Magellan and also in the Andes. Taken together with the remains of extinct animals, however, the radiocarbon age of the caves is a good indication that man had reached the tip of South America toward the end of the last continental glaciation or at the latest in very early postglacial times.

Evidence that men lived in South America in early postglacial times has been found in many parts of the continent during the past decade. Numerous campsites of hunters and gatherers in this epoch have been identified, and they have been dated by stratigraphic and radiocarbon studies. It is now evident that soon after the end of the glacial period all South America, with the possible exception of the deep Amazon Basin and the Pacific coast of Colombia, was inhabited by men. The assemblages of stone tools belonging to these postglacial cultures are characterized by well-made projectile points, knife blades, scrapers and gravers flaked by pressure (as opposed to simple percussion). Some of the assemblages also include grinding stones and other tools for the preparation of plant foods [see "Early Man in Peru," by Edward P. Lanning; SCIENTIFIC AMERICAN, October, 1965].

Remains of a very different kind of culture have also been found throughout the Andes. They lack all the expertly made artifacts of the postglacial tool kit. These assemblages are characterized by elongated chopping tools and spearpoints coarsely flaked on both sides by percussion. The first such "bifacial" assemblage was discovered in 1956 by the Venezuelan archaeologist José M. Cruxent on the terraces of the Pedregal River in northwestern Venezuela. Soon thereafter the authors of this article found related tool assemblages on the central coast of Peru, as did Father Gustavo LePaige in the interior desert of northern Chile and Eduardo Cigliano in the Andes of northwestern Argentina. The similarity of the artifacts in all these assemblages made it apparent that they belong to a single widespread cultural stage for which we have proposed the name "Andean Biface Horizon." Among archaeologists working on these materials there was general agreement that the horizon was an early one, but for several years there has been no evidence to place it exactly in time.

Cruxent's work on the Pedregal River terraces yielded a sequence of ancient cultures, for the reason that the highest river terrace is always the first to be formed and the lowest the last. The oldest Pedregal assemblage was therefore the one found on the highest terrace. Called the Camare culture complex, it consisted almost exclusively of crude choppers and large flakes of quartzite, together with a few large, thick bifacial tools. The second culture complex, the Lagunas, was found on somewhat lower terraces. It is a typical member of the Andean Biface Horizon. Two even later complexes, characterized by pressure-flaked projectile points of the early postglacial type, were found on still lower terraces. Although his dating is only relative, Cruxent's work shows that the Camare complex is earlier than the Andean Biface Horizon. At several sites



STONE TOOLS used by the early inhabitants of western South America were of different kinds at different times, as these representative implements show. At Cerro Chivateros in Peru, between 12,000 and 11,000 B.C., most were small tools made from flat pieces of quartzite (*a*). Elsewhere in coastal Peru, between 10,500 and 9500 B.C., the implements were also small but somewhat more advanced (*b*). Between 9500 and 7000 B.C. new kinds of tools were made at Cerro Chivateros. They included spearpoints (*c*) and choppers (*d*) flaked on both sides, and implements such as the simple one resembling a spokeshave (*e*) for making other tools out of wood or bone.

around Venezuela's Lake Maracaibo, Cruxent has also found rough choppers and a few large bifacial tools similar to those of the Camare complex but made of fossilized wood rather than quartzite. This fossil-wood assemblage he calls the Manzanillo complex.

At fossil-bearing sites of Pleistocene age at Muaco and Taima Taima on the Pedregal, Cruxent has found the bones of extinct animals, some of the bones scored by stone tools. This seems indisputable evidence that man was hunting such animals in northwestern Venezuela in late-Pleistocene times. Four radiocarbon dates from these sites (the samples include some of the scored bones) range from about 11,000 to 14,500 B.C. We do not know, of course, whether similar dates apply to either the Camare or the Lagunas complex or whether the hunters were still earlier inhabitants of the region. The situation is the same with a radiocarbon date of 11,970 ± 200 B.C. from Lake Maracaibo; this date could apply to the Manzanillo complex but is not clearly associated with Manzanillo artifacts.

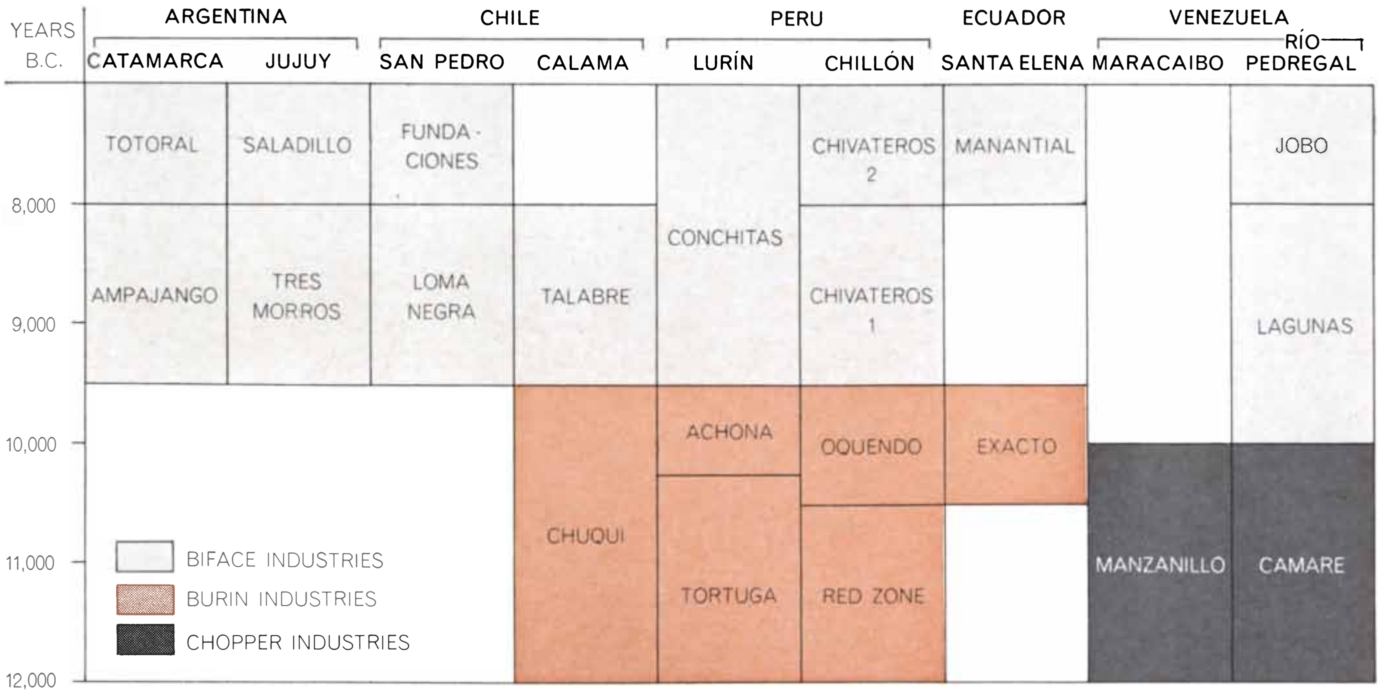
While surveying the delta of the Chillón valley on the central coast of Peru in 1962 we located several sites containing the remains of another unusual stone tool industry. We named this culture complex Oquendo, after the hills in which the sites are located. Its assemblage of tools, mostly composed of small and simply made implements, is noteworthy for the lack of any artifact that could have been used as a spearpoint and for the abundance of the little cutting tools known as burins. A few burins are known from the postglacial site of El Inga in Ecuador, but the burins at the Oquendo sites number in the hundreds and are associated with a completely different kind of assemblage. Over the past five years one of us (Lanning) has come on similar burin industries on the coast of Ecuador and in the Atacama Desert of northern Chile, and the other (Patterson) has found two successive assemblages of the same kind in the Lurín valley of Peru. Neither the initial research in the Oquendo area nor studies of other related assemblages has produced any evidence for dating them.

Until very recently, then, there was no clear proof that man had lived in South America much before 8000 B.C., although the Fell's Cave radiocarbon measurement suggests a somewhat earlier date. The oldest Venezuelan radiocarbon date goes back even further, but it is not associated with any identifiable culture complex. Although several of us engaged in this work thought that the chopper, bifacial-tool and burin industries belonged to the Pleistocene, we had neither stratigraphy, radiocarbon dates nor associations with extinct animals to support our assumption.

Evidence of a late-glacial age for both the bifacial-tool and the burin industry is now available. It is provided by a stratified site in the lower Chillón valley, where one of us (Lanning) worked in 1963 and the other (Patterson) in 1966. The site, Cerro Chivateros, is about a mile from the sea in a range of steep hills composed of metamorphosed Cretaceous marine sediments, mostly sandstone and coarse-grained quartzite with outcrops of fine-grained quartzite here and there. Cerro Chivateros is the largest of the fine-grained quartzite outcrops, which were used by the makers of burins and bifacial tools as raw material. The slopes of the site are thickly covered with the debris of tool manufacture. The site seems to have been used as a quarry and workshop but not as a campsite. Nevertheless, a considerable depth of culture deposit accumulated during the time the outcrop was frequented by man.

Disregarding minor variations and subdivisions, our excavations at Cerro Chivateros revealed five major strata, each representing a different period of time and somewhat different climatic conditions. The lowest level, the "Red Zone," is a reddish silt that contains numerous chunks of unworked quartzite as well as a distinctive assemblage of artifacts. The assemblage of the Red Zone complex consists of little quartzite tools, the working edges of which had been made steeper by direct percussion with a cobblestone hammer. Prominent among these small tools are simple scrapers (straight-edged and notched), perfora-

MAN'S PRESENCE in South America during late Pleistocene times has been suggested by the discovery of distinctive stone tools at a number of sites. Until Cerro Chivateros, one of the sites in Peru excavated by the authors, provided a radiocarbon date of 8500 B.C., however, there was no concrete proof that the bifacially flaked tools discovered there were of great age. The finding suggests that other tool assemblages belonging to the same Andean Biface Horizon (*names in color*) are equally old and that tools of other kinds are even older.



THREE STYLES OF TOOLS were used in various parts of South America. The stone implements used in Venezuela for 2,000 years or so after 12,000 B.C. included crude choppers and heavy tools flaked on both sides (*dark gray*). During the same period typical implements in Ecuador, Peru and Chile were much smaller (*color*). They included many chisel-like burins for working in wood and bone. Tools of the succeeding style, the Andean Biface Horizon (*light gray*), were larger and included a previously unknown artifact: the spearpoint. Perhaps evolved from Venezuelan choppers, bifaces spread widely between 10,000 and 9500 B.C. Except for the one firmly dated Andean biface stratum at Cerro Chivateros, the ages assigned to the various cultures listed here represent the authors' estimates.

tors pointed either at one end or both, and a few burins. How the silt that composes the Red Zone was formed has not yet been determined. It may have been laid down by the wind, and its color may be due to the oxidation of quartzite. If so, this would indicate that the area had a dry climate, similar to today's desert conditions, at the time of deposition.

A hard crust on the upper surface of the Red Zone constitutes the next stratum at Cerro Chivateros. Such formations, called *salitres,* are created on the surface when salty sediments are exposed to humid air; the salt crystals soak up moisture, expand and link up with one another. The process can be observed today on the Peruvian seashore where sea breezes provide the necessary moisture. Cerro Chivateros is too far from the sea for active salitrification today; the stratum we call the Lower Salitre could only have been formed at a time of increased humidity. In the Peruvian coastal desert such conditions would depend on a persistent belt of dense fog, perhaps coupled with a sequence of years in which some rain fell. Only a few artifacts of the Red Zone complex were found in the Lower Salitre.

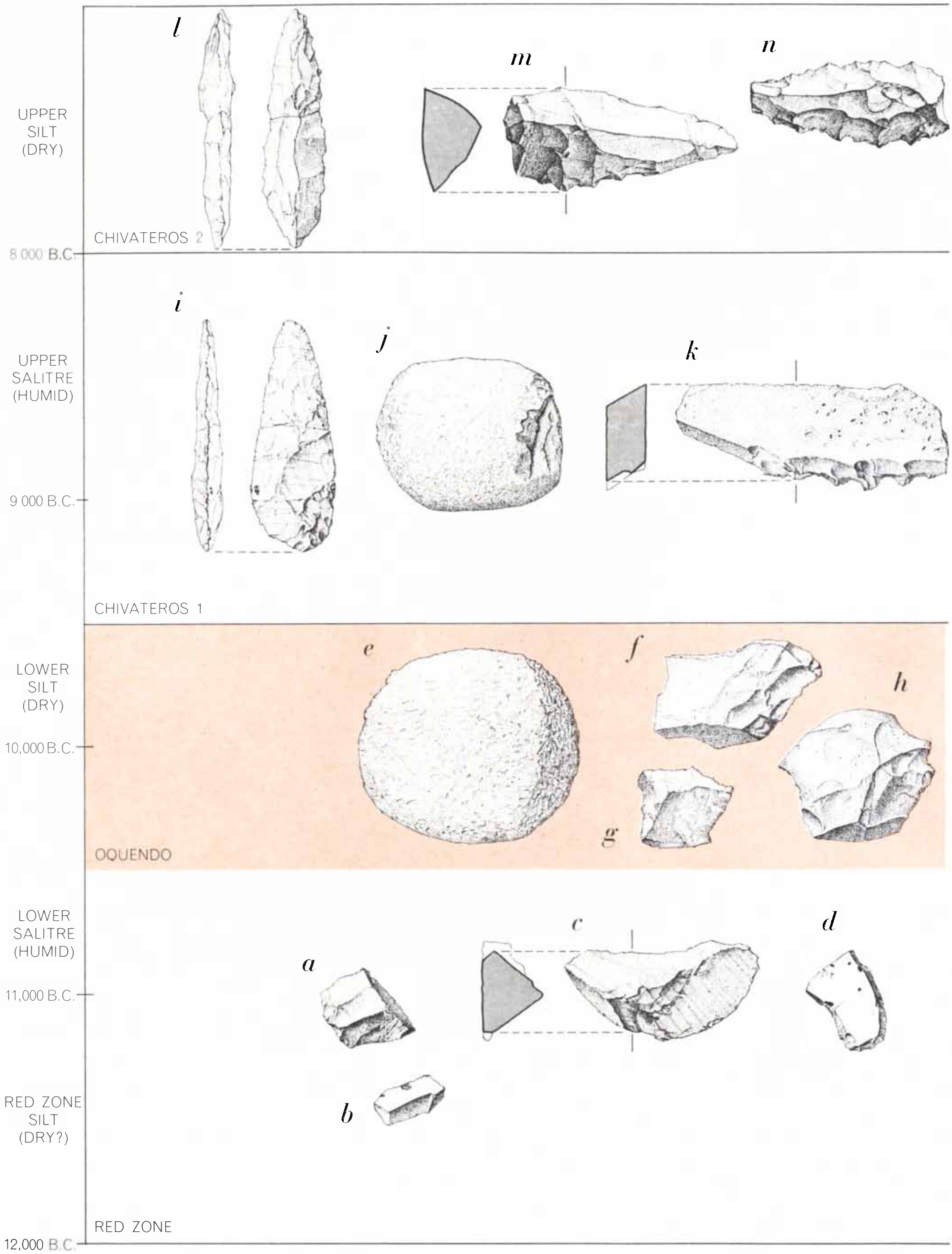
The third stratum, another layer of silt, was deposited by the wind under very dry conditions. Wherever the silt is more than four inches thick the cultural material is confined to its upper portion. The assemblage of stone tools in this part of what we call the Lower Silt is typical of the Andean Biface Horizon; we have designated the complex Chivateros 1. The complex consists of many thick, pointed bifacial tools, large tools with serrated edges, and heavy unretouched flakes that were simply struck from a bigger piece. There are also a few large scrapers, notched stones and bifacially flaked spearpoints and knife blades.

The Upper Salitre, a salt-cemented deposit that overlies the Lower Silt, is the next stratum. It too contains Chivateros 1 artifacts. The evidence from these two levels therefore suggests that the manufacture of Andean Biface Horizon tools at Cerro Chivateros began partway through an extended dry period and continued during a humid one that followed.

The upper and most recent level at Cerro Chivateros—the Upper Silt—represents wind deposition during a dry period. The cultural content of this silt is two small workshops belonging to the complex we have designated Chivateros 2. The artifacts from these workshops are much the same as those of Chivateros 1, but they include many smaller double-point spearpoints and pointed tools with a rounded keel. The Chivateros 2 specimens, like those of the Red Zone, the Oquendo sites and Chivateros 1, were manufactured exclusively by cobblestone percussion.

No bones have been found in any of the strata at Cerro Chivateros. We attribute this partly to the fact that the site was not a camp and partly to the generally poor preservation of bones in the dry surface sediments of the Peruvian coast. We were fortunate enough, however, to find several pieces of wood in the Upper Salitre. From these samples the radiocarbon laboratory of the University of California at Los Angeles has obtained readings of 8420 ± 160 and 8440 ± 160 B.C. The dates apply to late Chivateros 1 and to the humid period that followed, during which the Upper Salitre was formed.

It is possible with the aid of these dates to correlate the alternating dry and humid cycles at Cerro Chivateros with the sequence of climatic changes elsewhere in the world during the late-glacial period. Long-term climatic changes associated with the late-glacial and postglacial periods have been documented in many parts of the Northern Hemisphere in the Old World and the New, and it has been shown that similar changes took place at about the same time in Europe and North America. The analysis of plant pollens in Colombia and Chile has shown that climatic changes in the New World's Southern Hemisphere are fairly well coordinated with those to the north. Glacial stages in the highlands of Peru are also correlated



CULTURE SEQUENCE at Cerro Chivateros is evidenced by the artifacts typical of each. The lowest stratum, a red silt, and the saline-soil stratum above it contain cores (*a*), tiny burins (*b*, *d*) and knives (*c; note cross section*). The hammerstone (*e*) and burins (*f*, *g*, *h*) in the colored band are not from Cerro Chivateros; they are typical of the tools found in a similar stratum of silt at Oquendo. Near the top of the Lower Silt and in the stratum above it are much larger implements: spearpoints (*i*), hammerstones (*j*) and simple tools with toothed edges (*k*). Similar biface tools occupy the top stratum: coarser spearpoints (*l*) and implements with steeply "keeled" cross sections (*m*, *n*). Except for *e*, tools labeled *a* through *h* are shown half-size; *e* and *i* through *n* are shown one-third size.

with these worldwide climatic stages.

In general the evidence in South America indicates that in cool periods the mountain glaciers of the Andes reached their maximum extent. In these periods the altitudinal zones—the snow line, the tree line and the zone of regular annual precipitation—were depressed 3,000 feet or more, rainfall increased throughout the Andes, and the desert along the Pacific coast shrank in extent. Although the central Peruvian coast apparently remained arid, the velocity of winds blowing toward the shore was lower, dense fogs lay near sea level and years of irregular rainfall were more frequent. Although temperatures in the highlands were lower during these periods, temperatures along the coast may have been somewhat higher than they are today. The humid periods at Cerro Chivateros, represented by the *salitres*, should therefore be associated with times of worldwide low temperatures, and the dry periods, marked by the increased deposition of silt by the wind, should belong to times of high temperatures.

We have proposed a tentative correlation of the strata at Cerro Chivateros with the glacial stages of the Peruvian highlands, with the levels of pollen from various plants in Colombia and Chile, and with the more familiar climatic stages of the Northern Hemisphere [*see illustration on next page*]. In the highlands of Peru the Agrapa, Magapata and Antarragá stages were times of glacial advance, lowered altitudinal zones, decreased temperatures and increased rainfall. During intervening periods the climatic and altitudinal zones had approximately the same distribution as they have today.

If our correlations are correct, they allow us to suggest dates for the earlier strata at Cerro Chivateros and their contents. As far as the Upper Silt, Upper Salitre and Lower Silt are concerned, there are no significant problems. Each corresponds to a well-dated major fluctuation in world climate. Because the Chivateros 1 complex is found in the upper part of the Lower Silt but not in the lower part, for example, we estimate the beginning of the complex at about 9500 B.C.

For periods earlier than 10,000 B.C. we must rely on the Colombian pollen sequence alone; the Peruvian-highland glacial stages are not directly dated and the Chilean pollen sequence does not show any fluctuations. It is our view that the culturally impoverished Lower Salitre corresponds to the cool period of the Colombian pollen level designated *I a 3* and that the Red Zone below it corresponds to the warmer pollen level *I a 2*. Both of these stages in Colombia are somewhat earlier than their counterparts in Scandinavia (respectively the Older Dryas stage and the Bølling stage), probably because of Colombia's proximity to the Equator and because of the absence of a continental ice sheet in the region. If the Red Zone is indeed as old as pollen level *I a 2*, its cultural contents can tentatively be dated between 12,000 and 10,500 B.C.

The problem of dating the Oquendo culture complex, which is not represented at Cerro Chivateros, remains. One of us (Patterson) excavated a test pit in an Oquendo site in 1966 and found that the artifacts were concentrated in a 15-inch stratum of wind-deposited silt (like the Upper Silt and Lower Silt at Cerro Chivateros) overlying a culturally empty deposit of *salitre*. Oquendo artifacts are related to the artifacts of the Red Zone, but they show some tool forms and chipping patterns similar to those of Chivateros 1. We believe the Oquendo complex fits between the other two, and that the silt and *salitre* at the Oquendo site correspond to the lower half of the Lower Silt and the Lower Salitre at Cerro Chivateros. On this basis we tentatively date the Oquendo complex at 10,500 to 9500 B.C., the interval between the Red Zone and Chivateros 1.

It is not impossible that our proposed dates for both the Red Zone and the Oquendo complexes are too early. We believe, however, that the relative chronology of both complexes is soundly based on their stratum and tool relationships to Chivateros 1. Late Chivateros 1, in turn, has been dated by radiocarbon to the middle of the ninth millennium B.C. Even if our age estimate is somewhat too high, it is clear that the entire sequence belongs to late-glacial times and that it must have begun well before 10,000 B.C.

The remarkable homogeneity of artifacts belonging to the Andean Biface Horizon from Venezuela, Peru, Chile and Argentina suggests that they were roughly contemporaneous. Until further evidence is available we believe it is safe to apply the Chivateros 1 dates to the entire Andean Biface Horizon. As a result we can date the burin industries of South America, which are evidently related to the Oquendo complex and the Red Zone, as being older than 9500 B.C. We have prepared a chronology for the known burin and bifacial-tool industries of the Andes, aligned in time on this basis [*see illustration on page 47*]. Of course, no two of these industries are exactly alike; they differ not only in raw materials but also in the frequency with which various tool types occur and in the presence or absence of certain locally specialized forms or techniques. The burin industries are also more diversified than the bifacial-tool industries. Even so, they have in common many highly specialized types of artifacts not known in any later ancient Andean culture.

The early chopper-tool industries of northwestern Venezuela—the Camare and Manzanillo complexes—are quite different from the burin industries contemporaneous with them in Ecuador, Peru and Chile. Their relation to the Andean Biface Horizon is attested not only by the inclusion among these artifacts of a few large pointed bifacial tools but also by a fairly high frequency of other bifacially flaked forms and by the large size of both the complexes' artifacts and their unretouched flake tools. The present evidence suggests that these northern chopper industries were ancestral to the Andean Biface Horizon and that the bifacial-tool industries spread southward through the Andes from Venezuela (or perhaps Colombia), replacing the earlier burin industries in each region. For this reason we propose that the Lagunas culture complex started somewhat earlier than the other bifacial-tool industries. Without more evidence it is impossible to say whether this change involved an actual replacement of human populations or nothing more than the diffusion of a new economy—with its associated assemblage of tools—from one people to another.

We know almost nothing so far about how these earliest South Americans actually lived. Except for Cerro Chivateros, all the known early sites are either on the surface or extend only a few inches below it. Until sites are found that have deep layers containing animal bones, shells, plant debris, hearths and perhaps even human remains, culture reconstructions can be based only on the stone tools and the locations where they are found.

An inventory of the tools shows an overwhelming preponderance of artifacts evidently intended for working wood or bone. They include choppers, burins, toothed tools and bifacial tools. In the chopper and burin assemblages spearpoints are absent; they are also rare in all the bifacial-tool assemblages except those at the Loma Negra site in Chile. Smooth-edged scrapers, which are best suited for the preparation of skins, are rare too, although rougher scrapers (useful for extracting fibers from plants similar to maguey) are fairly abundant. This suggests that the Pleistocene human population placed little emphasis on hunting game of the kind that would be killed with spears or that would provide the hunter with both leather and meat. At the same time the majority of the stone tools show no particular specialization suggesting as a way of life either fishing or the gathering of plant foods. Instead most of the artifacts appear to have been secondary tools, that is, tools with which primary tools were made. They give us no information at all about what kinds of primary tool—made out of wood or bone—the earliest South Americans had.

Most of the known Pleistocene sites are stone quarries or workshops, although a few of them may also have served as camps. Their usual location is among steep hills near rivers or small streams, some of which have now disappeared. The Exacto sites in Ecuador, the Talabre sites in Chile and the Tres Morros sites in Argentina are exceptions. They are all in flat areas; a few Exacto sites are on or near the edge of sea cliffs and the Talabre sites are on the edge of a lake that has been dry since the end of Pleistocene times. Evidently the earliest South Americans preferred wooded valleys but exploited other areas when it was convenient.

From what we know of man's life elsewhere in the world in late-glacial times, we can make some guesses about Pleistocene life in South America. Presumably the people lived in small groups, probably including not more than a few families. Their economy must have been one of generalized hunting and gathering in which plant foods, and possibly in some cases seafood, predominated. Like most food-gatherers, they probably migrated seasonally from one part of their territory to another, taking advantage of the ripening of different food plants at different times of the year.

If man indeed lived in South America as early as 12,000 B.C., he must have been present in North America at a still earlier date. The oldest evidence of human occupation in North America is the tools of the specialists in big-game hunting belonging to the Clovis (or Llano) culture complex; the oldest such tools are dated about 9600 B.C. [see "Elephant-hunting in North America," by C. Vance Haynes, Jr.; SCIENTIFIC AMERICAN, June, 1966]. Dates earlier than this have been proposed. Some are based on radiocarbon measurements of material that is not associated with identifiable assemblages of artifacts. Others involve assemblages for which direct evidence of age is not available. Some of the latter are quite similar to the artifacts of the Andean bifacial-tool industries and others include edge-retouched implements reminiscent of those in the Red Zone complex at Cerro Chivateros.

The interpretation of North American prehistory that is most widely accepted at present holds that the Clovis complex represents the continent's earliest human occupation. It seems to us that the new evidence from South America necessarily places man in North America well before Clovis times and perhaps even before the start of the late-glacial period. This conclusion does not, of course, prove that any of the current claims for earlier cultures in North America is correct, although it suggests that some of them may be. Primarily it shows that contemporary knowledge of early man in North America is far from complete and indicates that we should be busy searching for cultures older than the Clovis complex. We propose that some North American stone industries that include bifacial tools and edge-retouched artifacts may precede the Clovis complex. Our experience in South America certainly suggests that these industries merit further study.

YEARS B.C.	SCANDINAVIA	CERRO CHIVATEROS: STRATIGRAPHY	CERRO CHIVATEROS: CULTURES	PERU HIGHLANDS (GLACIAL STAGES)	CHILE (POLLEN ANALYSIS)	COLOMBIA (POLLEN ANALYSIS)
	PREBOREAL	UPPER SILT (DRY)	CHIVATEROS 2	INTERSTADIAL 4	IV WARMING	IV WARMING, DRY
8,000	YOUNGER DRYAS	UPPER SALITRE (HUMID)	CHIVATEROS I	ANTARRAGÁ ADVANCE	III COLD, WET	III COLD, DRY
9,000	ALLERØD	LOWER SILT (DRY)		INTERSTADIAL 3	II WARM, WET	II WARM, DRY
			(OQUENDO: NOT REPRESENTED AT CERRO CHIVATEROS)			
10,000	OLDER DRYAS			MAGAPATA ADVANCE	I COLD, WET	I b-c WARMER
	BØLLING	LOWER SALITRE (HUMID)	RED ZONE			I a 3 COLD, WET
11,000		RED ZONE (DRY?)		INTERSTADIAL 2		I a 2 WARMER, DRIER
	OLDEST DRYAS					
12,000				AGRAPA ADVANCE		I a 1 COLD, WET

RELATIVE AGES of undated strata excavated by the authors at Cerro Chivateros are estimated on the basis of changes in climate during late-Pleistocene times. The column at left presents the well-established sequence of climate changes in Scandinavia. The next two columns show the separate soil levels at the site and their culture content. The last three columns summarize the evidence for late-Pleistocene climate fluctuations in South America known from the study of mountain glaciers and analyses of ancient pollen.

The hope of doing each other some good prompts these advertisements

The drummer's grandson's place in the chronicle of progress

You have been sitting there for two hours minding your own business and getting a little tired of it. So, while finishing your dinner, you attempt conversation with the guy in the aisle seat.

"Care to divulge your occupation?"

"No objections. I'm in the plasticizer business."

"I'm a professor. I hope that doesn't bother you. Are you a salesman for a big company?"

"Pretty big. Eastman Chemical Products in Kingsport, Tennessee. Subsidiary of Eastman Kodak."

"My field is the history of science. I spend my life reading, talking, and writing. What do plasticizers do for me?"

"They assist in maintaining your way of life."

"How's that?"

"Want an elephant shot or a tortoise caught to make your eyeglass frames?"

"Are you giving your plasticizers all the credit for the entire polymer technology?"

"Not quite. But with many polymers, to make them into useful plastic products or surface coatings you generally have to introduce the right kind of low-vapor-pressure liquid in the right way at the right stage. Did you know that?"

"Dimly. Your success is measured in tank cars?"

"Long-range, yes. Short-range, I'm on my way to a customer with a design for a plasticizer recovery unit that will cut down my sales to him for several years. Maybe you won't believe this, but we prefer to see our plasticizer move out inside the customer's product instead of through his chimney as air pollution."

"Hadn't realized salesmen were allowed to entertain such thoughts."

"Conditions have changed since grandpa was a drummer. Only way I can sell as many tank cars of plasticizer this year as I am expected to, I have to talk mold design, extrusion equipment, UV inhibitors, plastisol curing techniques. How the customer's product behaves in public depends not only on having the plasticizer stay in and on the job but on setting up the working relations between the customers and our experts on subjects that don't seem essential for making plasticizer. Some customers demand this help and some want no part of it. We like both kinds."

"You sound like ad copy."

"Forgive me. I must need a new writer."

For a more private, more realistic type of dialogue on plasticizers, the man in the aisle seat can be reached at 615-246-2111. The ZIP is 37662.

For the attention of geologists, ecologists, plant pathologists, wildlife management people, or others considering aerial photography:

Either send $2 to Dept. 454, Eastman Kodak Company, Rochester, N.Y. 14650 for brand new book, M-29, "Kodak Data for Aerial Photography" . . .

or ask Dept. 926, Eastman Kodak Company, Rochester, N.Y. 14650 to send you names of some reliable people who can relieve you from reading the book.

Exobiology, eh?

The late Edwin E. Jelley came to Rochester in our earlier days from the Research Laboratories of Kodak Limited in Harrow. He was fascinated by the interaction of dye molecules one with another. Physical chemists have honored his name by the term "J-band" for the intense, narrow absorption band he found down-frequency from the monomeric absorption band of a dye when it attaches itself to an anionic macromolecule.

Leslie G. S. Brooker has invented an incredible number of useful dyes since he, too, came to us from England. His patent on 4,5,4′,5′-dibenzo-3,3′-diethyl-9-methylthiacarbocyanine bromide expired on February 23, 1949. Now, a second 17 years later, we find we can render a significant service by offering the dye itself for sale, rather than just the benefit of its application in some of our photographic products.

It appears to offer an extraordinarily sensitive test for biological macromolecules in inorganic matter. Not only does a J-band appear at 650mμ in the presence of proteins, but other spectral changes mark other important classes of macromolecules, including nucleic acids and substituted polysaccharides.

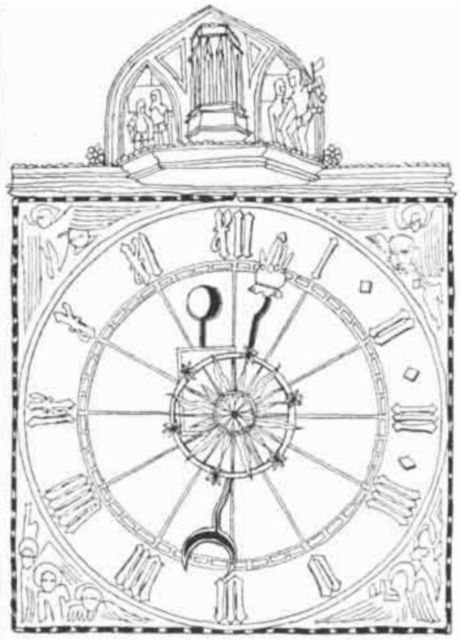
Evaluation of this apparently remarkable dye is the purpose of NASA CR-466, a 76-page report entitled "Experimental Studies for the Detection of Protein in Trace Amounts," for sale at $3 by the Clearinghouse for Federal Scientific and Technical Information, Springfield, Va. 22151. At $10.45, a gram of the compound itself as EASTMAN *2718, under the name* 1-Ethyl-2-[3-(1-ethylnaphtho[1,2d]-thiazolin-2-ylidene)-2-methylpropenyl]-naphtho[1,2d]thiazolium Bromide, *can be ordered from Eastman Organic Chemicals Department, Distillation Products Industries, Rochester, N.Y. 14603 (Division of Eastman Kodak Company).*

Even before the NASA report we had had inquiries for this Brooker dye. They had resulted from a paper in *J. Phys. Chem. 68:1896* by workers who had obviously been applying themselves to some of the basic literature that has come out of our half-century of research on the photographic process. *It proposes that, for a great many complexes that the dye forms with trace amounts of protein, the exact wavelength of the induced maximum is characteristic of the protein.* Results are listed for 32 proteins and 37 peptides, as well as for 9 nucleotides and the difference between DNA and RNA.

Chemical price f.o.b. Rochester, N. Y. and subject to change without notice.

Kodak

SCIENCE AND



Terror Unbalanced?

The U.S. and the U.S.S.R. have achieved their present balance of fear by taking a series of discrete steps, each based on a previous step taken—or thought to have been taken—by the other side. In September the U.S. took another step. Secretary of Defense Robert S. McNamara announced that a "light" antimissile system would be deployed—a system designed to defend U.S. cities and populations against a limited nuclear attack, such as China is expected to be capable of mounting in the early 1970's, but not against a saturation attack by the U.S.S.R. The decision came after a long debate within the Administration.

In announcing the decision McNamara pointed to the developing nuclear capability of China and to the possibility that China might miscalculate U.S. readiness to retaliate or might somehow behave irrationally. It is feasible, he said, to build a light "area" defense against a relatively small-scale attack. Such a defense might deter the attack and in any case would protect the U.S. population; its existence should convince Asian "friends" that the U.S. would risk a Chinese nuclear attack in order to help them. In addition, he said, the proposed Nike-X system would provide some security against the accidental launching of a nuclear weapon by another power. And it would provide a "point" defense—even against Russian missiles—of U.S. Minuteman silos, thus protecting this country's offensive capability against recent advances in the Russian offensive-missile forces.

McNamara came out strongly, however, against the construction of a heavy area defense against possible Russian attack. It is simply not possible, he insisted, to build a meaningful area defense against a sophisticated missile attack, one employing large numbers of missiles, each armed with several independent warheads, decoys and radar-obscuring devices. Any defense can be countered by an increase in the number of offensive warheads, he said; the U.S. and the U.S.S.R. could each spend $40 billion for a heavy area defense and find that it brought them no increase in security. The only real defense against a heavy missile attack is the deterrent effect of a "fully credible" retaliatory capability, he maintained.

Critics called the antimissile decision another sign of military domination of U.S. policy-making and argued that it marked a fateful escalation in the nuclear arms race and could only worsen relations with the U.S.S.R. Reasoning from McNamara's premises, they pointed out that if the proposed system is useful only against a minor nuclear power, then it will be effective against China only for a few years; if retaliatory power is the best means of deterring a Russian attack, why should it not be effective against China? Finally, critics warned, the decision to build a light defense would surely reinforce demands for a heavy system.

Such demands did, in fact, follow closely on the Administration's announcement. A number of legislators took the lead. Pointing out that the U.S.S.R. is building some antimissile defenses, they said the Administration's proposed Nike-X system was only "a step in the right direction"; the U.S. should construct "an overall system" that will "blunt" Russian offensive strength. McNamara indicated he would resist new pressures for the next step.

Chemistry of the Moon

A chemical analysis of a small patch of the moon's surface by a radiation device in the spacecraft *Surveyor V* has yielded the tentative conclusion that the moon is made of essentially the same materials as the earth. The test was a complement to one made earlier by *Surveyor III*, which carried a device that sampled

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a patch of lunar surface mechanically and found the surface material to have the consistency of damp sand (see "The Feel of the Moon," by Ronald F. Scott, page 34). One hypothesis consistent with the findings is that the moon originated as a body of matter torn from the earth millions of years ago, rather than as a separate body captured by the earth's gravitational field or as an accretion of loose interstellar material.

The radiation device on *Surveyor V* consisted of a small box that, on radio command from the earth, was lowered to the lunar surface on a nylon cord. Alpha particles from a radioactive source, curium 242, bombarded the top few microns of a four-square-inch patch of the lunar surface. The particles that struck nuclei of atoms in the surface material were scattered in known ways depending on the nature of the material. In addition some of the struck nuclei emitted protons. Detectors associated with the radiation device measured the number of returning alpha particles and emitted protons and the spectrum of their energies. Because both the numbers and the energies of the alpha particles and protons depended on the type of atoms that had been encountered during the bombardment, observers on the earth could ascertain the nature of the surface material from the measurements made by the detectors.

The analysis thus obtained indicated that the lunar surface consists of 53 to 63 percent oxygen, 15.5 to 21.5 percent silicon, 10 to 16 percent of the elements from phosphorus through nickel, 4.5 to 8.5 percent aluminum and probably smaller amounts of some other elements. The pattern indicates a surface of basalt, a volcanic rock found over wide areas of the earth. Anthony Turkevich of the University of Chicago, who was director of the radiation-analysis experiment, said: "The general pattern which emerges is that the most abundant elements on the lunar surface are the same as the most abundant elements making up the surface of the earth."

Pollution with Antipollutants

The effort to ward off oil pollution along the coast of Cornwall after the wreck of the supertanker *Torrey Canyon* in March of this year evidently constituted a cure worse than the disease as far as marine life was concerned. A review of the various measures taken by French and English agencies shows that, with the seaside resort season at stake, the English decided to disperse the crude oil and forthwith sprayed some six million gallons of detergent along the Cornish coast and its offshore waters. As their chief countermeasure the French chose collection rather than dispersal and dumped some 600,000 cubic feet of coagulant materials—sawdust, pumice and polyester chips—into the oil approaching the coast of Brittany.

During the weeks that followed, plants, mollusks, crustaceans and fish in the shallows and tidal zones on both sides of the English Channel were injured or destroyed wherever the arriving oil was thick enough to deplete the oxygen content of the water and cut off sunlight. Thanks to abnormal wind patterns that kept most of the oil at sea, however, such instances of heavy oiling were comparatively rare. In France the oil that finally accumulated in shallow waters was removed by bucket brigades and tank trucks. The blighted areas soon recovered their normal population of flora and fauna.

In contrast, the English use of detergents—which contain solvents and other constituents that are more toxic than crude oil alone—wrought wholesale destruction. Conservationists writing in a special supplement to the *Journal of the Devon Trust for Nature Conservation* note that they continually urged local officials to confine the use of detergents to the main holiday beaches but that "little or no regard was paid to these requests." The regional officer for the Nature Conservancy, W. O. Copeland, adds that most local councils were sympathetic to the conservationists' pleas "but it was natural, with the start of the holiday season so close, that improvement in the visual appearance of beaches was regarded as top priority."

Plant Insecticides (Cont.)

Evidence is rapidly accumulating that several plants synthesize substances having the effect of ecdysone, the hormone that regulates growth in insects. The discovery adds an intriguing element to the earlier finding that some plants synthesize analogues of juvenile hormone, the substance that must be present at certain times and absent at others if an insect is to develop normally (see "Third-Generation Pesticides," by Carroll M. Williams; SCIENTIFIC AMERICAN, July). All the discoveries have a dual significance: they promise useful insights into insect physiology and they may lead to the development of pesticides that are highly specific, affecting only the insects at which they are directed.

The first discovery of plant ecdysone was made by K. Nakanishi and T. Takemoto of Tohoku University in Japan. Independently but somewhat later similar findings were made in the laboratory of F. Sŏrm in Prague. The plants so far found to produce ecdysone or analogues of it include species of weeds, evergreen trees and ferns. When the larvae of insects are injected with the substances, the insects often develop abnormally. The situation is summarized in *Proceedings of the National Academy of Sciences* by Tetsuya Ohtaki, Roger D. Milkman and Carroll M. Williams, who have been working on the problem at the Biological Laboratories of Harvard University. They tested a man-made synthetic ecdysone and six plant ecdysones on the larvae of flesh flies to see if the substances, when injected into the larvae, caused them to metamorphose into pupae. They reported that "all materials showed high activity" when injected but were "inactive when topically applied to the unbroken skin."

Why certain plants should produce ecdysone or analogues of it is a mystery. One might conjecture that the plants use the substances to protect themselves against insect predators, but the hypothesis is weakened by the fact that the substances seem to be ineffective when they are applied to the skin of insects—a form of dosage similar to the kind that insects would receive in nature from coming in contact with the plants. "Therefore," the Harvard group observes, "the presence of high concentrations of these agents in certain plants constitutes something of an enigma."

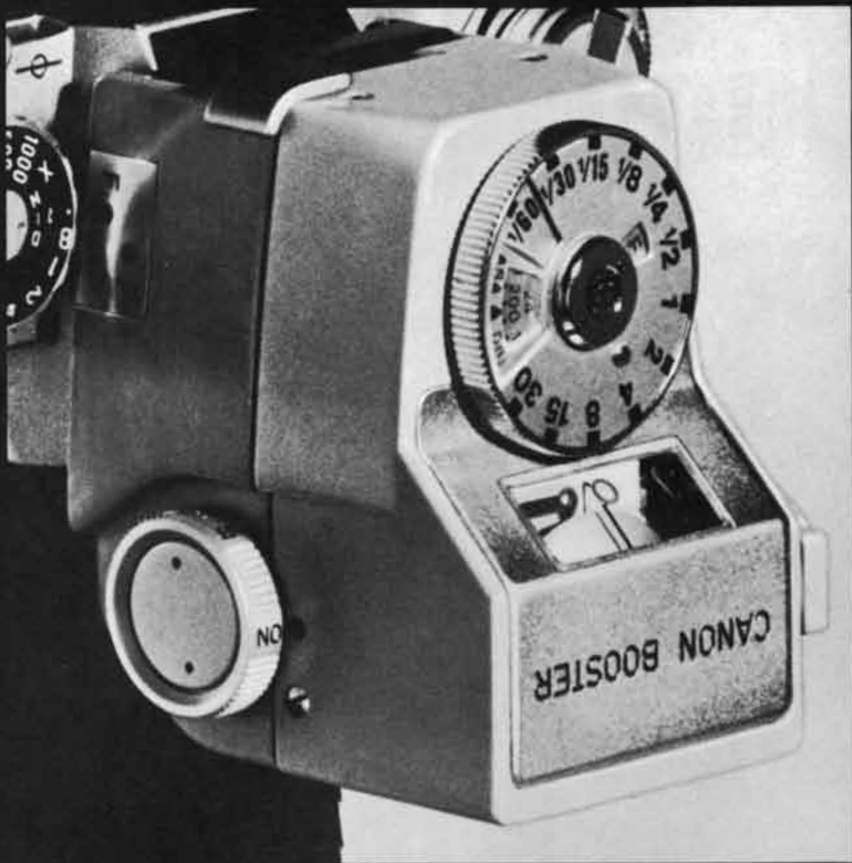
Self-fulfilling Prophecies

Can a teacher's expectations as to his pupils' performance affect that performance? Apparently so. When teachers in an elementary school were told that certain children were likely to "bloom" intellectually, those children (whose names had been picked at random) showed greater gains than other children during the school year. This "self-fulfilling prophecy" in education was reported at an American Psychological Association meeting in September by Robert Rosenthal of Harvard University and Lenore Jacobson of the South San Francisco Unified School District.

In an earlier investigation Rosenthal had found that an experimenter's hypothesis can bias his results in behavioral research. Half of a group of experimenters were led to believe their subjects (rats) had been bred for superior learning ability; the other half were told that their rats were genetically inferior. In actuality there was no such difference in the two groups of rats. Yet the animals that were believed to be brighter showed learning superior to that of the "dull" ones in both maze and Skinner-box tasks. The reason may have been that the allegedly bright rats were handled more—and handled more gently—than the allegedly dull animals.

If rats showed superior performance when their trainer expected it, might children do the same if their teacher expected it? A relatively nonverbal intelligence test that was purported to be a test that predicted imminent "blooming," or intellectual growth, was administered in a West Coast elementary school. In each of the 18 classes (an average, below-average and above-average "track" in each of the six grades) about 20 percent of the children were reported to their teachers as being likely to show unusual intellectual gains in the coming year. Actually the names had been picked by means of a table of random numbers. The children were retested eight months later, the tests were scored by the investigators and the change in I.Q. for each child was computed. As Rosenthal and Jacobson first reported in *Psychological Reports* in 1966, for the school as a whole the supposed "bloomers" showed a mean gain of 12.2 points compared with 8.4 for the control group. The effect of expectations was greater in the lower grades than in the upper grades: the "bloomers" in the first and second grades gained respectively 15.4 and 9.5 points more than the control children. The effect was more striking (and more independent of age) on the "reasoning" than on the "vocabulary" portions of the test; it was about the same regardless of "track" level.

Teachers were also asked at the end of the year to describe their pupils. They characterized the "bloomers" as having a better chance of becoming successful; as being significantly more interesting, curious and happy, and as somewhat more appealing, adjusted and affectionate. Curiously those control-group children who gained in I.Q. were not rated this favorably by their teachers; in fact,



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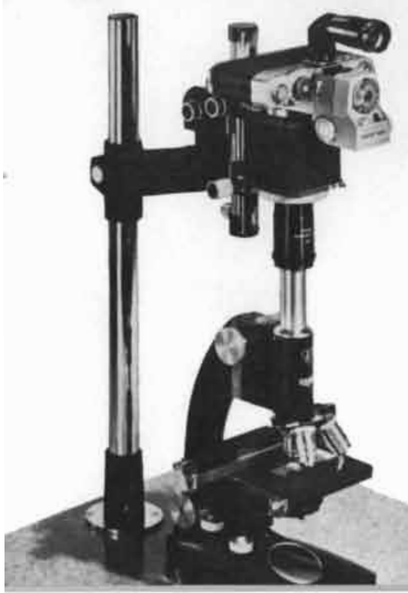

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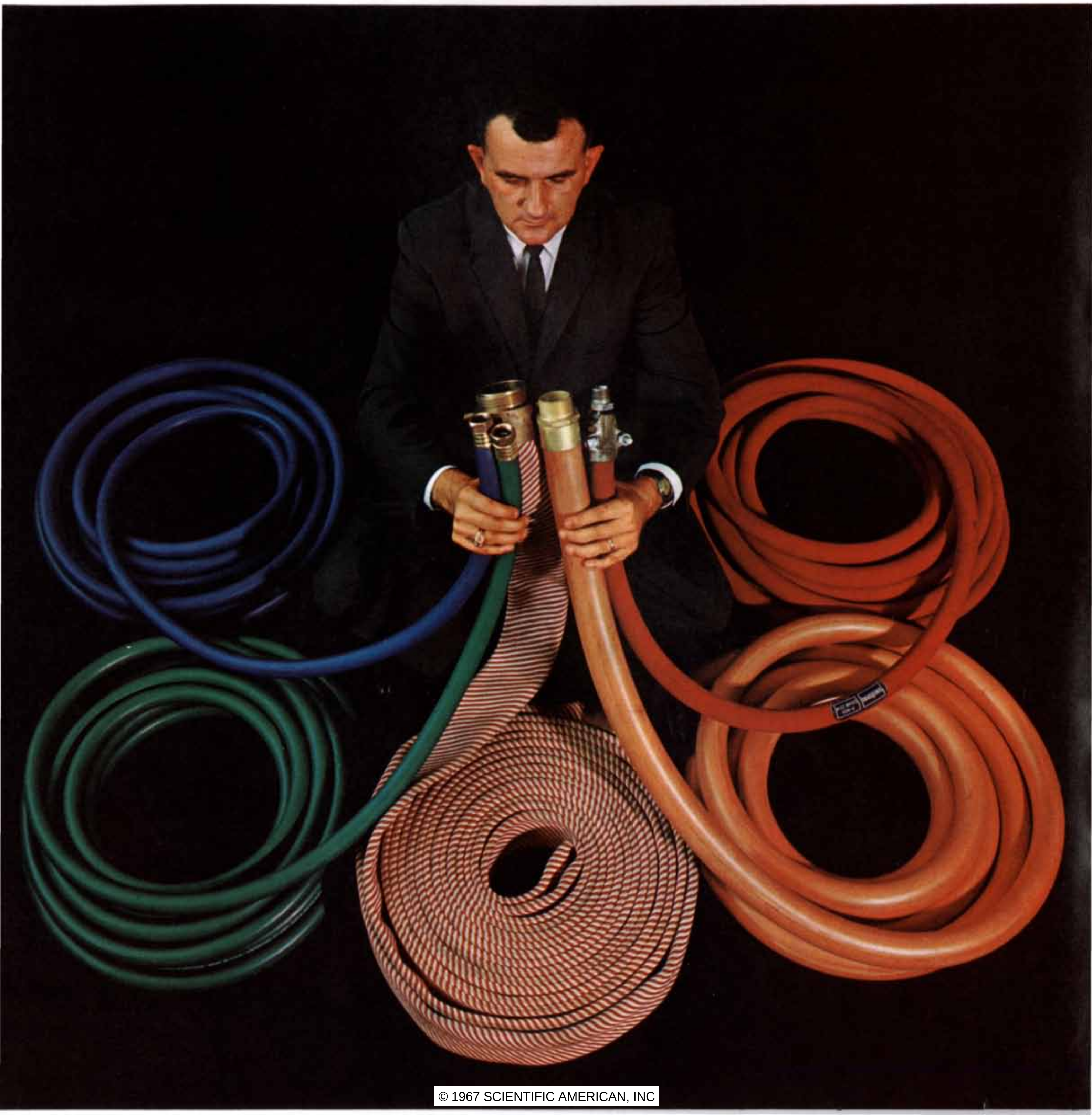
Announcing a new idea for plant safety.

Functional colors can help a plant engineer spot unsafe practices because misapplications of hose are apparent.



Uniroyal introduces first system of functionally colored hose. Standardizing on the five types simplifies plant operation and cuts inventory.

Today, everything comes in color. Including the millions of feet of air, water, steam, oil and fire hose that American industry buys each year.

The trouble is, no one takes advantage of the functional benefits of color because hose manufacturers have treated it as a sales gimmick. One manufacturer promotes blue for his line of hose. Another favors orange. A third, yellow.

That's why Uniroyal is introducing an idea we hope others will adopt. Functional color for plant hose.

The choice of colors was easy to make. Cool colors, green and blue, for the "safe" materials, air and water. Warm colors, red and orange, for the "dangerous" materials, steam and petroleum products.

The fifth choice is just as logical. Uniroyal already has a red-and-white fire hose called "Safety Stripe" which is gaining acceptance among safety people because it stands out like a sore thumb.

Color can save money and even lives. Hose often carries hazardous liquids and gases. The employee who picks up a steam hose thinking it carries water may be in for a painful experience.

The reverse is also dangerous. Using a piece of water or air hose to transport steam is one common cause of hose failure. Each year "mistaken identity" accidents chew up hose and sometimes people.

(Unlike green air hose or blue water hose, red Uniroyal steam hose has several braids of steel wire plus a special heat-resistant "crackless" rubber construction to handle high-pressure 250 psi saturated steam as hot as 407 degrees F.)

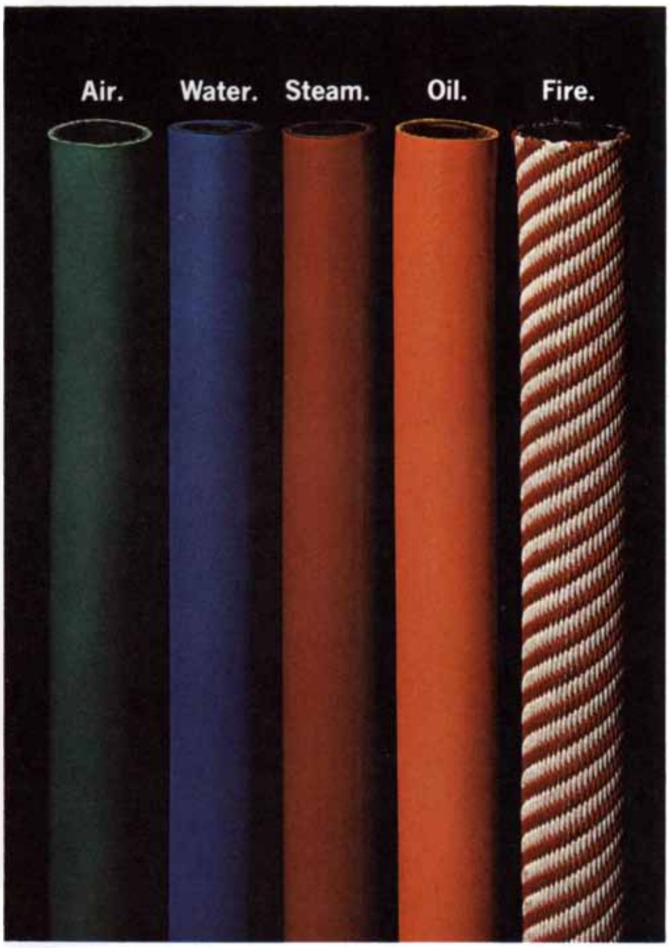
Standardizing on our "big five" color-coded hose line makes it easier to take hose inventory (you can tell at a glance what you have.)

The "big five" line also reduces inventory. We estimate that these five types can handle 85 percent of a plant's hose needs. (Uniroyal makes more than 100 types of hose so we take part of the blame for a plant stocking more types than it really needs.)

One more thing. We don't charge a premium for the new line. We couldn't very well take one step forward and two backward.

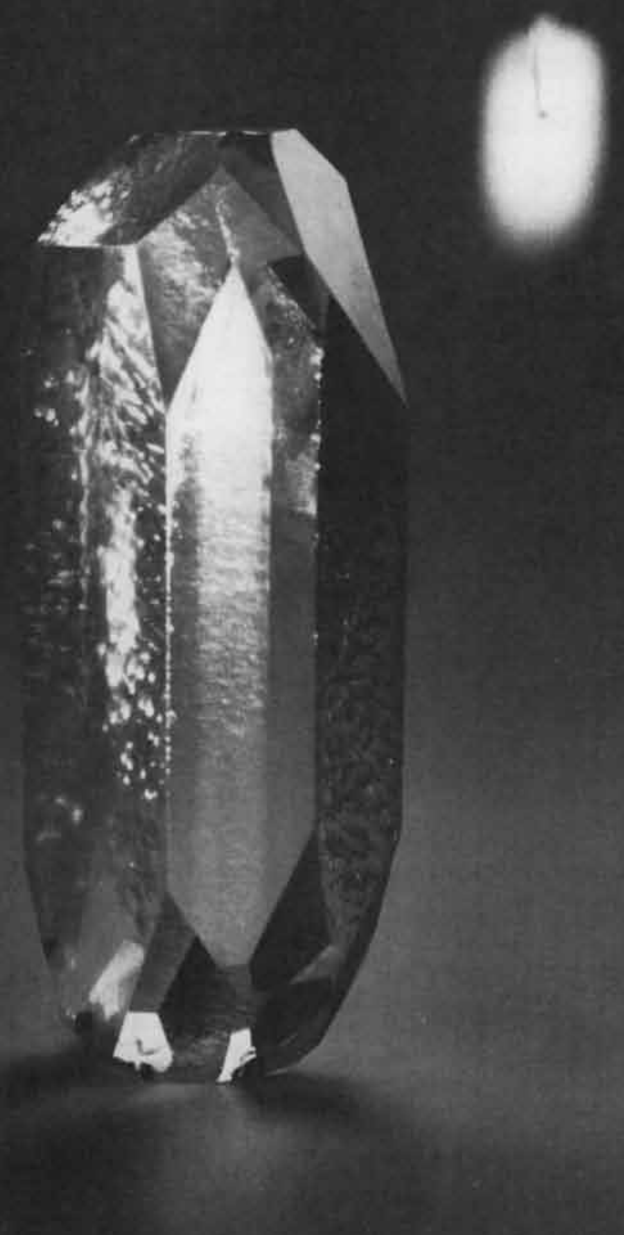
Write for our 48-page master hose catalog featuring the "big five" line.

Write to: Uniroyal Technical Advisory Service, 1230 Avenue of Americas, New York, New York 10020.



The "big five" is the first line of functionally colored hose. Cool colors are used for "safe" liquids and gases; warm colors for hazardous products.

Uniroyal holds more patents than any other rubber company.



the more the undesignated children—particularly the slow-track control children—gained in I.Q., the more they were regarded as being *less* well adjusted, interesting and affectionate. Rosenthal and Jacobson point out that their findings, which have been supported in subsequent studies, may bear importantly on current efforts to improve the education of children in city slums. In addition to the question of what a teacher's attitude may do to a disadvantaged child, there is a methodological problem: How much of the effect of a given experimental educational project is due to the favorable expectations of teachers and administrators?

The New Math of Physics

For more than 20 years theoretical physicists have been trying to construct equations that will predict what happens when subnuclear particles collide at high energies. Their efforts to use the full content of quantum mechanics have met with little success. Within the past few years, however, limited but satisfying predictions have been made with the help of a mathematical technique called the algebra of currents. Because it parallels one of the methods devised by Werner Heisenberg in 1925, just before quantum mechanics came to fruition, some physicists hope that history is about to be repeated and that a comprehensive theory of high-energy nuclear interactions will shortly emerge.

Current algebra involves a set of mathematical relations introduced in 1964 by Murray Gell-Mann of the California Institute of Technology. The term "current" refers to a current of some property of a particle in analogy with electric current. Gell-Mann proposed a way of describing this current in terms of "operators," or symbols, that do not commute, in the mathematical sense of the term. For example, operator J_1 times J_2 does not equal J_2 times J_1; in fact, the difference between these two products lies at the heart of the method. It is not easy to say what these noncommuting current relations mean in terms of known physical phenomena. They can, however, be related to "quarks," the hypothetical particles of fractional electric charge that Gell-Mann has also invented. Although many efforts have been made to find quarks, so far none has succeeded.

The first important success with current algebra was achieved by Stephen L. Adler of Harvard University and William I. Weisberger, then at Stanford University. Working independently, they made modifications in the current-algebra technique that enabled them to calculate very accurately a particular value (the axial-vector coupling constant) that can be measured when a neutron decays into a proton, an electron and an antineutrino.

Other physicists quickly adopted the new computational method and applied it to a variety of difficult problems. An important improvement in the method was introduced by Steven Weinberg of the University of California at Berkeley. Largely with the help of such modifications, physicists have been able to calculate for the first time how pi mesons with energies up to 140 million electron volts are scattered when they strike proton targets and how such low-energy pions are emitted when other particles decay. Beyond that energy, however, the method begins to fail.

The ferment is continuing. Recently Julian S. Schwinger of Harvard has introduced a rival computational method, which he calls "effective Lagrangian," to obtain similar results. Weinberg, T. D. Lee of Columbia University and Bruno Zumino of New York University have sought to show that the "current" of current algebra must be related to the fields that transmit nuclear forces and accordingly have named their modification the algebra of fields.

Hidden Flaw

The probable cause of the accident that seriously damaged the Enrico Fermi fast breeder reactor at Lagoona Beach, Mich., on October 5, 1966, has been identified. A foreign object about eight inches long and a few inches wide has been discovered inside the reactor. Evidently it blocked the flow of sodium, the cooling liquid, and allowed the uranium-235 fuel to overheat and melt in two of the fuel subassemblies. The fission products released when the fuel elements melted had triggered the emergency shutdown of the reactor, the first breeder in the U.S. designed to supply commercial power. The reactor had been built at a cost of $120 million by the Power Reactor Development Company, of which the Detroit Edison Company was a leading sponsor.

Although the accident injured no one, it was particularly unfortunate because concern about the reactor's safety had provoked a long legal battle to prevent its construction. Permission to proceed finally required a Supreme Court decision. In their dissenting opinion justices William O. Douglas and Hugo L. Black described the Atomic Energy Commission's support of the proposal as "a lighthearted approach to the most awesome, the most deadly, the most dangerous process that man has ever conceived."

In a recent talk describing the examination of the damaged reactor, Walter J. McCarthy, general manager of the Power Reactor Development Company, suggested a number of ways to reduce the possibility of similar accidents in the future. The most obvious need is for a strainer inside the system that will catch large foreign objects. (The object inside the Enrico Fermi reactor, seen so far only in photographs, may have been left in the system during construction.) A filtering and monitoring system is needed to protect against smaller contaminants. A flow-monitoring system at the outlet of each fuel subassembly would be desirable but may be difficult to design. There was adequate evidence of a malfunction before the Fermi accident, but it would have taken a computer to analyze the data and provide the warning. A computer system should be provided in the future. The fission-product detector that finally closed down the Fermi reactor had a delay time of about 13 minutes. A device that monitored neutrons in the primary coolant system should be able to respond in a tenth of that time. Finally, McCarthy pointed out, nearly a year was required to dismantle the damaged reactor and get at the cause of the accident because provisions for such emergency repairs had been inadequate.

Tale of Three Cities

A comparison of common illnesses and medical services available in three widely separated communities—one in the U.S., one in Britain and one in Yugoslavia—has brought to light some striking similarities as well as significant differences. Chosen for their comparability and their proximity to a medical center, the three communities are Chittenden (near Burlington, Vt.), Chester (near Cheshire in England) and Smederevo (near Belgrade). The study, published in a recent issue of *The New England Journal of Medicine,* was carried out by an international team of 20 senior investigators from eight institutions under the direction of Kerr L. White of the Johns Hopkins University School of Hygiene and Public Health.

The report is based on interviews with about 1,000 children and adults in each community, representing from 1 to 1.5 percent of the population. The subjects were asked if in the last year they had had such common "symptom/conditions" as backache, boils, frequent colds, severe headaches, stomach trouble, hemorrhoids, rheumatism, skin rashes or varicose veins and if they could read a newspaper and recognize friends without glasses. They were also asked if they had seen a doctor in the preceding two weeks and if they had used "medicines, salves or pills" in the preceding two days.

In all three communities almost exactly 25 percent of those interviewed said they had one and only one of the 12 physical complaints on the survey list. There was a marked variation, however, in the number who complained of more than one condition: 29 percent in Britain, 35 percent in the U.S. and 49 percent in Yugoslavia. Moreover, Yugoslavs reported more conditions associated with "great discomfort" than either Americans or Britons did. The report notes that "the possibility of cultural differences in perception and reporting cannot be excluded." In any event, about twice as many Yugoslavs as Americans and Britons said they had recently been unable to carry on normal daily activities or were confined to bed because of illness. About 22 percent of the Yugoslavs had limited their activity and about 11 percent were confined to bed for one or more days in the preceding two-week period. The report notes that "the higher levels in Smederevo do not appear to be . . . 'malingering' by workers since the same patterns are observed for children, who receive no sickness-insurance benefits."

Two other areas in which Yugoslavs differed significantly from Americans and Britons were in the use of eyeglasses and in the use of drugs. Only 27 percent of the Yugoslavs over 18 years old reported wearing glasses at any time, compared with 61 percent of both Americans and Britons. And in the two days prior to being questioned only 19 percent of the Yugoslavs used drugs of any kind, whereas drugs were used by 38 percent of the Britons and 48 percent of the Americans.

Some of the similarities among the three countries were equally striking. For example, the number of people who had consulted doctors in the preceding two weeks was almost the same: 13 percent in Yugoslavia, 15 percent in Britain and 16 percent in the U.S. On the other hand, there was a general reluctance in all three communities to see a doctor even for conditions causing great discomfort. Among Yugoslavs 86 percent of such conditions were not reported to doctors and in both the U.S. and Britain the figure was 79 percent.

The similarities in behavior are all the more striking when it is considered that the U.S. community provided one doctor for every 470 persons compared with one doctor for 950 persons in Chester and one for 1,170 persons in Smederevo. For the U.S. as a whole there is one doctor for about 650 persons, a figure that has been constant for the past two decades. In the past 15 years, however, there has been a 33 percent decline (on a per capita basis) in the number of doctors who devote themselves to family medicine. The ratio now stands at one doctor for 2,000 persons.

As if speaking to this last point, the report concludes that "in spite of substantial differences in ways of life, in organization of health services and in reported morbidity and disability, people in three widely differing communities appear to consult doctors in a similar fashion. The possibility exists that there is a propensity for consulting doctors for curative services, which may be unrelated to the number of doctors available."

The Hazards of Smoking (Cont.)

Astronomers at the Haute-Provence Observatory in southern France are presumably smoking less now but enjoying it more. The roots of their decision go back to 1962, when D. Barbier and N. Morguleff of the observatory staff reported the appearance of highly unusual emission lines at 7,665 and 7,699 angstrom units on the spectrogram of an otherwise normal dwarf star designated *HD* 117043. The spectrogram was made at the coudé focus of the observatory's 193-centimeter reflecting telescope. The spectral lines were associated with neutral potassium atoms and appeared to indicate the presence of an unusually bright "potassium flare" on the star. Two years later the same investigators recorded a second such flare on the spectrogram of a similar star, *HD* 88230. This finding stimulated a systematic search for potassium flares on stars representing a wide variety of spectral types, employing the Newtonian spectrograph of the observatory's 120-centimeter telescope. Although this survey produced no further flare observations, a third flare was observed in 1965 by Y. Andrillat, who again used the coudé spectrograph of the 193-centimeter telescope.

In a comparative study of the three

potassium-flare spectrograms published in 1966, the French astronomers noted that in spite of repeated observations of the three stars in question the phenomenon had not been observed to recur. Moreover, with the exception of the potassium lines, the flare spectrograms differed in no significant respect from other spectrograms of the same stars. They pointed out that in all three cases the emission lines were extremely strong and broad. In two cases observations made before and after the flare showed that the phenomenon did not last as long as 95 hours.

At this point a group of astronomers at the University of California at Berkeley undertook a survey of 162 bright stars for emission at 7,699 angstroms, using a highly efficient narrow-band photoelectric scanner located at the prime focus of the 36-inch Crossley reflector at the Lick Observatory. No definite potassium flares were observed. The Berkeley group did, however, come up with a suggestion as to the possible artificial origin of the bright emission lines.

Writing in *Publications of the Astronomical Society of the Pacific,* Robert F. Wing, Manuel Peimbert and Hyron Spinrad report that the artificial origin of the lines was suggested by the fact that the infrared resonance lines of potassium are by far the strongest feature in the spectra of ordinary matches. They therefore proceeded to examine match spectra with the coudé spectrograph of the 120-inch Lick telescope. Several kinds of matches were tested, including book matches, kitchen matches and safety matches; all were found to have similar emission spectra, including strong emission lines at 7,664.9 and 7,699 angstroms. A similar series of match tests was then conducted at the Haute-Provence Observatory, following the same procedures used in obtaining the stellar spectrograms. In addition to showing that "there appear to be no significant differences between French and American matches," the tests demonstrated that the strong potassium lines could have been recorded on the spectrograms by light from matches struck away from the optical axis of the telescope and reflected down the axis by a guiding device in the coudé room.

The Berkeley astronomers conclude that although "it has not been possible to prove that the flare spectrograms either were or were not a result of matches struck in the coudé room . . . the match hypothesis presents the simplest and most likely explanation of the spectroscopic observations."

LYSOSOMES AND DISEASE

Lysosomes are organelles of the living cell that contain digestive enzymes. They play an important part in normal life processes, and there is evidence that they are also involved in pathological ones

by Anthony Allison

In the 19th century, when advances in microscopy made possible the study of pathology at the cellular level, it became clear that changes in diseased tissue depend on changes in the growth and function of cells. In recent years the electron microscope and the centrifuge have made for increasingly effective investigations at the subcellular level. The aim of the cell biologist is to identify the enzymes that catalyze cellular reactions and find out in what organelles of the cell each reaction takes place. A specific task for the pathologist is to identify and localize the primary error in function that may lead to a secondary disorder in other organelles and systems; in other words, to learn how disease processes may begin with a specific malfunction in an organelle. In certain disorders, for example, the primary damage is to the energy-producing reactions in the mitochondria; in others it is to the protein-synthesizing apparatus of the ribosomes.

When lysosomes were first recognized as distinct organelles, it was clear that they would be of special interest in subcellular pathology. It was in 1949 that Christian de Duve and his colleagues at the Catholic University of Louvain realized that certain enzymes were segregated within particles in the cytoplasm; it was not until 1955 that they identified the particles visually. Lysosomes are small baglike organelles, usually spherical and about a quarter of a micron (a four-thousandth of a millimeter) in diameter, containing a variety of enzymes that among them break down all the major constituents of living things: proteins, carbohydrates, fats and nucleic acids. (Most of the enzymes function more efficiently under slightly acid conditions, and so they are known collectively as acid hydrolases.) As one might expect, such enzymes are involved in a wide range of normal and disease processes [see "The Lysosome," by Christian de Duve; SCIENTIFIC AMERICAN, May, 1963]. They can digest things that enter the cell; they can also break down part or all of the cell itself or tissues outside the cell. It now appears that in doing so they are implicated in the development and the death of tissues, in diseases such as silicosis and gout, in cell division, in the immune process and thus perhaps in autoimmune disease, and in damage to chromosomes. Their effect on chromosomes suggests that lysosomes may possibly play a central role in the induction of cancer.

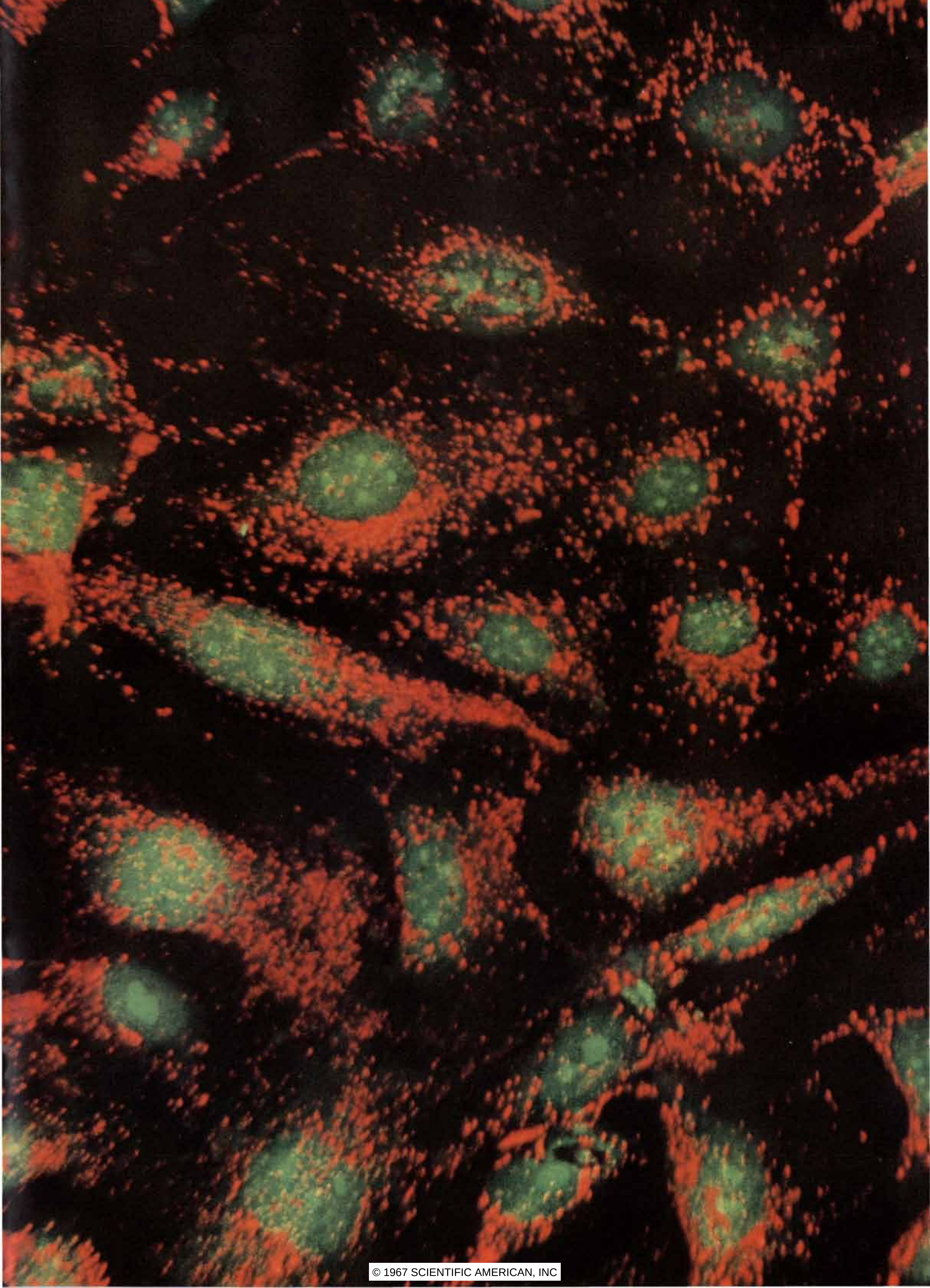
Lysosomal enzymes, like other proteins, are synthesized in ribosomes within the folded membranes of the endoplasmic reticulum [*see illustration on page 67*]. In the outer part of a series of vesicles known as the Golgi apparatus the lysosomal enzymes are packaged into organelles surrounded by single lipoprotein membranes. These "nascent granules" develop into "primary lysosomes" in which the enzymes are stored in an inactive form, ready for use.

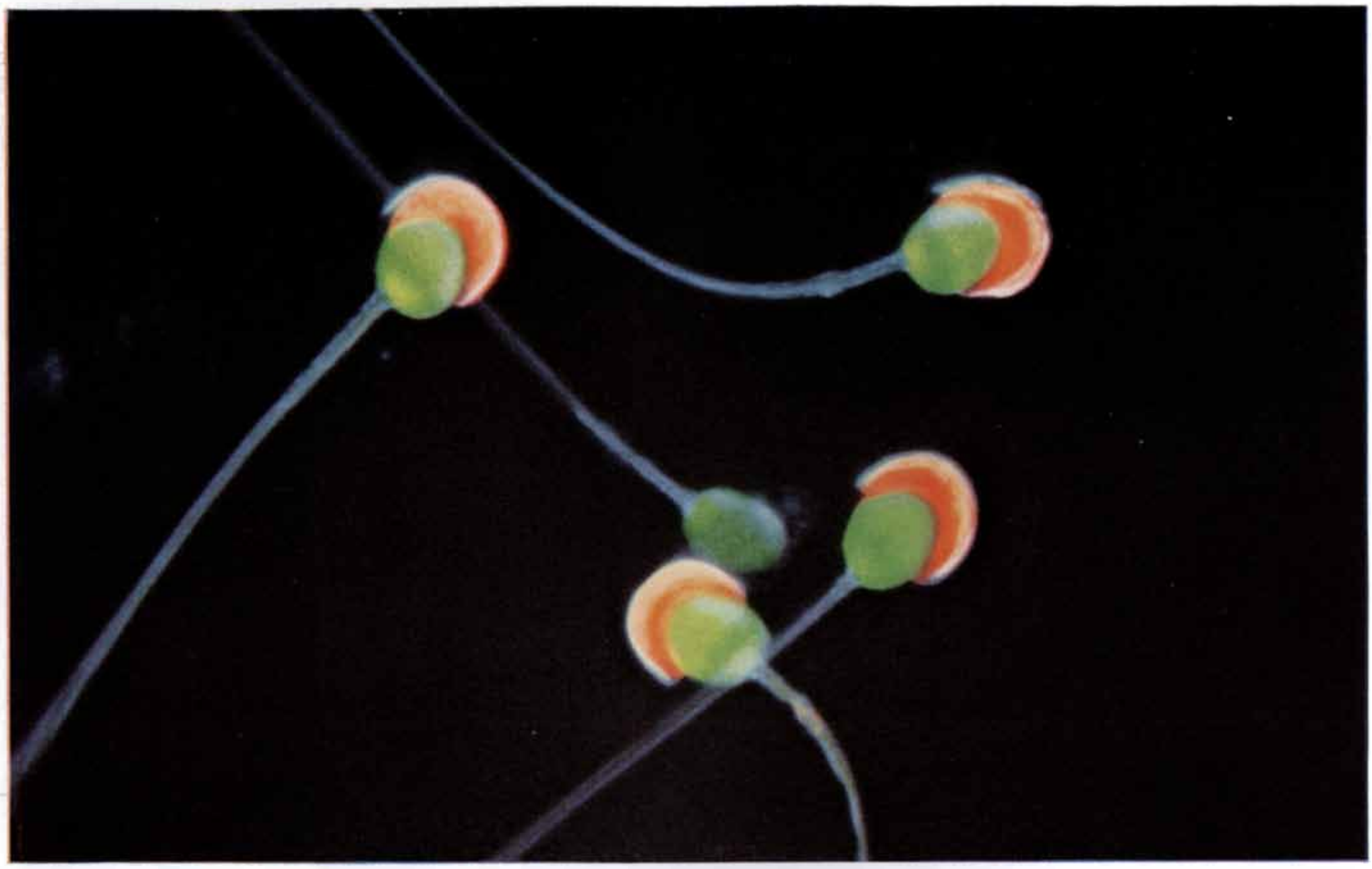
Once the identity of lysosomes was established it soon became apparent that a number of rather different looking cytoplasmic bodies familiar to cell biologists are lysosomes. The granules that are characteristic of the cytoplasm of white blood cells are perhaps the most typical lysosomes, but all animal cells studied so far, with the exception of red blood cells, have organelles containing some of the characteristic hydrolytic enzymes and falling within the general definition of lysosomes. Similar organelles have been observed in plants, including fungi and yeasts. Bacteria do not contain lysosomes in the forms recognized in higher organisms, but hydrolytic enzymes with properties like those of lysosomal enzymes can be released from bacteria by certain procedures. In other words, the presence of lytic, or digestive, enzymes that are normally enclosed in membranes but can be released by appropriate stimuli seems to be a widespread characteristic of living organisms.

The Functions of Lysosomes

The simplest and the most obvious role of a packet of digestive enzymes within a cell is in necrosis and autolysis, the death and self-dissolution of tissues. The membrane of the primary lysosome simply dissolves, liberating the enzymes to consume the cell. This can follow wounding or other damage to tissue or it can take place naturally in the course of development: when the corpus luteum of the ovary degenerates, for instance, or when a tadpole loses its tail. Any time a tissue or an organ is isolated from its supply of oxygen or nutrients under sterile conditions it breaks down rapidly; the large molecules such as proteins, lipids, nucleic acids and carbohydrates are digested, and there is evidence that enzymes from lysosomes play a part in the process. Rudolf Weber of the University of Berne found that the concentration of lysosomal enzymes in the tail of an amphibian increases before metamorphosis, and the concentration of these enzymes—which as catalysts are

LYSOSOMES glow orange-red in the fluorescence photomicrograph on the opposite page, made by M. R. Young and the author. The cultured monkey-kidney cells were vitally stained (stained without being killed) with acridine orange, which concentrates in lysosomes. Lower concentrations of the dye in the nuclei produce the green fluorescence.





SPERMATOZOA of a guinea pig were vitally stained with acridine orange and then photographed by fluorescence microscopy. The nuclei are green and the acrosomes, small sperm-cell organelles that contain some of the same enzymes as lysosomes, are orange.

ACROSOMES of long, thin rat spermatozoa are similarly stained. The enzymes in acrosomes break down the protective film around an egg and then apparently disrupt "cortical granules" in the egg, thus initiating a process that leads to cleavage and development.

not consumed in the process of tissue digestion—increases as the tail is resorbed.

Soon after lysosomes were first described it was suggested that the release of their enzymes into the cytoplasm or outside the cell might be the primary event that accounted for many other and different types of tissue damage. More detailed scrutiny showed that biochemical changes in other organelles sometimes preceded those that could be demonstrated in lysosomes; the conviction grew that lysosomal release was a secondary effect. It now seems that both situations can prevail. In some cases it is virtually certain that the primary event is an increase in the permeability of the lysosomal membrane, with the consequent release of hydrolytic enzymes. In other cases the lysosomal changes may indeed be secondary to reactions in other systems.

A specialized form of autolysis occurs in the cells of starved protozoa or mammals: organelles such as ribosomes and mitochondria somehow become incorporated in cytoplasmic vacuoles, or membrane-enclosed cavities, that fuse with lysosomes. The contents of the resulting "autophagic vacuoles" are thereupon digested, but the cell may often survive. Autophagy appears to be a mechanism by which, under unfavorable conditions, part of the cell's substance—presumably currently unneeded elements—can be broken down and its constituents utilized to provide energy or material needed to maintain the life of the cell.

The second obvious function of lysosomes is in intracellular digestion. This process, as Élie Metchnikoff recognized more than half a century ago, follows essentially the same course in single-celled animals and in what he termed the "phagocytic" cells of mammals. Metchnikoff postulated then that bacteria ingested by phagocytic cells were digested by "ferments" contained in the granules visible in those cells. In 1960 James G. Hirsch and Zanvil A. Cohn of the Rockefeller Institute showed that the granules of the white blood cells called leukocytes do contain the enzymes characteristic of De Duve's lysosomes—that they are lysosomes. Foreign particles such as bacteria are ingested by the process now known as endocytosis [*see illustration on page 67*]. The cell membrane folds inward to form a pocket, the edges of which fuse to enclose the particles in "phagosomes." The primary lysosomes become attached to the phagosomes and discharge enzymes into them, forming "secondary lysosomes." Here the particles are more or less completely digested; indigestible material remains segregated from the cytoplasm within "residual bodies," which may remain in the cell for a long time or may fuse with the cell wall and so discharge their contents.

The digestion of bacteria by leukocytes is of course an important form of defense against disease. Not surprisingly, bacteria have developed adaptations that enable them to survive lysosomal attack. Several bacteria elaborate poisons that kill leukocytes before the bacteria are themselves destroyed; others, including those causing tuberculosis, have thick, waxy coats that resist attack by the enzymes. There are rare inherited diseases in which the lysosomal system is ineffective. In one condition, the Chédiak-Higashi syndrome, the lysosomal granules are abnormally large and ingested bacteria may not be killed. Comparable conditions exist in animals: in mink with the Aleutian, or blue, gene and in certain albino cattle [see "The Kinship of Animal and Human Diseases," by Robert W. Leader; SCIENTIFIC AMERICAN, January]. In another disease the enzyme leukocyte oxidase is inactive; bacteria or viruses are phagocytized but are not digested in the usual manner. In much the same way the inactivity of individual lysosomal enzymes may be responsible for certain "storage" diseases in which a metabolic product that should be broken down in the cell is not and therefore accumulates in pathological amounts.

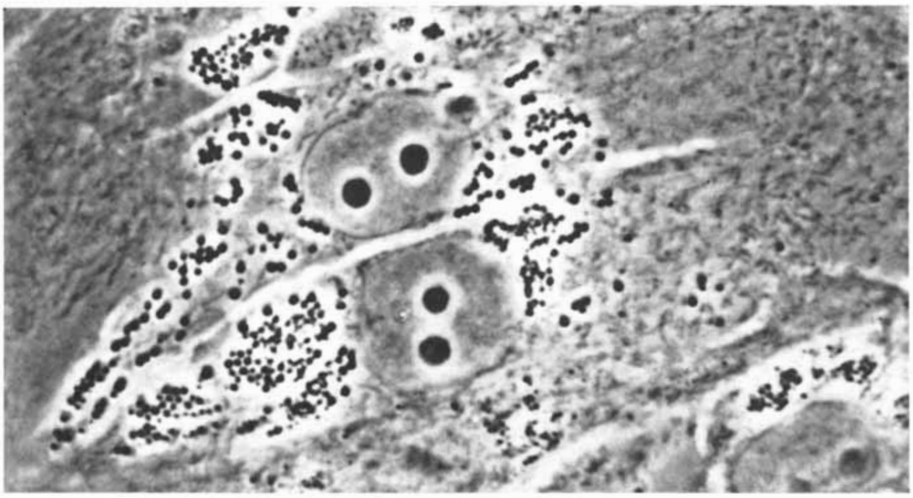
Particles and Lysosomes

Most of the lysosomal disease processes investigated so far involve situations in which the untimely rupture of the lysosomal membrane leads to some form of cell damage. At the National Institute for Medical Research in London my colleagues and I have spent much time studying the effects of small particles of silica, asbestos and other substances on cells. It is relatively easy to follow the fate of these particles by microscopic examination, and so one can be sure that the initial effects are lysosomal; moreover, the particles have simple chemical compositions, so that the number of reactions they can initiate is limited. The results bear not only on diseases such as silicosis and asbestosis but also on gout and perhaps inflammatory processes in general. The fact that exposure to asbestos particles is associated with the development of some kinds of cancer also provides one of the links between lysosomes and carcinogenesis.

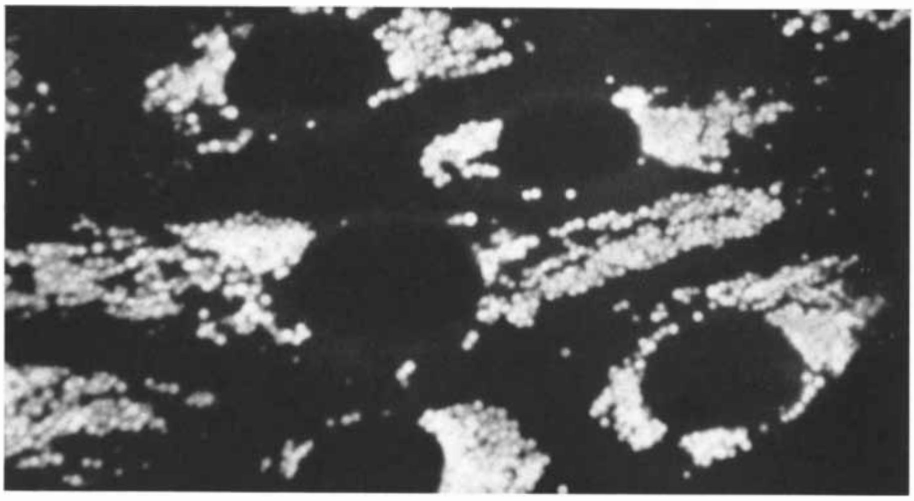
Most foreign particles taken into the human body by inhalation—such as the carbon particles that remain for years within phagocytic cells in the lungs of people who breathe smoke-polluted air—are innocuous. However, certain inhaled particles, including several crystalline forms of silica (silicon dioxide), stimulate a severe reaction in the lungs, ending with the deposition of fibrous tissue that can lead to marked impairment of lung function. The reaction proceeds in two stages. First, the inhaled silica particles are ingested by phagocytic cells in the lungs; these cells die, releasing the particles, which are taken up by other cells with the same result. Second, the repeated death of phagocytic cells stimulates a reaction of fibroblasts, cells that synthesize and lay down nodules of collagen fibers.

We analyzed these mechanisms separately by studying each stage independently in tissue culture. When phagocytic cells in culture take up silica particles, they are rapidly killed. When the cells ingest nontoxic particles of the same size and shape, such as diamond dust or titanium dioxide dust, they survive. We can show that lysosomal enzymes are discharged into vacuoles containing either the toxic or the nontoxic particles, but that the nontoxic particles and enzymes remain within the lysosomes for long periods, whereas silica particles and enzymes escape quite rapidly into the cytoplasm [*see bottom illustration on page 68*]. The key factor seems to be the readiness with which silica particles react with lysosomal and other membrane systems. We illustrate this by suspending red blood cells with particles of different materials that have the same size and surface area. The red cells are lysed by particles of many types of crystalline silica—but not by one type that also fails to damage phagocytic cells or to stimulate fibrosis in experimental animals, or by other nontoxic particles.

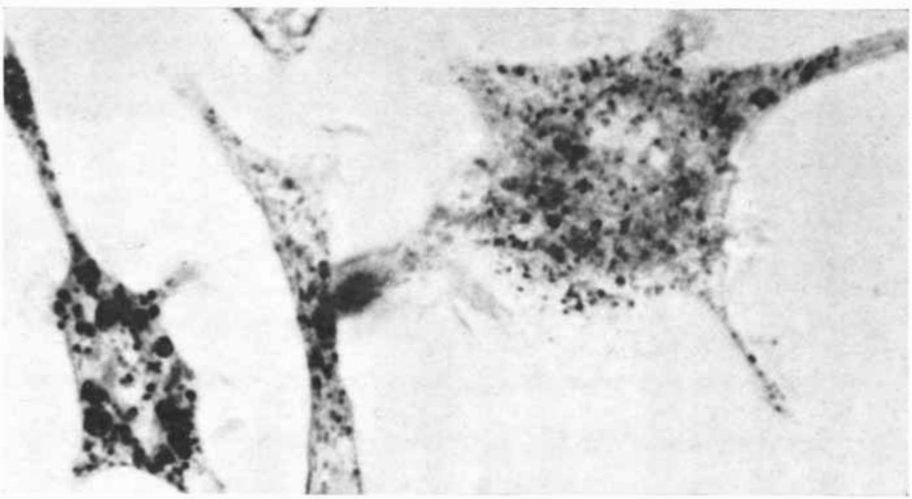
The reactivity of silica particles appears to be due to the fact that silicic acid is formed on their surface. Silicic acid is unusual in having hydroxyl groups that can form powerful hydrogen bonds with suitable acceptor molecules—including certain groups in the phospholipids and proteins that are characteristic of cellular membranes. Such hydrogen bonding is sufficient to account for the disruption of lysosomal (or red-cell) membranes. Evidence in support of this interpretation comes from the observation, made some years ago by H. W. Schlipköter and his colleagues at the University of Düsseldorf,



PHASE-CONTRAST microscopy shows lysosomes as small black granules because of their different light-refracting properties. These living kidney cells in culture are enlarged 1,000 diameters. Lysosomes clump near nuclei; mitochondria (*dark gray*) lie in the background.



FLUORESCENCE microscopy shows lysosomes as brightly glowing particles. These kidney cells were photographed after being treated with methylcholanthrene, a cancer-inducing substance that is concentrated in lysosomes. Nuclei and mitochondria do not fluoresce.



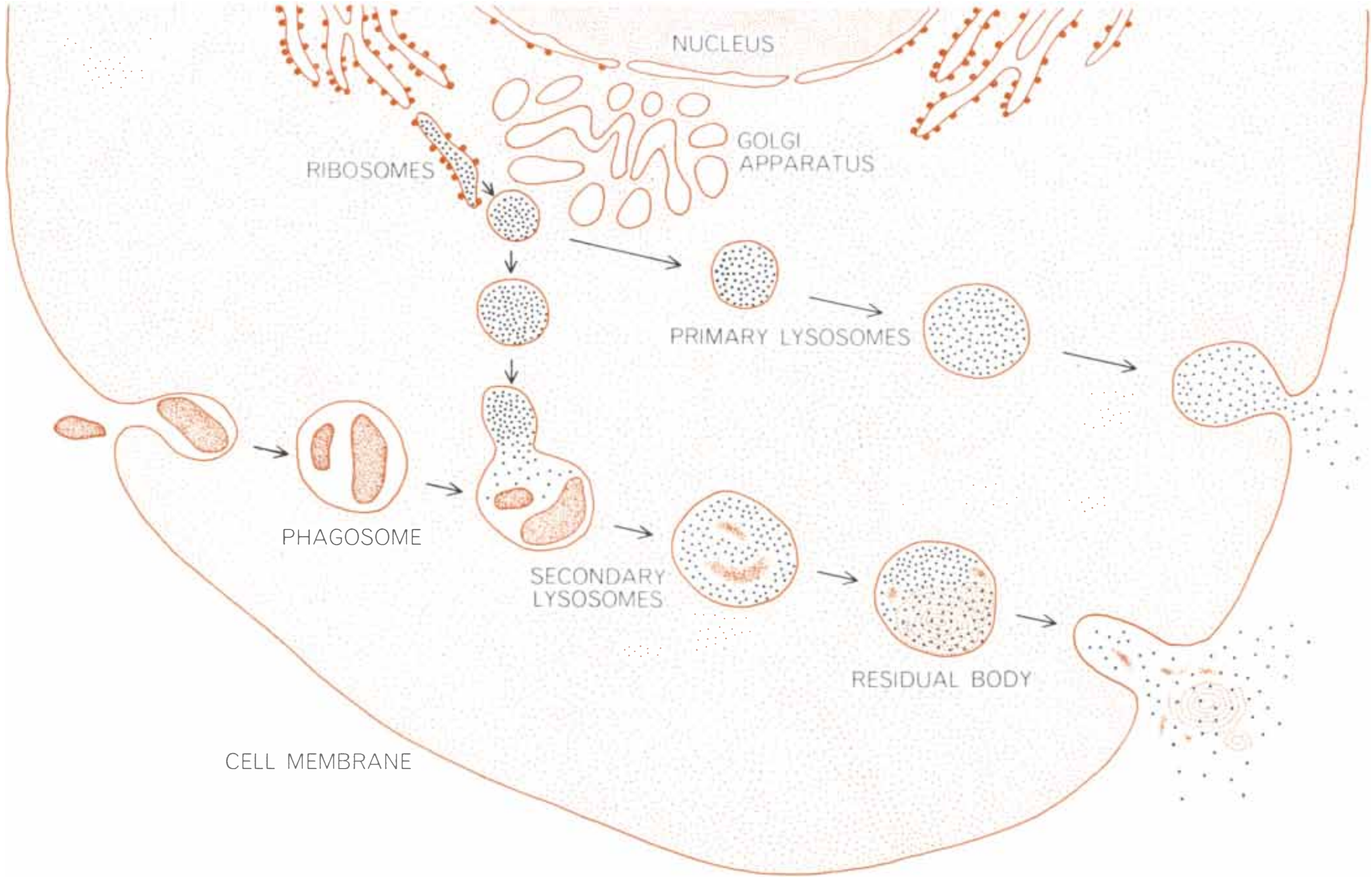
GOMORI METHOD, which depends on the presence in lysosomes of the enzyme acid phosphatase, yields a reaction product, lead sulfide, that stains lysosomes black. The photomicrograph shows mouse macrophages, large phagocytic cells, enlarged 1,600 diameters.

that the polymer polyvinylpyridine-N-oxide protects cells against the toxic effects of silica. This polymer is taken up into lysosomes along with the silica. The oxygen atoms of polyvinylpyridine-N-oxide readily form hydrogen bonds with the hydroxyl groups of silicic acid, and thereby prevent the latter from bonding with, and thus attacking, lysosomal membranes.

That explains why silica is so toxic to phagocytic cells: the particles are taken up into lysosomes and damage lysosomal membranes through hydrogen-bonding interactions. The second problem remains: How does the death of phagocytic cells stimulate the deposition of collagen fibers? A. G. Heppleston and J. A. Styles of the University of Newcastle upon Tyne have found that when phagocytic cells in culture are incubated with silica particles, they release a factor that, when added to a second culture of fibroblasts, stimulates the synthesis of connective tissue fibers in it; the release of such a factor could perhaps account for the fibrous nodules of silicosis. The chemical structure of this factor is still not known, but certain polymers of the sugar galactose are known to stimulate fibrogenesis, and it is of interest that these polymers are all taken up into lysosomes.

Prolonged exposure to asbestos dust can lead to asbestosis, a disease that, like silicosis, is associated with the deposition of fibrous tissue in the lungs. A second hazard was recognized in 1960 by C. J. Wagner and his colleagues in South Africa: the development of malignant tumors in asbestos workers. Many of these tumors are mesotheliomas, an unusual type arising from the mesothelium, the layer of cells that lines the body cavities. Similar tumors are found in animals that have received injections of asbestos particles in the chest cavity, even when the particles have been purified to remove possibly carcinogenic hydrocarbon contaminants. Electron-microscope and other studies show that asbestos particles are taken up into lysosomes, from which some of them later escape. Wagner has also found that injections of silica particles into the thoracic cavities of rats lead to malignant tumors of the thymus gland.

Another example of pathology due to the effects of particles on cells is provided by gout, in which a metabolic defect causes small crystals of sodium urate to accumulate in the joints and produce pain, swelling and other symptoms. Several investigators have shown that the crystals of sodium urate are ingested by



LYSOSOMAL ENZYMES (*black dots*) are synthesized, like other proteins, in ribosomes of the endoplasmic reticulum and are then packaged within the Golgi apparatus into small baglike particles called nascent granules. These develop into primary lysosomes, which sometimes secrete their contents outside the cell (*middle right*) but in most circumstances store the enzymes until they are required for intracellular digestion. Particles taken into the cell by the amoeboid process called endocytosis (*left*) are enclosed in membrane-bounded vesicles called phagosomes. Primary lysosomes fuse with the phagosomes and discharge digestive enzymes into them, forming secondary lysosomes. The particles are thereupon digested. Undigested material remains enclosed in residual bodies, which may persist in the cell for some time or may fuse with the cell membrane and so excrete their contents (*bottom right*).

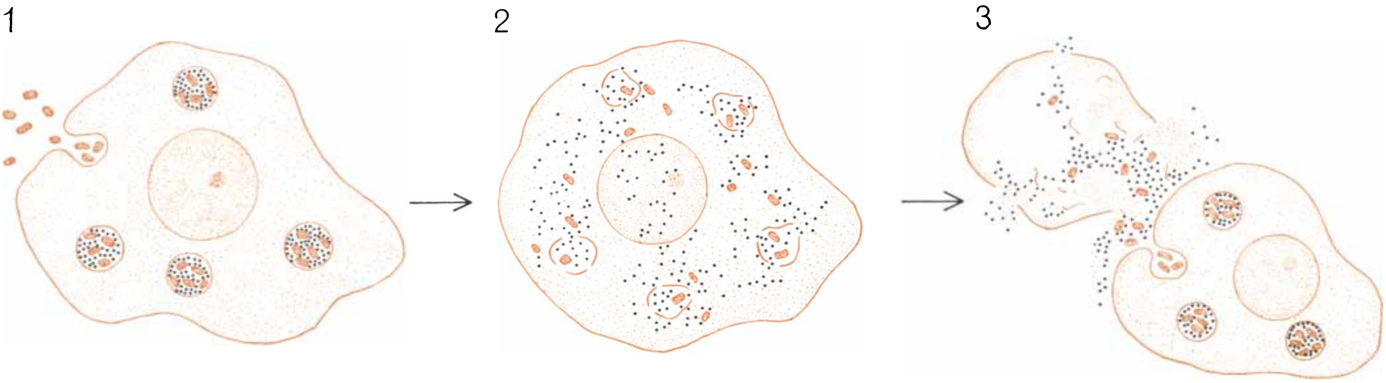
phagocytic cells and that this leads to the formation of factors producing pain and other manifestations of inflammation. There is evidence that lysosomal enzymes may be released in the process.

The role of lysosomes in inflammation in general is a difficult problem. Inflammation is marked, as ancient observers realized, by four signs: swelling, heat, redness and pain. It is a common reaction in tissues damaged as a result of infection, burns or the presence of a noxious substance, and in many disease processes. The swelling, redness and warmth are caused by enlargement of the blood vessels supplying the inflamed area and the passage of fluid containing protein (which is normally confined within blood vessels) through the walls of blood vessels into the spaces between them. One of the proteins, fibrin (which provides the structural basis of blood clots), is deposited in the tissue spaces. White blood cells also leave the vessels and move into the tissues. Several chemical mediators are liberated from damaged cells or formed in inflamed tissues. Among these are factors that increase the permeability of blood vessels, including histamine, serotonin and bradykinin, a peptide produced from serum proteins by enzyme action. There are also pain-producing factors and in some cases pyrogens, which bring about a rise in body temperature.

In this complex situation it is difficult to know which reactions are primary and which take place later. It seems clear, however, that lysosomes are implicated in some of the reactions. Basic protein fractions from leukocyte lysosomes, isolated by Hassan Zeya and John K. Spitznagel of the University of North Carolina, were shown by Aaron Janoff of New York University to effect the release of histamine from certain cells. John Herion and Hussein Saba of North Carolina showed that such fractions inhibit a step in blood coagulation. S. Y. Ali and C. H. Lack of the Royal National Orthopaedic Hospital in London found that a factor from lysosomes activates the enzyme plasminogen, which in turn breaks down fibrin. Lysosomal proteases (protein-digesting enzymes) probably contribute to tissue damage in inflammation and participate in the formation of bradykinin. Spitznagel and his colleagues have shown that lysosomes contain a pyrogen, although it may not be the only factor that is responsible for fever. The role of lysosomes in inflammation is now under intensive study and more precise definition is likely to emerge in the next few years.

Effects of Dyes and Drugs

Among the substances that are selectively concentrated in lysosomes are a number of soluble dyes and drugs. The localization of the dyes makes lysosomes clearly distinguishable in photomicrographs [*see illustration on page 63*] and the localization of the drugs offers some suggestive evidence as to their mode of action. Among the drugs that are concentrated in lysosomes are the antimalarial compounds chloroquine, quinine and quinacrine. When malaria parasites take hemoglobin from red blood cells,



SILICOSIS, a lung disease, begins with the endocytosis of silica (silicon dioxide) particles by phagocytic cells in the lung (*1*). Once inside secondary lysosomes, the silica particles damage the lysosomal membrane through a hydrogen-bonding reaction between silicic acid and the membrane (*2*). The lysosomal enzymes kill the cell, releasing silica particles to be taken up by other cells (*3*). The dying cells elaborate a factor that somehow stimulates specialized cells to synthesize fibrous nodules that can impair lung function.

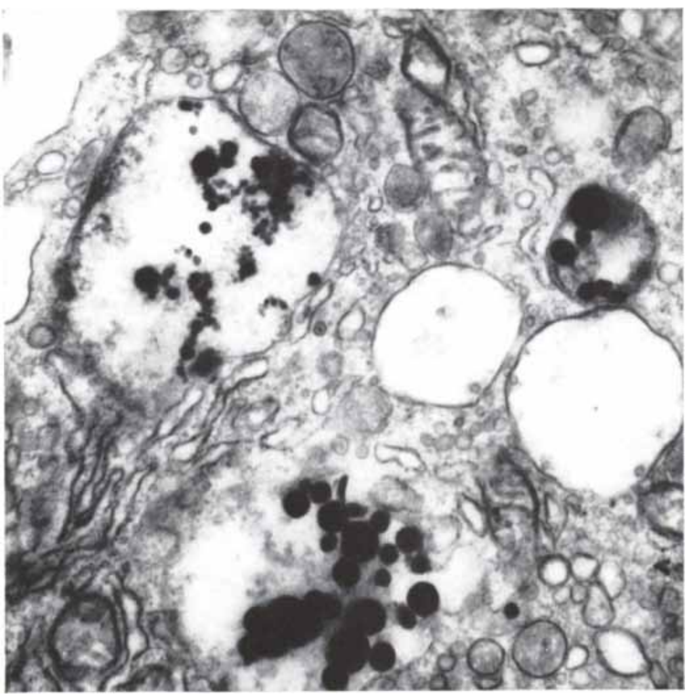
they ingest it into their lysosomes much as leukocytes ingest bacteria, and so it may be impairment of the lysosomal mechanism that explains the effects of some antimalarial drugs.

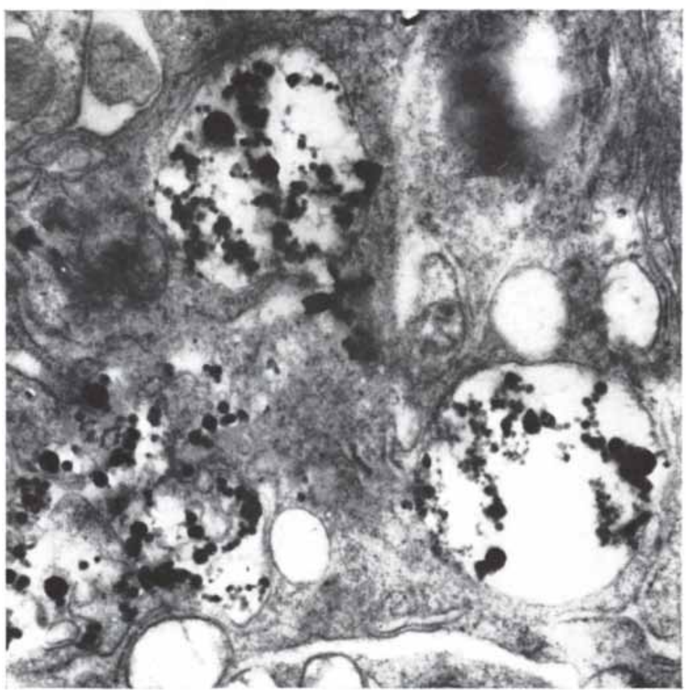
The precise effects of some drugs on the lysosomal membrane are known. Cortisone and related corticosteroids, for example, stabilize the membrane, making it less liable to rupture; this may explain the broad anti-inflammatory effects of these drugs. A number of steroids and other compounds weaken the membrane, making it more permeable. One such compound is carbon tetrachloride, which is used against certain worms that parasitize the intestines of mammals. The digestive tract of these worms is a tube of amoeba-like cells, each of which ingests food and breaks it down in lysosomes. Small doses of carbon tetrachloride damage the worm-cell lysosomes, and the massive release of hydrolytic enzymes kills the worms.

Dame Honor Fell and John Dingle of the Strangeways Research Laboratory in Cambridge have found that high doses of vitamin A added to cultures of chick embryo rudiments bring about the release of large amounts of lysosomal enzymes; the lysosomal protease that is thus released digests the intercellular matrix.

Lysosomes apparently also take part in the action of certain hormones. Soon after thyrotrophic hormone is administered, for instance, there is an increased uptake of colloidal substances into the lysosomes of thyroid cells; the colloid is digested and then the synthesis and secretion of thyroid hormones proceeds. Again, some effects of insulin on blood sugar are counteracted by glucagon; liver lysosomes show marked changes after glucagon is administered.

Some compounds that become concentrated in lysosomes produce fetal abnormalities. If the dye trypan blue or the detergent Triton WR-1339 is administered to pregnant animals, it is taken up by the lysosomes of cells in the placenta, the membrane that nourishes the fetus, and a high incidence of abortions and congenital defects results. High doses of vitamin A, which have been shown to decrease the stability of the lysosomal membrane, produce similar results.





PHAGOCYTIC CELL that has recently taken up silica particles (*dark spheres*) into phagosomes is enlarged 25,000 diameters in an electron micrograph made by M. J. Birbeck and the author *(left)*. Primary lysosomes are free in the cytoplasm just above the phagosome at upper left or are about to discharge enzymes into the lower phagosome. In a micrograph made 18 hours after uptake of silica (*right*), the lysosomal membranes have been damaged. Silica is escaping into the cytoplasm, which is now visibly disorganized.

Whether the abnormalities are due simply to a lack of nutrition for the embryo or to some other effect is still not established; moreover, it is likely that some other drugs produce fetal abnormalities by nonlysosomal mechanisms.

There is a category of compounds that tend to make the skin sensitive to the action of light. Some years ago my colleagues Ian Magnus and M. R. Young and I noticed that many of these photosensitizing compounds accumulate in the lysosomes of living cells, and we proceeded to study the phenomenon in experimental animals and in cultured cells. The experiments with cells led to the development of a convenient way to damage various components of the living cell selectively.

We incubate the cells in the dark with substances such as neutral red, anthracene or porphyrin, all of which are concentrated in lysosomes, and then illuminate the cells with light of a wavelength absorbed only by the photosensitizing substance, not the living material. In this way photooxidative damage to lysosomal membranes is achieved, without any immediate damage to the cell membrane or nucleus or to the rest of the cytoplasm. (If enough enzyme is released from lysosomes, the cells die after a short delay.) Other photosensitizing dyes, such as Janus green or acriflavine, selectively sensitize mitochondria or nuclei respectively. Still others, including eosin and rose bengal, do not enter most cells at all. They collect on the surface and in the presence of light cause damage to the cell membrane, killing the cells.

The induced photosensitization procedure has several advantages over other methods of selectively destroying cellular organelles. Photons of radiation produce photochemical reactions only where they are absorbed, and the relatively long wavelengths we use are not absorbed by most cell constituents. Ultraviolet or X rays, on the other hand, attack many biological constituents, and even if one aims a very narrow beam at the nucleus or cytoplasm, it can damage the cell membrane.

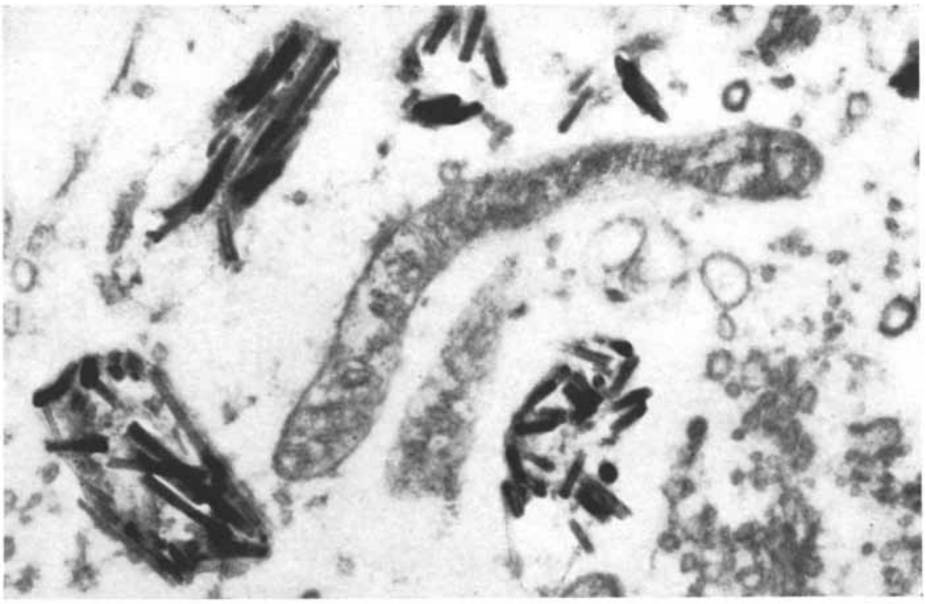
Lysosomes and Cell Division

One of the features of cells stained with acridine orange is that mitotic, or dividing, cells have comparatively few lysosomes, and these lysosomes lie on the periphery of the cell instead of near the nucleus, as is usually the case. This suggests that the breakdown of lysosomes may act as a trigger for mitosis in cells that are prepared for it. To establish that the relation is causal, however, it is necessary to show that agents increasing the permeability of lysosomes induce mitosis in cells that would not otherwise divide, whereas agents stabilizing the lysosomal membrane can prevent this mitogenic effect.

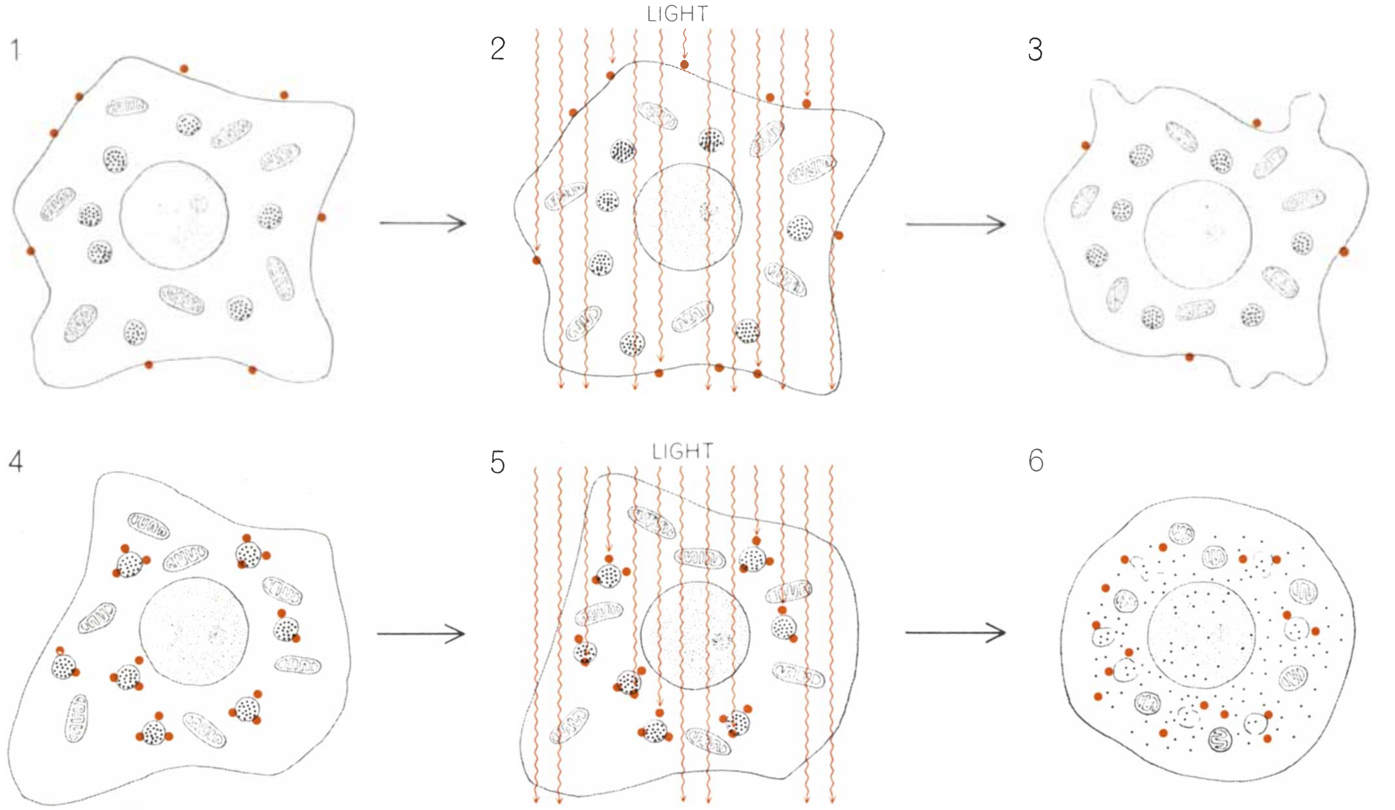
These questions have been studied in experiments with lymphocytes, a species of white cell involved in immune responses. Lymphocytes from the peripheral blood do not ordinarily undergo mitosis in a cell culture, but if they are treated with phytohemagglutinin, an extract of red kidney beans, they are "transformed": they enlarge, synthesize nucleic acids and protein, and then divide. A similar mitogenic effect is produced by a factor extracted from the pokeweed, by a vegetable-oil fraction called phorbol A, by certain bacterial toxins and by antibodies against the lymphocytes themselves. The mode of action of these agents has been studied primarily by Kurt Hirschhorn, Gerald Weissmann and Rochelle Hirschhorn at the New York University School of Medicine and independently by Livio Mallucci and me in London. It has been shown that at least some of the agents—the bacterial toxins, the antilymphocyte antibodies and phorbol A—increase the permeability of lysosomal membranes. The mitogenic effects, moreover, can be prevented by cortisone and chloroquine, which are known to stabilize the membranes. It seems, therefore, that mitosis is ordinarily inhibited by some kind of "repressor" substance and that the lysosomal mechanism is involved in "derepressing" it.

The phenomenon of lymphocyte transformation assumes biological significance with the demonstration that if lymphocytes have been sensitized by prior exposure to a particular foreign substance, or antigen, transformation follows a second exposure to the antigen. The sensitized cells multiply and can participate in a particular type of immune response that is carried out by the lymphocytes themselves instead of by free immunoglobulin molecules. Cell-mediated immune responses of this type are important in the reaction against foreign cells or tumor cells. It is of interest that the transformed cells contain more lysosomes than normal lymphocytes; the lysosomes may participate in the reactions by which the foreign cells are destroyed. These reactions are important because they prevent the transplantation of kidneys and other organs from one human to another, so that it would be useful to understand the underlying mechanisms and control them.

The animal egg is another cell that does not normally divide unless it is stimulated to do so, as in the case of fertilization. The spermatozoon has a special organelle, the acrosome, that becomes detached as soon as the egg is penetrated. E. F. Hartree and I found that the acrosome shows the same uptake of dyes as lysosomes and contains several enzymes characteristic of lysosomes [*see illustrations on page 64*]. These include hyaluronidase and proteases, which break down the gelatinous material around the egg. In the outer part of the egg itself there are "cortical granules" with the same enzymes and staining reactions as lysosomes. Apart from their role in facilitating the penetration of the sperm head into the egg,



ASBESTOS PARTICLES, dark rodlike objects, concentrate in phagosomes of a phagocytic cell, is enlarged 50,000 diameters in this electron micrograph made by J. A. Armstrong.



PHOTOSENSITIZATION offers a means of selectively killing parts of the cell. Some dyes, such as eosin, remain associated with the cell membrane (*1*). Exposure to visible light of a wavelength absorbed by the dye (*2*) damages the membrane, causing the death of the cell and the extrusion of cytoplasm (*3*). Other dyes are taken into the cell; neutral red becomes concentrated in the lysosomes (*4*). Exposure to light of a wavelength absorbed by such a dye (*5*) damages the lysosomal membrane, releasing enzymes that only later cause the cell to swell up and die (*6*). Photons of light that miss lysosomes pass through the cell without causing damage.

enzymes from the acrosome seem to initiate disruption of the cortical granules, beginning a chain reaction that spreads rapidly around the egg. (The cortical granules in frog eggs can be disrupted physically, as by puncturing the membrane of the egg with a needle, to stimulate parthenogenetic cleavage in the absence of a sperm. In sea urchin eggs parthenogenetic cleavage can be induced by other agents, including antibodies that react with cortical granules.) After disruption of the cortical granules the outer layers of the egg are broken down, a new membrane resistant to enzymatic attack is formed underneath and various synthetic reactions proceed, culminating in cleavage.

There are some hints as to how hydrolytic enzymes might, paradoxically, initiate synthetic reactions. Alberto Monroy and his colleagues at the University of Palermo have found that ribosomes from unfertilized sea urchin eggs synthesize very little protein, whereas ribosomes from fertilized eggs synthesize freely. Brief exposure of the former to proteases stimulates protein synthesis, apparently by removing an inhibitor that is a protein or a peptide. Whether the derepression that follows the release of enzymes is entirely due to the destruction of inhibitors or whether other factors are involved is still not known.

Chromosome Damage

The photosensitization technique has the advantage that by regulating the amount of radiation one can control accurately the amount of lysosomal enzyme release and consequent cell damage. Gillian Paton and I found that if a moderate amount of enzyme is released in human body cells by this technique, chromosome breaks and rearrangements appear. We concluded that strands of deoxyribonucleic acid, the genetic material, had been attacked by the enzyme deoxyribonuclease (DNAase) from lysosomes.

Lysosomal DNAase has been studied intensively by Giorgio Bernardi of the Center for Research on Macromolecules in Strasbourg and others. It has some interesting properties. The enzyme molecule has two active sites, and so it can attack both strands of a double helix of DNA at the same time [*see illustration on page 72*]. Whereas breaks in one strand of a DNA double helix are known to be very efficiently repaired, breaks of the type induced by lysosomal DNAase are not; they are more likely to persist. (Although the lysosomal enzyme works best under acidic conditions, there is considerable activity at physiological hydrogen-ion concentrations, provided that the concentration of salts is not too high.)

We have found that when isolated chromosomes are incubated in the presence of lysosomal DNAase, breaks are produced; enzymes attacking protein or ribonucleic acid remove some material from chromosomes, but they do not produce breaks. Apparently the linear integrity of chromosomes is maintained by the DNA helix. We do not have direct evidence that lysosomal DNAase can enter nuclei and break chromosomes in living cells, although our recent observations strongly suggest that this is the case.

Lysosomes and Cancer

Lysosomal induction of chromosomal changes may help to explain the origin of certain types of cancer. The agents known to produce cancer fall into three major classes: physical, chemical and viral. The important physical agents are ultraviolet and other ionizing radiations. The chemical carcinogens are numerous and structurally diverse, including polybenzenoid hydrocarbons, various organic compounds containing nitrogen, female sex hormones given in excess under certain conditions, metals and asbestos and silica particles. Many cancer-producing viruses are known, and they differ in their properties. Some contain DNA, others RNA; some multiply in the nucleus, others in the cytoplasm; some contain lipid and are formed in close association with cell membranes, others do not contain lipid and are assembled independently of cell membranes.

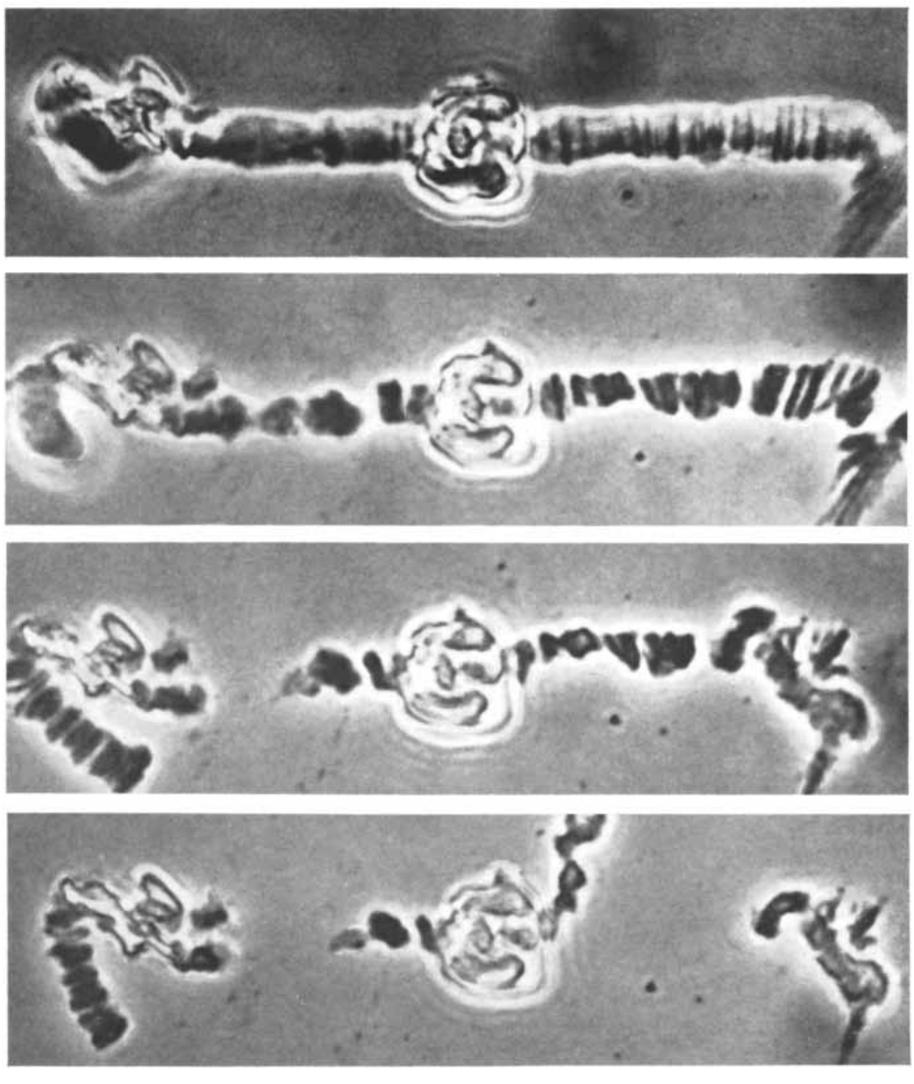
In this situation a central problem in cancer research is to find some common reaction in cells that can be triggered by such a bewildering variety of cancer-inducing agents. To be sure, there may be several different cancer-producing mechanisms. Perhaps, however, there is only one, and in our present state of knowledge we should follow Occam's principle and try to reduce the number of hypotheses about cancer induction to a minimum.

Chromosomal changes might be the common factor. Most authorities agree that transformation from normal to malignant cells must be regarded as a mutation, in the sense that progeny cells inherit the abnormal growth potential and other properties of parental malignant cells. It can therefore be concluded that some change in genetic material occurs. Mutations are usually produced in one of two ways: point mutations involve substitutions of one or a few base pairs of DNA, and often lead to formation of a single abnormal protein; chromosomal mutations involve the breakage of chromosomes and their reunion with pieces (much larger than those affected by point mutations) deleted, inverted or duplicated. There are reasons for believing that changes of the second type are more relevant to carcinogenesis.

It has been known for many years that the chromosome constitution of malignant cells is often abnormal. Most authorities feel that the marked abnormalities often seen in fully developed or transplanted tumors, involving unusual numbers of chromosomes and other changes, are secondary modifications in cells that are already malignant, that although these abnormalities may contribute to such properties of the tumor cells as lack of differentiation and invasiveness, they cannot be invoked to explain the original transformation. Other evidence suggests, however, that chromosomal anomalies can precede and lead to malignancy.

An example is the chromosomal abnormality associated with a human cancer of blood cells, chronic myeloid leu-

HUMAN CHROMOSOMES, enlarged 2,000 diameters in this photomicrograph from the author's laboratory, were broken by enzyme from lysosomes damaged by photosensitization effects. There is a simple break (*A*) and another that was followed by a relocation (*B*).



GIANT CHROMOSOME of the midge *Chironomus* is attacked by highly purified lysosomal deoxyribonuclease (DNAase) in this series of phase-contrast photomicrographs made in collaboration with M. Lezzi and Giorgio Bernardi. The enzyme attacked the DNA at vulnerable sites and within 15 minutes had broken the chromosome in two places.

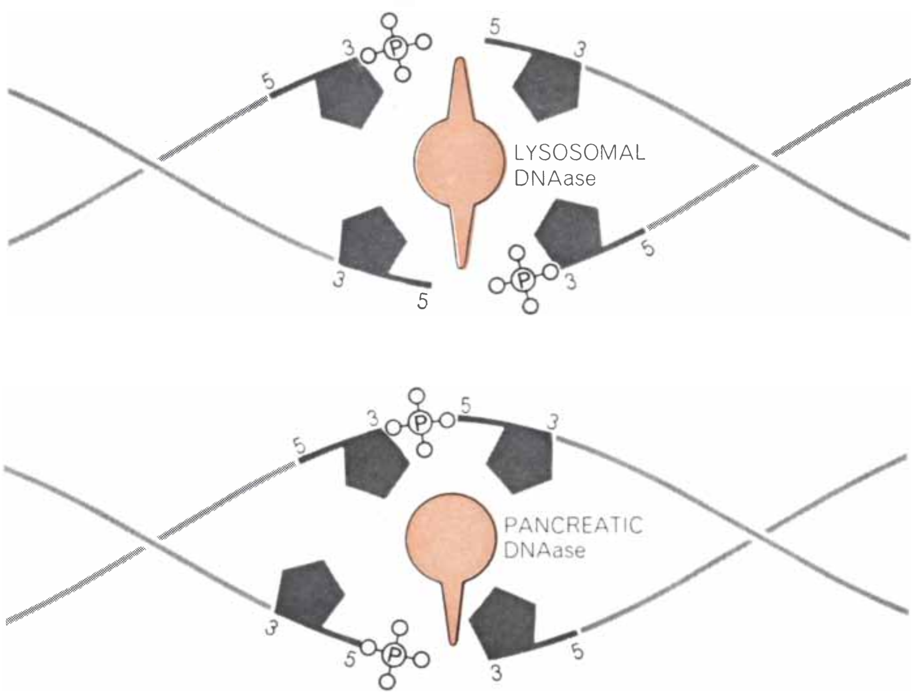
kemia. This is a partial deletion of a small chromosome, No. 21; the deletion can precede detectable malignancy and may in some cases have been produced by ionizing radiation. Other examples come from two rare inherited diseases of children, known after their discoverers as Fanconi's anemia and Bloom's syndrome. Children with either of these conditions have a greatly increased tendency to develop cancer of the blood or epithelial tissues. Several groups of investigators have found that when cells from these patients are cultured, they show numerous chromosome breaks and other aberrations. It has been suggested that this chromosome breakage is due to an abnormal release of lysosomal enzymes, although it is not yet certain whether this is true. It is at least clear that the tendency in human subjects for chromosome breakage to develop spontaneously is correlated with an increased risk of cancer. Agents increasing the incidence of malignancy also increase the rate of production of chromosome rearrangements.

The central question, then, is whether the chromosomal abnormalities are the cause of malignancy or simply a concurrent phenomenon. If the latter is the case, then one would have to postulate that many different processes can independently produce both malignant transformation and chromosomal aberrations. It is simpler to accept as a working hypothesis that chromosomal aberrations are induced by carcinogenic factors and are themselves responsible for the malignant process. The main argument against such a view is that if cells from early cancers are studied, they often seem to be normal. Still, deletions that are quite large in terms of the number of genes involved might be overlooked by current cytological procedures.

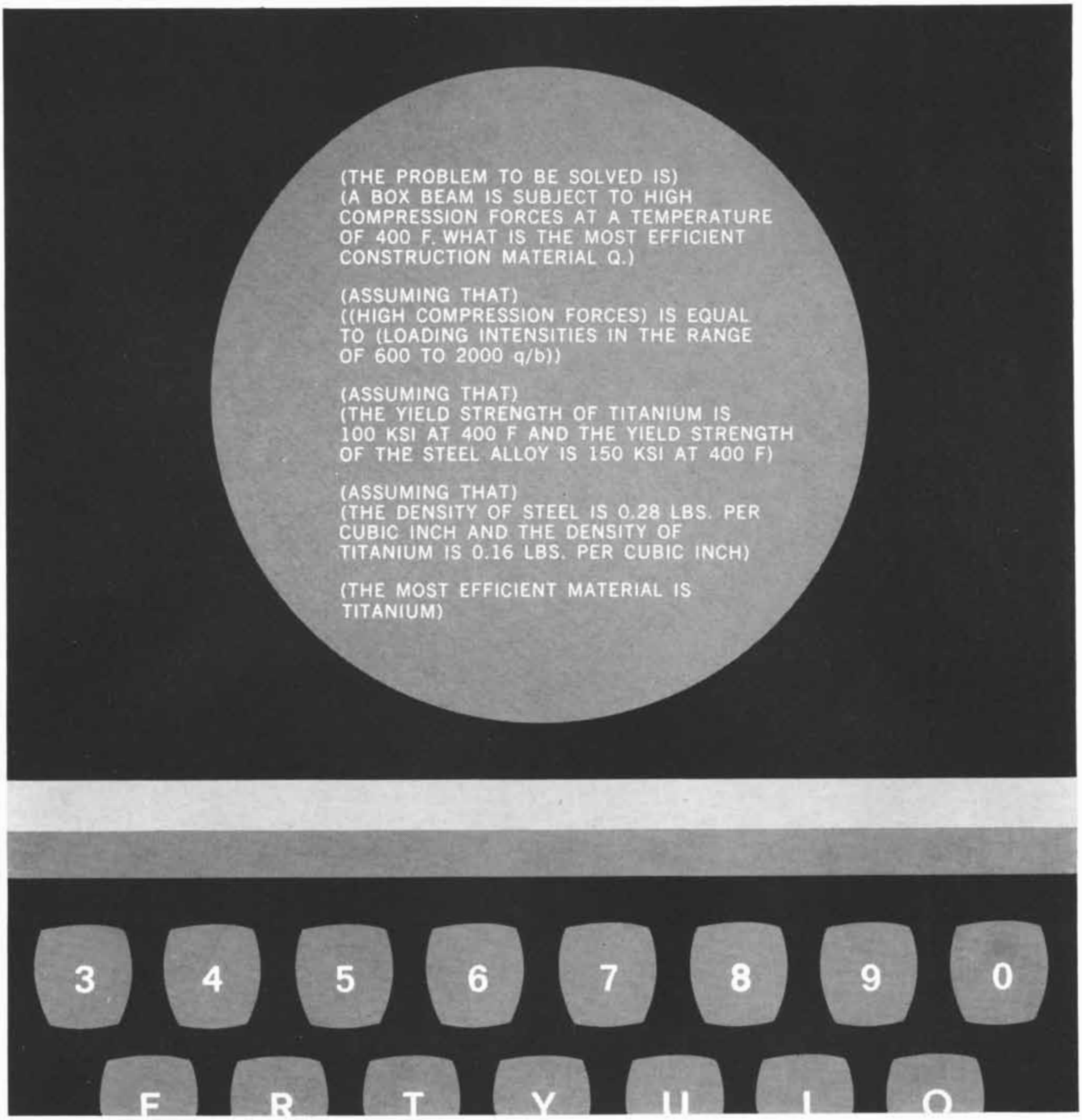
This line of reasoning explains why the involvement of lysosomes in chromosome breakage may be important in certain types of tumor induction, and why we have examined the effects of various cancer-producing agents on lysosomes. As I have indicated, asbestos and silica particles certainly affect lysosomes. The polybenzenoid hydrocarbon carcinogens such as benzopyrene and methylcholanthrene are concentrated in the lysosomes of living cells. Small amounts of these hydrocarbons produce cancers in mice if they are followed by treatment with so-called cocarcinogens. The most effective cocarcinogen is phorbol A, which Weissmann has shown to increase the permeability of isolated lysosomes. The only steroids that are effective in cancer production are the female sex hormones and the synthetic analogue diethylstilbestrol, all of which weaken lysosomal membranes. Release of enzymes from lysosomes also follows moderate doses of ultraviolet or ionizing radiation in several experimental systems. Cancer-producing viruses all produce chromosomal aberrations, although these may be incidental to the transformation from normal to malignant cells.

My colleagues and I have found that if selective damage to lysosomes is produced in embryonic cells by the photosensitization technique, a small proportion of these cells develop malignant potential: they produce tumors when they are injected into young animals of the same genetic constitution. Their efficiency in tumor production is low compared with that of certain viruses, but the results suggest that lysosomal damage represents one way by which tumors can be induced. Many years ago the Italian geneticist Adriano A. Buzzatti-Traverso found that if the eggs of the fruit fly *Drosophila* were treated with neutral red and light, some cells of the hatched flies would be normal while others had abnormal chromosomes. The mechanism was not understood at the time, but it may well have been lysosomal enzyme release, and the results are remarkably analogous to the genetic changes expected in tumor induction. I have mentioned the inherited abnormality of lysosomal structure and function in the Chédiak-Higashi syndrome. Many affected children who survive early bouts of recurrent infection develop malignant disease of the spleen and lymph glands. This again suggests a connection between lysosomes and susceptibility to cancer. The possibility is not yet excluded, however, that these children harbor a cancer-producing virus or other organism.

This raises the general problem of whether all tumors are due to viruses, with other cancer-inducing factors such as chemicals or radiation merely facilitating the action of latent viruses. Unfortunately there is no way of testing this hypothesis; it has not been possible to obtain animals free of viruses, even by rearing them in germ-free tanks. Moreover, although the *presence* of a virus can be demonstrated, it is never possible formally to prove the *absence* of viruses. Since only hypotheses that can be tested are productive, the concept that all tumors are virus-induced is simply not useful at present, and one is justified in looking for alternative hypotheses. The suggestion that lysosomes may be involved in certain types of cancer induction provides a working hypothesis that can be tested at various points. It has helped to let in some new light on an old and obscure problem, but it would be premature to conclude that it offers a definitive solution.



DOUBLE HELIX of DNA is completely cleaved by lysosomal DNAase molecule (*color*), which has two active sites and can cut both strands (*top*). The DNA backbone consists of sugar molecules (*pentagons*) connected by phosphate groups; the lysosomal enzyme leaves a phosphate group attached to the so-called 3-carbon of a sugar molecule. DNAase from the pancreas cuts only one strand (*bottom*), releasing 5-phosphate instead of 3-phosphate.



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RAPID EXCAVATION

Excavating from the surface is normally cheaper than tunneling underground, but its undesirable side effects and the evolution of excavating machines make tunneling increasingly attractive

by Thomas E. Howard

Man has always dug into the crust of the earth. His initial motivation, which is still his most important one, was to mine the raw materials from which to shape the tools and structures that would enable him to control his environment. Indeed, the early epochs of man—the Stone, Bronze and Iron ages—derive their names from the primary mined material on which their technology was based.

Throughout history the advance of a civilization has been marked by increasing amounts of excavation. Rises in population and affluence have always been accompanied by expanding activity in the quarries and mines as public and private buildings became more numerous and elaborate and as technology required more and better materials. As urbanization advanced with increased wealth the tools and techniques of the miner were applied for other purposes. The improved transportation and communication networks, the aqueducts, sewers, irrigation canals and other public utilities that are the requisites of concentrated population and social progress called for increasing modification and penetration of the earth's surface.

Clearly excavation technology has been basic to the advance of mankind through the ages. Yet until recently its adequacy for the tasks at hand has never been widely questioned. It is therefore significant that during the past year or two the term "rapid excavation" has been used with increasing frequency. The reasons for this development are that the need for improved excavation technology has become urgent and that the opportunities for a substantial leap forward are excellent.

As in the past, increasing population and urbanization are creating critical needs for materials, facilities and structures dependent on excavation. Some new factors, however, are placing unprecedented demands on excavation technology. One factor is the sheer size of the modern excavation task. Just to obtain the minerals and solid fuels produced in the U.S. in 1965, nearly 10 billion tons of earth had to be moved. Within the next 20 years the nation's mineral requirements are expected to increase more than twofold. Excavation for highways, water supply, sewers, rapid transit systems and urban development is also increasing rapidly.

The major share of excavation today is done by surface methods. Obviously for many types of structure, such as canals, building substructures and most highways, there is no good alternative to surface technology. For many purposes, however, there is a choice; surface methods are usually selected because of the substantial advantages they offer in economics or speed or both. It is for these reasons that more than 80 percent of the metals we use comes from open-pit mines, even though tremendous volumes of the waste rock that usually covers an ore body must be removed just to expose the ore for mining. In the case of copper the present average stripping ratio is two tons of waste to one ton of ore; for strip coal mines the ratio averages more than 20 to one.

In highway construction large open cuts in rock can usually be made at less cost than the tunnels that might otherwise be preferable and that would require excavation of a much smaller volume of material. Cut-and-cover techniques generally are used to excavate in soft, unconsolidated ground for subways, sewers and other urban utilities simply because the costs are much less than the cost of tunneling.

Public concern and resistance to these surface excavation methods, however, is growing. The deleterious effects of strip-mining on the land and environment are receiving increasing attention from state governments and the Federal Government. The use of cut-and-cover methods in congested urban areas is becoming progressively more undesirable because of the inconvenience, and often the financial loss, that frequently results when a busy street is ripped up. The bitter controversy that almost inevitably attends the selection of surface routes for urban superhighways would certainly be reduced and might be eliminated if economically feasible subsurface alternatives were available.

Why have surface excavation equipment and methods so far outstripped underground excavation technology? Among the reasons are the easy availability (until recently) of mineral deposits near the surface; the comparatively modest requirements (until recently) for underground public utilities; the stage of development of the earth sciences, and the state of technology relating to materials and machines. The principal reasons, however, are related to the nature of excavation technology.

Making an excavation in the earth always involves four basic steps. First, the soil or rock must be broken loose. This step can be accomplished in many ways, ranging from pushing a spade, an auger or a power shovel into the ground to detonating explosives placed in drill holes.

Second, the loosened material must be picked up and moved out of the way so that a fresh face can be attacked. Sometimes the material can be merely cast aside with the shovel used to pick it up, but in many instances it must be loaded into a container and transported to a distant point for disposal.

The third step is to make sure that the

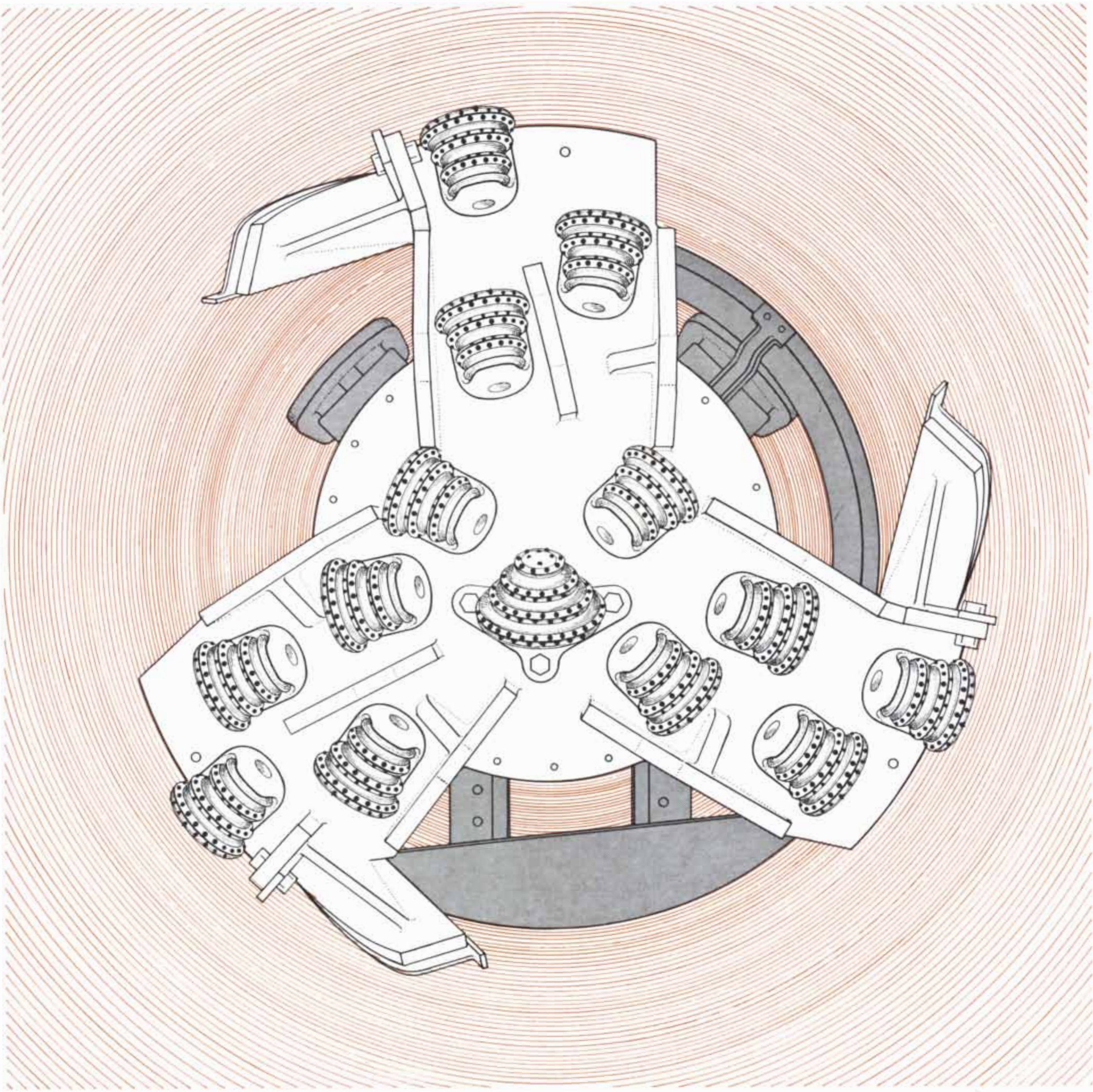
boundaries of the excavation remain intact. In many kinds of ground and for many types of excavation the only requirement here is that the geometry and size of the hole be such that its walls, bottom and roof (if there is one) will stand unsupported. Where the opening will not stand unsupported, shoring of some kind must be installed.

Finally, the environment within the hole must be controlled. Fluids in the earth's crust, such as water and gas, must either be prevented from entering the excavation or quickly removed from it. Temperature and atmosphere must be controlled to provide a safe environment for workmen.

Obviously these four steps are interrelated and more or less interdependent. In many cases two or more of them can be combined, particularly when a shallow surface excavation in soil or soft rock is being made. The spade or the power shovel, for example, can be used both to break the ground and to move it away from the working face.

The relative importance of each of these steps depends on the situation. For instance, in tunnels driven in soft, water-saturated soil the difficulty of supporting the ground to maintain the opening is paramount and governs the rate of advance and the economics of excavation. For tunnels in hard rock, which will stand open with little or no artificial support, rock breaking is the most critical element.

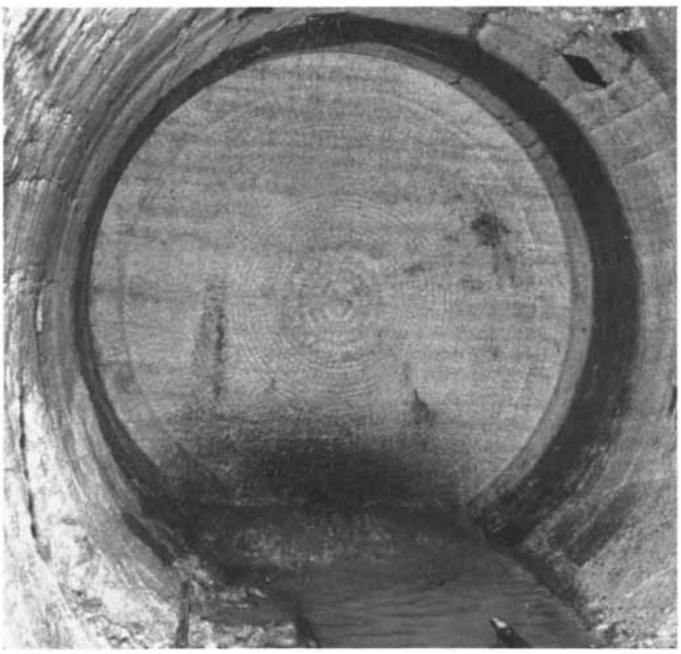
The technology of excavating in rock has changed little in its essentials since drilling and blasting with gunpowder were introduced early in the 17th

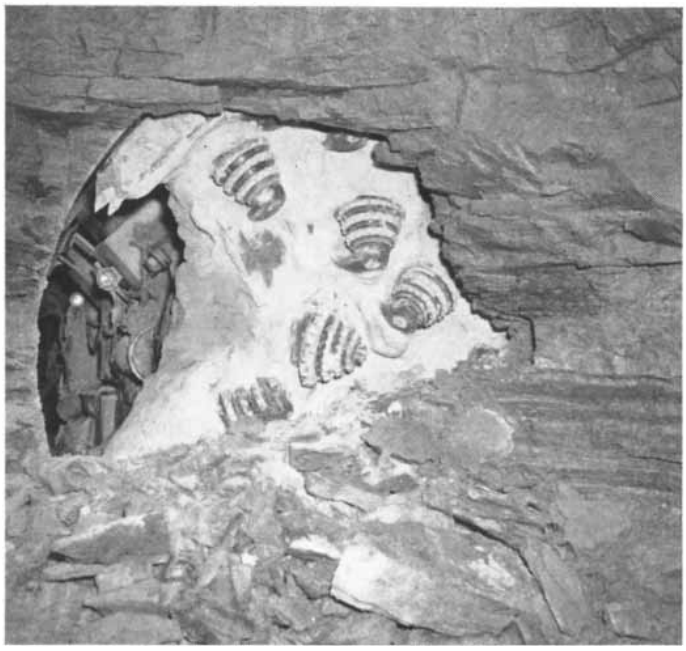


CUTTING HEAD of a continuous tunneling machine consists of an array of rotating bits with tungsten carbide teeth. A closeup view of the cutting devices appears in the painting on the cover of this issue. These cutters are designed for tunneling in hard rock; other types of cutters can be put on the head for use in softer formations. The machine can advance at a rate of about four feet per hour.

MACHINED TUNNEL was made in St. Louis by a continuous tunneling machine. The smooth wall in the foreground was produced by the machine; the rougher walls in the background are in a portion of the tunnel that was driven by conventional techniques of drilling and blasting. The tunnel, which is eight feet in diameter, was driven through hard limestone. Best day's progress was 72 feet.

century. Until very recently advances consisted chiefly in improved mechanical versions of the same types of tools used by medieval miners. To be sure, the performance of the modern compressed-air rock drill is spectacular compared with the old method of drilling with a hammer and chisel. Similarly, modern dynamite and other high explosives are much more efficient and comparatively less expensive than black powder. Just as striking are comparisons of large power loaders used today with hand shovels and of modern trucks, trains and belt conveyors with wheelbarrows. But the sequence of acts as performed today to make an excavation in rock is essentially the same as it has been





TUNNEL FACE made in the St. Louis sewage line by the continuous tunneling machine appears at left. At right the cutting head of the machine is shown breaking into the hand-driven portion of the tunnel. Average life of the machine's cutter wheels was 500 hours.

905/7

Laboratory on wheels. This one-in-the-world Mercer-Cobra sports car was created by the copper and brass industry to dramatize styling and engineering innovations. Its design relates to the classic Mercer of 1911 vintage and features the rich, warm tones of copper, brass and bronze for an elegance and individuality often lost in the evolution of auto design. The Mercer-Cobra has impressed automotive manufacturers and millions of motor enthusiasts in North and South America and Europe by focusing interest on the beauty and functional advantages of copper and copper alloys in automobiles.

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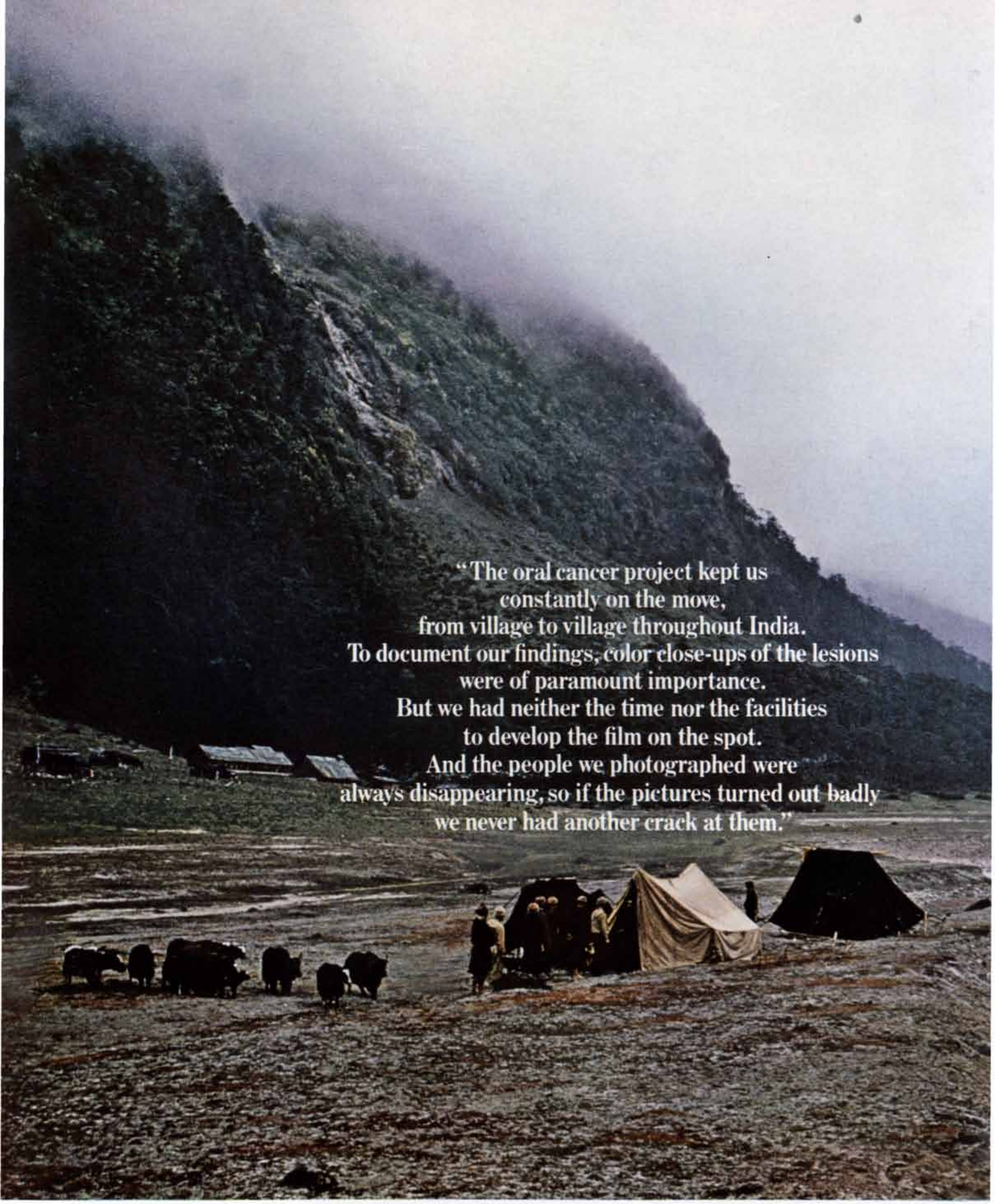


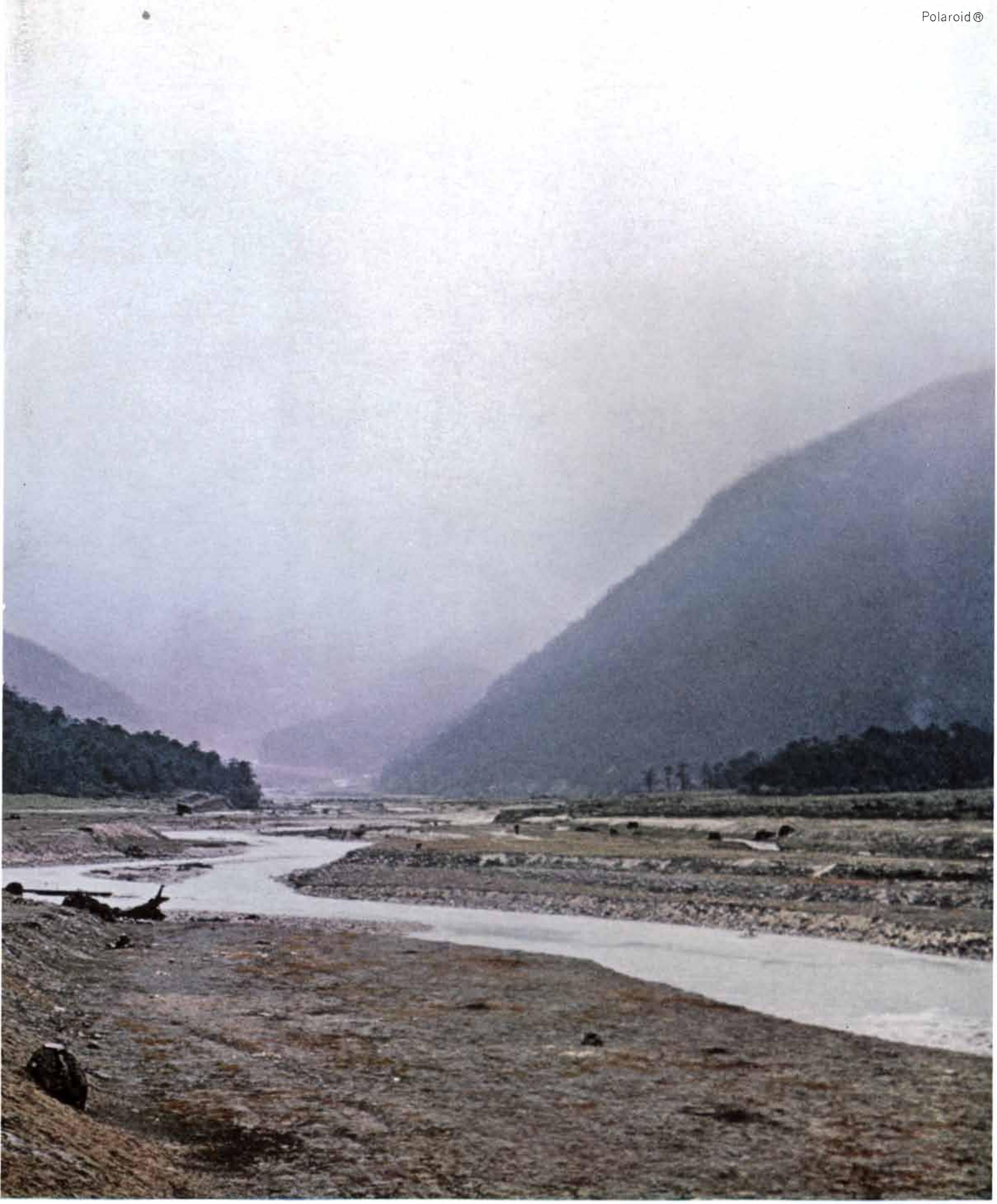
The Head of the Dental Research Unit really needed a professional photographer, complete with a portable refrigerated darkroom.

His project, at the Tata Institute of Fundamental Research, was to correlate the tobacco smoking and chewing habits of the rural population of India with incidences of oral cancer and precancerous lesions.

For every lesion found, he needed a detailed color close-up for documentation and further study back at the Institute in Bombay. But since a photographer and darkroom were expensive as well as unmanageable, he decided to use the Polaroid CU-5 Close-up camera.

His assistants could work it easily as it takes care of lighting, focus, exposure and field size all by itself.

Instead of sending the film 600 or 700 miles back to Bombay for developing (which would take about two weeks),



he had a sharp, perfect color close-up in 60 seconds.

And this was vital, because if he didn't get the shot he wanted the first time around, it was often impossible to get the villagers to come back for a second sitting.

A few might show up at the medical station for treatment. Others might return to their farms or villages. Or make a pilgrimage. In most cases, they were lost to the study.

With the CU-5, however, if the first shot was unsatisfactory, they'd know about it in 60 seconds and could snap a second one on the spot.

After constant use on the cancer project, the Head of the Research Unit sent us a letter with his coldly objective appraisal of our CU-5 camera.

He said, "It's just stupendous."

The Polaroid CU-5 Research Camera

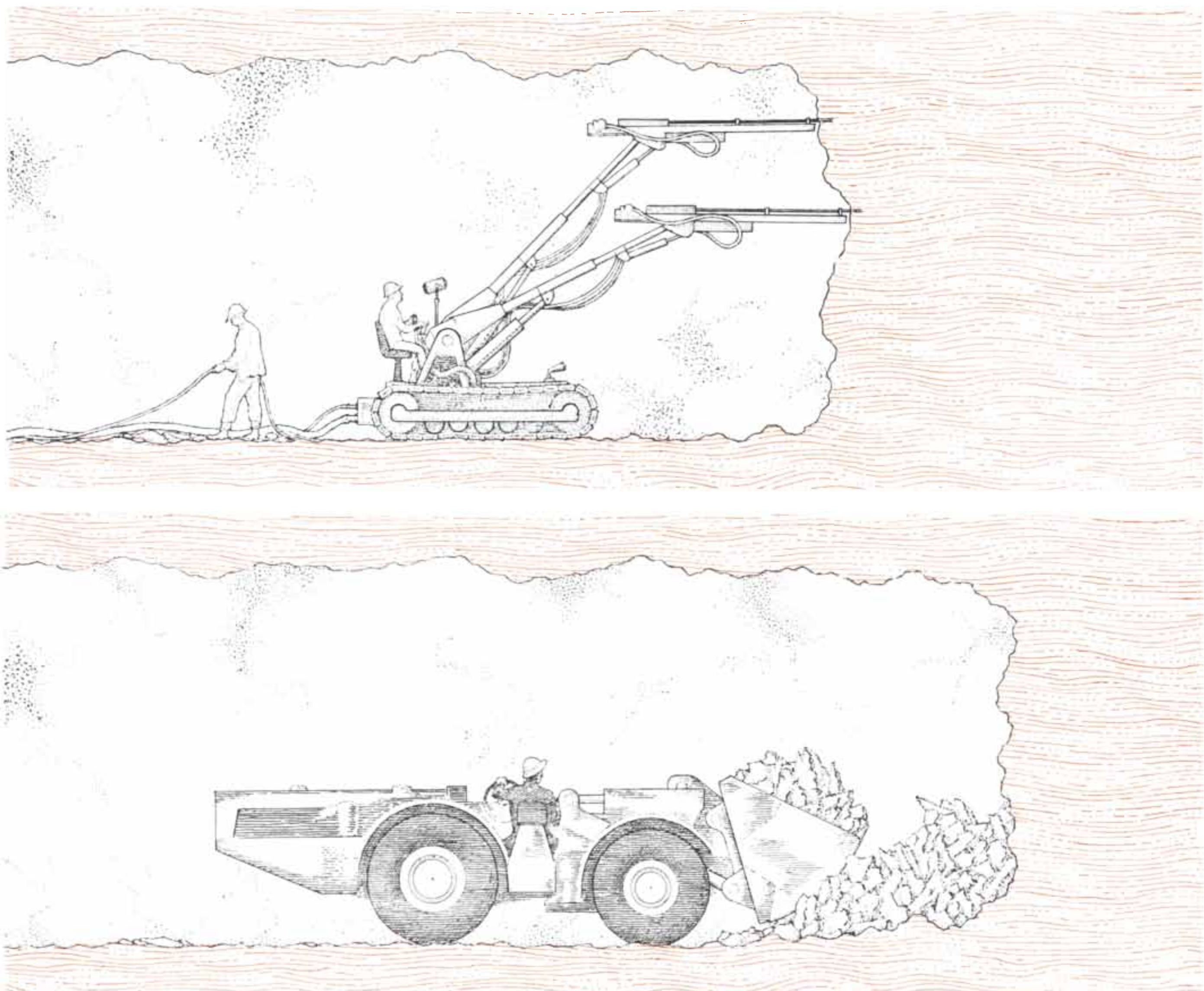
Polaroid Corporation, Cambridge, Mass. 02139

for more than 300 years. The trend has been toward larger and larger machines, which increase labor productivity, or in effect reduce the amount of expensive human energy required per unit volume of rock excavated. Here is the key to the substantial advantages in efficiency and economics of modern surface excavation methods compared with underground technology.

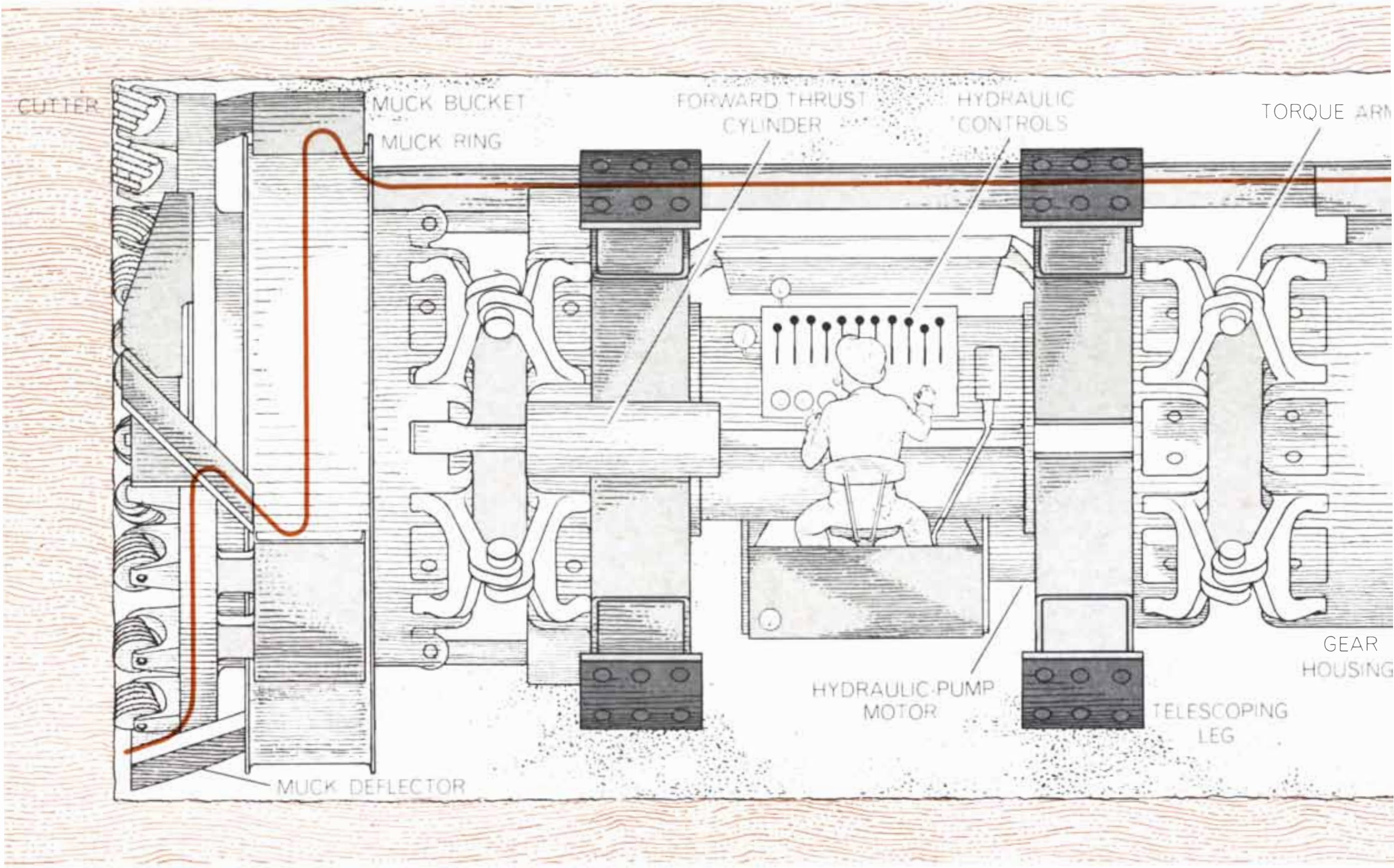
Working from the surface, of course, offers other advantages. The job can be spread out over long distances and large areas, so that the various steps of the excavation cycle can be attacked simultaneously. Drilling can be conducted in one location while the loading of broken rock proceeds concurrently at another, which was previously drilled and blasted. The scale and duration of the various steps may be much larger and longer on the surface than underground. For example, many thousands of tons of rock can be broken with a single blast in a surface operation, compared with the mere hundreds of tons that are the maximum possible in a mine or tunnel heading. Thus it is possible for even a large shovel or drill to work on the surface at essentially one location for days at a time rather than minutes or hours, as is usually the case underground. Access for moving equipment and materials to and from the working place or places can usually be provided during surface excavation without significant interference with operations in progress.

The nature of the problems of underground excavation can be illustrated by considering the simple driving of a horizontal bore or tunnel into moderately hard sedimentary rocks such as sandstone or limestone. In order not to complicate the problem let us assume that we are penetrating a ridge above the water table in an area where the geology is simple. The rock formations would be essentially horizontal and continuous and relatively uniform in hardness and strength. We would expect to encounter only a few areas of minor faulting and jointing where it might be necessary to install timber or shoring of some kind to support the walls and roof of the tunnel.

The size and configuration of the tunnel would depend on the use for which it was intended. It might have a 10-by-12-foot rectangular cross section if it were driven to gain access to a mineral deposit. It could have a circular cross section 11 feet in diameter and be lined with concrete if it were to be used to convey water to a city or to irrigate an arid region. Or it might have a horseshoe shape 30 feet high and 20 feet



CONVENTIONAL METHOD of tunneling involves a series of operations that must be carried out more or less separately because of the limitations of space. The first step (*top*) involves drilling small holes in the face of the tunnel for explosives. In the second step the explosives are detonated, creating a pile of "muck," or rubble, that in the third step must be carried away (*bottom*). Other operations that are often necessary include shoring the tunnel, extending rail lines into the tunnel and ventilating the tunnel.

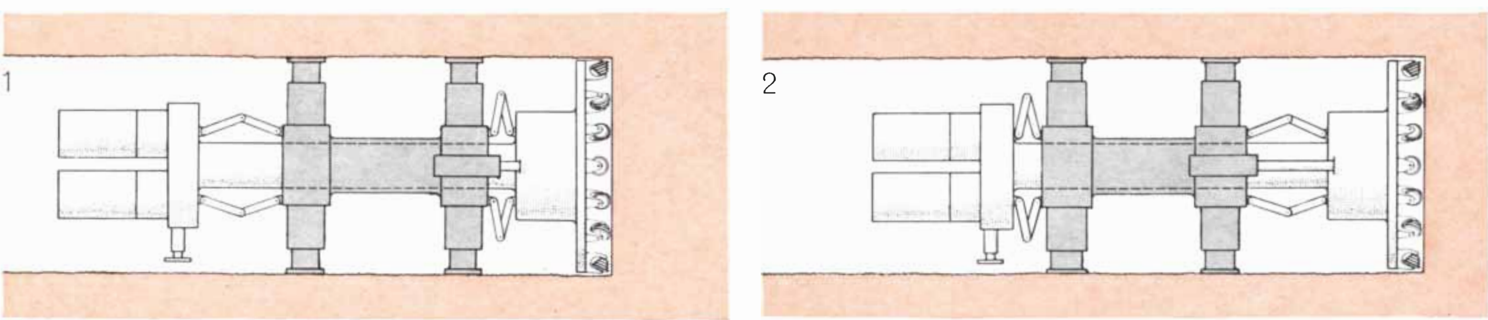


CONTINUOUS METHOD of tunneling makes use of a self-propelled machine that pushes the cutting head against the face of the tunnel at high pressure. The muck cut away from the tunnel face by the cutting head is deflected into the muck buckets, which deliver

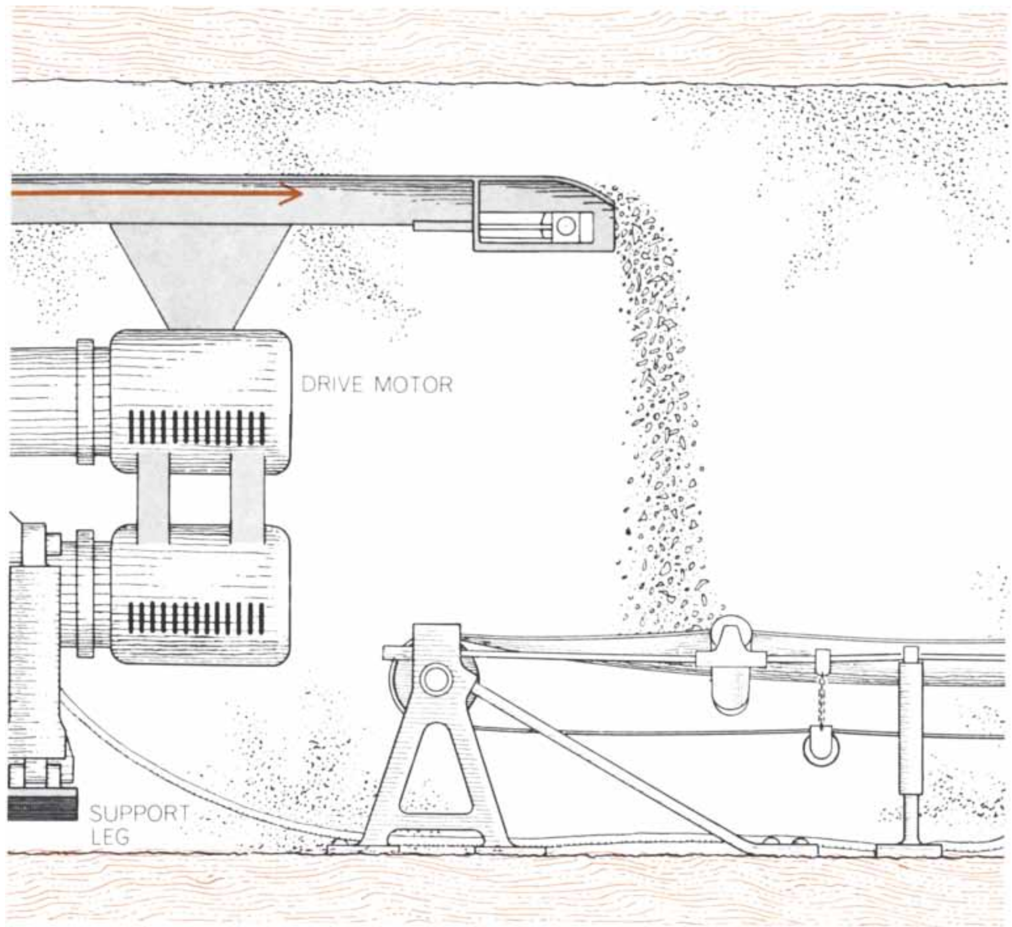
wide if it were to be a railroad tunnel. In order to simplify the illustration further let us assume that we have made the initial penetration, have established the portal and have progressed some distance into the ridge.

The size, kind and amount of equipment we could use for such a project would of course depend on the size of the tunnel. For smaller cross sections the contractor would begin the excavation cycle by bringing two to four pneumatic rock drills to the tunnel face. The drills might be large, heavy machines carried on booms that can be moved into position hydraulically and that in turn are mounted on a "jumbo," or drill carriage. Or they might be light drills, equipped with pneumatic "pusher legs," easily carried by one man. For larger tunnels a jumbo of some kind carrying 10 or more drills would invariably be used. In any case, we must now proceed to drill from 20 to more than 100 holes of small diameter, at various angles, from eight to 20 feet into the face. Next we must charge the holes with explosive, insert a detonator into each and prepare the fuses or attach the electric lead wires necessary to set off the blast. After the men and equipment have been removed to a safe distance from the face, the charges are detonated to break the rock.

As soon as the smoke and fumes are cleared through the forced-ventilation ducts that must be provided in any underground operation, the mechanical loader is moved to the face and "mucking," or loading of the broken rock, begins. For large tunnels drill jumbos are usually designed to straddle or project over the muck pile so that they can be moved to the face as early as possible. Thus it is possible to begin drilling for the next blast before mucking is completed. In small tunnels, however, and even in some of large diameter, the



TUNNELING OPERATION with the continuous tunneling machine begins (*1*) with the machine clamped against the walls of the tunnel by means of telescoping legs. The cutting head of the machine is pushed against the face of the tunnel by the thrust cylin-



it to a conveyor on the top of the machine. From there the material is taken to the rear of the machine, where it can be dumped either into vehicles or onto another conveyor belt.

muck must be completely removed from the face before the next step of the cycle can be initiated.

Hauling the broken rock away from the tunnel face rapidly and efficiently presents a particularly formidable problem. First, the size of railcars or trucks that can be used is limited, as is the size of the mechanical loader itself, by the size of the heading. In a long tunnel loaded cars must be able to pass empty ones, which further restricts the size and capacity of the hauling equipment. Just exchanging an empty car for a loaded one in the cramped space available at the loader can present major difficulties.

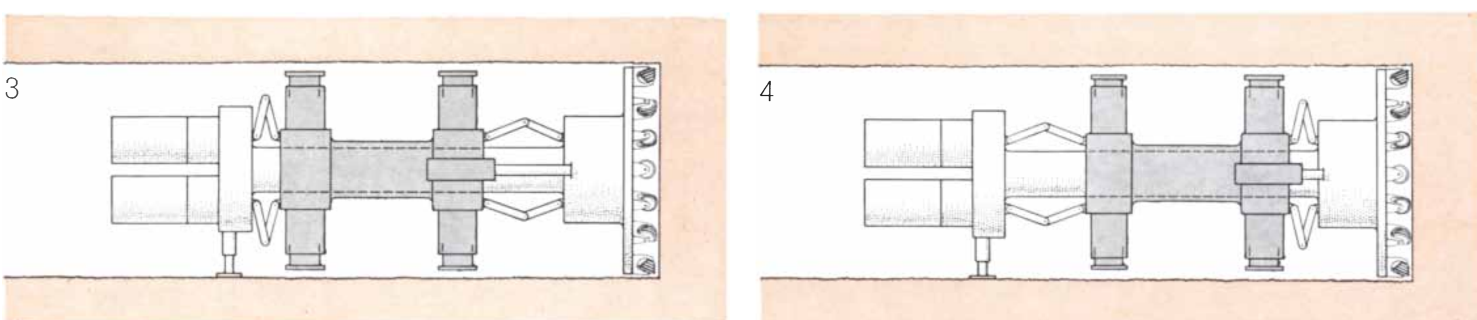
Other factors complicate the problem of handling materials underground. The face of the tunnel, the point of origin of most of the material that must be handled, is constantly moving. The transportation system therefore must be such that it can be extended easily. It must be flexible and capable of constriction or modification to accommodate necessary work behind the face such as placing concrete lining, extending lines for water, compressed air and power and installing ventilation ducts.

Many devices and techniques, some very ingenious, have been developed to cope with the bottlenecks that are inherent in tunneling by the drill-blast method. The gantry drill jumbo, which allows at least partially concurrent drilling and mucking, is one of them. Car-changers, such as the "California switch," or movable double-crossover, which permits quick exchange of an empty railcar for a loaded one under the loader, are another. Trucks have been developed with controls that allow the driver to face toward either the front or the rear, thus eliminating the need for turnaround space in the heading. Enlargement of a short section of the tunnel to provide a turnout has been one of the rather obvious solutions to the passing problem. Another has been the use of trains of sufficient capacity to contain the entire round.

Developments such as these—together with improved drills, drill rods and bits; mechanical loading machines, electric locomotives, self-dumping cars and underground diesel trucks; new types of support and lining materials, and techniques that have evolved over the past century—have resulted in significant increases in tunneling speed and efficiency. Indeed, the average advance rate for rock tunneling with a drill-blast system has increased tenfold in the 100 years since mechanical rock drills were introduced.

Even so, we are left with a very complex cyclic system that requires a large number and wide variety of machines and appurtenances and, compared with a surface operation, a great many men. Each cycle involves a number of steps that more or less interfere with one another because of space limitations, so that the steps must be essentially sequential. The most critical machines—the face equipment—must operate in a small, confined space, access to which is usually limited to a single busy path, along which all the material and supplies taken in or out of the tunnel must travel.

The approaches that have enabled surface excavation methods to outstrip



ders. At the end of a boring cycle (*2*) the rear support mechanism is drawn toward the telescoping legs and (*3*) the rear support leg is extended and the telescoping legs are retracted. The rear support mechanism then pushes the machine forward (*4*) for a new cycle.

GIANT POWER SHOVEL is used for strip-mining in a coal mine near St. Louis. The bucket can move 250 tons of earth in one bite. Automobile indicates size of machine.

tunneling technology in economics and efficiency obviously are not applicable to an underground situation. Huge machines just will not fit underground. We cannot appreciably lengthen the steps in the cycle, because the size of the blasts we can make underground is limited by the cross section of the heading we are driving.

Clearly, then, another approach is required. The logical avenue has long been recognized, but it became feasible only recently. The key to the revolutionary advances that can be anticipated now in underground excavation technology is the continuous tunnel borer. It is around these machines, and the potential of the excavation systems in which they can be employed, that today's discussions of rapid excavation are centered.

Miners and tunnel men have known for years that the answer to high-speed, low-cost tunneling lies in elimination of the cycle inherent in drilling and blasting. Attempts were made as long as a century ago by a few daring men to drive rock tunnels with "moles," or large boring machines, of their own design. Unfortunately the materials that were available and the state of the mechanical arts were not sufficiently advanced until very recently for the machines to be practical except in soft rock.

Nevertheless, the idea was sound. Continuous penetration of a tunnel face with a single machine that simultaneously abrades or breaks away the rock and scoops up the fragments greatly simplifies the tunneling operation. The lost motion of bringing one kind of machine to the face, using it and then replacing it with another type necessary to accomplish the next step in the process is immediately eliminated. The way is opened for making the other elements of the tunneling system, such as installation of the supports and haulage of the broken rock, also continuous and concurrent, so that the entire tunneling process becomes continuous.

The first widely accepted commercial application of the principle of a continuous underground mining machine was in U.S. soft coal mines after World War II. Experience with mechanical coal miners contributed to the evolution of the machines that bore tunnels in rock. So did experience with the large-hole drills used in oil fields. The availability of improved metals, bearings and power systems was also a factor.

Some success was achieved in the 1940's with machines that tunneled through soft rock. Tunneling through slightly harder rock, however, proved to be a different matter. The cutter heads were dulled and broken without significant effect on the rock.

The first breakthrough resulted from efforts to drill large vertical holes using clusters of the roller bits that had been successful in drilling oil wells. Such bits are usually conical and are studded with teeth of tungsten carbide or hardened steel. They cut by the crushing action of the teeth as they roll across the rock face under heavy pressure.

Oversize vertical holes were drilled by mounting a large number of roller bits on the face of a drill stem and rotating the stem while applying thrust. During the late 1950's the same principle was applied by several manufacturers to large horizontal holes. Clusters of roller bits were arranged concentrically on a rotating faceplate.

Machines of this kind were successful in principle but were mechanically unable to cope with abrupt changes in ground conditions. By 1964, however, mechanical and metallurgical improvements made possible the construction of a number of machines that have been increasingly successful in boring tunnels from eight to more than 20 feet in diameter. Such a machine, weighing between 40 and 300 tons, has a number of roller bits mounted concentrically on a large head. The head is rotated slowly while being forced against the rock face hydraulically with thrusts of up to 1.5 million pounds. Cuttings are removed by small scoops attached to the periphery of the cutting head, are carried along the top of the machine and are deposited in some kind of conveyor at the rear. The machine is equipped to hitch itself forward in the tunnel [*see illustrations on preceding two pages*].

These machines are still at an early stage of development. As yet they have not been successful in hard rock, but in soft to medium-hard rocks, where conditions are suitable, they are already outperforming drill-blast methods in both speed and economy. Penetration rates of up to 20 feet per hour have been reported, although the average rate of advance is usually much lower, primarily because the other elements of the system, such as haulage and support installation, cannot keep up with the machine.

The performance of mechanical tunnel borers is steadily improving, and there is widespread confidence that it is only a matter of time and effort before their applicability is extended to the harder rocks and substantially better advance rates are attained. Moreover, considerable research is in progress on novel methods of breaking rock that might be suitable for incorporation into a continuous tunneling machine. Unconventional sources of energy such as the hydraulic jet, the plasma jet, the laser, high-frequency vibration, dielectric and induction heating and chemical softening all offer attractive possibilities. One can assume that tunneling machines capable of spectacular penetration speeds are possible.

A boring machine alone, however, will not be enough. Unless the other elements of the process are improved commensurately, the full potential of this innovation cannot be realized. For example, currently available underground haulage technology is completely inadequate to provide for disposal of the tremendous amounts of broken rock that would be produced by a truly high-speed tunneling machine. The types of tunnel supports and linings used now and the present methods of installing them were developed to fit the cyclic drill-blast system and thus present another block to full realization of the advantages of continuous tunneling. The present methods of ventilating an underground working and of preventing or removing the inflow of the water and gas that are frequently encountered must be substantially improved.

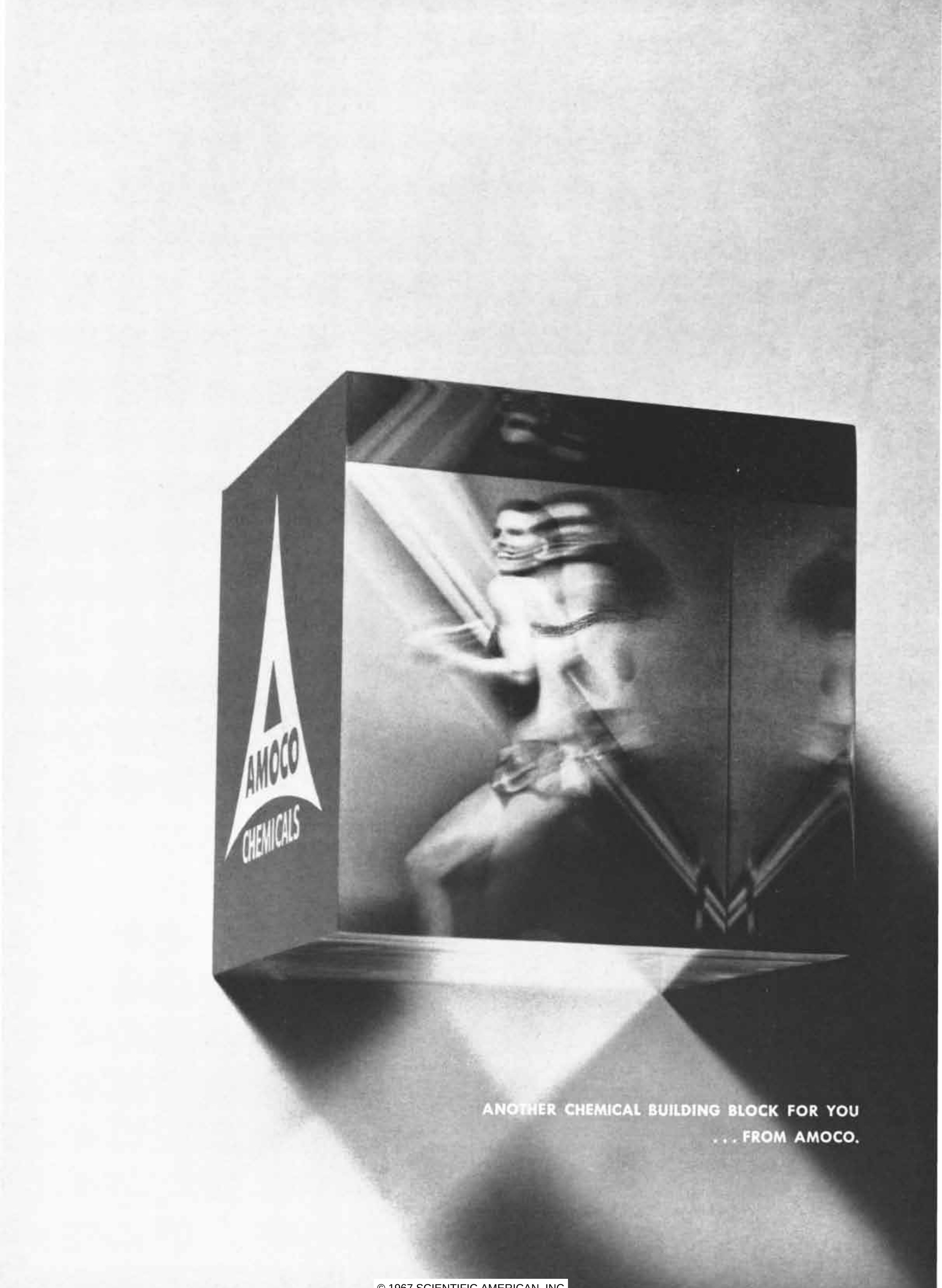
A host of other problems must also be solved. The simple geologic situation we assumed in the tunneling example discussed earlier hardly ever obtains in a real tunneling operation. The crust of the earth is made up of an exceedingly complex and highly variable material. The more usual case would be to encounter many different kinds of rock that would vary widely in hardness and strength. We might penetrate faulted zones where the rock had been fractured and crushed or even ground into clay. Water-filled fissures, pockets of explosive gas or zones of high rock temperature might be in our path.

Unexpected encounters with situations such as these have caused trouble for miners and tunnel builders for centuries, and measures for coping with them have had to be devised. Probably the principal advantage of the conventional drill-blast method is its adaptability to changing physical conditions. These problems assume new dimensions in high-speed tunneling. Penetration of a previously unknown major fault zone or a fissure filled with water under high pressure could be economically disastrous with an inherently less flexible continuous machine tunneling system. Thus we must greatly improve our capability for detecting or predicting the presence of geologic features that will affect the performance of the system. Improved measures for coping with the operational difficulties they present must also be developed.

Even after all these problems are solved and we have a truly rapid continuous rock tunneling system, our new technology will not be complete. Obviously underground excavation involves more than making a cylindrical, horizontal bore in rock. Vertical and inclined shafts to provide access ways must be driven. Rooms of various sizes and shapes must be excavated to provide space for critical parts of underground facilities. Holes must be drilled for ventilation and for power-supply cables. In many instances this auxiliary excavation constitutes a major portion of the cost and time required for a subsurface excavation project.

Clearly the job of producing the rapid excavation technology needed by modern society will not be easy. The initial breakthrough has been made, however, with the continuous tunnel boring machine. Moreover, the resources necessary for developing the supporting technology required to realize the machine's full potential are available.

BUCKET-WHEEL EXCAVATOR is an example of the kind of machine that has been developed for rapid, large-scale surface excavation. The machine in use here is supplying fill material for a dam in California; the excavation and loading were continuous.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GRAVITATIONAL COLLAPSE

Gravity, the weakest force known, may be the agent for crushing matter out of existence. This could happen after a star collapses to a critical size, whereupon gravity overwhelms all other forces

by Kip S. Thorne

Gravitational collapse—the tendency of material bodies to fall toward some common center of gravity—plays a central role in shaping the universe. It is through gravitational collapse that stars are born, that clusters of stars are formed and probably that entire galaxies are created. It is in gravitational collapse that some stars, star clusters and perhaps galaxies eventually die. Gravitational collapse is thus both the midwife and the undertaker of astrophysics.

The dominance of gravity in astrophysical events may seem paradoxical because at the atomic and nuclear levels gravity is by far the weakest of the four known forces in the universe. The "weak" force involved in the radioactive decay of atomic nuclei is stronger than gravity by a factor of 10^{25}; the electromagnetic force, which holds atoms and molecules together, is stronger by a factor of 10^{37}, and the nuclear force, which holds atomic nuclei together, is stronger by a factor of 10^{39}. On the astrophysical scale, however, the gravitational pulls of huge numbers of atoms (10^{57} in the case of the sun) combine efficiently to form one gigantic pull, whereas none of the other three forces can combine efficiently. Consequently on the astrophysical scale gravity can overwhelm all other forces and establish itself as the one irresistible force in the universe.

The role of gravitational collapse as midwife and undertaker can be summarized as follows. The raw material from which stars, star clusters and galaxies are born is a dilute gas, chiefly hydrogen. Occasionally a large blob of this gas, on being squeezed slightly by random motions in nearby blobs, begins to collapse on itself in response to the mutual gravitational attraction of its particles. Because the gravitational attraction between any two particles increases rapidly as the distance separating them is reduced, the collapse accelerates. It cannot be halted until large turbulent motions have been created inside the collapsing blob, providing enough thermal pressure to balance gravity. When this happens, the blob becomes a star, a star cluster or a galaxy. (We shall henceforth regard galaxies as gigantic star clusters.)

On reaching its new state of equilibrium the object—star or star cluster—cannot remain stable forever. It gradually loses energy to surrounding space. Stars radiate energy in the form of heat and light. Clusters lose energy by the occasional ejection of a star. As it loses energy the object becomes more tightly bound by gravity and therefore contracts. The contraction can be only temporarily halted by the burning of nuclear fuel. In the long run all nuclear fuel will be exhausted and the contraction will resume.

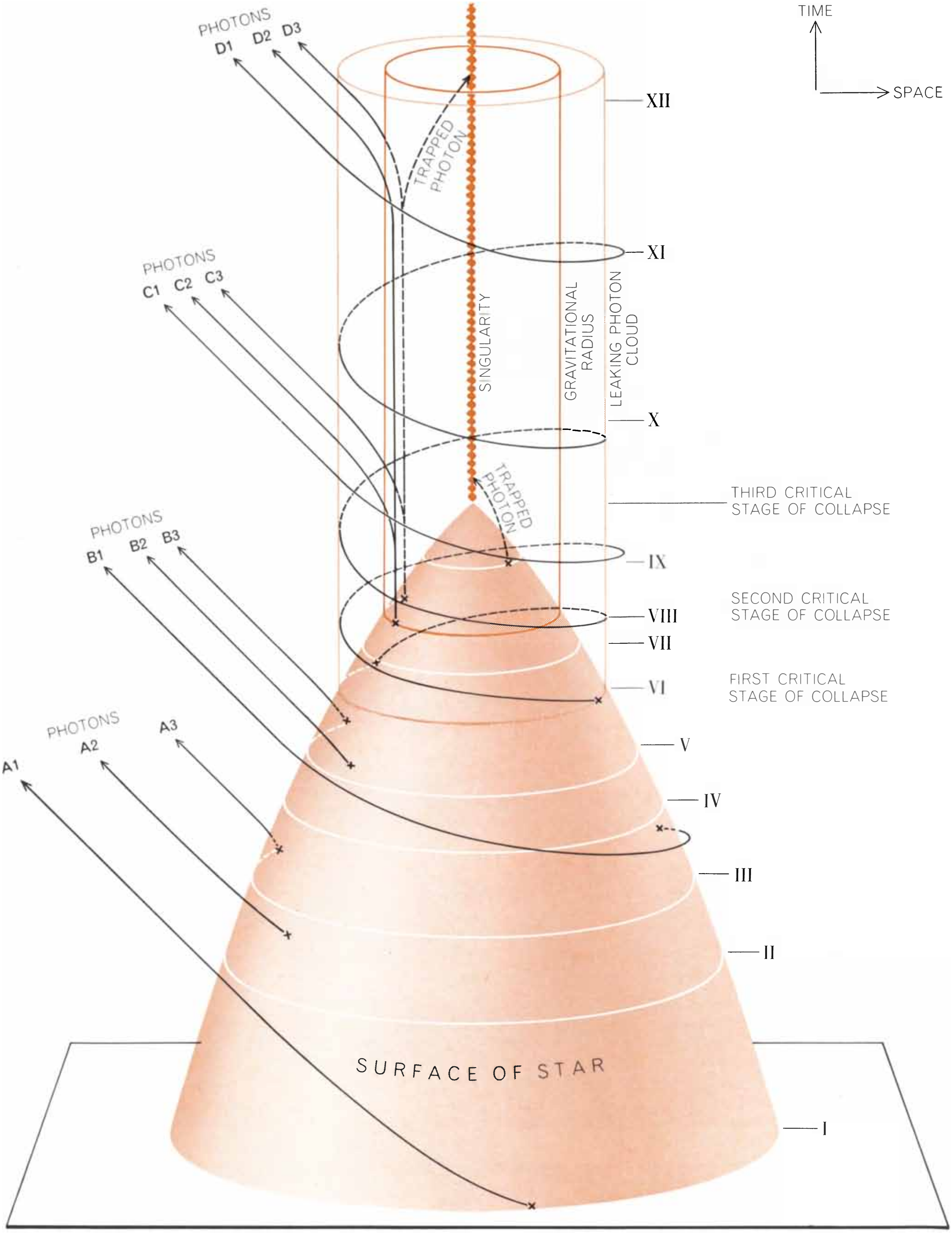
In order to follow the history of such an object it is helpful to draw a diagram in which radius is plotted along the horizontal axis, increasing to the right, and mass is plotted along the vertical axis, increasing upward [*see illustration on page 90*]. The collapsing blob of gas enters the diagram from the right, and as its radius diminishes it moves horizontally to the left. Later, as a slowly contracting star or star cluster, it begins to lose mass and moves slowly down as well as to the left.

At the lower left in such a diagram would lie objects of small mass and radius, in which gravity would be completely dominated by nonthermal internal pressures. Any astrophysical body that found itself in this region would immediately explode because its internal pressure would so completely overpower gravity. As a result no astrophysical bodies are ever observed in this region.

Observable bodies occupy the region of the diagram in which thermal pressure is able to balance gravity. The term "thermal pressure" is meant to include both the pressure inside hot stars due to the random motion of atoms and the similar pressure in star clusters due to the random motion of individual stars.

At the upper left in the diagram gravity dominates all types of pressure—thermal and nonthermal. (Nonthermal pressure includes the pressure of electrons in atoms and ultimately the pressure of neutrons and protons inside atomic nuclei.) In this region no object can ever achieve a state of equilibrium; gravity will always overwhelm the object's internal pressure and pull it into catastrophic gravitational collapse.

A star or star cluster cannot depend on internal thermal pressure to balance the force of gravity indefinitely as it contracts to the left in the mass-radius diagram. After a million to 10 billion years for stars—whose contraction is temporarily halted by nuclear burning—and after a period longer than the present age of the universe for star clusters, including galaxies, the slow contraction must terminate in one of three processes. First, a nuclear explosion may blow the object apart before it has had a chance to die in any other way. Second, if the object has a mass less than 1.2 times the mass of the sun, and if no explosion blows it apart, its contraction can be halted forever by nonthermal pressures; the object then becomes a white-dwarf star like the "dark" companion of Sirius, or a cold object like the earth. The third process operates if the object has a mass greater than 1.2 solar masses and does not explode; contraction then leads eventually to a state so condensed that gravitational forces overwhelm all internal pressure, thermal or nonthermal. At this point catastrophic gravitational

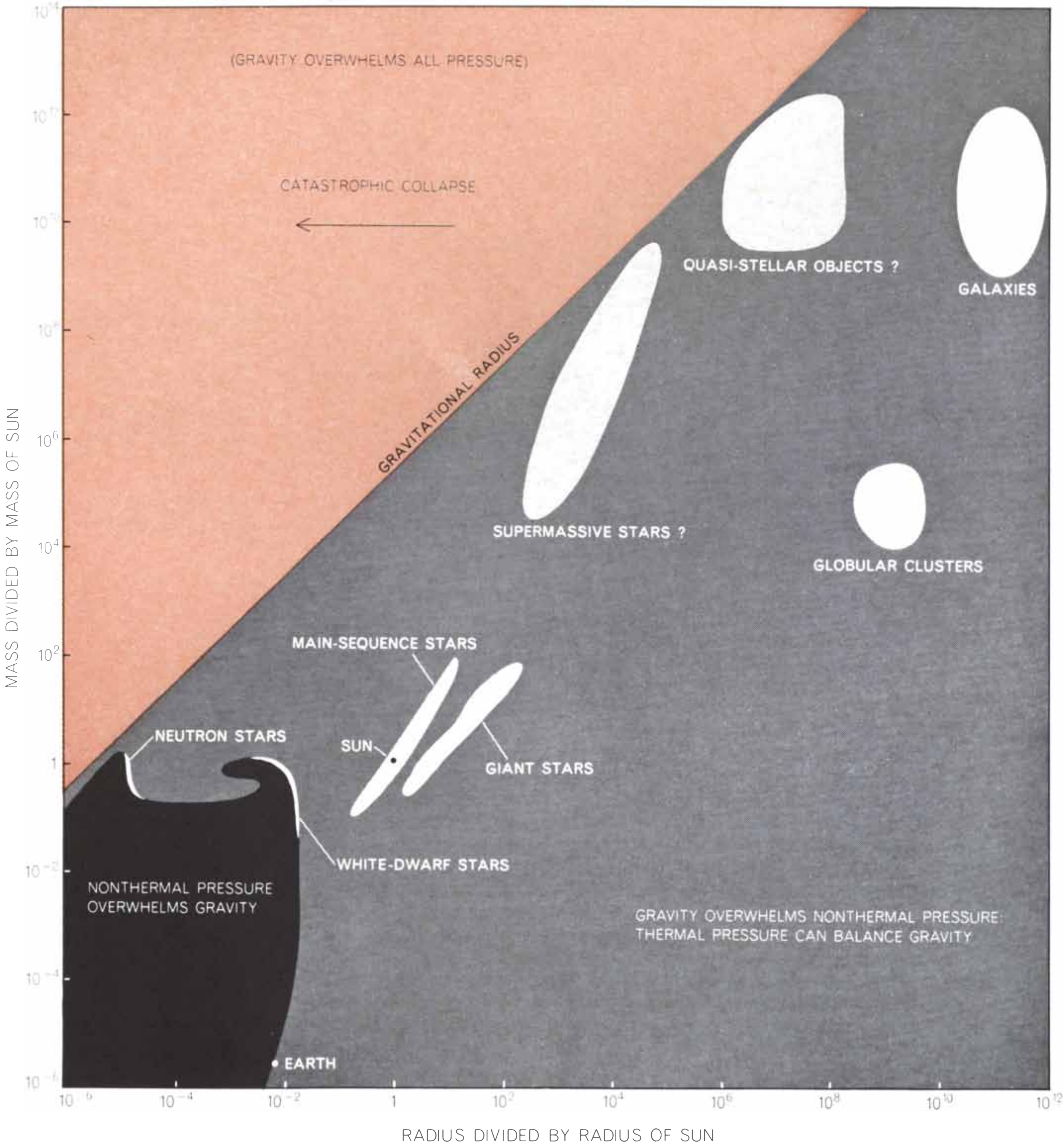


SPHERICAL GRAVITATIONAL COLLAPSE of a star can be depicted in a space-time diagram in which the time dimension is plotted upward and two of the three space dimensions are plotted horizontally. The Roman numerals identify slices at particular moments in time that reappear in the illustrations on page 92. The strong gravitational field of the collapsing star bends the "world lines," or space-time paths, of photons emitted by the star. Such photons inform a distant observer about the collapse. Collapse is marked by three "critical stages." The first occurs when the star is 1.5 times the gravitational radius. Photons emitted tangentially to the star's surface at this stage are caught in a spherical "leaking" photon cloud, which surrounds the star forever thereafter. The second critical stage occurs when the star reaches its gravitational radius, the point beyond which collapse can no longer be halted or observed. Photons emitted radially at this stage form another leaking cloud. But no photons emitted thereafter can ever reach a distant observer. The third critical stage is the "singularity" in which the star is crushed to zero volume and infinite density.

collapse begins, terminating the ordinary life of the object.

In the rest of this article I shall concentrate on the third type of death. Catastrophic gravitational collapse has never been observed directly. The collapse of a star would happen so fast that an astronomer would have virtually no chance of looking at the right spot at the right instant to observe it. But even if he had the luck to be watching, he might not realize he was seeing a star collapsing. The details of collapse (sudden dimming and disappearance of the star) might be masked by light from the star's outer envelope, thrown off as the interior collapsed.

Nevertheless, it is possible to infer on theoretical grounds the stages by which catastrophic collapse would proceed. This kind of collapse was first examined in 1939 by J. Robert Oppenheimer and Hartland S. Snyder, a student of Oppenheimer's at the University of California at Berkeley. It has been studied in greater detail since 1960 because of a suspicion that collapse may be the source of the huge energies radiated by super-



MASS-RADIUS DIAGRAM depicts three regions of astrophysical significance. All known astrophysical objects outside the solar system lie in the open region to the right, where gravity overwhelms nonthermal pressure (such as the pressure of electrons in atoms) but can be balanced by thermal pressure. This term includes both the pressure inside hot stars due to the random motion of atoms and the similar pressure in star clusters due to the random motion of individual stars. Ultimately this thermal pressure is dissipated and gravity forces the objects to contract. The contraction terminates in one of three ways: when nonthermal pressure balances gravity forever (earth, white-dwarf stars, neutron stars); in an explosion that destroys the object, or in catastrophic gravitational collapse.

novas and by the baffling quasi-stellar objects (quasars).

Once a star begins to collapse, whether it can stop or must continue without stopping depends on whether it reaches a critical dimension known as the gravitational radius. Collapse can be halted anywhere outside this radius but never inside it. Similarly, energy can be released from a collapsing star that is still larger than the gravitational radius but not from a star that has contracted inside that radius.

For an object of mass M (in grams) the gravitational radius Rg (in centimeters) is given by the equation $Rg = 2GM/c^2$, where G is Newton's constant of gravitation (6.67×10^{-8} centimeters^3 per gram per second^2) and c is the speed of light (2.998×10^{10} centimeters per second). This equation shows, for example, that the gravitational radius for the sun is 2.9×10^5 centimeters, or about three kilometers (two miles). Current studies suggest that only the most massive stars can collapse through their gravitational radius when their thermonuclear energy is exhausted. Less massive stars probably collapse to a certain point and then explode, perhaps producing the supernovas that astronomers observe at a rate of about one per century per galaxy.

OBJECT	GRAVITATIONAL RADIUS	DENSITY AT GRAVITATIONAL RADIUS (GRAMS PER CUBIC CENTIMETER)
200-POUND MAN	1.4×10^{-23} CENTIMETERS	8×10^{72}
THE SUN	2.9 KILOMETERS	2×10^{16}
A QUASAR OF 3×10^{12} SOLAR MASSES	ONE LIGHT-YEAR	2×10^{-9}
THE ENTIRE UNIVERSE	$\backsim$10 BILLION LIGHT-YEARS	$\backsim 10^{-29}$

GRAVITATIONAL RADIUS defines a fundamental limiting dimension that increases with the mass of the object. If compressed below its gravitational radius by any force, including gravity, an object will be collapsed by gravity to zero volume and infinite density. For a 200-pound man the gravitational radius (1.4×10^{-23} centimeters) is one 10-billionth the size of the nucleus of an atom. A 200-pound mass compressed to that radius would have 10^{58} times the density of nuclear matter. The density of the sun at its gravitational radius would be some 50 times nuclear densities. On the other hand, a hypothetical quasar (quasi-stellar object) of three trillion solar masses would have only two billionths the density of water if compressed to its gravitational radius. And the density of the universe at its gravitational radius is approximately the density actually observed. In other words, if the universe is finite (which is not yet established) and if its mass were entirely contained within a radius of 10 billion light-years, it should begin to collapse. Eventually it may do just that.

Let me describe in words the principal events that theory predicts should take place when a star collapses through its gravitational radius. The reader may also find it helpful to refer to the illustrations on page 89 and on the next page.

Imagine that we are observing a massive star whose nuclear fuel has been used up after several billion years, and that the thermal pressure that has resisted the force of gravity has finally started to weaken. The star begins to collapse, slowly at first and then more rapidly. Because the surface of the star has a temperature of at least several thousand degrees centigrade, it continues to emit photons, or quanta of light. As the collapse progresses photons that leave the surface at an angle are bent into curved orbits by the increasing intensity of the star's gravitational field, in accordance with the celebrated prediction of Einstein's general theory of relativity. The farther the collapse proceeds, the more strongly the photon orbits are bent. Until the star contracts to 1.5 times the gravitational radius, a point called the first critical stage, all photons emitted from the surface eventually escape into space and could be seen by a distant observer. Photons emitted at a tangent to the star's surface at the first critical stage are caught in a spherical cloud from which they slowly leak forever. Consequently a distant observer viewing the late stages of collapse will always see the rim of the star as it was when the star passed 1.5 times the gravitational radius.

As the star continues to collapse, its gravitational field becomes increasingly intense and an increasing number of the photons emitted from its surface are recaptured. The second critical stage of collapse is reached when the star has contracted to the gravitational radius. At this point only photons that leave perpendicularly to the surface can escape, and these form a second leaking cloud just outside the gravitational radius. An instant later, when the star has contracted inside the gravitational radius, no photons at all can escape. For the distant observer there are only the few photons left in the leaking clouds. Thus he will see the center of the star's disk as it was when the star passed the gravitational radius, just as he will henceforth see the rim as it was when the star passed 1.5 times its gravitational radius.

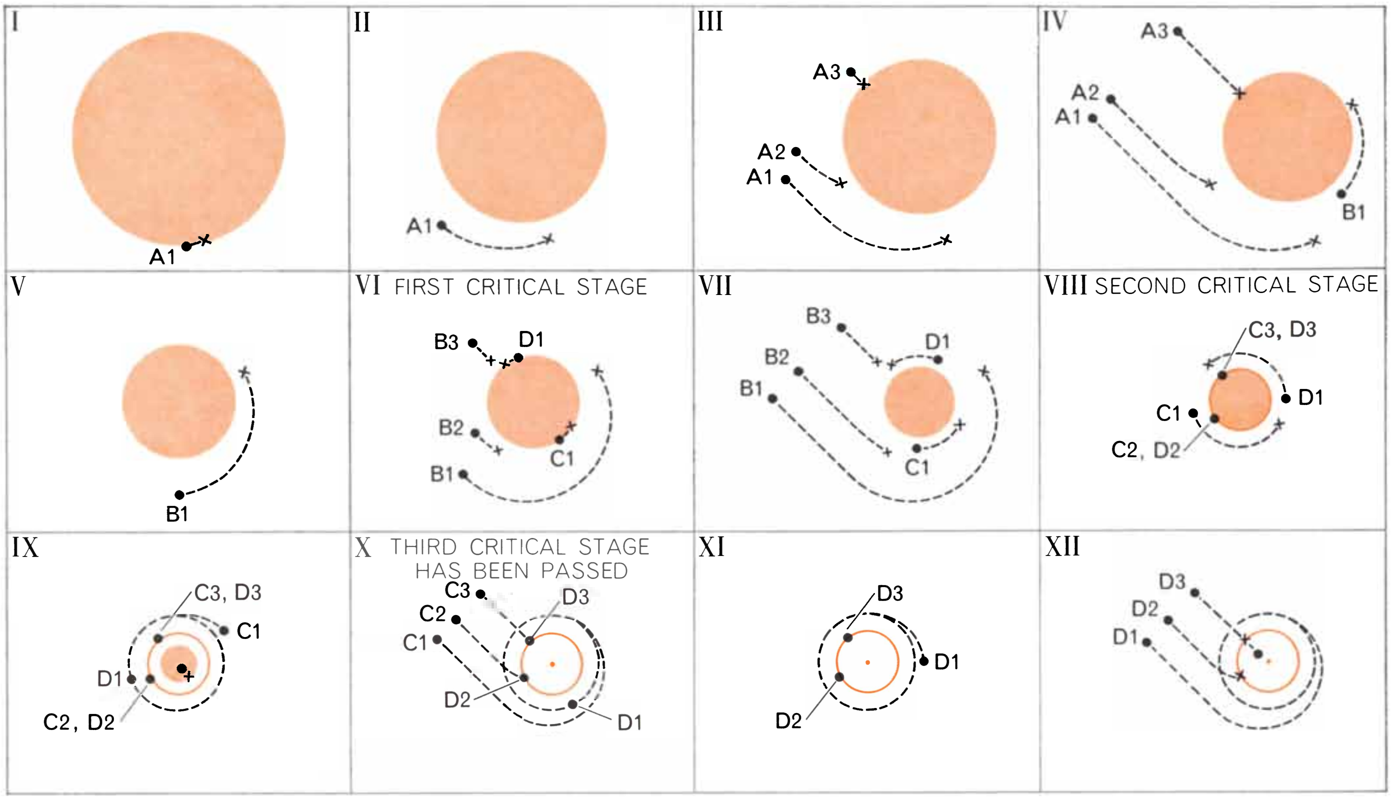
The distant observer should also be able to see a qualitative difference between the photons associated with the two radii. As the photons stored in the cloud at the gravitational radius leak out, the disk of the star becomes not only dimmer but also redder. The reason is that the photons that leave later have lost more energy in escaping from the increasing pull of gravity than those that leave earlier. The photons leaking out of the cloud at 1.5 times the gravitational radius leak away with constant energy and therefore the rim of the star does not change color.

What is the time scale of catastrophic collapse? As seen by a distant observer the time is very brief indeed. For a star 10 times the mass of the sun in the process of collapse only .0005 second would be required for the visual radius to shrink from 135 kilometers to about 80 kilometers, the radius of the leaking photon cloud created at the first critical stage, where it would appear to hover forever [*see top illustration on page* 95]. In each succeeding .0005 second, although the star would remain nearly fixed in radius, it would dim by about two magnitudes, thus becoming rapidly invisible. Because the time scale is proportional to the star's mass, more massive stars would collapse less rapidly.

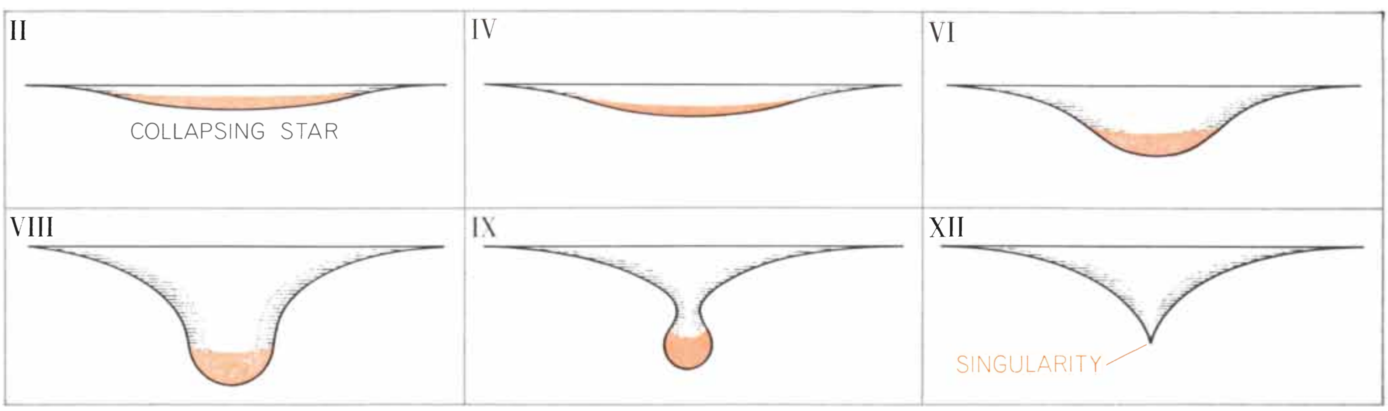
Although no distant observer could see the star collapse beyond its gravitational radius, a hypothetical observer standing on the star's surface would see the collapse proceed freely inward. As this observer passed the gravitational radius he would not feel a bump or see a red line of demarcation. For him, as for the distant observer, however, the gravitational radius is a critical point: once the star has passed inside it the observer can never escape to the outside universe. Inside the gravitational radius all matter and photons are pulled inexorably—in a time of about .0005 second for a star of 10 solar masses—toward the third critical stage of collapse: the "singularity" in which spherical gravitational collapse terminates. This singularity is a region of space-time where infinitely strong gravitational forces deform matter and photons beyond recognition and squeeze them out of existence.

Physicists tend to be unhappy with a theory that predicts the evolution of a truly singular physical state for matter. In the past whenever singularities have been encountered in a theory they have been a warning that the theory was breaking down. For example, early in this century Ernest Rutherford's model of the atom suffered from a singularity: there was nothing in the theory to prevent electrons in orbit around the atomic nucleus from falling into the nucleus, thereby destroying the structure of the atom. Niels Bohr realized that this unsatisfactory prediction signaled a breakdown in classical mechanics and that a modification of the theory (quantizing the energy states of the atom) would save the atom from destruction. Eventually quantum theory was completely successful in solving the problem of atomic structure.

Similarly, John A. Wheeler of Princeton University is convinced today that the singular end point of gravitational collapse is a warning to physicists that wherever space-time is very highly curved, Einstein's gravitational field, like



STEPS IN STELLAR COLLAPSE are keyed to the illustration on page 89. These "snapshots" correspond not to what might be seen by a distant observer but to the state of the star and of the emitted photons in the space-time framework of the star itself. The trajectories of the photons, bent by the star's strong gravitational field, are indicated by broken lines. When the cross marking the origin of the photon lies outside the circumference of the star, it means that the photon left the stellar surface when the star was larger. Thus in snapshot *III*, *A*2 represents a photon that left the surface shortly after snapshot *II*. At the first critical stage (*VI*) photons *C*1 and *D*1 have just been emitted tangentially and will be trapped in a leaking photon cloud. Their fate can be followed in subsequent snapshots. Photons *C*2, *C*3, *D*2 and *D*3, emitted perpendicularly to the surface just as the star reaches the second critical stage (*VIII*), become trapped in a smaller spherical cloud (*color*) at the gravitational radius. They can still escape and reach a distant observer, but none released after the star collapses inside its gravitational radius can ever be seen. All must disappear into the singularity.



CURVATURE OF SPACE during the collapse of a star can be represented by "embedding" diagrams in which one of the three dimensions of space is suppressed from view and the remaining two are depicted by a curved two-dimensional surface. This surface is embedded in a surrounding three-dimensional space that has no physical significance but serves simply as an aid to visualization. The numerals in this series correspond to steps in the stellar collapse illustrated above on this page and on page 89. This region of space inside the star (*color*) is strongly curved. Away from the star the curvature becomes less and less. This is equivalent to saying that the star's gravitational field diminishes with distance. The extreme curvature produced by the singularity persists forever.

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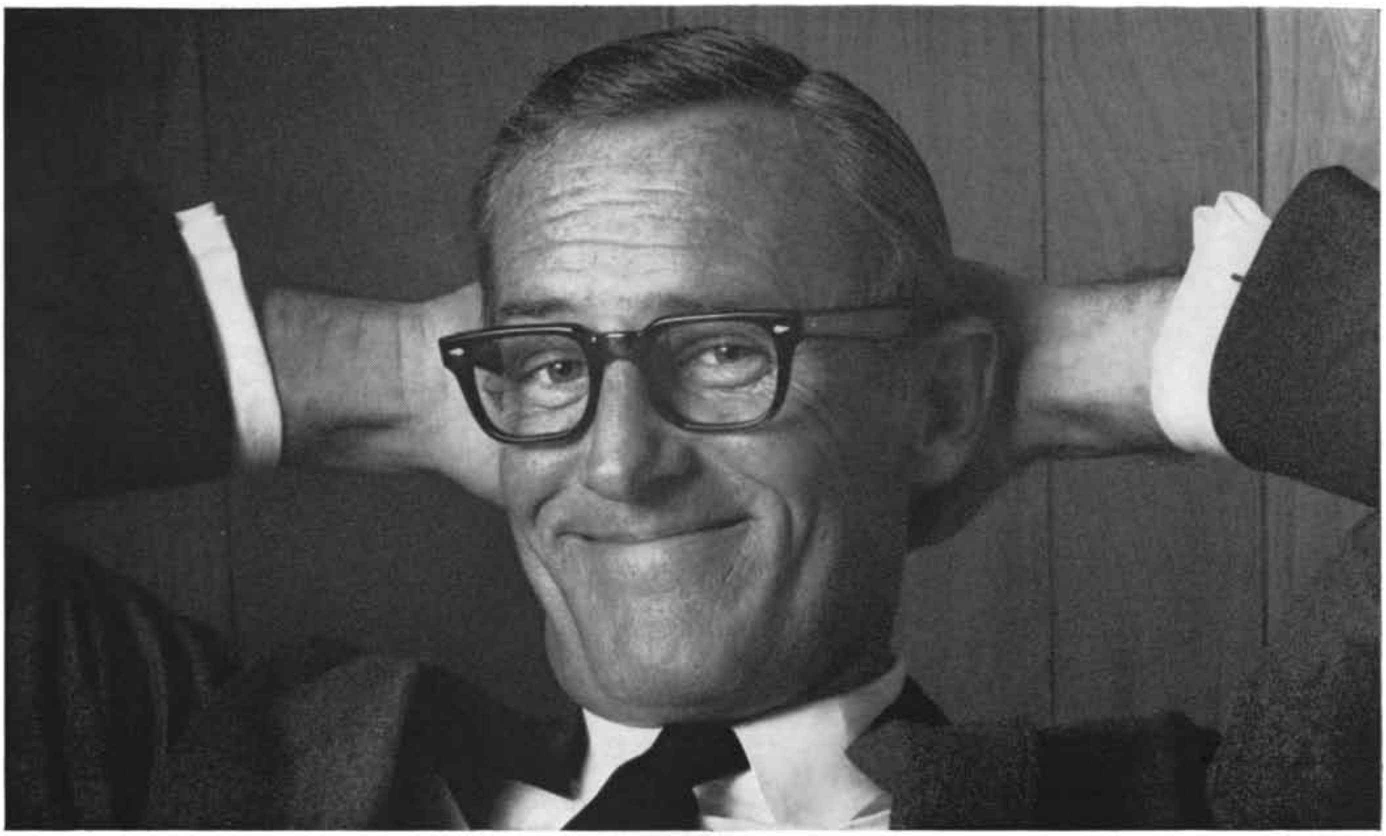

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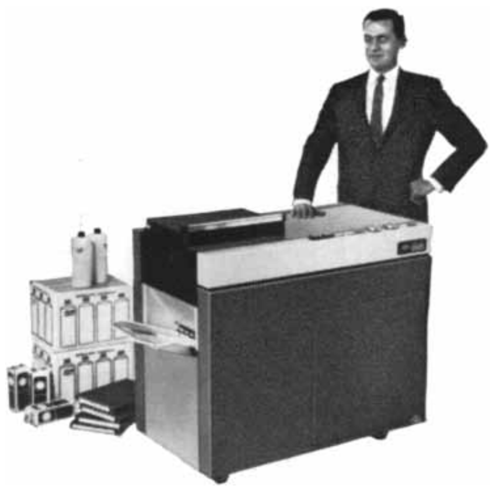

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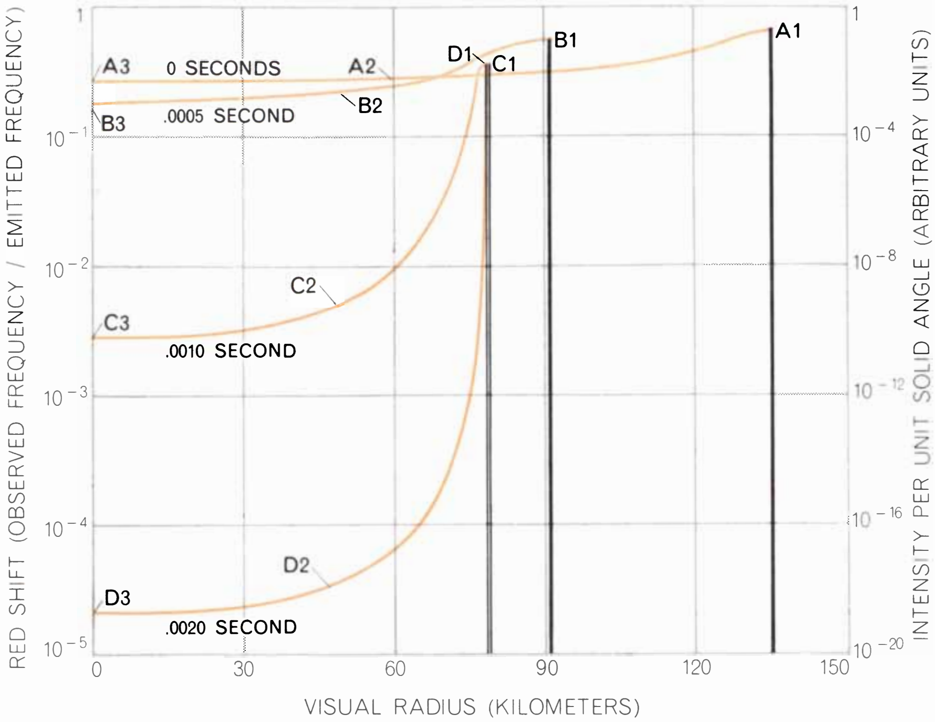
Rutherford's atom, must be quantized. That is to say, nature may avoid the singularity of collapse by changing completely, near the singularity, the laws of physics and the continuous, deterministic nature of space-time. Although a complete quantum theory of gravity has not yet been developed, one can be fairly certain that, as such a theory is applied to gravitational collapse, it will affect only the region of space-time near the singularity. The dynamics of collapse outside the gravitational radius and through it should remain unchanged.

The picture I have presented of spherical gravitational collapse can be made clearer, perhaps, by a fanciful analogy. Once upon a time six ants lived on a large, thin rubber membrane [*see illustration on next page*]. These ants, being highly intelligent, had developed a way to communicate with one another by means of signal balls that would roll with a constant velocity (the "velocity of light") along the surface of the membrane. Unfortunately they had not calculated the strength of the membrane.

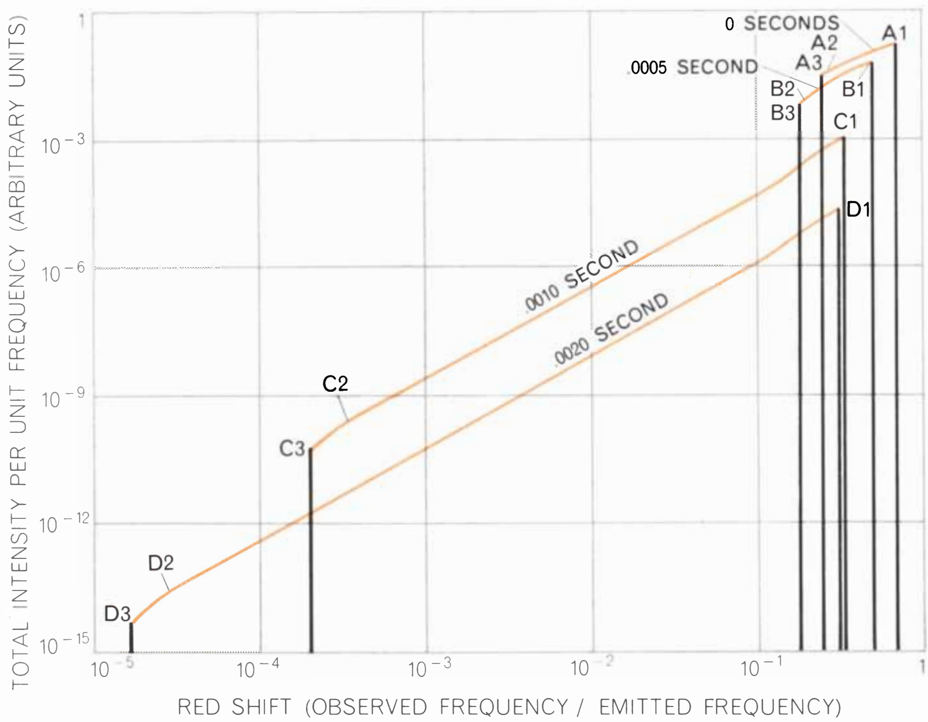
One day five of the ants happened to gather near the center of the membrane and their weight caused it to begin to collapse. The sixth ant—an astronomer ant—was a safe distance away with his signal-ball telescope when the collapse began. The five ants caught in the collapse of the membrane decided to follow it downward rather than try to escape. As the collapse proceeded one of the ants dispatched signal balls in the hope that they would enable the astronomer ant to follow the progress of the collapse.

The collapse of the membrane was characterized by two types of motion. The first was a contraction along the membrane's surface, which, like the gravitational attraction of a star, dragged surrounding objects in toward the center of the collapse. The second was a bending into a sharply curved shape, which, like the curvature of space-time in a collapsing star, would eventually crush everything in the region of collapse to infinite density.

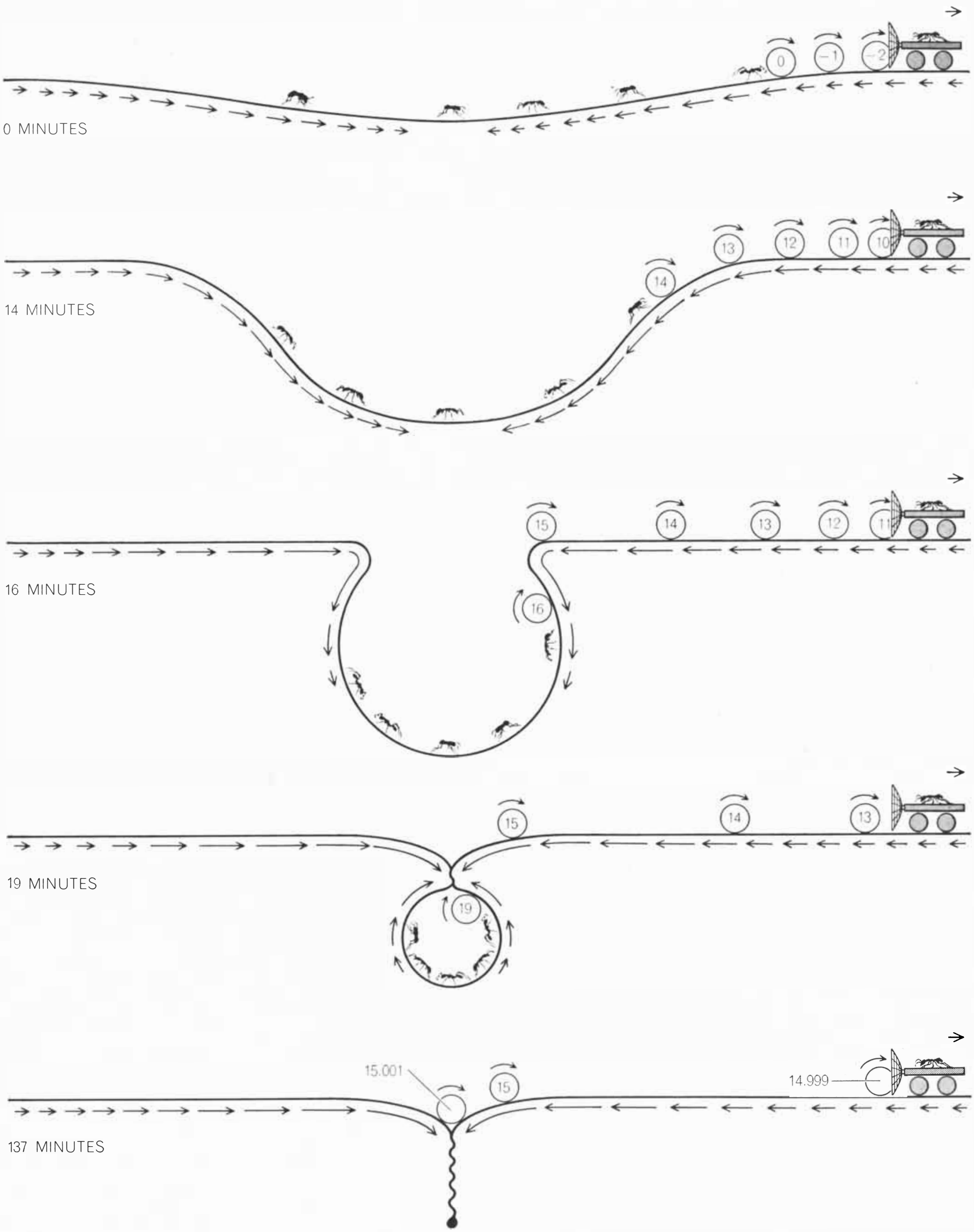
The membrane contracted faster and faster as the collapse proceeded. As a result the signal balls, which were sent at equally spaced intervals by the collapsing ant, were received by the astronomer ant at more and more widely spaced intervals (analogous to the reddening of light by an intense gravitational field). Ball No. 15 was sent out 15 minutes after the start of collapse, just as the collapsing ant was sucked past the gravitational radius. It stayed forever at that radius because the membrane at that point was



RED SHIFT AND INTENSITY OF LIGHT from a collapsing star change swiftly as viewed by a distant observer. The photons (*letters plus numbers*), whose trajectories appear in preceding illustrations, represent the light from a collapsing star whose mass is 10 times that of the sun. As seen by a distant observer only .0005 second elapses between the receipt of photons in group *A* and those in group *B*, .0005 second between groups *B* and *C* and .001 second between groups *C* and *D*. These photons are all emitted from outside the gravitational radius. In the late stages of collapse the star's disk consists of a bright blue rim and a dark red center. As time goes on the central region rapidly becomes darker and redder and eats its way outward into the bright rim, whose color and brightness remain constant.



SPECTRUM OF TOTAL LIGHT from a collapsing star also changes rapidly with time. The diagram shows the effect on a single sharp spectral line. The *A* group of photons, which are emitted sequentially but reach the distant observer simultaneously, exhibit only a small spread in frequency and intensity. Photons in groups *C* and *D*, although received only milliseconds later, show a very wide spread. But since the low-frequency tail of these lines would be so much dimmer than the high-frequency peak, an observer would see a single broad line centered at about three times the emitted wavelength. These two figures are based on a study by William Ames and the author, both of the California Institute of Technology.



COLLAPSING RUBBER MEMBRANE populated by ants provides a fanciful analogue of the gravitational collapse of a star. The full story is told in the text. Briefly, five ants precipitate the collapse of the thin membrane on which they dwell. A sixth "astronomer" ant escapes their fate by turning on the rocket engine of the vehicle carrying his "telescope" and outracing the moving membrane. The telescope is designed to receive signal balls transmitted at regular intervals by one of his trapped colleagues. The first two balls (*−1*, *−2*) are transmitted one and two seconds respectively before the start of the collapse. The others are transmitted in sequence as labeled. Ball No. 15 is sent out just as the transmitting ant is sucked past the gravitational radius. The ball stays forever where it is because the membrane is contracting at that point with precisely the speed of the ball. Ball No. 14.999, sent out .001 minute earlier, finally reaches the astronomer ant after traveling for 122 minutes. Ball No. 15.001 and all later ones disappear into the singularity.

contracting precisely with the speed of the signal. At .001 minute before reaching the gravitational radius the collapsing ant dispatched ball No. 14.999. This ball, barely outracing the contracting membrane, did not reach the astronomer ant until 122 minutes had passed. Ball No. 15.001, sent out .001 minute after the gravitational radius was passed, finally got sucked into the singularity.

As seen by the ants inside the collapsing membrane, the collapse ended in a singularity of infinite density after 20 minutes. But as observed by the astronomer ant, whose only information was obtained from the signal balls, the collapse never proceeded beyond the gravitational radius.

This analogy to the gravitational collapse of a star is remarkably faithful in reproducing not only what is seen by a distant observer and what might be seen by an observer inside the star, but also the manner in which space-time becomes highly curved in spherically symmetrical gravitational collapse and crushes matter into a singular state.

So far I have mentioned only the gravitational collapse of perfectly spherical, nonrotating objects. What would happen in more realistic situations? Because the mathematical analysis of realistic cases is so difficult the question cannot be answered definitively. In 1964, however, Roger Penrose of Birkbeck College of the University of London proved a powerful theorem that provides considerable insight into gravitational collapse in realistic situations.

Penrose's theorem says roughly this: In realistic nonspherical collapse, as in spherical collapse, a critical stage can be reached beyond which no communication with the outside universe is possible. Once this stage has been passed one or both of two "pathological" events may occur: the geometry of space-time may develop a singularity, as it does in spherical collapse, or, stranger yet, a universe with which we had no previous contact may suddenly be joined together with our universe by the collapse event. Stated more precisely, Penrose's theorem says that if a space-time geometric structure known as a trapped surface evolves during the collapse of a star, and if our universe obeys certain rather plausible conditions, the result of the collapse must be either the evolution of a singularity or a sudden joining of our universe with another universe.

Our universe must satisfy three conditions if Penrose's theorem is to be valid. First, the future direction of time must always be distinct and distinguishable from the past. Second, the density of mass-plus-energy in the universe must never be negative. Third, at some initial moment before the collapse begins the universe must have infinite volume. Of these three conditions only the third is troublesome. We do not know whether or not our universe has infinite volume. Most relativity theorists conjecture, however, that Penrose's theorem is valid whether or not the universe is infinite. The theorem still remains to be proved for the finite-volume case.

What is the object called a trapped surface, which signals the approach of pathological events? It is a closed two-dimensional surface, like the surface of a sphere, that has the following strange property. As with an ordinary sphere, light rays emitted perpendicularly inward from a trapped surface will converge. In contrast to an ordinary sphere, however, light rays emitted perpendicularly *outward* from a trapped surface will *also* converge.

In the case of spherical gravitational collapse there are trapped surfaces throughout the interior of the gravitational radius. This accounts for the fact that all photons, regardless of the direction in which they are emitted, ultimately converge toward the singularity.

The meaning of Penrose's theorem is most clearly conveyed by a space-time diagram [*see illustration on next page*]. In this diagram one of three space dimensions is suppressed from view, so that the trapped surface appears as a closed one-dimensional curve rather than as a closed two-dimensional surface. The "world lines," or space-time paths, of photons emitted inward from the trapped surface all converge until they hit a singularity or until they intersect either in a point or in what geometers refer to as a caustic surface—a surface like the peak of a tent. Similarly, the world lines of photons emitted outward all converge until they hit a singularity or until they intersect.

The proof of Penrose's theorem proceeds by contradiction. One assumes that none of the ingoing or outgoing photons encounter a singularity of space-time before their world lines intersect (that is, one assumes that the singularity shown in the illustration on the next page is absent). In that case the two families of photon world lines, taken together, form a closed, three-dimensional, "lightlike" surface. Topologists call this a 3-surface.

Penrose's proof concentrates attention on two particular three-dimensional surfaces in space-time: the closed photon 3-surface just described and an open, or infinite, 3-surface. The latter surface describes the state of the universe at some initial moment before collapse begins. Let us imagine that there exists a certain family of free-falling "observers" who leave the universe's initial open 3-surface and eventually fall through the closed photon 3-surface. For this to happen the world lines of these observers would have to provide a smooth, almost one-to-one mapping of all points of the closed photon 3-surface into points of the open initial 3-surface. It is well known in topology, however, that such a one-to-one, continuous mapping can never be accomplished from a closed surface into an open surface. (A familiar example of this fact is that a map of the earth's surface cannot be drawn on a flat sheet of paper without slicing the earth along some line, which usually becomes the left and right edges of the map.)

Thus a contradiction arises that must be resolved in one of two ways. Either some of the ingoing or outgoing photons from the trapped surface encounter a singularity of space-time that prevents them from converging to form a closed 3-surface, or the initial state of the universe was not sufficient to predict its entire future. The second alternative implies that another universe must join onto our own, bringing in outside information that influences future events. Hence Penrose's theorem is proved. (The actual proof of course involves an intricate mathematical argument.)

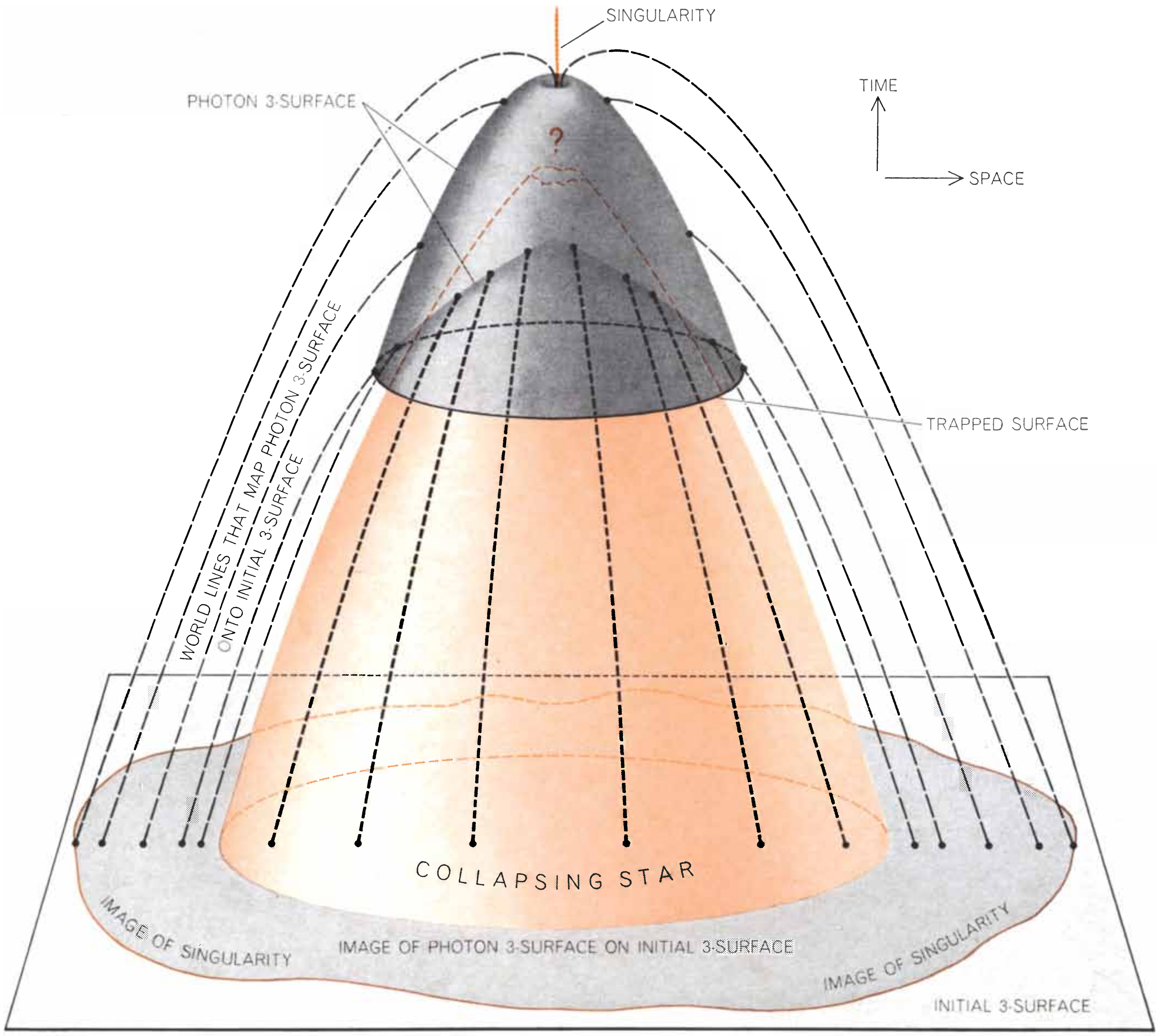
There is an important difference between the singularity encountered in spherical collapse and the one that *may* be encountered in nonspherical collapse. In the spherical case the matter inside the star is crushed to infinite density and zero volume when it encounters the singularity. In the general case Penrose's theorem tells us only that some of the photons leaving a trapped surface should encounter a singularity. It predicts nothing about the behavior of matter in the collapsing star.

There is one way in which the matter might escape being crushed. There might be a topological hole inside the photon 3-surface through which the matter of the star could flow without being crushed to zero volume. The matter might then emerge, bubbling upward like a spring in the mountains, in some other region of our own universe or in some other universe. Indeed, Igor D. Novikov of the Institute of Applied Mathematics in Moscow and James M. Bardeen of the University of Washington have independently presented a mathematical example of gravitational collapse in which precisely this happens.

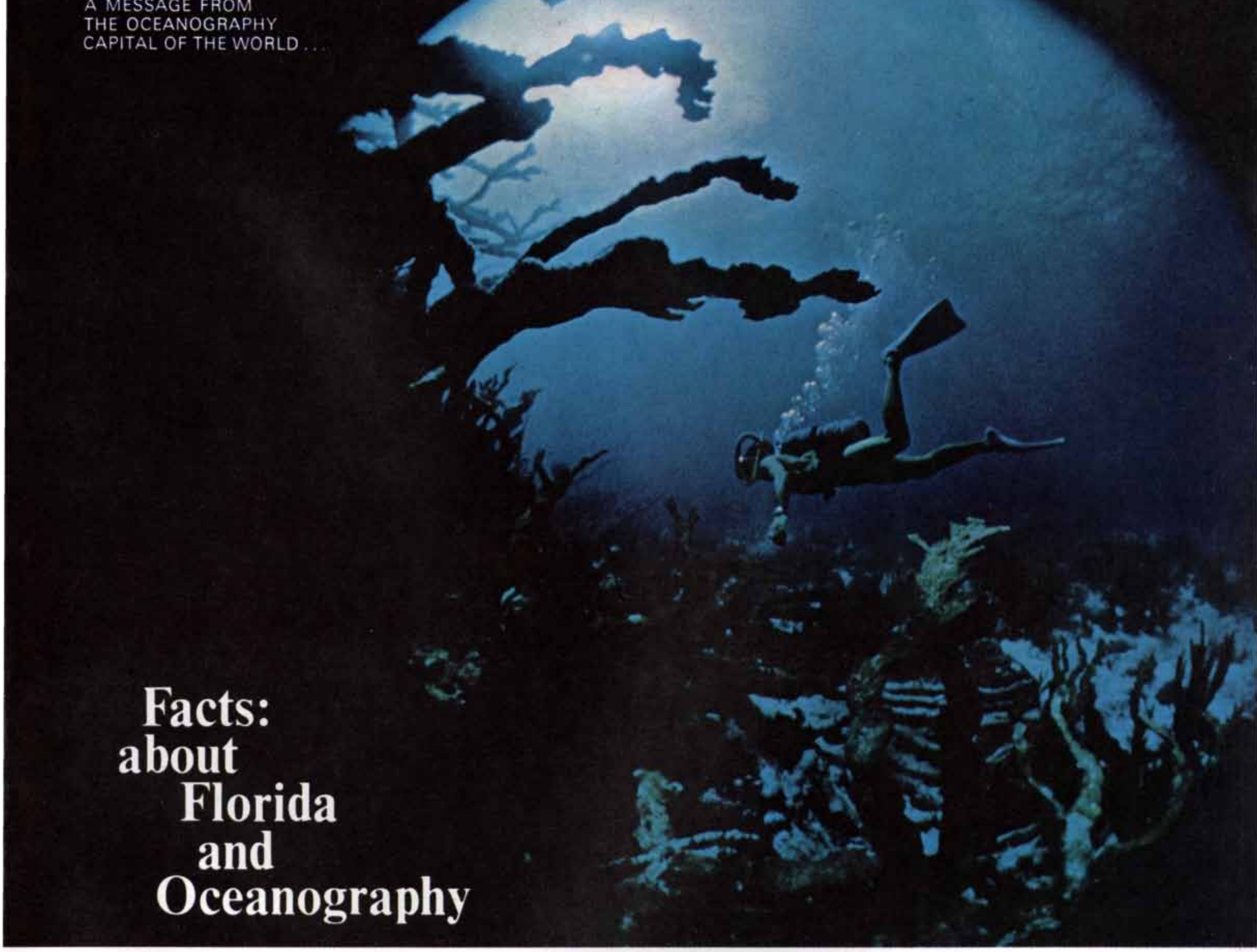
These results on collapse through the

gravitational radius are sufficiently strange to make some people wish to abandon Einstein's general theory of relativity for one that would predict less bizarre phenomena. Penrose has pointed out, however, that in most other geometric theories of gravitation one can expect these same kinds of phenomena to occur. The reason is that Penrose's theorem relies almost solely on the motion of photons through curved space-time, and this motion will be roughly the same in all geometric theories of gravitation.

Let me emphasize again that the bizarre phenomena predicted as occurring inside the gravitational radius can never be seen by any outside observer. Thus anyone who is put off by the foregoing predictions can ignore them. On the other hand, the evolution of our universe in many ways resembles the evolution of a collapsing star. If our universe has a finite volume, we cannot expect it to go on expanding forever. Eventually it will stop expanding and begin to contract. The contraction phase should closely mimic the gravitational collapse of a star. Accordingly people who are concerned about the ultimate fate of our universe, but who are not interested in the gravitational collapse of a star, must still worry about the bizarre end point of collapse.



ASYMMETRIC GRAVITATIONAL COLLAPSE resembles spherical gravitational collapse except that matter is not necessarily crushed to infinite density. As in the illustration on page 89, the time dimension is plotted upward and two of the three space dimensions are plotted horizontally. New features are introduced in this diagram to illustrate an important theorem about asymmetric collapse proved by Roger Penrose of Birkbeck College of the University of London. (For clarity the diagram has been made more symmetrical than it should be.) The "initial 3-surface" represents the state of the entire universe (i.e., an infinite universe) at some moment before collapse begins. The "photon 3-surface" is the three-dimensional volume formed by the paths of all photons emitted perpendicularly both inward and outward from the two-dimensional "trapped surface." Their convergence is part of the definition of such a surface. (Because one of the three space dimensions is suppressed in this diagram, the trapped surface appears as a closed one-dimensional curve rather than as a closed two-dimensional surface. Similarly, one dimension is omitted from the photon 3-surface.) Because matter can never travel faster than light, the photon 3-surface would appear to be squeezing down on the matter of the star, crushing it to zero volume. But Penrose's theorem says nothing about the behavior of matter in a collapsing star. Thus matter may be able to escape through a topological hole inside the photon 3-surface (*question mark*) and reappear elsewhere in our universe or in some other universe. The world lines that map the photon 3-surface onto the initial 3-surface are discussed in the text.



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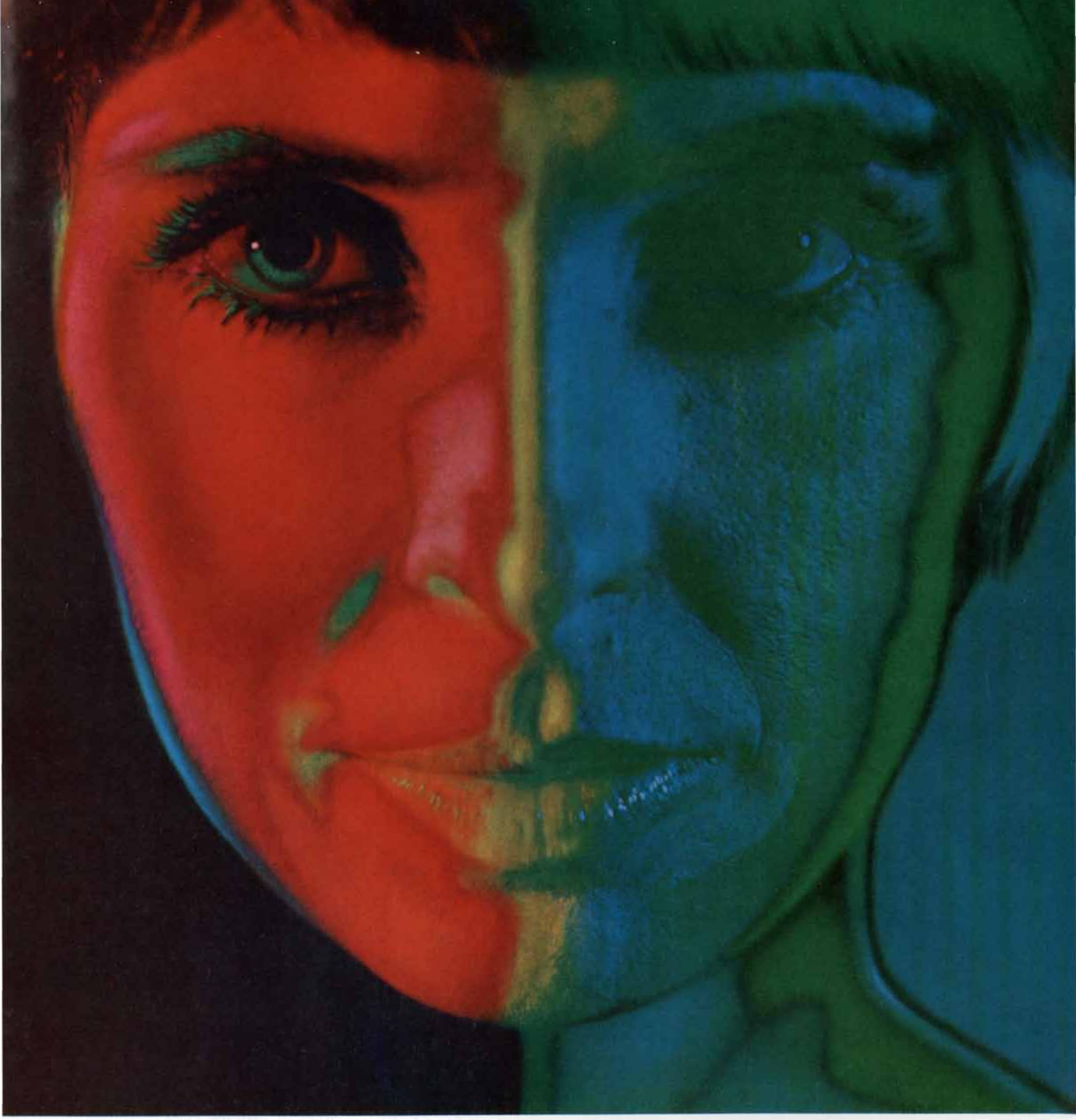

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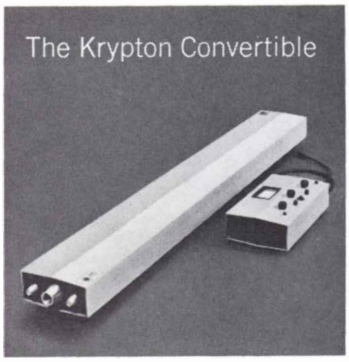

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MAXWELL'S DEMON

This hypothetical being, invoked by James Clerk Maxwell nearly a century ago as a violator of the second law of thermodynamics, has occupied the minds of many prominent physicists ever since

by W. Ehrenberg

One of the best established facts in thermodynamics is that it is impossible in a system enclosed in an envelope which permits neither change of volume nor passage of heat, and in which both the temperature and the pressure are everywhere the same, to produce any inequality of temperature or of pressure without the expenditure of work. This is the second law of thermodynamics, and it is undoubtedly true as long as we can deal with bodies only in mass, and have no power of perceiving or handling the separate molecules of which they are made up. But if we conceive a being whose faculties are so sharpened that he can follow every molecule in its course, such a being, whose attributes are still as essentially finite as our own, would be able to do what is at present impossible to us. For we have seen that the molecules in a vessel full of air at uniform temperature are moving with velocities by no means uniform, though the mean velocity of any great number of them, arbitrarily selected, is almost exactly uniform. Now let us suppose that such a vessel is divided into two portions, A and B, by a division in which there is a small hole, and that a being, who can see the individual molecules, opens and closes this hole, so as to allow only the swifter molecules to pass from A to B, and only the slower ones to pass from B to A. He will thus, without expenditure of work, raise the temperature of B and lower that of A, in contradiction to the second law of thermodynamics.

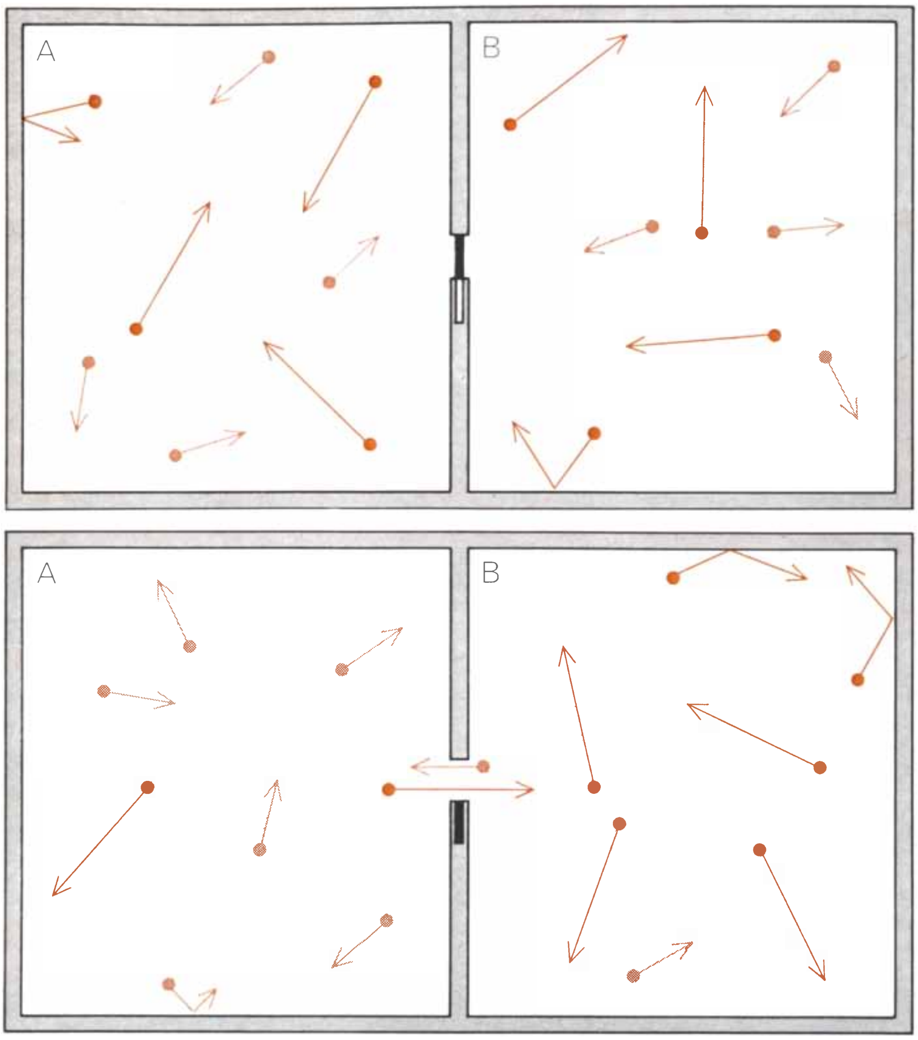
—JAMES CLERK MAXWELL

For nearly a century the "demon" invoked by Maxwell in the foregoing passage has haunted the world of physics. This hypothetical being makes his appearance under the heading "Limitation of the Second Law of Thermodynamics" near the end of Maxwell's book *Theory of Heat*, published in 1871.

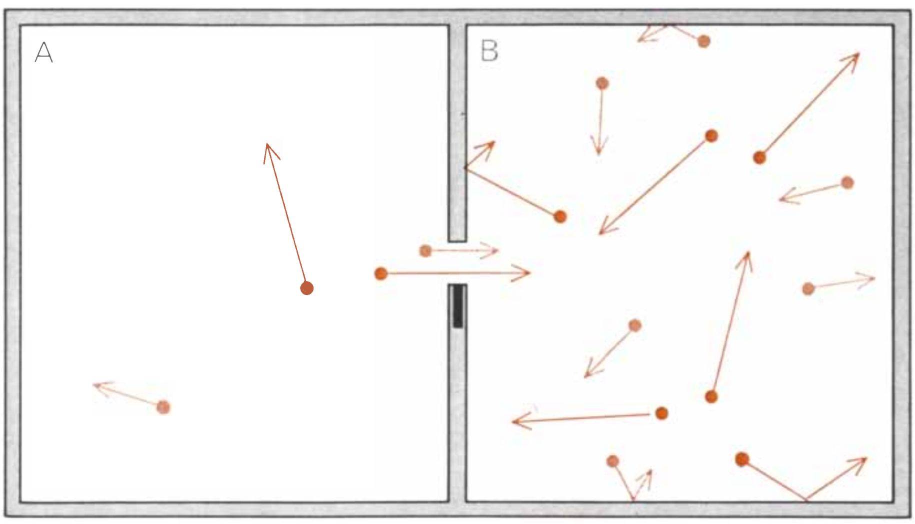
How seriously Maxwell took his demon is hard to say. In any case, he neither carried out nor promoted experiments to test his hypothesis. His almost offhand remark has nonetheless intrigued many prominent physicists, because it holds out the possibility of a perpetual-motion machine deriving its mechanical effect from the temperature difference between the two portions of the vessel.

As it happens, there is an easier way to design a perpetual-motion machine that employs the services of such a sorting demon. Beginning with equal pressures and temperatures on each side of the division, the demon could, by opening and closing the shutter at the right times, allow molecules to pass only from portion *A* to portion *B*. This would eventually result in a difference in pressure between the two sides, a situation that would be even more adaptable than a difference in temperature.

JAMES CLERK MAXWELL (1831–1879) put forward his idea of the sorting demon in a brief remark that appears near the end of his book *Theory of Heat*, published in 1871.



SORTING DEMON OPERATES by opening and closing a small hole in a division between two portions of a vessel full of air at a uniform temperature (*top*). The demon can see the individual molecules, which move at many different velocities. By opening and closing the hole so as to allow only the swifter molecules to pass from *A* to *B* and only the slower ones to pass from *B* to *A*, the demon could, without expenditure of work, raise the temperature of *B* and lower that of *A* (*bottom*), in contradiction to the second law of thermodynamics. It would then be an easy matter to design a perpetual-motion machine that derived its mechanical effect from the temperature difference between the two portions of the vessel.



ANOTHER APPROACH to the problem of designing a perpetual-motion machine that employs the services of a sorting demon also begins with equal pressures and temperatures on both sides of the division. By opening and closing the shutter at the right times the demon could allow both swift and slow molecules to pass only from *A* to *B*. The resulting difference in pressure between the two sides could then be readily translated into mechanical work.

The purpose of this article is to review the various turns Maxwell's idea has taken since 1871. It is an idea that should not be discarded lightly. A practical system with immunity from the second law of thermodynamics would be the ultimate prime mover, capable of returning the fuel after the work is done. Undoubtedly such a system would have economic consequences far greater than, say, nuclear power, and a few decades ago a nuclear power station would have been considered a project equally fantastic.

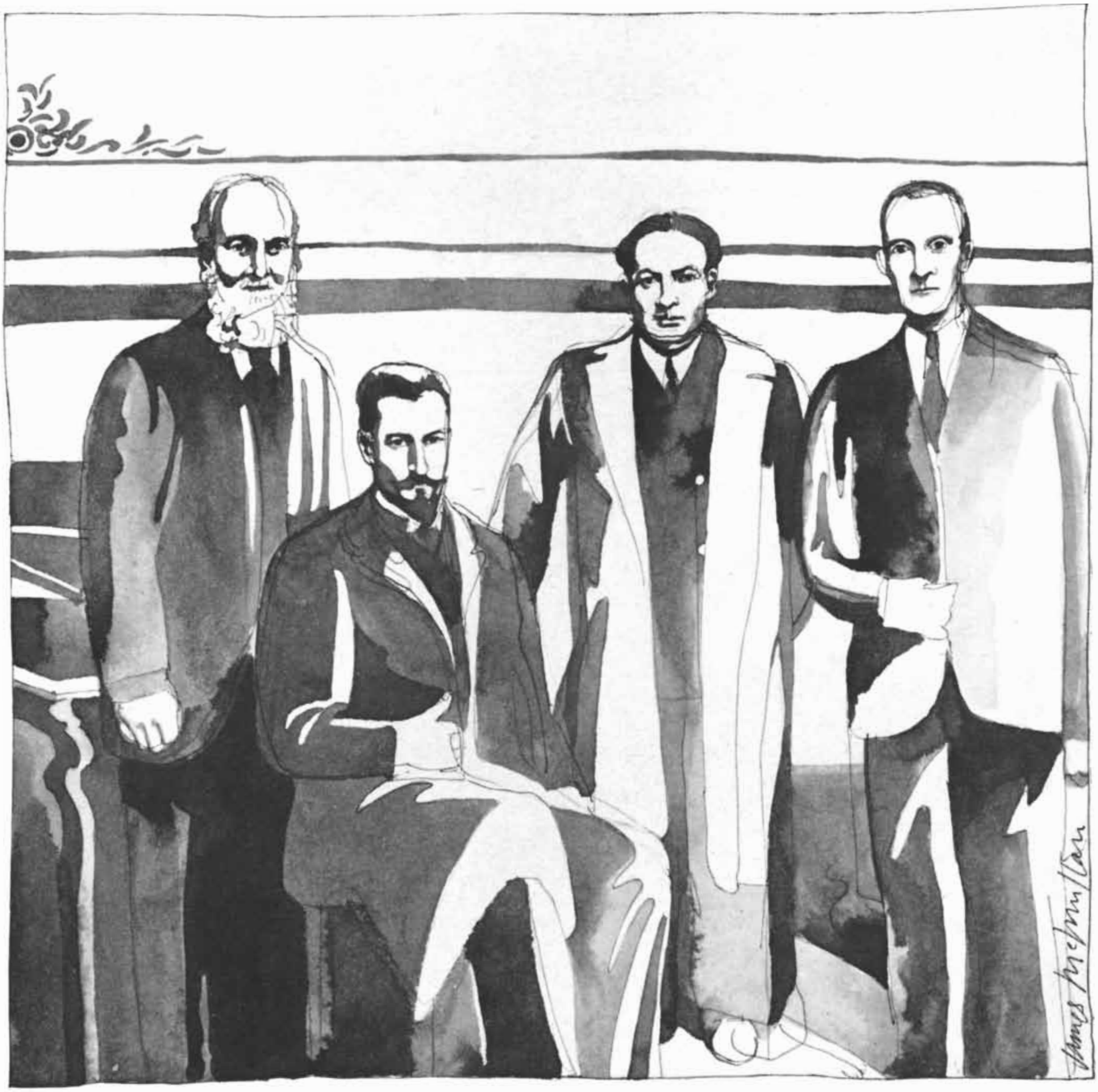
Since the second law of thermodynamics was first formulated by Rudolf Clausius in 1850 it has been restated in a number of different ways. In Clausius' original formulation the second law asserts: "It is impossible for a self-acting machine, unaided by any external agency, to convey heat from one body to another at a higher temperature." It was Clausius who introduced the concept of entropy, a measure of the unavailable energy in a thermodynamic system. He concluded that the entropy of any large system increases perpetually, leading to the eventual "death" of the universe.

The second law was worded much more cautiously by William Thomson (Lord Kelvin) in 1851. "It is impossible," he wrote, "by means of an inanimate material agency, to derive mechanical effect from any portion of matter by cooling it below the temperature of the coldest of the surrounding objects." The phrase "inanimate material agency" is noteworthy here. It is not merely Thomson's term for Clausius' "self-acting machine." This Thomson made quite clear by adding: "The animal body does not act as a *thermodynamic engine*. The means in the animal body by which mechanical effects are produced cannot be arrived at without more experiment and observation. . . . Whatever the nature of these means, consciousness teaches every individual that they are, to some extent, subject to the direction of his will. It appears therefore that animated creatures have the power of immediately applying to certain moving particles of matter within their bodies, forces by which the motion of these particles are directed to produce desired mechanical effects."

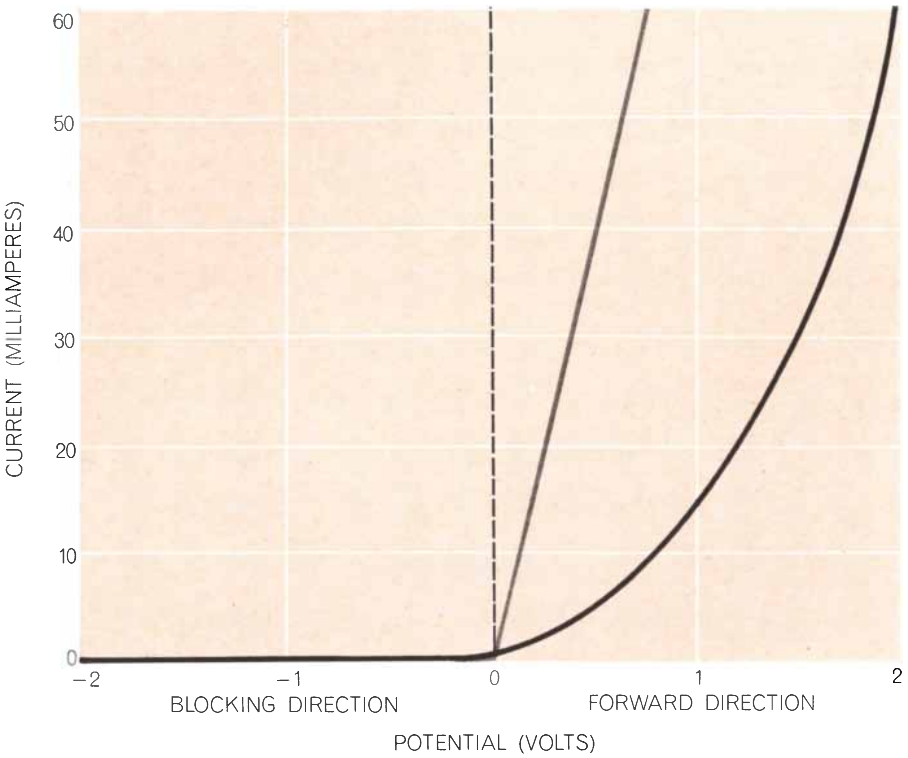
Maxwell's remark about the demon gave these general reservations of Thomson's new force by relating them to the results of the new kinetic theory of gases, which treated the thermodynamic properties of a gas in terms of the average motions of its constituent particles. This led Thomson to comment: "The definition of a demon, according to the use of this word by Maxwell, is an intelligent being endowed with free-will and fine enough tactile and perceptive organization to give him the facility of observing and influencing individual molecules of matter.... A Clerk Maxwell's demon differs from real living animals only in the extreme smallness and agility—he cannot create or annul energy—he can store up limited quantities and reproduce them at will.... The conception of the 'sorting demon' is purely mechanical, and is of great value in purely physical science. It was not invented to help us deal with questions regarding the influence of life and of mind on the motions of matter, questions essentially beyond the range of mere dynamics."

In Thomson's view, then, the hypothetical lawbreaker should have some or all of the following properties: animation, atomic dimensions, intelligence. Two questions arise: Are these properties really necessary, and are they sufficient?

In recent years the difficult question of the relation between the law of increasing entropy and the nature of the living body has been taken up separately by Erwin Schrödinger and C. F. von Weizsäcker. Briefly their argument boils down to this: Whenever one investigates living processes by physical means, the findings always satisfy the rules of phys-



FOUR PHYSICISTS who made major contributions to the theoretical development of Maxwell's idea are depicted here. At left is William Thomson (Lord Kelvin), who in the 1870's postulated that the demon should have some or all of the following properties: animation, atomic dimensions, intelligence. Second from left is M. Smoluchowski, who in 1913 argued that the original small demon could not be automated, but that an intelligent being (not necessarily a real man) could operate a perpetual-motion machine based on Maxwell's idea. Second from right is Leo Szilard, who in 1929 identified the intelligence required of the demon as a kind of memory. At right is Leon Brillouin, who in 1951 concluded that Maxwell's demon could not operate, because an intelligent being, whatever its size, has to cause an increase in entropy, or unavailable energy, in the system before it can effect even a small reduction.



RECTIFICATION of an alternating voltage by such solid-state electronic devices as diodes and transistors is analogous to the old demon's trick of permitting only fast molecules to go from left to right. The characteristic curve that relates the voltage to the current across an ideal diode (*gray line*) has a sharp "knee" at zero voltage, the resistance in the forward direction being much smaller than in the blocking direction. A real characteristic curve (*black line*) never has a sharp bend and can only rectify voltages in excess of a certain finite threshold, which according to Smoluchowski's reasoning is a true thermodynamic limit.

ics. And although it is remarkable (as Schrödinger points out) that living bodies, far from increasing their entropy, in fact decrease it, organizing more and more matter in their own pattern, this decrease is more than balanced by the trail of increased entropy they create in their surroundings. Thus animate agencies as such are subject to the second law. Following this line of reasoning, it appears that animation alone does not lead to the ultimate prime mover.

What about the other attributes of the demon, namely atomic dimensions and intelligence? The problem here was clearly stated in 1880 by P. G. Tait of the University of Edinburgh: "The second law is only accidentally correct.... The true basis of the second law of Thermodynamics lies in the extreme smallness and enormous number of particles of matter and in consequence the steadiness of their average behavior. Had we the means of dealing with the particles individually, we could develop on the large scale what takes place continuously on a very minute scale in every mass of gas, the occasional, but ephemeral, aggregation of warmer particles in one small region and of colder in another." Tait's optimistic appeal fell on deaf ears. The discoveries of the next 30 years transformed the physicist from a person who had mastered all but a few minor details into a person aware of his ignorance of the fundamental processes of the physical world.

It was not until 1913 that the whole issue was reopened by the Polish physicist M. Smoluchowski in a lecture at Göttingen on the limits of the validity of the second law. He first recalled that in the late 19th century physicists believed the atomistic kinetic theory was discredited because of its incompatibility with Clausius' second law. By 1913, however, the speculative tendency in physics was again in vogue, largely because of the success of electron physics and the analysis of such fluctuation phenomena as the Brownian motion. As a result the second law had lost its role as dogma.

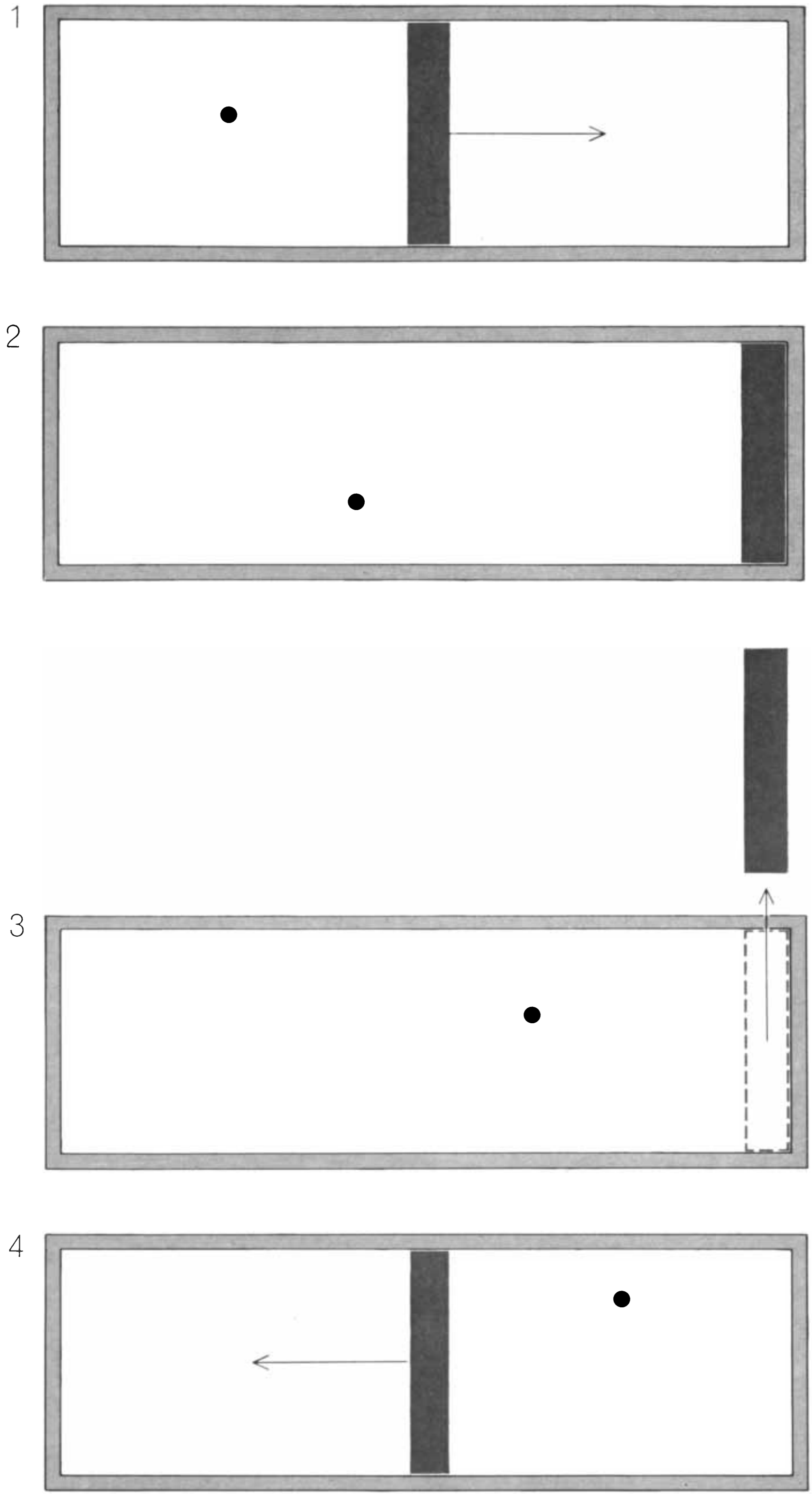
In order now to reassert the validity of the second law, Smoluchowski adopted the probabilistic approach of Ludwig Boltzmann, in which Clausius' concept of entropy was redefined as the value applicable to the average, or most probable, state of a system. According to Boltzmann, a value for the entropy of a system could, however, also be associated with improbable states, that is, states that correspond to fluctuations in the thermodynamic properties of the system. Such fluctuations were not accounted for in "classical" thermodynamics, which had no way to cope with them. Smoluchowski, however, cited several situations in which such fluctuations can be readily observed, for example the fluctuations in the number of colloidal particles visible in a small field of view (which from time to time may be counted as zero, one, five and so on) or the density fluctuations that give rise to such macroscopic effects as the opalescence of liquids near the boiling point and the blue of the sky. The rate of occurrence of these fluctuations can be estimated quantitatively: Large fluctuations are rare and very small ones are quite common. The decisive point is that the frequency of occurrence of a deviation decreases so rapidly with its magnitude that an agent relying on such fluctuations for mechanical effect without having the gift of foresight would be well advised to be satisfied when he finds the entropy reduced by a small amount rather than to let the occasion slip in the hope that the observed reduction is only the beginning of a larger one. The normal thermodynamic increase of entropy is of course not part of such a fluctuation cycle but occurs during a readjustment to altered conditions.

The upshot is that an observer who can wait an astronomical length of time has the chance to witness events in which the entropy decreases by a large amount, so that the world need not die the death of uniform temperature. Small reductions of entropy also occur, however, in small but still macroscopic assemblages. Therefore a perpetual-motion machine based on the services of a sorting demon would not necessarily require operation on single molecules. At this stage, however, a new snag becomes apparent: A device that could perpetuate and accumulate the states of reduced entropy (for example a mechanism that would place a weightless support under a Brownian particle that had risen particularly high) would itself be subject to fluctuations not correlated with the desired effect. This factor, concluded Smoluchowski, makes automatic operation impossible, because the mechanism operated by the particle could not be more massive than the particle itself.

Smoluchowski's point can be better appreciated by translating it into modern terms. Although he refers to recent progress in electronics, ideas such as the rectification of an alternating voltage had barely arisen in his time. Today the principle of rectification plays a major role in such solid-state electronic devices as diodes and transistors. These devices are analogous to the hypothetical gadgets that translate the up-and-down movement of a Brownian particle into a purely upward motion, or that perform the old demon's trick of permitting only fast molecules to go from left to right. Now, ideally the characteristic curve that relates the voltage to the current across the perfect electrical rectifier (in this case a perfect diode) has a sharp "knee" at zero voltage, the resistance in the forward direction being much smaller than that in the blocking direction [*see illustration on opposite page*]. Real characteristic curves, however, never have a sharp bend, and much as diodes have been improved, one still has to offer them voltages in excess of a certain finite threshold. Smoluchowski's reasoning indicates that this threshold is a true thermodynamic limit. The fluctuations of the potential across a diode prevent it from rectifying alternating voltages that are less than the threshold voltage.

The general conclusion, then, is that the original small demon cannot be automated. Smoluchowski did not give up at this point, however, but instead reviewed the possibility of intelligence. He pointed out that an intelligent being could operate such devices; it could, for example, push a weightless support under an elevated particle. Thus a perpetual-motion machine is possible if man is continuously informed and able to operate macroscopic devices that do not involve an exchange of energy; he does not have to be able to deal with single molecules. But this intelligent man, Smoluchowski warned, differs from real man, who cannot work without increasing entropy. Hence we cannot be sure that living intelligent beings can violate the second law.

So the demon has become *Homo sapiens,* and the ball is thrown to the biological sciences, in particular to the study of man. Unfortunately no response to such suggestions has come from the biologists, perhaps because so little of human physiology and psychology is actually involved in Smoluchowski's problem. The function he asks the intelligent being to perform is really very simple, namely to act as nothing more than a kind of relay, which replaces the direct action of the fluctuating property. Hence it may be no accident that when eventually the question was taken up again, the man who took it up was not a biologist but a young physicist who had started his career as an



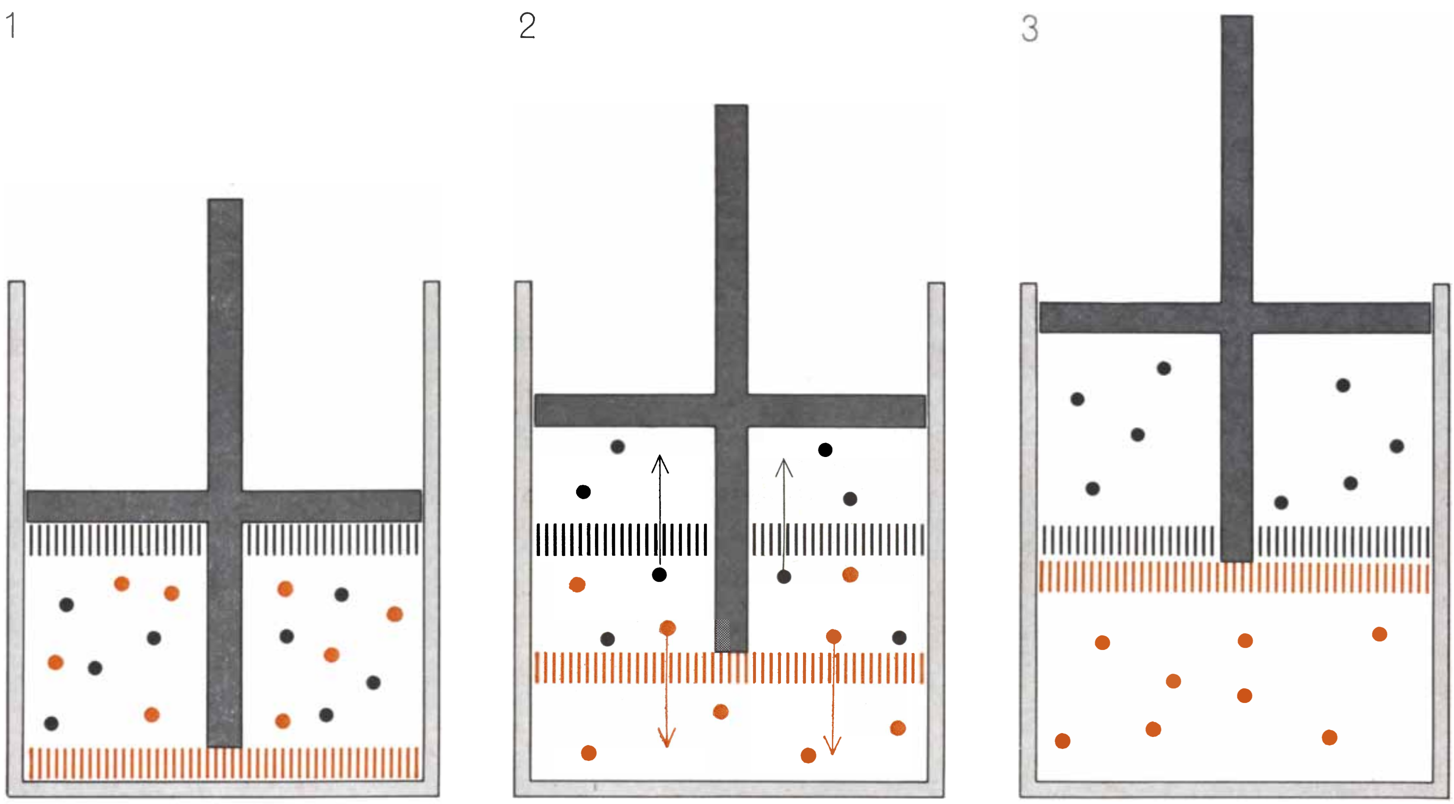
SZILARD'S FIRST EXAMPLE of a procedure for reducing the entropy of a system by the use of memory is shown in this sequence of drawings. The cylinder in *1* contains a single molecule and a mechanism for first inserting a dividing wall, or piston, in the middle and then moving it either way. If one remembers which side the molecule is on initially, one can move the piston so as to double the volume available to the molecule (*2*), thereby gaining work by isothermal expansion. At the completion of each expansion the piston is withdrawn from the cylinder without doing work (*3*), and is inserted again in the middle (*4*) so that the experiment can be repeated indefinitely. The entropy of the surrounding heat "bath," which maintains the temperature, or speed, of the molecule, decreases with each expansion.

electrical engineer. He was Leo Szilard, who in 1929 published a paper "On the Reduction of Entropy of a Thermodynamic System caused by Intelligent Beings."

According to Szilard, it suffices that a kind of memory exists. This memory can entail a continued reduction of entropy unless the processes of measurement themselves imply necessarily a production of entropy. To measure, Szilard argued, is to establish and memorize a value for a time-independent variable y, which indicates the value that a function x—say the position of a pointer—has at a particular time t. This is what one does in carrying out a measurement and recording the results in a notebook; the notebook is a kind of memory, since the record is made in order to use it later on. Szilard illustrated the procedure of using the memory to reduce entropy by several examples, of which I shall cite two.

Consider a cylinder in thermal contact with its surroundings that contains a single molecule and a mechanism for first inserting a dividing wall, or piston, in the middle and then moving it either way [*see illustration on preceding page*]. If we know which side the molecule is on initially, that is, if our senses can distinguish between the two alternatives and retain this information (here the function y can have only two values), we can move the piston so as to double the volume available to the molecule, thereby gaining work by isothermal expansion (expansion not accompanied by a change in temperature). At the completion of each expansion the piston is withdrawn from the cylinder without doing work, and it is inserted again in the middle of the cylinder so that the experiment can be repeated indefinitely. Elementary thermodynamics shows that the entropy of the surrounding heat "bath," which maintains the temperature, or speed, of the molecule, decreases by a certain amount with each expansion.

The second of Szilard's examples is perhaps even neater: Take a mixture of two molecular forms of some substance (for example ortho-hydrogen and para-hydrogen), which can change into each other and in equilibrium are present in the ratio W_1/W_2. The gas is contained in a cylinder with a solid bottom and a peculiar semipermeable top that is transparent to one form and opaque to the other [*see illustration below*]. A hollow piston of equal volume has a solid top and a bottom permeable only to the second form. (This device was actually conceived in 1883 by Max Planck in order to illustrate Willard Gibbs's rule for the entropy of mixtures of perfect gases.) Initially the piston is at rest at the bottom of the cylinder and the two volumes coincide; then the piston is moved without doing work or admitting heat so that the total volume available to the gas is doubled and the two forms are separated. On waiting, the equilibrium ratio (W_1/W_2) is reestablished in both halves (by changes in the form of some of the molecules), an exchange of heat takes place between the two compartments and the entropy increases; there is no net change in heat, however, since W_1 and W_2 remain the same. The result of the operation is that the volume has been doubled isothermally, the change having been carried out irreversibly. We could reverse the process by first remembering which of the molecules were originally ortho-hydrogen and which were para-hydrogen and then making the semipermeable walls of the piston and the cylinder pass or block molecules according to their original form. This procedure



SZILARD'S SECOND EXAMPLE of the use of memory to reduce the entropy of a system is illustrated on these two pages. A gas consisting of a mixture of two molecular forms of some substance (which can change into each other and in equilibrium are present in the ratio W_1/W_2) is contained in a cylinder with a solid bottom and a peculiar semipermeable top that is transparent to one form and opaque to the other. A hollow piston of equal volume has a solid top and a bottom permeable only to the second form. Initially the piston is at rest at the bottom of the cylinder and the two volumes coincide (*1*); then the piston is moved without doing work or admitting heat, so that the total volume available to the gas is doubled and the two forms are separated (*2, 3*). On waiting, the equilibrium ratio (W_1/W_2) is reestablished in both halves (by changes in the form of some of the molecules), an exchange of heat would reduce the entropy of the gas to its original value.

The foregoing examples show clearly why Szilard identifies "intelligence" and "memory"—memory understood as a tag or record denoting a state of affairs at a past instant of time. It also shows why he proceeded to state: "If we are not willing to admit that the second law is violated, we have to conclude that the action which couples y and t—i.e., establishes the 'memory'—is indissolubly connected with production of entropy."

Szilard's analysis of Smoluchowski's proposal that intelligent man could operate a perpetual-motion machine that violated the second law of thermodynamics led him neither to a working model nor to a proof that the proposal is unworkable but rather to a postulate relating entropy to information. One may therefore praise or blame Szilard for having opened the path leading to information theory and its mysteries. I am sure, however, that this was not his intention. He believed his paper put the final seal on half a century of argument.

If we do not accept Szilard's postulate, we can still contend that his projects would be unsuccessful by simply stating that membranes or walls capable of discriminating between properties of the y type do not exist. But this would be a dogmatic rather than a scientific approach; we could have been equally dogmatic before and informed Maxwell's little demon that in reality he and his wall are only a semipermeable membrane of a type that does not exist, although we would have to concede that similar devices on a macroscopic scale are well known and sometimes useful—for example in catching fish. The virtue of Szilard's postulate is of course its generality. Once we start solving our problem by denying the possibility of offending devices, we have to go on denying, and sequences of *ad hoc* solutions are never satisfactory in science.

Let us therefore accept the postulate that any action resulting in a decrease in the entropy of a system must be preceded by an operation of acquiring information, which in turn is coupled with the production of an equal or greater amount of entropy. We are then entitled to ask how the generation of this entropy—as a quantity that can be measured and added to the entropy of, say, a bucket of water—fits in with the general framework of the physics of heat.

For the few decades following Szilard's paper physicists were preoccupied with so many basic developments that Szilard's postulate was not seriously reviewed before 1951, when Leon Brillouin published a paper in the *Journal of Applied Physics* entitled "Maxwell's Demon Cannot Operate." By his choice of title Brillouin meant not that the demon was disabled but, following Szilard, that an intelligent being, whatever its size, has to cause an increase of entropy before it can effect a reduction by a smaller amount.

Brillouin argued as follows: Before an intelligent being can use its intelligence, it must perceive its objects, and that requires physical means of perception. Visual perception in particular requires the illumination of the object. Seeing is essentially a nonequilibrium phenomenon. The cylinder in which the demon operates is, optically speaking, a closed black body and, according to the principle enunciated by Gustav Kirchhoff in 1859, the radiation inside a black body is homogeneous and nondirectional because for any wavelength and any temperature the emissivity of any surface equals its coefficient of absorption. Hence, although an observer inside a black body is exposed to quanta of radiation, he can never tell whether a particular photon comes from a molecule or is reflected from a wall. The observer must use a lamp that emits light of a wavelength not well represented in the black-body radiation, and the eventual absorption of this light by the observer or elsewhere increases the entropy of the system.

Brillouin then proceeded to show mathematically that this increase of entropy more than balances the decrease of entropy the demon can effect. Similar calculations appear to be applicable whenever intelligent beings propose to act as sorting demons. All instrument pointers, for example, are subject to thermal fluctuations from which power could be derived. In order to record the position of a pointer, however, one has to illuminate it from outside, thereby increasing the entropy of the system by more than one can eventually reduce it.

I think that these arguments are very convincing. Perhaps less convincing is another conclusion Brillouin draws from them: "Information," he says, "is thus defined by the corresponding amount of negative entropy." Quite apart from any other connection that may exist between thermodynamics and information theory, it can be argued that the reasoning given by Brillouin eliminates the intelligent portion of the being by demonstrating the existence of a physical entropy-producing link in the relay action this intelligent being represents. As a result the agent does not rely on his intelligence, since he needs physical means to obtain the information—but given the physical means we do not need the agent any longer because we can replace him by a machine!

The error committed by Maxwell and his followers appears to be the neglect of this relevant portion of the power cycle. This is the type of error that has been committed again and again by inventors of perpetual-motion machines that violate the first law of thermodynamics, which states that the total amount of energy in an isolated system remains unchanged while internal changes of any kind occur. It is never good enough to remind these inventors of the law of conservation of energy; the critic has not completed his task until he has shown where exactly the error lies. We have now seen that the agent is either subject to fluctuations that make his action impossible or he needs means of observation that entail a considerable increase of entropy of the system. We may perhaps be left with the suspicion that Brillouin's reasoning is based on a vicious circle. Kirchhoff's theorem itself is derived directly from the second law—no

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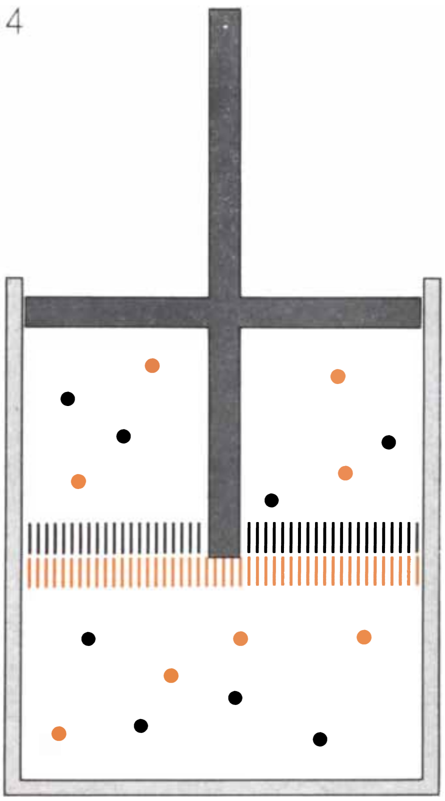

takes place between the two compartments and the entropy increases (4). The entire process could be reversed by first remembering the original forms of the molecules and then making the semipermeable walls of the piston and the cylinder pass or block molecules according to their original form.

wonder we can prove the second law to be satisfied if we assume Kirchhoff's law to hold! Actually I do not think this matters; physics is an empirical science, and Kirchhoff's theorem has been confirmed independently.

There is, however, one situation that is not covered by Brillouin. A demon, or another intelligent being, may first meditate about improving the ratio of entropy lost to entropy gained by using large fluctuations. After all, it does not require more quanta to watch a pebble rising than to watch a molecule rising. He will soon satisfy himself that this would not help him because he would have to try very often before he is likely to see the pebble rise appreciably. He must expect to expend more photons than the jackpot is worth, but what if he takes courage, trusts his luck and succeeds the first time? After all, some people do win the Irish Sweepstakes. But then he is no longer acting as an intelligent being who is developing a new technology!

Think of ball lightning or catastrophes such as the Aberfan disaster, in which a heap of mine refuse suddenly began to move and engulfed many houses. The question of negligence was discussed at length without profit because rare disasters are, as one says in an uncomplimentary way, acts of God. Or think of the events of which spiritualists talk. I found recently in the *Radio Times* a notice announcing that Dr. George Owen, Research Fellow at Trinity College, Cambridge, was to introduce a program on the subject of poltergeists. Dr. Owen wrote, referring to his forthcoming talk: "What are we to think of this poltergeist outbreak?... These outbreaks, it should be said, have always been hard to assess because they are short-lived. They are also rare, far scarcer than the uncommon crime of murder.... Puzzled by accounts of poltergeist cases I have read, I was inclined to think them tall stories. But how surprised I was when I reached Scotland and found numerous eminently sound and reliable witnesses who, for me, established the case as beyond all doubt." The case may not be established beyond all doubt for us, but I give these examples in order to show that very rare events including exceptional fluctuations may be of enormous importance from a human or from a cosmological point of view but are at best scientifically awkward and technically useless.

It remains to ask why the problem of the demon arose in the first place and why it was to occupy the minds of so many leading physicists. Why did we never hear of a demon acting against gravitation or against Lagrange's equations or against Maxwell's electrodynamics? The reason for this is the peculiar redundancy of the second law. It has been obvious, at least since the time of Boltzmann, that the second law only covers the same ground that is treated in greater detail by mechanics, dynamics and other physical sciences. Thermodynamics has no field of study of its own. Hence it should be possible to show rigorously either that the molecular and thermodynamic descriptions are compatible or that they contradict one another. I shall not venture to say whether or not this problem has been solved. A very extensive and difficult literature has developed about this question. It was certainly not solved before the advent of quantum mechanics. John von Neumann contended that he had proved the decisive theorem in 1929, but as late as last year Harold Grad of New York University remarked: "It is safe to say that a major portion of the nontrivial results in statistical mechanics have been derived from inconsistent formulations!"

The inconsistency in the analysis of thermal phenomena inherent in the duality of molecular and thermodynamic descriptions now has its counterpart in the duality of wave and particle descriptions in quantum mechanics. Moreover, in quantum mechanics the process of measurement is a significant problem, and it introduces an element of irreversibility. The absolute irreversibility in thermodynamics is interpreted by discrediting the macroscopic world with which thermodynamics deals and treating it only as a manifestation of a world of atoms and molecules.

The analogous irreversibility and duality disclosed by quantum mechanics has led to the proposal that atomic phenomena are only aspects of an as yet unexplored structure with hidden variables. In this view the objects of quantum mechanics are related to a subatomic world. Accordingly Louis de Broglie has proposed the notion of the thermodynamics of the isolated particle, attributing to the atomic particles themselves both entropy and temperature.

Shall we then find a new, smaller and better demon, who interferes with the hidden variables? Let us stop here and be grateful to the good old Maxwellian demon, even if he does not assist in providing power for a submarine. Perhaps he did something much more useful in helping us to understand the ways of nature and our ways of looking at it.

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The Fungus Gardens of Insects

Several kinds of insects live only in association with one kind of fungus, and vice versa. In some instances the insect actively cultivates the fungus, browsing on it and controlling its growth

by Suzanne W. T. Batra and Lekh R. Batra

Anyone with at least a passing interest in biology is aware that fungi, being plants that lack chlorophyll and cannot conduct photosynthesis, live on other organisms or on decaying organic matter. It is less well known that many insects are similarly dependent on fungi. Indeed, there are insects that tend elaborate gardens of a fungus, controlling the growth of the plant according to their own specialized needs.

Some insect species are always found in association with a certain fungus, and some fungi only with a certain insect. Such complete interdependence is called mutualism. The mutualistic partners of insects are not limited to fungi; they include other microbial forms such as bacteria and protozoa. In some cases the insect feeds on its partner or on the partner's own partly digested food. In others the partner lives in the insect's alimentary tract and digests food the insect cannot digest for itself; frequently the partner supplies an essential constituent that is deficient in the insect's diet, such as nitrogen or a vitamin. Scme mutualistic partners serve more than one of these functions.

The insects that are mutualistic with microbial organisms are divided into two groups. In one group the fungus, bacterium or protozoon lives inside the insect, either in the alimentary tract or in specialized cells. In the other group a fungus lives in the insect's nest. Here we shall discuss the relations between fungi and insects in the latter group, leading up to those insects that actively cultivate fungus gardens. Such relations have been studied for more than a century, but they offer many new possibilities for investigation. One wants to know more about the physiology of the relations, about how the partners interact at the molecular level. A deeper knowledge of the physiological mechanisms would undoubtedly clarify how the mutualistic partnership came to be established in the course of evolution. It might also have important by-products. For example, much work has been done on the possibility of using fungi that are harmful to insects as a means of selectively controlling insect pests; such work might be advanced by knowing more about the relation between insects and beneficial fungi. As a second example, those insects that control the growth of fungi in gardens may do so by means of antibiotic substances that might well be useful to man.

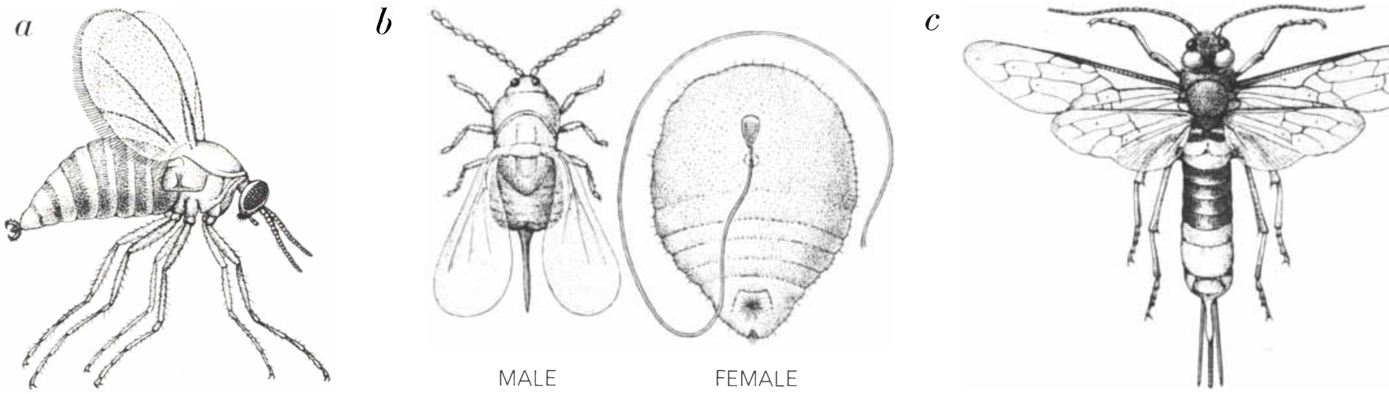
The first kind of insect-fungus relation we shall take up centers on the tumor-like galls that sometimes appear on the bud, leaf or stem of a plant. These galls develop when certain insects deposit their eggs in the plant and somehow cause it to form an abnormal tissue which then nourishes the larva that emerges from the egg [see "Insects and Plant Galls," by William Hovanitz; SCIENTIFIC AMERICAN, November, 1959]. The galls caused by the mosquito-like midges of the family Itonididae also contain fungi. Growing parasitically on the gall tissue, these fungi usually form a thick layer on the inside of the gall. They appear at an early stage of the gall's development, and a single species of fungus is consistently found in association with larvae of each midge species. Many of these fungi, however, also grow independently of the insect. How fungus and insect come to be together in the gall is not known, but scme workers believe the female midge deposits spores of fungus at the time she lays her eggs. Many of the fungus galls are caused by insects that feed by sucking plant sap, and except for a few cases it is unlikely that the fungus acts directly as a source of food. It may be that the fungus assists the insect indirectly by partly breaking down the gall tissue so that the insect can digest it.

Many plants bear insect-fungus galls but only a few of the fungi have been identified. Some galls we have studied in our laboratory at the University of Kansas are leaf-blister galls on several kinds of goldenrod and aster caused by at least nine species of the midge *Asteromyia* (all of them associated with the fungus *Sclerotium asteris* in the U.S.), and flower-bud galls of the broom (*Cytisus*) caused by the midge *Asphondylia cytisii* (associated with the fungus *Diplodia* in the U.S. and Europe).

In contrast to the casual association between insects and fungi in plant galls, several species of the fungus *Septobasidium* and various scale insects (family Coccidae) that inhabit the fungal tissue coexist in a manner that is clearly mutualistic. *Septobasidium* resembles a thick lichen: it clings tightly to the leaves or branches of trees. The scale insects that inhabit this fungus in some way modify its growth in their vicinity, giving it a different texture or color; as a result some colonies of *Septobasidium* have a mottled surface.

The relation between this fungus and the insects that colonize it has been described by John N. Couch of the University of North Carolina. The insect, which feeds on sap, is attached to the tree by its sucking tube. The mycelium of the fungus—its thick mat of fine threads—shelters the insect from the weather and shields it from birds and parasitic wasps. In turn a few of the insects are penetrated by specialized threads, called haustoria, that extract nourishment from the insects' blood. Scale insects characteristically ingest more sap than they need; the fungus may take advantage of this fact by uti-

FUNGUS-GARDENING ANT *Mycetosoritis hartmani* is shown in its underground nest feeding on a "kohlrabi body." These bodies are made up of bromatia, particles that consist of the swollen tips of the filaments of the fungus and that form only in the presence of the insect. Surrounding the ant are the filaments themselves. Photograph was provided by John C. Moser of the U.S. Forest Service.

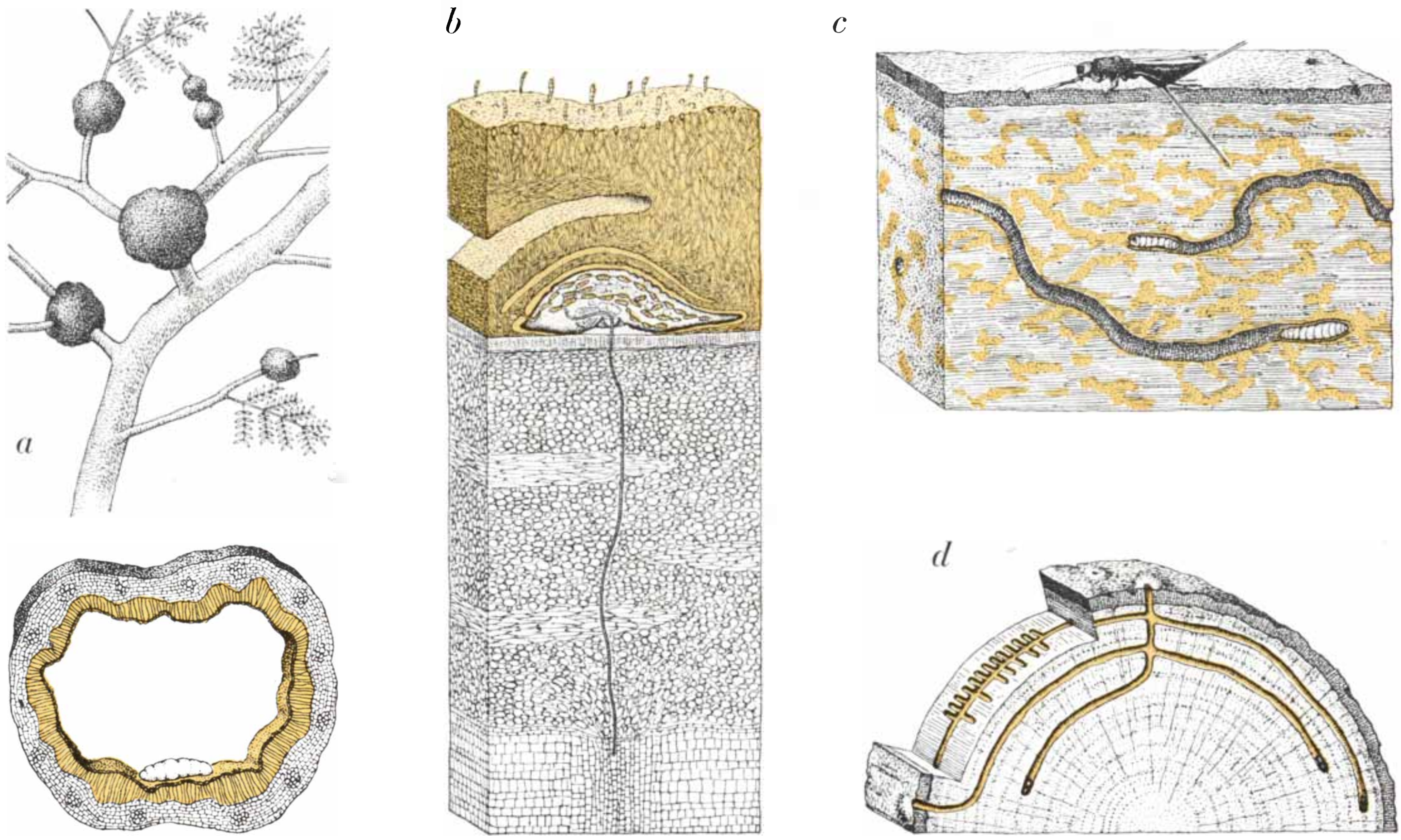


INSECT GARDENERS comprise unrelated species. Depicted here are representatives of six groups of insects that nest with a fungus. At left is a gall midge of the genus *Lasioptera;* its larvae probably feed on plant material that a fungus has partly digested. The scale insect *Aspidiotus osborni* (*b*) lives on trees under a protective canopy of fungus. The wood wasp *Sirex gigas* (*c*) deposits eggs cov-

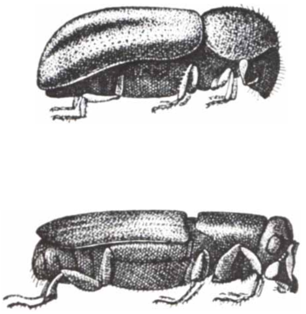
lizing such nutrients while they are still circulating in the insect's body.

Septobasidium is distributed by scale insects as well as nourished by them; it does not live independently in nature. When the insects are young, some of them crawl on the surface of the fungus and become covered with spores. A few of the contaminated insects migrate to new areas on the tree, where they insert their sucking tube. Shielded by new mycelium, they survive. They are also invaded, however, by haustoria from the developing spores, and as a result they do not attain maturity and reproduce. The new mutualistic colony is nonetheless able to continue because uncontaminated insects now find shelter in the mycelium. In some species of *Septobasidium* the entire process has apparently been made more efficient by the development of hollow "insect houses" that attract and hold the migrating scale insects. Thus the fungus furnishes a shelter for the insects and the insects provide both a food supply and a means of dispersal for the fungus. Some insects are sacrificed for the benefit of the colony as a whole; both fungus and insect benefit at the expense of the tree.

A different kind of mutualism has been observed involving on the one hand the wood wasps of the genera *Sirex, Tremex* and *Urocerus* and on the other the fungi *Stereum* and *Daedalea.*



INSECT NESTS contain a fungus (*color*). The nests were made by the insects at the top of these two pages, or by an insect of the same group. The plant gall that encloses larvae of the midge is lined with a fungus parasitic on the plant (*a*). *Septobasidium* fungus sends threads into some of the insects it shelters and extracts nourishment from their blood (*b*). The burrows of wood *d*



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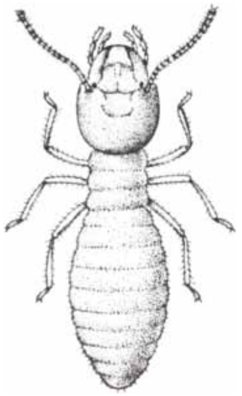

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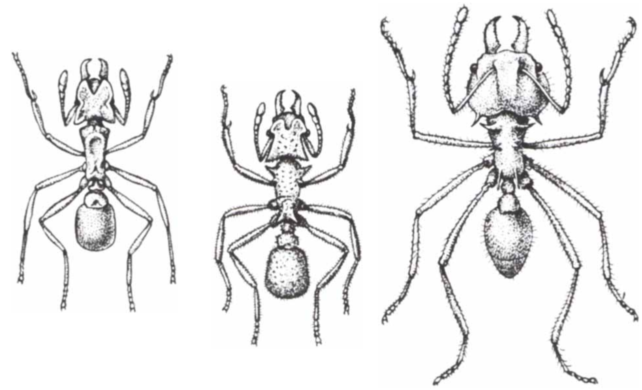

ered with fungus in moist wood. Ambrosia beetles of the genera *Trypodendron* (*d, top*) and *Crossotarsus* (*d, bottom*) carry spores from which grow their fungus. The termite *Odontotermes gurdaspurensis* (*e*) fertilizes its fungus garden. Ants of the genera *Cyphomyrmex, Trachymyrmex* and *Atta* (*f, left to right*) actively cultivate fungus gardens. The insects are not drawn to the same scale.

These common fungi sometimes build a semicircular "bracket" out from a tree. The adult female wood wasp deposits her eggs in moist wood by means of a long, slender ovipositor, and at the base of this organ are tiny pouches that contain fungus cells called oidia. When the egg is deposited, oidia cling to it. Then the mycelium of the fungus grows into the wood, and when the wasp larva emerges from the egg it follows the path of the mycelium. The fungus partly digests the wood before it is eaten by the larva. In the laboratory wood wasp larvae have been reared on a diet consisting only of *Stereum,* but whether the fungus is essential to the insect's nutrition is not known. Both in nature and in the laboratory the fungus grows well without the help of any insect.

The wood wasp nonetheless acts as an agent for the dissemination of *Stereum.* A larva that later develops into a female has organs that ensure the preservation of the fungus. These organs are tiny pits hidden in folds between the wasp's first and second abdominal segments; in them bits of fungus are trapped in a waxy material. Here an inoculum of fungus remains viable, whereas fungus in wood is inactivated when the wood eventually dries out. When the larva metamorphoses into a pupa, the organs that hold the fungus are discarded. Then, when the adult female wasp emerges from the pupal skin, tiny flakes

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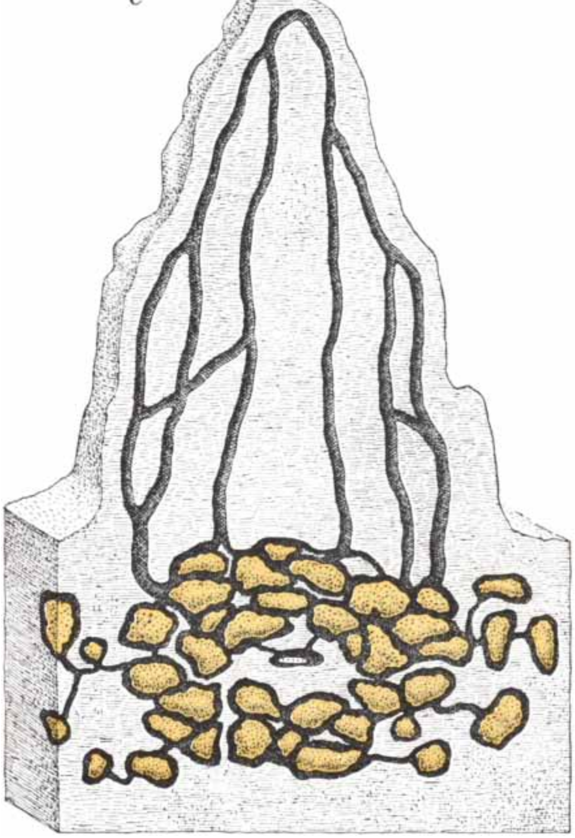

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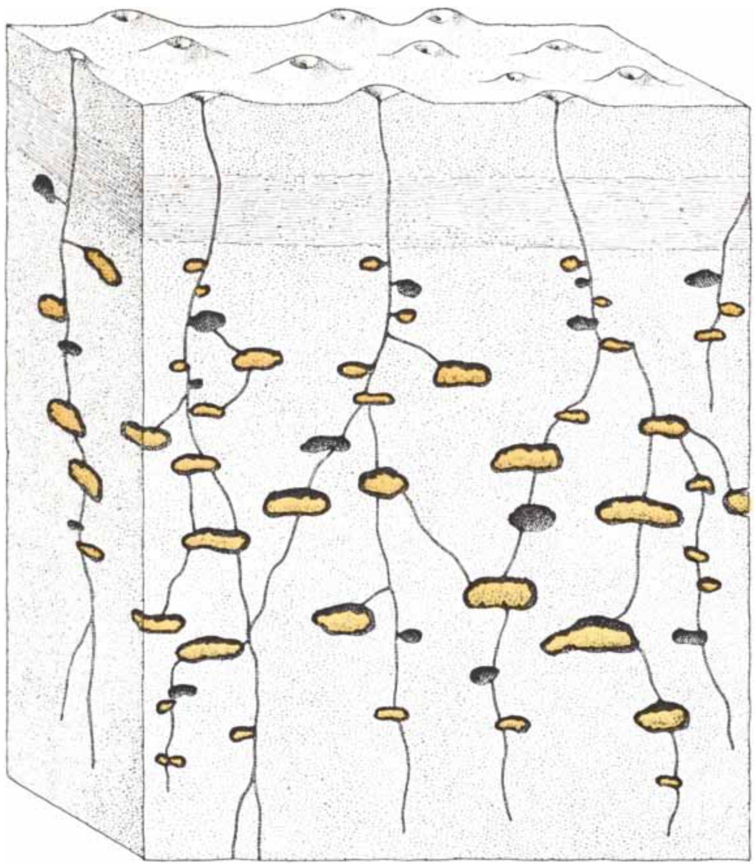
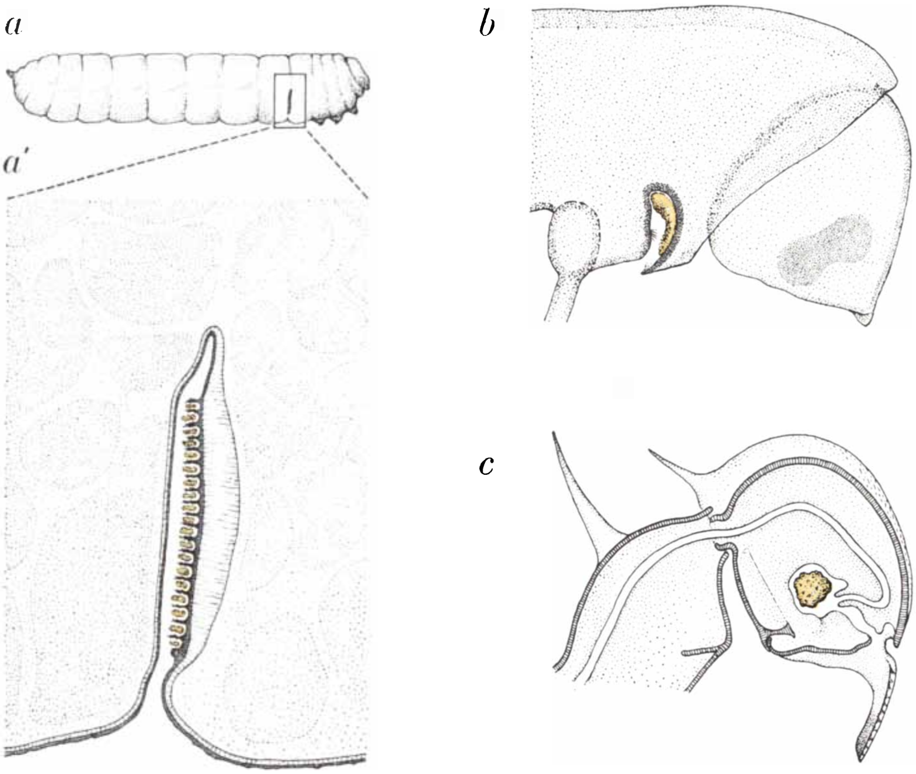


wasp larvae are made in wood infested with *Stereum* fungus, propagated by the insect (*c*). Fungus carried by an ambrosia beetle grows inside the insect's tunnels in timber (*d*). Mounds of earth in which the termite nests contain fecal material permeated with fungus (*e*). *Atta texana* cultivates a garden of fungus in a huge underground nest (*f*). Here also the nests are not drawn to scale.



FUNGUS CONTAINERS of three insects are depicted with the fungus indicated in color. Larvae of wood wasps that develop into females carry an inoculum of fungus behind the thorax (*a*). A section through the first two abdominal segments of the larva shows one of the fungus-filled organs (*a′*). The ambrosia beetle, shown here in longitudinal section, conveys spores of fungus in pockets located at the base of its front legs (*b*). A longitudinal section of the head of a fungus-growing ant reveals the pouch in which it transports fungus (*c*).

of fungus-impregnated wax that have fallen from the organs become lodged in the moist pouch at the base of the ovipositor. The flakes now give rise to a fungal mycelium, which develops the oidia that will coat the eggs. The transfer of the fungus from generation to generation of wood wasps is thereby assured.

Ambrosia beetles also carry fungi within their bodies. The numerous species of these wood-boring insects (families Scolytidae, Platypodidae and Lymexylonidae) cannot survive without ambrosia fungi (several genera of Ascomycetes and "imperfect" fungi). In their external skeleton are small pockets called mycangia (literally "fungus containers"); these pockets always contain a supply of viable fungus spores. When an ambrosia beetle tunnels into wood, spores are dislodged from the mycangia, and soon a mass of velvety fungus lines the interior of the tunnel. On this "ambrosia," which concentrates in its cells nutrients that have been extracted from the wood, the beetles feed.

Ambrosia beetles have been the subject of considerable research because they destroy much timber all over the world. Their tunnels, sometimes called "shot holes," extend deep into the sapwood of trees and are surrounded by streaks of a stain manufactured by the enzymatic action of the fungus. The beetles most often attack hardwoods, preferring trees that have been weakened by drought, disease or fire, or fallen timber that is moist and filled with sap. Attracted by the odor of fermenting sap, the beetles fly upwind, usually at dusk; it is easy to collect them in the evening around a newly felled log. They are similarly attracted by the yeasty smell of beer and beer drinkers, and it is also convenient to collect them at a beer picnic! Some kinds bore into beer and wine kegs, which is why in Europe they are called "beer beetles."

The tunnels of ambrosia beetles can be distinguished from those of other wood-boring insects by a black or brown discoloration of the wood around the neat circular tunnel opening. There is, moreover, no wood dust or fecal matter inside the tunnel. When the beetles are excavating, fine wood particles, sometimes mixed with the insect's brown feces, accumulate outside the tunnel entrance. The beetle does not as a rule eat wood, and it rids its nest of wood borings. The males of some species assist the females with tunnel excavation. Inside the ambrosia beetle's tunnel system one finds, depending on the species, either separate niches, each enclosing a single glistening larva or a pearl-like egg, or several larvae sharing an enlargement of the tunnel. In many species the adult insect, on emerging from the pupal skin and proceeding to feed on the mass of ambrosia fungus lining the tunnel, rocks back and forth in a curious manner. What this does is force fungus spores into the mycangia before the insect flies away to found its own nest.

Each species of ambrosia beetle is normally associated with only one species of ambrosia fungus. Ambrosia fungi are pleomorphic: they can readily change, when their growth medium is changed, from a fluffy moldlike form to a dense yeastlike form. In the mycangia and the tunnels of the ambrosia beetles the yeastlike form prevails. Recently we have discovered that ambrosia beetles can also change the form of other fungi from the moldlike form to the yeastlike one. This is a significant phenomenon, and we shall be returning to it.

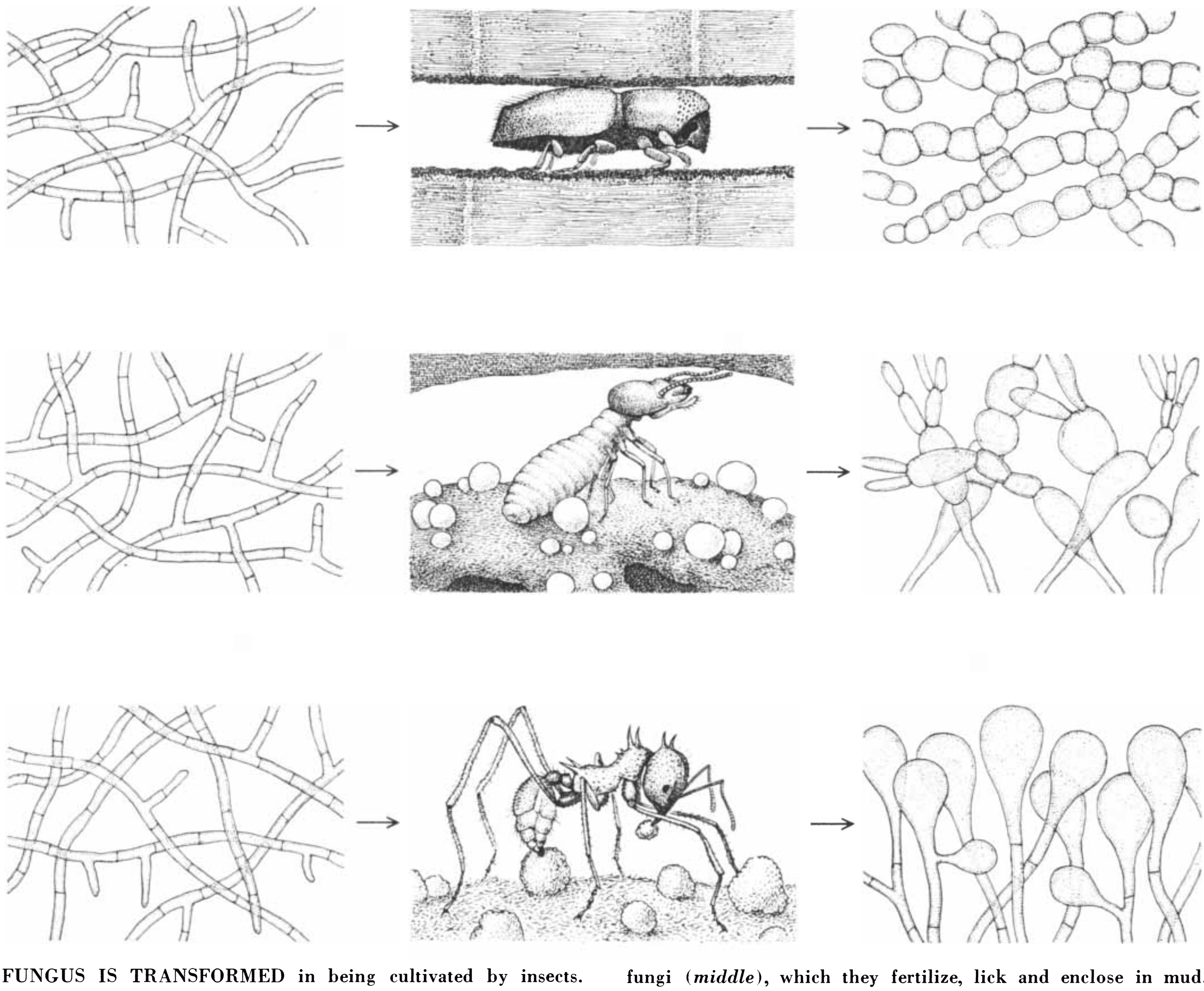
The most conspicuous and most destructive of the fungus-growing insects are termites. The termites that cultivate fungi are native to the Tropics of Africa and Asia. In West Africa it is estimated that the yearly cost of repairing the damage done by these insects to buildings is equal to 10 percent of the buildings' value. In addition to wood the insects eat growing and harvested crops and objects made of rubber, leather and paper; they destroy documents, works of art, clothing and even underground cables. The enormous mounds that some termite species build for nests interfere with farming and hinder road construction. If they are incompletely destroyed, the insects rebuild them.

Many species in the genera *Macrotermes* and *Odontotermes* make their nests in spectacular steeple-like mounds of hardened earth, which in Africa reach a height of as much as 30 feet. Other species, in the genus *Microtermes,* are completely subterranean, and if it were not for their mating flights and the damage they do, they would be quite inconspicuous. Each nest contains a white, sausage-like queen and a king, usually enclosed together in a protective cell of earth; the much smaller workers, soldiers and young termites (nymphs) of various ages and both sexes are found throughout the nest. At certain seasons winged male and female reproductives (future kings and queens) are also present. In each nest are one or several fungus gardens, the number and shape depending on the species of termite. Material collected by the workers is chewed and swallowed, and the partly digested fecal material is deposited on a fungus garden when the workers return to the nest. In the nests of some species there is a single large mass of fungus garden; in one of the nests of *Odontotermes obesus* that we studied in India the mass was two feet in diameter and weighed 60 pounds. In other nests many fungus gardens one or two inches long are scattered along burrows throughout the nest. Each fungus garden is enclosed in a close-fitting cavity lined with a mixture of saliva and dirt. The chambers of some species are ventilated by an elaborate system of vertical conduits extending to the surface of the nest [see "Air-conditioned Termite Nests," by Martin Lüscher; SCIENTIFIC AMERICAN, July, 1961].

The fungus gardens look like a gray or brownish sponge or may be convoluted like a walnut meat. They are moist but usually firm and brittle, and are permeated by threadlike mycelium. Scattered over the surface and inside the pores of the gardens are numerous minute, glistening, pearly white spherules composed of masses of rounded fungus cells.

The role of the fungi in the nutrition of the fungus-growing termites is not clear. It is well known that many common Temperate Zone termites cannot digest the cellulose in the wood they eat but rely on certain cellulose-digesting protozoa that live in their intestines to do it for them. No protozoa live in the gut of the fungus-growing termites; therefore it seems likely that the fungi growing in the gardens break down cellulose and may provide vitamins also. In fact, these termites soon die on a diet restricted to wood. The termites continually eat away the fungus gardens as they add fresh fecal material. There is thus a communal interchange of food, the fecal material being partly broken down by fungi in the garden, then eaten again and redeposited in the garden for further digestion by the fungi.

The white spherules are frequently picked up by the workers and moved to other parts of the fungus garden or are sometimes eaten. The king, queen, young nymphs and soldiers are apparently fed saliva by the workers; no trace of fungus or plant material can be found in their digestive tract. Some winged reproductive termites contain material from the fungus gardens, with which



FUNGUS IS TRANSFORMED in being cultivated by insects. Under ordinary conditions in the laboratory fungus associated with the ambrosia beetle is threadlike (*top left*). In the beetle's tunnel, where it is continually grazed, the fungus is denser and more like a yeast (*top right*). The fungus-growing termites also modify their fungi (*middle*), which they fertilize, lick and enclose in mud. Under these conditions white spherules appear. The fungus of a fungus-growing ant (*bottom*) looks much like the others when grown in a culture; in association with the ant, which licks, manipulates and defecates on its garden, the fungus has thickened tips.

they may begin a new garden when they start a new nest.

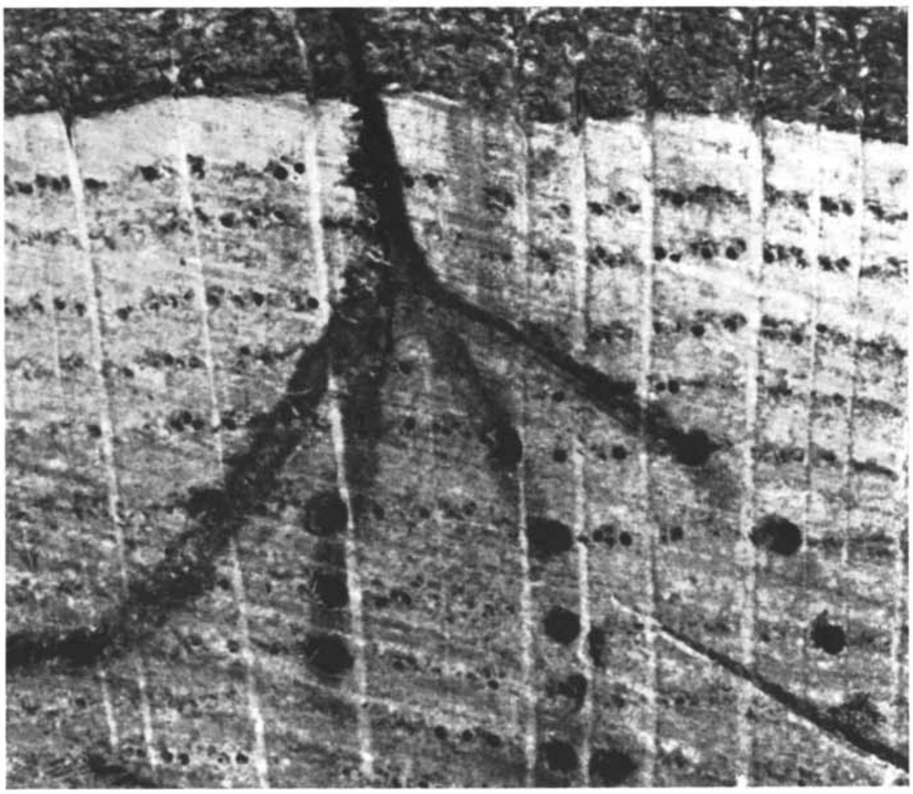
Several genera of unrelated fungi grow in the fungus gardens of termites; the most abundant are species of the mushroom *Termitomyces.* The various species of *Termitomyces* are found only in nests of fungus-growing termites. Somehow the fruiting structure—the mushroom—of the fungi is not allowed to grow from fungus gardens while they are being actively tended by termites. If the termites are removed or die, however, some of the spherules grow into the mushrooms of *Termitomyces.*

In Africa and southern India termites in many nests simultaneously remove the outer layers of their fungus gardens and spread crumbs of them in a thin layer on the ground during the rainy season. Soon *Termitomyces* mushrooms appear, and after their spores have been disseminated by the wind the termites come to the surface to collect fungus that may have grown from a mixture of spores from many nests. It is believed that in this way the termites provide for the cross-fertilization of their fungi, as man does for corn and other crops.

Closely resembling the fungus-growing termites in behavior but only distantly related to them are the fungus-growing ants (tribe Attini). Here we have an example of convergent evolution, in which two nearly unrelated animals and their fungi occupy a very similar ecological niche. These ants are found only in the Western Hemisphere, and most of them are tropical. Some species are found in the deep South and the Southwest of the U.S.; a small species (*Trachymyrmex septentrionalis*) is found in sandy areas near the Atlantic coast as far north as Long Island.

Atta texana, which lives in eastern Texas and southern Louisiana, does considerable damage to citrus groves, gardens and plantations of young pine trees by cutting leaves from them for its fungus gardens. This ant is known locally as the "town ant," and it inhabits an ant metropolis that is sometimes 50 feet across and 20 feet deep. (One student of these ants, John C. Moser of the U.S. Forest Service, opens their nests with a bulldozer!) Other species of fungus-growing ants build smaller nests; some are so small that they are extremely difficult to find.

The fungus-growing ants probably represent the most advanced stage in the evolution of fungus gardening because they feed only on the fungus, and they actively cultivate it. The workers, depending on the species, collect cater-



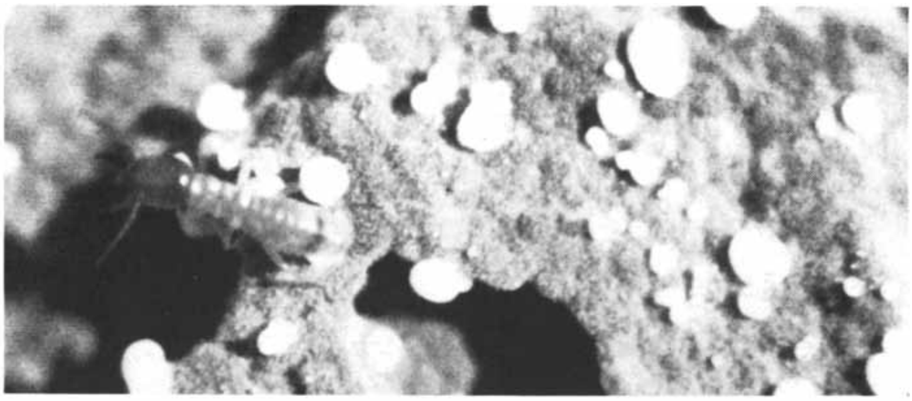
BEETLE TUNNELS are marked by the dark fungus that lines the interior surface. The photograph above shows a cross section of excavations made in wood by ambrosia beetles. Dark circles are niches at right angles to the tunnel that hold larvae. The beetles have penetrated through the bark into the sapwood; in this way they destroy felled timber.

pillar excrement, fallen flower anthers and other soft plant debris as well as leaves cut from trees. Rather than eating the material the ant cuts it into pieces and adds them to a fungus garden in the nest. The ants' gardens look somewhat like those of the termites: they are gray, flocculent masses of finely divided moist plant material loosely held together by threads of mycelium. In the underground chambers of the nest the fungus garden often is suspended from the roots of plants. Scattered over the surface of the older parts of the garden are white specks just visible to the unaided eye. These specks, called kohlrabi bodies, are clusters of bromatia, the swollen tips of the filaments forming the mycelium. The kohlrabi bodies look much like the white spherules found in the gardens of termites. When the ants are not feeding on the bromatia, they lick them.

The flying, nest-founding ant queen carries a small pellet of fungus in a pouch below her mouthparts, much as the ambrosia beetle carries fungus in its mycangia. In starting a new nest the young queen grows a small fungus garden on her excreta; with this she feeds the first worker larvae. When the workers are mature, they leave the nest to gather the material with which the garden is enlarged. They feed bits of bromatia to the larvae that nestle in the mycelium of the gardens.

As long as the ants actively tend the garden the fungus does not develop fruiting structures, but mushrooms of four genera have been found growing from abandoned nests of some species or have been cultured from fungus gardens in the laboratory. We do not know how the ants control the growth of their fungi so that they produce bromatia and nothing else; perhaps it is by constantly "pruning" away excess growth of the mycelium. It is also possible that the excreta and the saliva of the ants, which are deposited on the fungus garden, contain some substance that influences the growth of the mutualistic fungus and inhibits the development of the many spores that accidentally enter the nest.

With the fungus-growing ants our brief survey of the mutualistic associations between insects and fungi ends. It can be seen that there are two distinct kinds of relation. In the gardens of wood wasps, ambrosia beetles, termites, ants and probably those of midge galls the fungus extracts nourishment from a substrate and the insect feeds either on the fungus, the substrate predigested by the fungus or both. The fun-



FUNGUS-GARDENING TERMITE of the genus *Odontotermes* is photographed crawling on the surface of its garden. The round white objects are spherules of the fungus, which arise only in gardens that are tended and fertilized by termites. The insect in the picture is a soldier defending the nest; it produces a copious supply of pungent saliva for this purpose.

gus is prevented from producing sexual fruiting structures but is supplied by an insect partner with a suitable habitat and a means of dispersal. In the colonies of the fungus *Septobasidium* and scale insects the situation is reversed: the insect feeds on the substrate and nourishes the fungus, and the fungus provides shelter for its castrated insect partner.

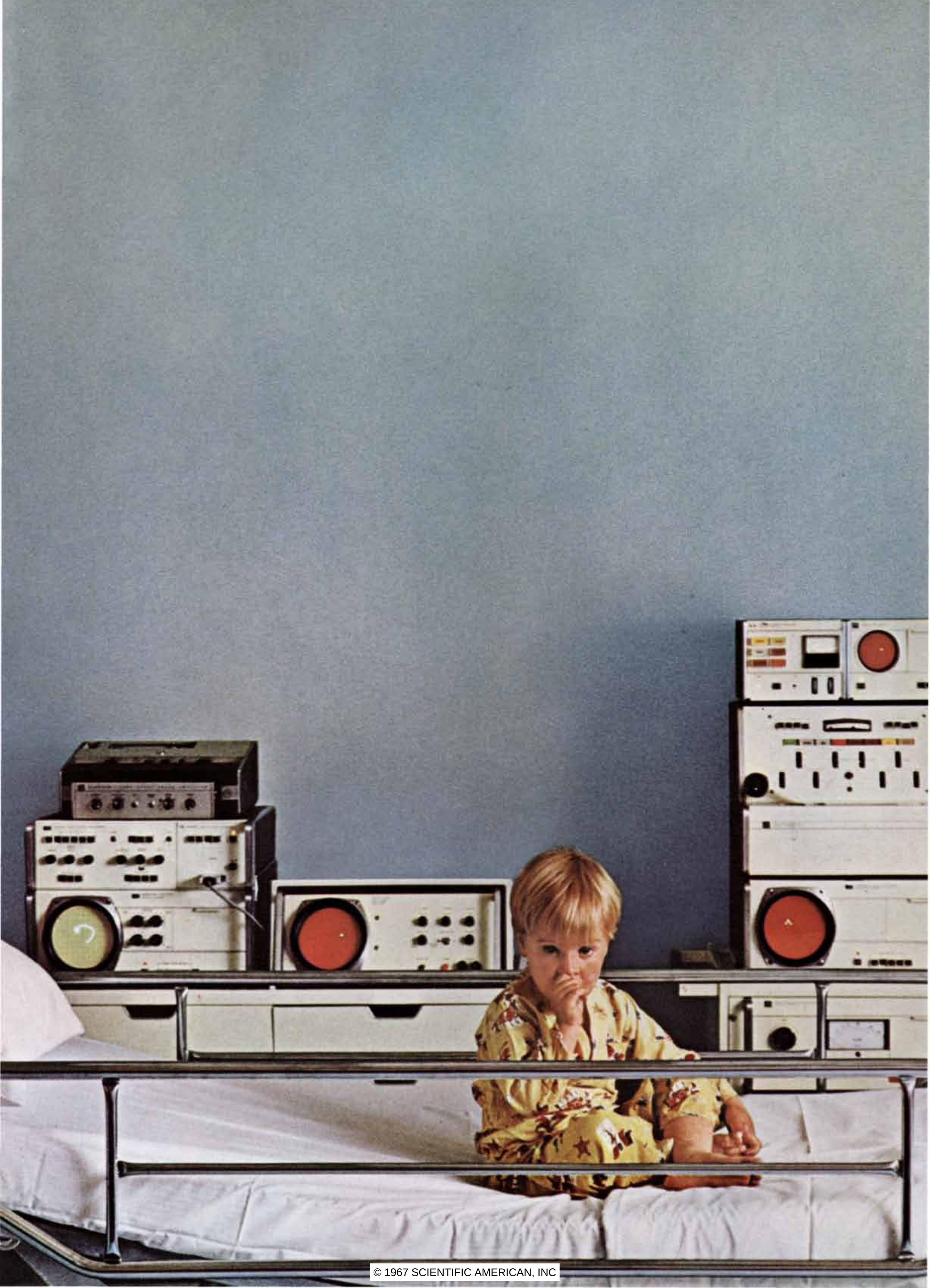
Insects are unique among animals in having developed mutualistic relations with fungi. This may have come about because so many insects and fungi share the same tiny habitats. Moreover, most insects are equipped to carry living spores of fungi, either in their gut, in folds between their joints that contain waxy secretions or among their bristles.

The fungus-gardening insects convey into their nest the spores of many fungi other than the one on which they depend. If the insects are removed, the alien fungi will grow and soon overrun the nest; they do not grow in the nest, however, when the insects live there. Apparently the fungus-gardening insects either secrete or excrete antibiotic substances that prevent the growth of alien fungi. The substances may also act to transform the mutualistic fungi, causing either ambrosia, spherules or bromatia to appear rather than sexual fruiting structures.

In the case of the termite, which licks the spherules of its fungus and encloses the fungus garden in saliva-moistened mud, the saliva may contain the substances in question. We have tested the effect of adding saliva taken from termites to a culture of their fungus, which under ordinary growing conditions in the laboratory does not produce spherules. After saliva was added to the culture spherules grew; the saliva also inhibited the growth of alien fungi. We have performed other tests on the excreta that ants deposit on their nest gardens. Although we have found that the excreta inhibit the growth of certain bacteria, much experimental work remains to be done. The saliva of the ant, which also licks its fungus, may help to form bromatia.

Spores of the ambrosia beetle's fungus remain in the yeastlike form while they are carried by the insect, and it is possible that the waxy secretion might also affect the form of fungi in the tunnel, where the beetle and the fungus are in close contact. On the other hand, it has been shown that the mutualistic fungi of some species of the beetle can be modified to the yeastlike form by certain physical conditions and in the absence of the beetle. These physical conditions duplicate conditions in the beetle's tunnel, where the feeding insect steadily mows the tips of the fungus as they grow.

In nature the presence of a living insect partner is necessary to maintain ambrosia, spherules or bromatia, but these forms can be produced in the laboratory on special mediums in the absence of the insects. When the mutualistic fungi are grown on ordinary carbohydrate-rich laboratory mediums, fluffy mycelium and sometimes sexual fruiting bodies appear. If the same fungi are grown on acid mediums that are rich in amino acids, and are exposed to more than .5 percent carbon dioxide, then bromatia, spherules or ambrosia are formed. These cultural conditions apparently resemble conditions in the nests of the insects. The fungi of some ambrosia beetles also become ambrosial if they are repeatedly scraped or are grown at low temperatures. Clearly the problem of how insects control the growth of a fungus partner remains an intriguing one.



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MATHEMATICAL GAMES

A mixed bag of logical and illogical problems to solve

by Martin Gardner

It is the custom of this department to present every eight or nine months a selection of short, unrelated problems of varying difficulty. These will be answered next month.

1.

This is one of those rare, delightful puzzles that can be solved at once if you approach it right, but that is subtly designed to misdirect your thoughts toward the wrong experimental patterns. Intelligent people have been known to struggle with it for 20 minutes before finally deciding that there is no solution.

Place four paper matches on top of the four matches that form the cocktail glass in the illustration on this page. The problem is to move two matches, and only two, to new positions so that the glass is re-formed in a different position and the cherry is *outside* the glass. The orientation of the glass may be altered but the empty glass must be congruent with the one illustrated. The drawing at *A* shows how two matches can be moved to turn the glass upside down. This fails to solve the problem, however, because the cherry remains inside. The drawing at *B* shows a way to empty the glass, but this does not solve the puzzle either because three, rather than two, matches have been moved.

2.

What is the largest cube that can be completely covered on all six sides by folding around it a pattern cut from a square sheet of paper with a side of three inches? (The pattern must, of course, be all in one piece.)

3.

Every member of the TL Club is either a truther, who always tells the truth when asked a question, or a liar, who always answers with a lie. When I visited the club for the first time, I found its members, all men, seated around a large circular table, having lunch. There was no way to distinguish truthers from liars by their appearance, and so I asked each man in turn which he was. This proved unenlightening. Each man naturally assured me he was a truther. I tried again, this time asking each man whether his neighbor on the left was a truther or a liar. To my surprise each told me the man on his left was a liar.

Later in the day, back home and typing up my notes on the luncheon, I discovered I had forgotten to record the number of men at the table. I telephoned the club's president. He told me the number was 37. After hanging up I realized that I could not be sure of this figure because I did not know whether the president was a truther or a liar. I then telephoned the club's secretary, who had been seated next to the president at the lunch.

"No, no," the secretary said. "Our president, unfortunately, is an unmitigated liar. There were actually 40 men at the table."

Which man, if either, should I believe? Suddenly I saw a simple way to resolve the matter. Can the reader, on the basis of the information given here, determine how many men were seated at the table? The problem is derived from a suggestion by Werner Joho, a physicist in Zurich.

4.

Two brothers inherited a herd of sheep. They sold all of them, receiving for each sheep the same number of dollars as there were sheep in the herd. The money was given to them in $10 bills except for an excess amount, less than $10, that was in silver dollars. They divided the bills between them by placing them on a table and alternately taking a bill until there were none left.

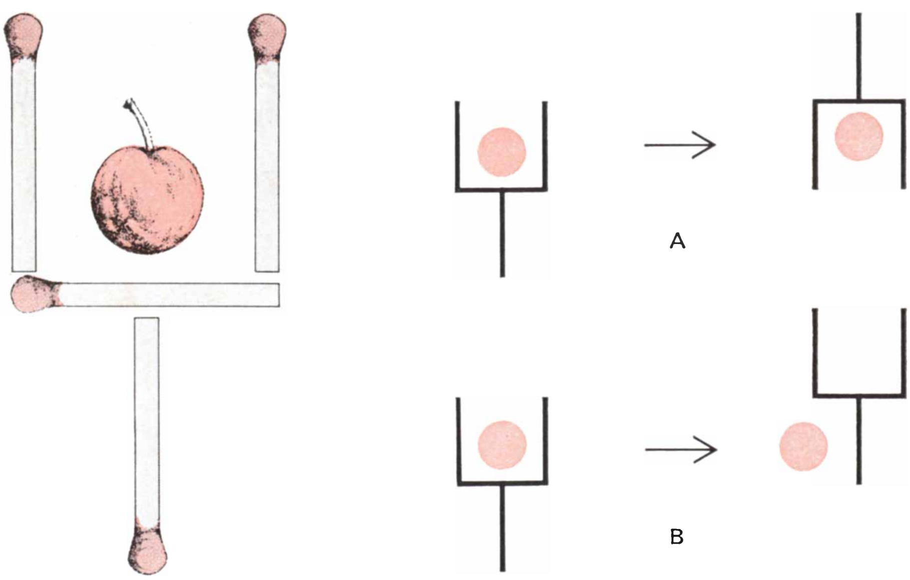
"It isn't fair," complained the younger brother. "You drew first and you also took the last bill, so you got $10 more than I did."

To even things up partially the older brother gave the younger one all the silver dollars, but the younger brother was still not satisfied. "You gave me less than $10," he argued. "You still owe me some money."

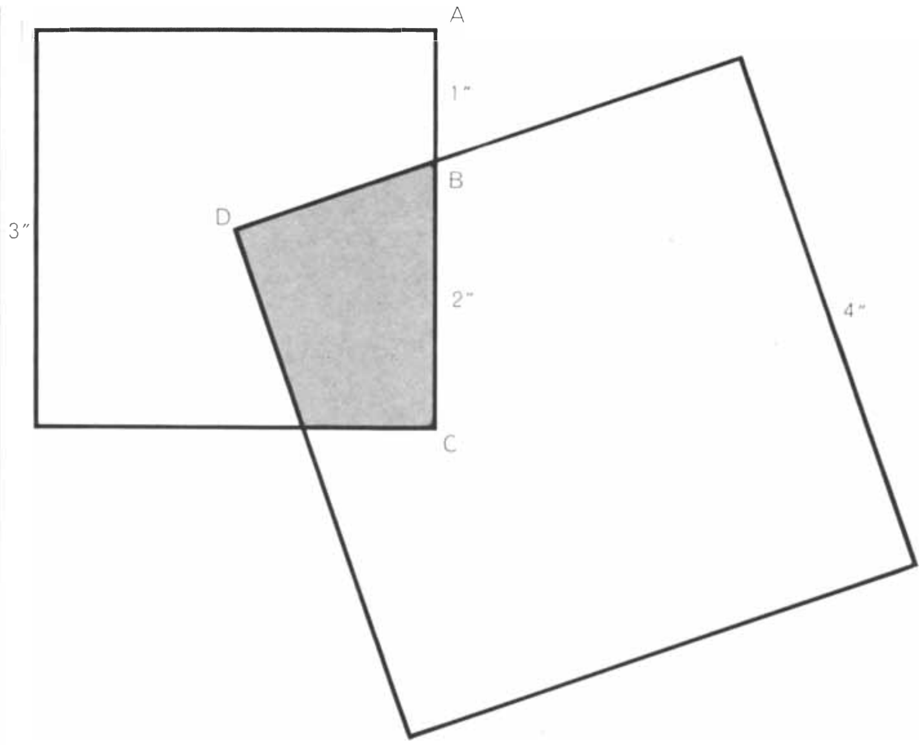
"True," said the older brother. "Suppose I write you a check that will make the total amounts we each receive exactly the same."

This he did. What was the value of the check? The information seems inadequate, but nevertheless the question can be answered.

Ronald A. Wohl, a chemist at Rutgers



The puzzling Manhattan

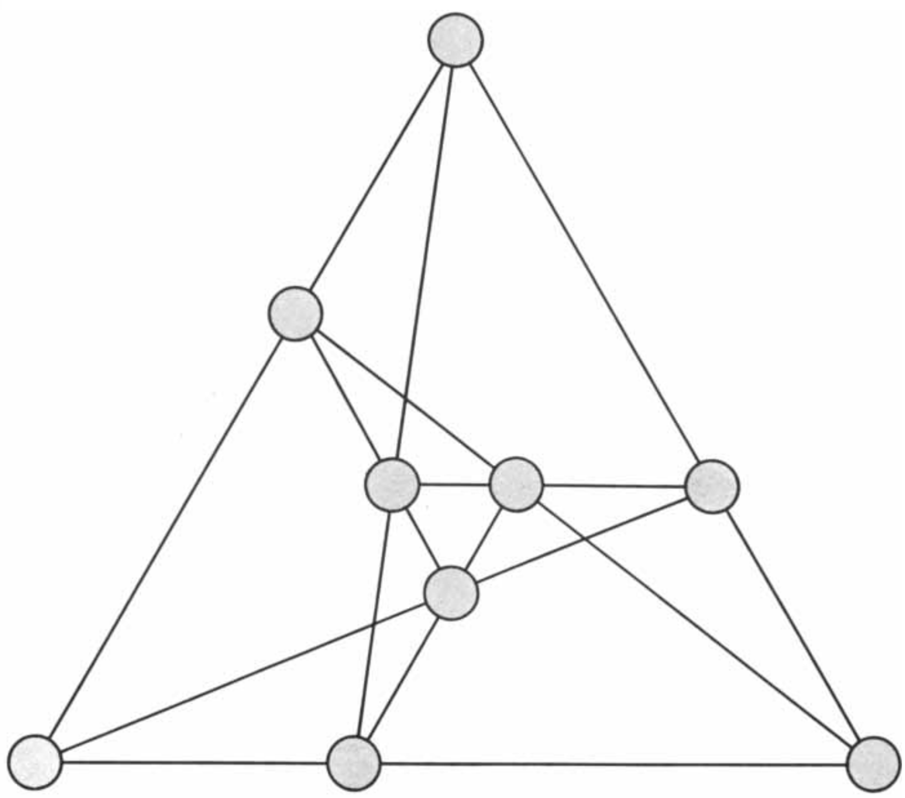


What is the area of overlap?

University, called my attention recently to this beautiful problem, which he had found in a French book. Later I discovered in my files a letter from Carl J. Coe, a retired mathematician at the University of Michigan, discussing essentially the same problem, which he said had been making the rounds among his colleagues in the 1950's. I suspect it is still not widely known.

5.

Ticktacktoe is played on a pattern that



The game of Tri-Hex

can be regarded as nine cells arranged in eight rows of three cells to a row. It is possible, however, to arrange nine cells in nine or even 10 rows of three. Thomas H. O'Beirne of Glasgow, author of *Puzzles and Paradoxes* (Oxford, 1965), experimented with all the topologically distinct patterns of nine rows to see if any were suitable for ticktacktoe play. He found trivial wins for the first player on all configurations except the one shown in the bottom illustration on the opposite page.

To play Tri-Hex, as O'Beirne calls this game, one player can use four pennies and the other four dimes. No fifth move is allowed the first player. Players take turns placing a coin on a spot, and the first to get three of his coins in a row wins. If both players make their best moves, is the game a win for the first player or the second, or is it a draw as in ticktacktoe?

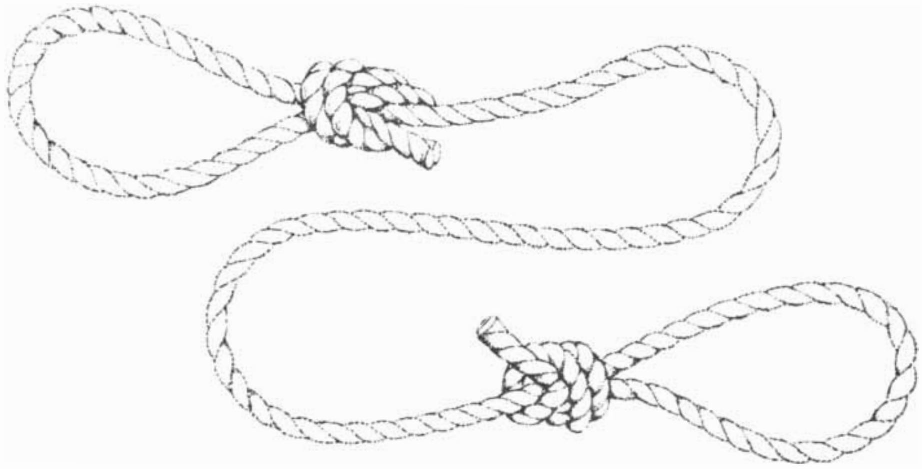
The role played by such configurations as this in modern geometry is entertainingly discussed by Harold L. Dorwart in *The Geometry of Incidence* (Prentice-Hall, 1966) and in the instruction booklet for his puzzle kit, *Configurations,* now available from the makers of the logic game WFF'N PROOF. In addition to its topological and combinatorial properties, the pattern shown here has an unusual metric structure: every line of three is divided by its middle spot into segments with lengths in the golden ratio.

6.

Many years ago C. Dudley Langford, a Scottish mathematician, was watching his little boy play with colored blocks. There were two blocks of each color, and the child had piled six of them in a column in such a way that one block was between the red pair, two blocks were between the blue pair and three were between the yellow pair. Substitute digits 1, 2, 3 for the colors and the sequence can be represented as 312132.

This is the unique answer (not counting its reversal as being different) to the problem of arranging the six digits so that there is one digit between the 1's and there are two digits between the 2's and three digits between the 3's.

Langford tried the same task with four pairs of differently colored blocks and found that it too had a unique solution. Can the reader discover it? A convenient way to work on this easy problem is with eight playing cards: two aces, two deuces, two threes and two fours. The object then is to place them in a row



Rope for the knot problem

so that one card separates the aces, two cards separate the deuces, and so on.

There are no solutions to "Langford's problem," as it is now called, with five or six pairs of cards. There are 25 distinct solutions with seven pairs. No one knows how to determine the number of distinct solutions for a given number of pairs except by exhaustive trial-and-error methods, but perhaps the reader can discover a simple method of determining if there *is* a solution. Next month I shall make some remarks about the general case and cite major references.

7.

In 1950, when Charles W. Trigg, dean emeritus of Los Angeles City College, was editing the problems department of *Mathematics Magazine,* he introduced a popular section headed "Quickies." A quickie, Trigg then explained, is a problem "which may be solved by laborious methods, but which with proper insight may be disposed of with dispatch." This fall McGraw-Hill has published Trigg's first book, *Mathematical Quickies,* a splendid collection of 270 of the best quickies he has encountered or invented in his distinguished career as a problem expert.

In an amusing quickie from Trigg's book [*see top illustration on page 126*] the smaller square has a side of three inches and the larger square a side of four. Corner *D* is at the center of the small square. The large square is rotated around *D* until the intersection of two sides at point *B* exactly trisects *AC*. How quickly can you compute the area of overlap (shown shaded) of the two squares?

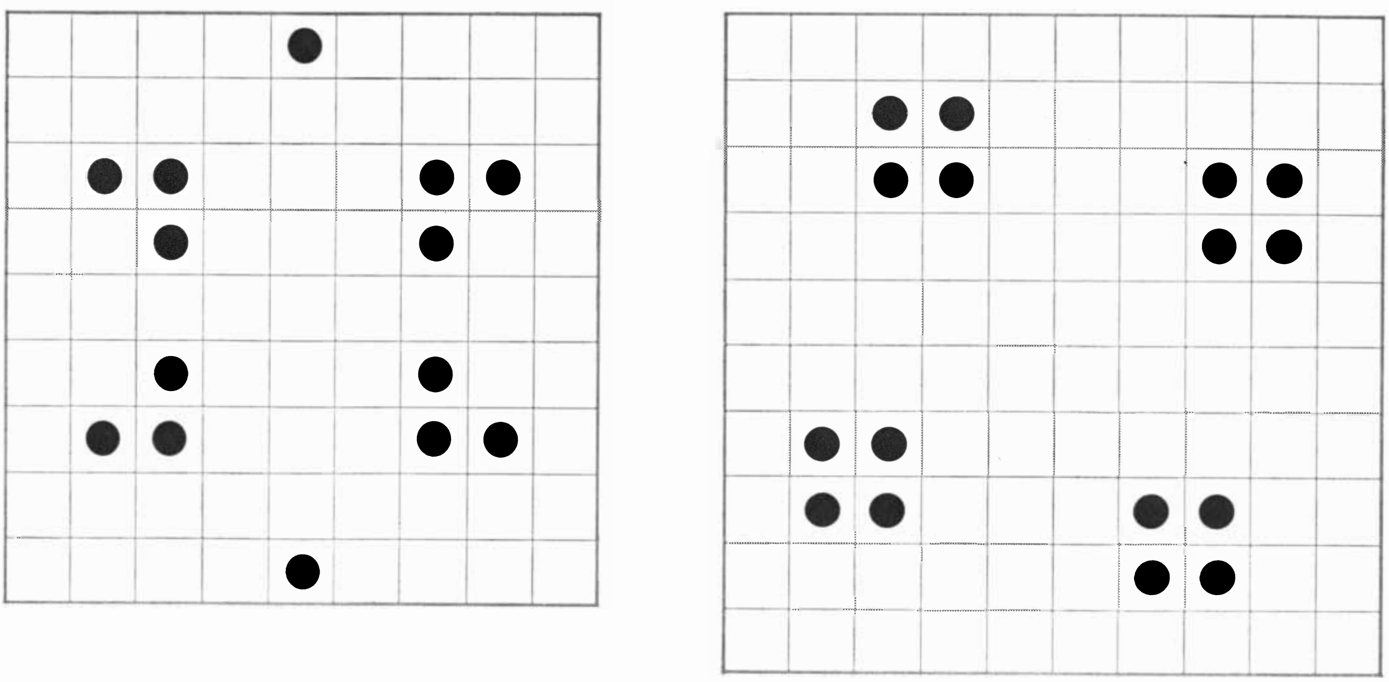
8.

People who have three daughters try
once more
And then it's fifty-fifty they'll have
four.
Those with a son or sons will let things
be.
Hence all these surplus women.
Q.E.D.

This "Note for the Scientist," by Justin Richardson, is from a Penguin collection called *Yet More Comic & Curious Verse,* selected by J. M. Cohen. Is the expressed thought sound?

No, although it is a commonly encountered type of statistical fallacy. George Gamow and Marvin Stern, in their book *Puzzle-Math* (Viking, 1958), tell of a sultan who tried to increase the number of women available for harems in his country by passing a law forbidding every mother to have another child after she gave birth to her first son; as long as her children were girls she would be permitted to continue childbearing. "Under this new law," the sultan explained, "you will see women having families such as four girls and one boy; 10 girls and one boy; perhaps a solitary boy, and so on. This should obviously increase the ratio of women to men."

As Gamow and Stern make clear, it



Solutions to last month's knight's-move puzzles

does nothing of the sort. Consider all the mothers who have had only one child. Half of their children will be boys, half girls. Mothers of the girls will then have a second child. Again there will be an even distribution of boys and girls. Half of those mothers will go on to have a third child and again there will be as many boys as there are girls. Regardless of the number of rounds and the size of the families, the sex ratio obviously will always be one to one.

Which brings us to a statistical problem posed by Richard G. Gould of Washington. Assume that the sultan's law is in effect and that parents in Fertilia are sufficiently potent and long-lived so that every family continues to have children until there is a son, and then stops. At each birth the probability of a boy is one-half. In the long run, what is the size of the average family in Fertilia?

9.

Obtain a piece of clothesline rope about 5½ feet long. Knot both ends to form a loop as shown in the top illustration on the opposite page. Each loop should be just large enough to allow you to squeeze a hand through it. With the loops around each wrist and the rope stretched between them, is it possible to tie a single overhand knot in the center of the rope? You may manipulate the rope any way you like, but of course you must not slide a loop off your wrist, cut the rope or tamper with either of the existing knots.

Last month readers were asked to place 14 chess knights on an order-9 chessboard, and 16 on an order-10 board, so that on each board all unoccupied cells are under attack by at least one knight. The solutions, which are thought to be unique except for rotations and reflections, are illustrated at the bottom of the opposite page.

Readers will be interested to know that early next year two scholarly quarterlies devoted to intellectual play will make their first appearance, each edited by an expert who has often been mentioned in this department. *The Journal of Recreational Mathematics,* edited by Joseph S. Madachy, will come out in January. *Word Ways: The Journal of Recreational Linguistics,* edited by Dmitri A. Borgmann, will appear in February. Both journals will be published by Greenwood Press, Inc., 211 East 43rd Street, New York, N.Y. 10017. The price for each is $9 per year for subscribers in the U.S., $10 in foreign countries.

SCIENCE/SCOPE

The odds against Surveyor 5's success jumped to 1000 to 1 when a loss of helium pressure was detected shortly after midcourse correction. Without sufficient pressure to move propellant to its three small vernier engines, the spacecraft could not be slowed and steadied to a soft landing on the moon.

Racing against time, a task force of NASA, Jet Propulsion Laboratory, and Hughes scientists worked around the clock to program a new landing sequence, telescoping 11 weeks of work into 40 hours. They verified their calculations on computers, tested duplicate vernier engines, then radioed the instructions that brought Surveyor 5 to a perfect soft landing.

When Surveyor 5 was turned off for the lunar night on September 24, it had returned 18,006 pictures of a new potential landing site for astronauts and had lowered a device to analyze the chemical composition of the moon's surface by radiation.

The new shipboard satellite communications sets Hughes is now delivering to the U.S. Navy promise to end the interruptions and blackouts caused by atmospheric and solar disturbances that have long plagued long-distance radio transmission. Shipboard or base commanders will be able to communicate with each other by voice or Teletype over vast distances. Messages will be relayed by DOD's random-orbiting satellites.

The birth of Hurricane Sarah was discovered in a cloud-pattern photo of the eastern Pacific taken September 6 by NASA's ATS-1 satellite. Succeeding photos showed Sarah's growth to a full-fledged hurricane on September 11 (its title was changed to "typhoon" when it crossed the international date line September 14). The 2,000 residents of Wake Island, warned days in advance, were safe in typhoon-proof buildings when Sarah's 140-mph winds left the outpost a shambles on September 16.

Full-color photos of the Atlantic cloud pattern will be taken by the ATS-C satellite scheduled to be launched this fall. The spin-scan cloud cameras for both ATS satellites were developed by Santa Barbara Research Center, a subsidiary of Hughes Aircraft Company, which is building the Applications Technology Satellites for NASA's Goddard Space Flight Test Center.

Hughes has immediate openings for engineers in the following fields: weapon systems, design and analysis, data processing, communications system design, radar system design and development, structural analysis, design and packaging, and display systems. Minimum requirements: two years of applicable experience, accredited engineering or scientific degree, U.S. citizenship. Please send your resumé to Mr. J. C. Cox, Hughes Aircraft Company, Culver City, California. Hughes is an equal opportunity employer.

Five different types of spacecraft carry traveling-wave tubes by Hughes. These little TWTs — the invisible links that make radio communications and picture sending possible — have already operated more than 133,000 hours in space. They are in use on Comsat's Early Bird and Intelsat satellites and on NASA's ATS and Syncom satellites and Surveyor spacecraft, all built by Hughes.

The Apollo manned lunar landing vehicle and the Saturn booster will also be equipped with Hughes TWTs. Other spacecraft include Lunar Orbiter V, Venus-bound Mariner V, and Pioneer.

Creating a new world with electronics

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THE AMATEUR SCIENTIST

How to make an electrochemical cell and also an unusual kind of sundial

Conducted by C. L. Stong

If all the electrical energy that is locked in the chemical bonds of gasoline could be transformed into useful work, an automobile of average size would run at least 100 miles on a gallon of fuel. The vehicle could be set in motion at the touch of a switch. It would operate silently and discharge no noxious fumes.

The performance of automobiles and of most other powered machines could be upgraded to this level of efficiency by a single technological advance: the development of a device for transforming the energy of chemical bonds directly into electric current. Most devices now used for harnessing the energy of fuel, such as internal-combustion engines, employ a process that involves three or more wasteful steps. Fuel is first burned, a reaction in which electrostatic energy is liberated in the form of heat. The heat is then converted into mechanical energy by the moving parts of the engine. In many installations the mechanical energy is finally transformed back into electrical energy by an alternator or a dynamo. Each transformation proceeds at the cost of wasted energy. For this reason experimenters, both professional and amateur, have long dreamed of developing an inexpensive, compact and durable electrochemical cell that would make the transformation in a single step.

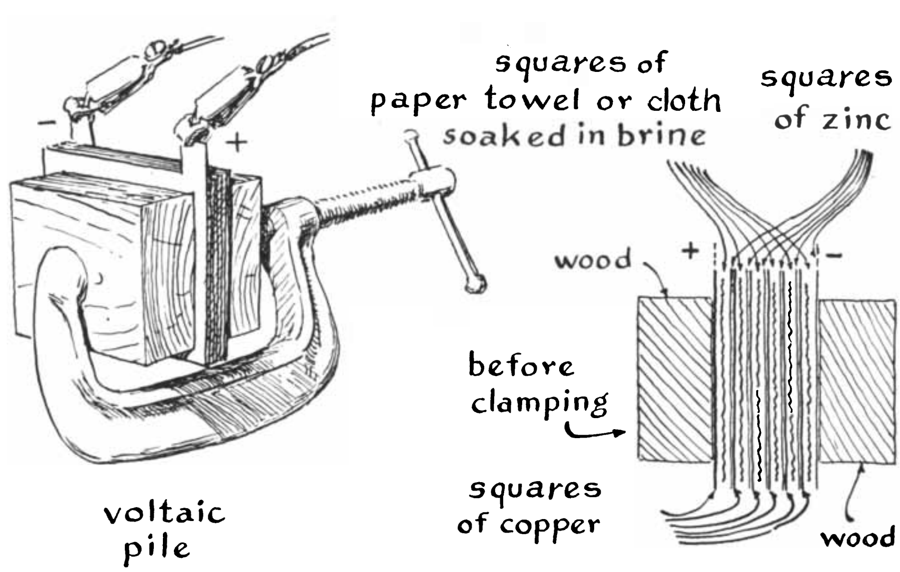
In theory such a cell could be made. The first promising step toward its development was taken by Alessandro Volta 175 years ago. Volta's apparatus, the predecessor of the ordinary dry cell, consisted of small pieces of cloth moistened with brine and sandwiched between alternating disks of zinc and silver. The device was an effective converter of energy, as indicated by Volta's report of an early experiment: "I have finally succeeded in stimulating my sense [of hearing] with my new apparatus. I introduced into my ears two metal rods with rounded ends and joined them to the terminals of the apparatus. At the moment the circuit was completed I received a shock in the head: and a few moments afterward, the circuit remaining closed, I began to hear a noise which I cannot well describe. It was a crackling... or boiling. This disagreeable sensation, which I feared might be dangerous, has deterred me so that I have not repeated the experiment." The energy responsible for Volta's discomfort was liberated at high efficiency in a single step by a chemical reaction in which the metal, particularly the zinc, served as fuel.

A cell that demonstrates essentially the same properties can be assembled inexpensively at home by substituting copper for the silver. The experiment can serve as an introduction to the basic properties of electrochemical cells in general. Both copper and zinc, in the form of sheet metal known as "flashing," can be bought from tinsmiths and from most dealers in hardware.

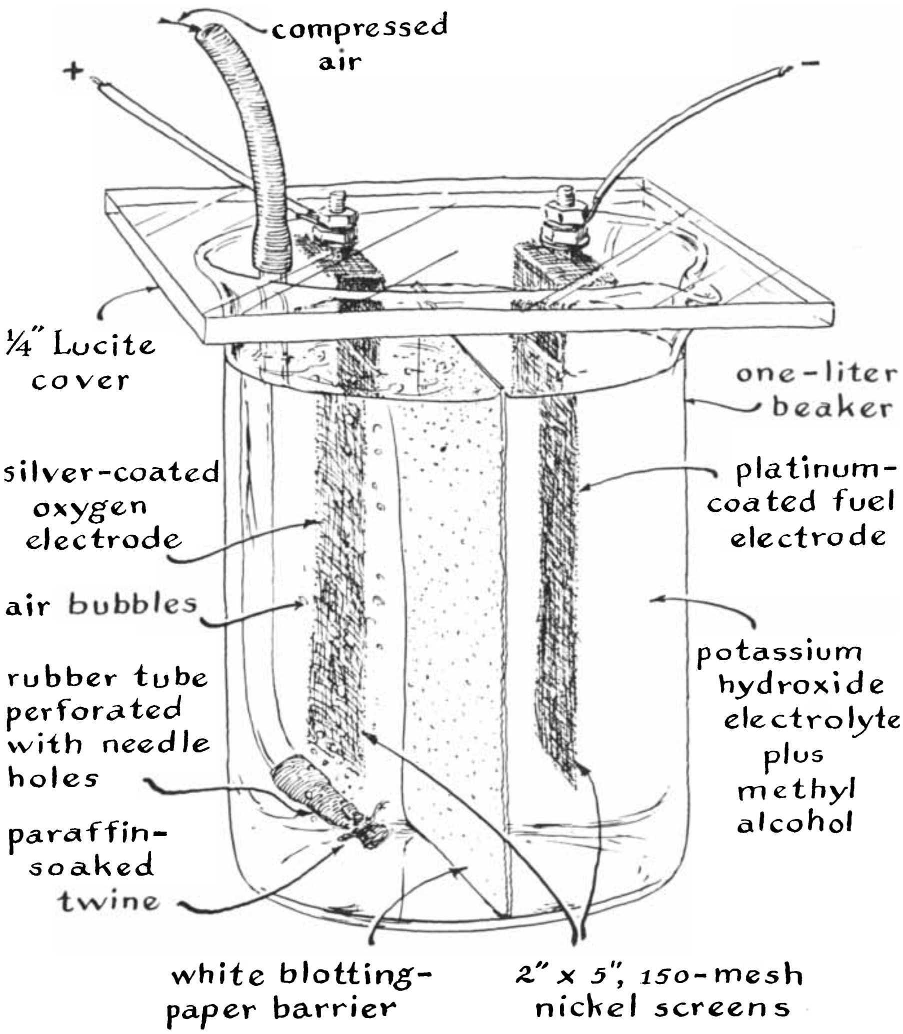
In order to make a small cell cut the sheets into two-inch squares and scour the surfaces with steel wool. Cut a few similar squares of cotton cloth or paper toweling. Soak them in a saturated solution of table salt and tap water. (Such a solution, at a given temperature, will dissolve no more salt.) Sandwich a sheet of wet cloth or paper between a copper plate and a zinc plate. Place the sandwich between flat wooden blocks and squeeze it with a *C*-clamp or a vise. Connect the positive terminal of a voltmeter to the copper plate and the negative terminal to the zinc plate. The pointer of the meter will swing to about .8 volt. An ammeter connected in the same way will indicate a current of about 15 milliamperes. The current will drop to approximately five milliamperes within a minute or two as reaction products accumulate in the cell.

Higher voltages can be generated by building a pile of cells. Place the copper plate of one cell on top of the zinc plate of its neighbor below, and so on. Clamp the completed pile and attach lead wires to the end plates. The output potential will increase in direct proportion to the number of cells in the battery. The maximum current delivered by the battery will vary directly with the area of the plates. Volta assembled batteries of 100 or more cells.

With a somewhat similar battery the



Elements of an electrochemical cell



Sol M. Gruner's fuel cell

English chemist Sir Humphry Davy sent electric current through molten salts and in 1807 succeeded in isolating the alkali metals sodium and potassium by electrolysis. Shortly thereafter the Royal Society of London constructed a battery of 2,000 cells, the plates of which measured 2½ feet by six feet. This giant powered the first carbon arc light and led to the discovery of the laws of electrolysis.

Volta's battery, although it was primitive in design, must not be dismissed as a harmless toy. The experimenter working with more than 20 cells must exercise caution. As Volta learned, electricity can make one's head roar; it can also be lethal.

Two factors have limited the usefulness of Volta's apparatus and of its lineal descendants as sources of electrical energy. One is the relatively high cost of the metallic fuel; the other is the fact that the cell consumes itself. The ideal cell would be kept fully charged by a supply of inexpensive fuel such as alcohol or gasoline, and its working parts would have a long service life.

Substantial progress toward meeting these objectives has been made in recent years. Some of the resulting cells are simple enough for amateur construction. For example, Sol M. Gruner of Elmer, N.J., has made working models of two types. One uses hydrogen as fuel and the other uses alcohol.

"My cells," Gruner writes, "were built as an experiment rather than as power sources. Both are small, comparatively inexpensive and designed for easy modification so that various chemical systems can be tested conveniently. The power output is limited to a few milliwatts but is sufficient for accurate measurement by instruments of modest cost. Both cells operate at room temperature and atmospheric pressure.

"Each cell consists of a glass container that can be a large test tube, a beaker or a similar vessel; a cover made of an insulating material such as plastic or rubber, and a pair of electrodes, which are suspended from the cover. The electrodes of the hydrogen cell were made of carbon rods from used dry cells. The rods were drilled lengthwise to form slender cups with walls somewhat less than a sixteenth of an inch thick. The carbons were heated to about 1,500 degrees centigrade to drive off the ammonium chloride and other substances carried over from the dry cells and were then impregnated with two metals that function as catalysts enabling the hydrogen gas to combine with oxygen at room temperature.

"The oxygen electrode, which is the positive terminal of the cell, requires a catalyst of finely divided silver oxide. It was prepared by injecting a concentrated solution of silver nitrate into one of the hollow carbons. The electrode was then drained, dried and heated to redness with a gas torch to decompose the silver nitrate thermally into silver and nitric oxides. The finely divided particles of silver oxide remained in the carbon as the catalyst and the nitric oxide was liberated as gas. I have also experimented with an alternate oxygen catalyst consisting of one part of nickel oxide to 10 parts of cobalt oxide. A concentrated solution of the nitrates of these metals is applied to the electrode and decomposed by the procedure just described.

"Finely divided platinum serves as the catalyst of the hydrogen electrode. Chloroplatinic acid is applied to the carbon and decomposed into platinum black by heat. The acid costs about $10 per gram, but a little goes a long way. A few milligrams of acid adequately coats an electrode made from the carbon of a size-*D* flashlight cell.

"The open ends of the electrodes are slipped into tightly fitting tubes of rubber or plastic through which the gases are fed to the cell. Leads of copper wire are wrapped in contact with the carbon adjacent to the tubing. The electrodes are then spaced a few millimeters apart and clamped in parallel alignment by a fixture improvised from rigid plastic that is fastened to the cover of the cell. The tubes and leads pass snugly through holes in the cover.

"The cell is completed by immersing the electrodes in a solution made by dissolving 300 grams of potassium hydroxide in one liter of distilled water. A sufficient quantity of this electrolyte is transferred to the cell container for immersing the electrodes. When fuel gas and oxygen are admitted, the cell develops a potential of about 3/4 volt. I generate the hydrogen and oxygen by the electrolysis of water. Gas from the electrolysis apparatus is fed directly to the electrodes through flexible tubing. The rate of gas flow is regulated by adjust-

ing the direct current that energizes the electrolysis apparatus.

"The alcohol cell is based on a demonstration cell that was first described by the Esso Research and Engineering Company. It is more convenient to use than the hydrogen-oxygen cell and appears to operate at higher efficiency. It is also somewhat easier to make because the electrodes consist of 150-mesh nickel screening. They are two inches wide and five inches long. (Nickel screening of this mesh can be obtained from the Newark Wire Cloth Company, 351 Verona Avenue, Newark, N.J. 07104. A sheet six inches square is currently priced at $1.75.)

"One end of each electrode is bent to a right angle and pierced for a nickel-plated machine screw that attaches the screening to the cover of the cell [*see illustration on page 132*]. The electrodes must also be coated with catalysts of platinum and silver. The fuel electrode, which is the negative terminal of the cell, is prepared by immersion for one hour in a solution of chloroplatinic acid dissolved in 100 milliliters of distilled water. During immersion the electrode is turned over several times to ensure a uniform coating. Platinum ions in the solution deposit on the nickel in the form of platinum black. Some nickel goes into solution as nickel ions. The oxygen electrode is similarly coated with silver by immersing the second piece of screening for an hour in a solution consisting of five grams of silver nitrate dissolved in 100 milliliters of distilled water. Avoid touching the surfaces of the coated electrodes.

"Both cells use the same electrolyte: a 5.5-molar solution of potassium hydroxide. Any glass vessel that will accommodate the electrodes can be used as the container. I prefer a beaker with a volume of one liter. The container should be filled so that the electrodes will be immersed almost up to the heads of the machine screws. The fuel consists of 35 milliliters of methyl alcohol, which is mixed with the electrolyte. (My experiments indicate that denatured ethyl alcohol works about as well.) A sheet of white filter paper or blotting paper should be inserted between the electrodes to prevent the screens from making accidental contact, which would short-circuit the cell.

"After the fuel has been added a potential of .5 volt will appear across the electrodes. A milliammeter connected to the terminals will indicate an initial current of about 20 milliamperes. At this current the terminal voltage will fall almost to zero because the oxygen electrode will quickly accumulate a coating of fine bubbles that are released by the reaction. Most of the voltage will appear between the electrolyte and the oxygen electrode, across the layer of bubbles.

"The coating can be disrupted by playing a stream of air bubbles continuously over the surfaces of the oxygen electrode. I accomplish this by installing an air dispenser immediately below the electrode. It consists of a short length of rubber tubing, tied closed at one end, that has been pierced several hundred times by a sewing needle. Air from an aquarium compressor is fed to the perforated tubing. The rate of airflow is adjusted by applying a pinch clamp to the supply hose from the compressor to produce a rising cloud of bubbles of pinhead size. The effect of the bubbles on the performance of the cell can be observed by connecting a 100-ohm resistor across the cell as a load and measuring the voltage with and without the air supply. When the switch is closed in the absence of air, the output potential will quickly drop to about .1 volt. When the compressor is started, the voltage will rise almost to its open-circuit value and the power output will approach 10 milliwatts. If the compressed air is replaced by pure oxygen, the output will increase to 30 milliwatts or more. I found that the output can be increased still more by adding 15 milliliters of concentrated sodium hypochlorite to the electrolyte and then slowly injecting hydrogen peroxide under the oxygen electrode at a rate of about five milliliters per hour. The sodium hypochlorite dissociates the hydrogen peroxide, yielding nascent oxygen.

"The cell generates electric current by 'burning' alcohol into formic acid. At the oxygen electrode a molecule of oxygen combines with two molecules of water and four electrons, which are supplied by the electrode, to form four hydroxyl ions. The hydroxyl ions migrate through the electrolyte to the fuel electrode, where they combine with a molecule of alcohol to yield one molecule of formic acid, three molecules of water and four electrons, which make their way back to the oxygen electrode through the external circuit [*see illustration above*]. The formic acid promptly reacts with the potassium hydroxide to form its salt.

AT THE OXYGEN ELECTRODE:

$$O_2 + 2H_2O + 4e \longrightarrow 4OH^-$$

AT THE FUEL ELECTRODE:

$$CH_3OH + 4OH^- \longrightarrow HCOOH + 3H_2O + 4e$$

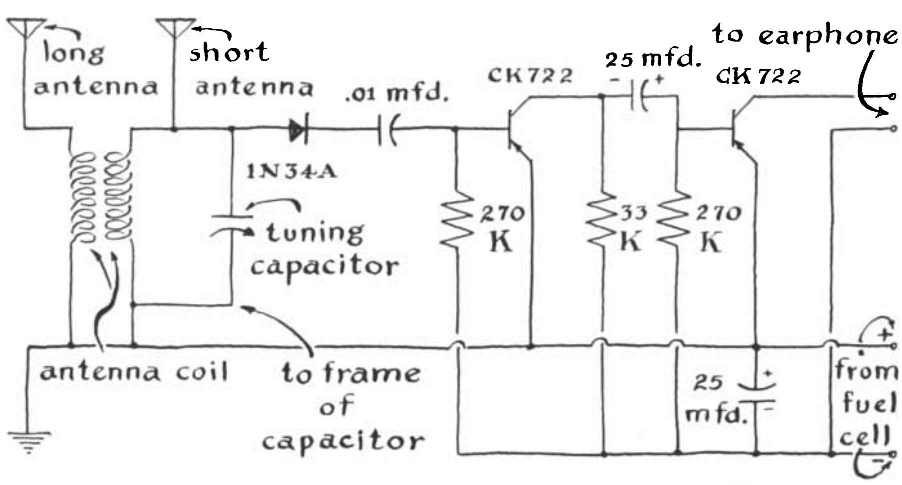
OVERALL REACTION:

$$O_2 + CH_3OH \longrightarrow HCOOH + H_2O$$

Chemical reactions in the fuel cell

"Although the cell is not intended as a power source, it will operate a small transistor-radio receiver continuously on a single charge of fuel for more than 1,500 hours. At the end of the period the cell can be recharged immediately by adding alcohol. The circuit of an appropriate receiver that can be assembled easily at home is shown in the accompanying illustration [*below*]. The construction can be simplified by buying a ready-made antenna coil and a variable capacitor from a dealer in radio supplies. The coil-capacitor combination should be capable of tuning from 540 to 1,600 kilocycles."

Every generation includes a substantial number of amateurs who design sundials, a hobby that continues to recruit enthusiasts even in these days

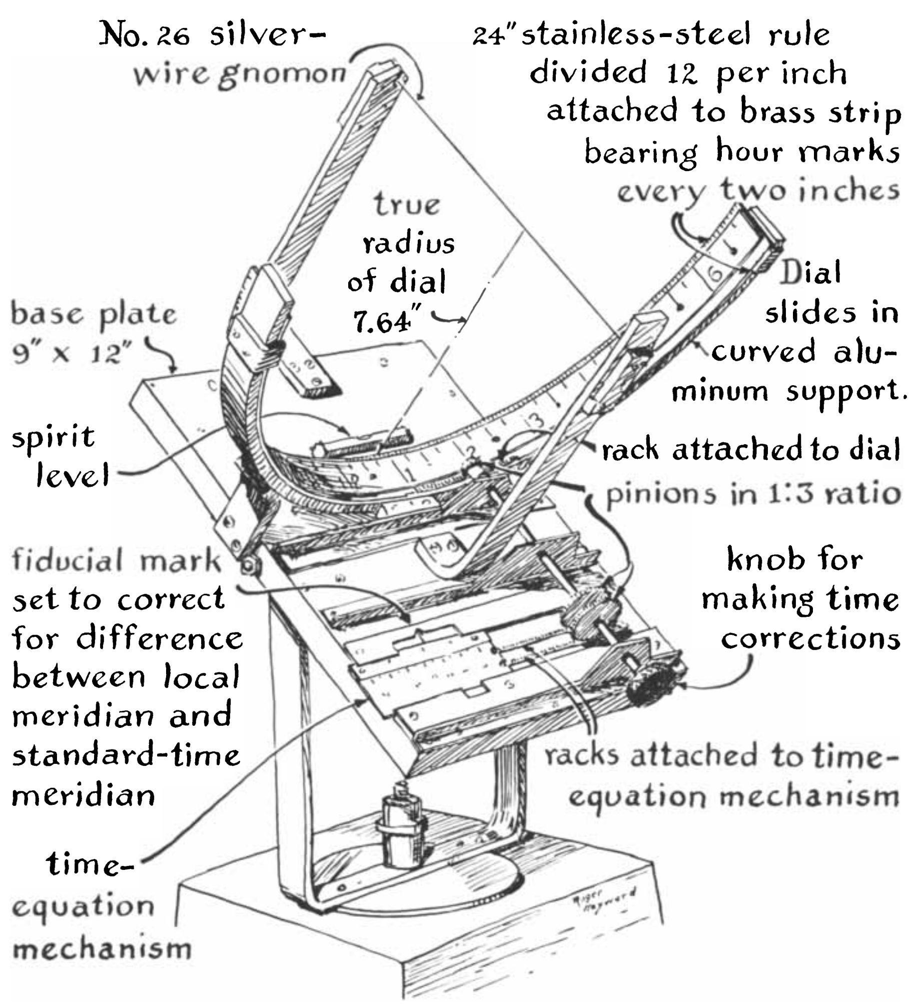


Circuitry of a cell-powered radio receiver when wristwatches are almost as common as shoes. To the collection of unusual dials that have appeared in recent years is now added one that tells clock time and daylight saving time. William C. Boyd, professor of immunochemistry at the Boston University School of Medicine, is the designer. He writes:

"Considering the thousands of years that sundials have been used, it seems unlikely that an amateur could invent a new design. It may well be that mine is not new, but I have never come across one like it, even though it is based on a simple principle. Its novel feature is an adjustable dial. The time, as indicated by the shadow of the gnomon, can be advanced or retarded by rotating the dial, just as a clock can be reset by moving the hour hand.

"The dial must be reset almost every day to keep the indicated time in step with clock time, because the shadow cast by the gnomon 'runs' faster or slower than clocks by a predictable amount that varies throughout the year. This predictable variation, known as the equation of time, can be recorded as a table of corrections that dictates the setting of the dial for every day of the year. Data for compiling the table are available in standard references such as *The American Ephemeris and Nautical Almanac*. (This reference is available in most public libraries and can be bought from the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402.) I engraved the table on a metal plate that is mounted on the base of the dial. A photocopy of the table posted indoors would serve as well.

"The instrument can be built by anyone with access to modest workshop facilities. My model was made largely of do-it-yourself aluminum that I bought at a hardware store. The apparatus is held together by brass machine screws that were tapped into the aluminum. I sidestepped the most difficult part of the job—graduating the dial—by using part of a carpenter's square. The square, made of stainless steel, had 1/12-inch graduations. I used a hacksaw to cut a two-foot length, which I then bent into a semicircle [*see illustration below*]. The semicircle corresponds to a 12-hour interval; the smallest division represents 2½ minutes. All the other dimensions of the instrument



Sundial designed by William C. Boyd

are determined by the size of the dial.

"The graduated dial slides on the surface of a semicircular aluminum support and is loosely attached to the support by brass screws that move in slots. The dial is restrained laterally by stops at the edges of the support and is rotated back and forth on its support by a brass rack bent to the same radius and soldered to the dial. The rack is engaged by a pinion gear fixed on one end of a shaft. The opposite end of the shaft is fitted with a knob that extends beyond the edge of the base. To reset the time indicated by the dial one merely turns the knob one way or the other.

"Another handy feature that increases the accuracy of the instrument is a time-equation mechanism that displays the setting of the dial. The mechanism consists of a flat graduated scale, geared to the dial by a pair of straight racks that engage a pair of gears mounted on the adjustment shaft. The graduated scale slides in a set of ways. The driving gears have three times as many teeth as the pinion that engages the rack of the dial, hence the linear displacement of the flat scale exceeds by threefold the movement of the dial. This multiplication of motion increases by threefold the precision with which the dial can be set. A change of 1/4 inch corresponds to a time interval of 2½ minutes. The scale of the indicator was cut from a machinist's steel rule. I ruled a vernier scale by hand. The vernier is fixed to the base of the instrument, adjacent to the graduated edge of the machinist's rule.

"The gnomon consists of a 9.4-inch length of No. 26-gauge silver wire supported 7.64 inches above the dial by a pair of adjustable blocks carried by arms made of aluminum strips. The base of the instrument is constructed for rotation in both declination and azimuth, so that the gnomon can be pointed both to true north and parallel to the earth's axis. When the gnomon is so aligned, it is possible even without reference to the vernier scale to set the dial to within 15 seconds of local clock time. On July 11 of this year I made a total of 18 readings, spaced roughly 40 minutes apart, and checked each reading against a good watch that had been set by reference to time signals broadcast by radio station WWV of the National Bureau of Standards. The maximum error amounted to +.5 minute and the average error to ±.17 minute, or about 10 seconds. Many watches are not as good. Moreover, errors made by the sundial are not cumulative. On the other hand, one does need the sun."

BOOKS

The foundations of language in man, the small-mouthed animal

by Charles F. Hockett

BIOLOGICAL FOUNDATIONS OF LANGUAGE, by Eric H. Lenneberg. With appendices by Noam Chomsky and Otto Marx. John Wiley & Sons, Inc. ($14.95).

Some 30 years ago Leonard Bloomfield published his book *Language,* ostensibly an elementary text but in fact a masterly synthesis and compendium of all that had been learned about the subject in the century and a half since scientific linguistics first emerged from the mists of medieval philosophical speculation. In spite of some errors of detail and one major theoretical discrepancy, Bloomfield had sifted the work of his predecessors so carefully, and had himself built so well, that his presentation has still not been superseded.

This is not because Bloomfield's successors have been lazy or incompetent. In fact, they have been very busy. The generalizations Bloomfield ventured on the basis of a small and rather biased sample of the world's languages have been checked on several hundred more, and in the main they have held up; a few about which he was hesitant have been rendered firm. In a more theoretical vein some investigators have tested his frame of reference by suppressing one or another of its features to see if the omission really matters (always to find that it does) or by adding some new twist (only to find that it gets in the way).

Bloomfield was largely or wholly silent on certain issues, not because they are unimportant but because no reliable information was yet available. He not only noted but also insisted that language is an exclusively human prerogative, and that its possession is in turn responsible for much else that is specifically human. He says nothing, however, as to how this may have come about in biological evolution. He makes no comment on the possible ways in which human genes, and the anatomy and physiology that stem from them, differ from those of other animals so that we have language and they do not. Certain directions of research that might in time shed light on these problems receive short shrift. He offers no systematic comparison of human language with the communicative behavior of other species; he covers the child's acquisition of language only in the briefest outline, and he condenses to a single page the then available reports on the speech behavior of people suffering from aphasia.

It is to just such matters as these that Eric Lenneberg refers by the phrase "biological foundations" in the title of the book reviewed here. Much has been done along these lines in the past three decades. Lenneberg has himself made extensive observations on the communicative behavior of the deaf, of mentally retarded or defective children, and of patients suffering from brain injuries. For this report he draws on his own experience but combines it with a careful combing of an enormous literature that presents the findings of others: psychologists, psychiatrists, brain surgeons, pathologists, primatologists and even a few linguists. The reader's expectations should not be unrealistic. Obviously one will not find in this book a map showing the chromosome loci responsible for our power of speech. Reasonable expectations are that the book be a progress report, explaining which lines of research and speculation have proved fruitless, which have shown promise and should be followed up, and perhaps venturing a few tentative generalizations.

Except in one important respect, these expectations are fulfilled. Several topics that Lenneberg handles in a very interesting way will be omitted here, but I shall give a summary of what to me are his most important positive findings.

The first point is mentioned only in passing, but it was new to me and caught my fancy. For vocal-auditory communication *Homo sapiens* has an advantage over the other hominoids in the relatively small external opening of his oral cavity. This is a matter of physical acoustics that can be tested in any kitchen. Allowing for differences of material and shape, a container with a small mouth, such as a beer bottle, resonates better than one with a large mouth, such as a jelly glass.

Was the selection for small mouths among our remote ancestors favored because it promoted vocal-auditory communication, or did it come about for other reasons and merely set the stage for the development of language? Lenneberg does not discuss this, but the tenor of his writing shows that he would insist, as I do, that questions in this simple either-or form are misleading. What happens in evolution is always the result of the most complicated interweaving of many factors, no one of which can be singled out as "the" cause. The reduction of mouth size must be related to the slow switch to upright posture, the transfer of grasping and manipulating from mouth to hands, the enlargement of the skull and advancement of the forehead, the recession of the jaw and reduction in size of the teeth, the changing mechanics of supporting the head implied by all of these, and changes of diet, perhaps even the invention of cooking. At present we have only vague notions of the relative timetable of all these developments.

The second finding is that there is no convincing evidence for any extreme localization of brain function, either for language in its various aspects or for any other facet of behavior. Behaviorally equivalent activities may be governed by different parts of different human brains. There is equally no reason to believe the cerebral cortex begins as a homogeneous mass any part of which can equally well come to be involved in any function. Rather there seem to be genetically monitored structural reasons (little understood as yet) why certain functions are most likely to be developed in certain portions of the brain, yet enough flexibility that if something such as a brain injury interferes, other regions are able to take over. This flexibility decreases with age. As far as language is concerned, the evidence from efforts to retrain aphasics suggests that by the age of 14 or 15 it is gone.

Lenneberg warns us, however, that the ways in which we classify and categorize behavior as viewed from the outside may be entirely different from the ways in which it is broken up into bits and pieces for internal storage. It is obviously meaningful to speak of the vocabulary of a language, as against its phonology and its grammar. But this does not imply that a speaker's brain tucks away the words he learns in some particular bank of adjacent cells or synapses, nor even that each individual vocabulary item must be stored as a unit in a cell or synapse somewhere. Of course, unless we are going to abandon altogether the notion that the brain plays a role in behavior (perhaps restoring the classical Greek proposal that its function is to cool the blood), then all the information for behavior must be stored somehow, somewhere. It is simply that behavioral units may not be storage units.

One suggestion of importance emerges. If anything recognizable in behavioral terms is in fact localized within the cerebral cortex, it is most likely to be the triggers for setting off whole complex behavioral routines: scratching, starting to walk, suckling, a cat's twisting of its body into upright position as it falls. The details of such a routine are then provided for elsewhere, probably in a diffuse way. Certain aspects of language behavior may constitute such routines.

The third conclusion is related to the foregoing. It is a proposal for which Lenneberg marshals a good deal of evidence: that lateral dominance, apparently a human universal, is also exclusively human. In other animals the functions of one cerebral hemisphere (whatever they may be) are virtually duplicated by the other. In humans certain things are assigned to one hemisphere alone, leaving the other free for other functions and thus increasing the total effective cerebral capacity without the need for additional biologically expensive tissue. For example, Broca's area, whatever its exact significance, exists (or functions) only on one side. In this connection it might be better to speak not of lateral dominance but of hemispheric asymmetry.

To Lenneberg's evidence one can add the tentative results of some experiments performed recently at the Haskins Laboratories but not yet published, which suggest that the two ears of a normal adult do not transmit the same information. One ear is better for music, the other for other kinds of sounds; one ear may be the chief channel for the recognition of vowel color in the speech signal, the other for the noise bursts that help to identify consonants. Of course, these differences—if they are genuine—do not reside in the ears as end organs but in the peripheral parts of the brain to which the ears feed their data.

If all of this is really true, one is tempted to speculate as follows. The use of tools may be much older than language. The effective manipulation of tools demands different patterns of motion by the two sides of the body. This may have selected for brains with hemispheric asymmetry, which were then available for exploitation by the various developments that in time gave rise to language.

The fourth and last of Lenneberg's findings I shall mention has to do with the timetable of language acquisition by the normal child. In reviewing this timetable Lenneberg makes only the mistake made by almost all nonlinguists in the same connection: he speaks of the child's utterances as consisting of "words" at a stage considerably earlier than that at which the use of this technical term can be justified, and therefore wrongly identifies some of the important transitions from one stage to the next. Luckily this error does not bear seriously on his conclusions, which are these:

The development of language does not begin in the human infant until the age of 18 to 24 months, but then it is almost impossible to prevent. No *formal* teaching is required. Peripheral impairments—for example deafness—force a resort to substitute channels, just as a congenital brain defect or early brain injury may require the involvement of other than the most usual regions of the cortex, but within very wide limits such difficulties are overcome. Eventually the child comes to speak whatever language is in use by surrounding adults. At the earliest childhood stages the language-like behavior of children in different speech communities is remarkably uniform. This suggests that all human languages are, and for a long time have been, erected on a single ground plan, a view amply supported by the results of linguistic research over the past two centuries. It suggests also that this basic plan is genetic and species-specific. Language acquisition does not begin earlier because the genetically monitored maturation of the nervous system (and perhaps of other parts of the body) has not yet reached the right stage. That it begins when and how it does, however, is not merely allowed but forced by maturation. It is as inevitable as menarche or the appearance of axillary hair, and genetically more stable than either. If the environment is so unusual as to keep the child alive until early puberty and yet frustrate his acquisition of language, it is then too late, again for maturational reasons. The adult's learning of a second language, however successful, is in process very different from the child's acquisition of his first, and the kinds of defective language behavior manifested by aphasics do not in any way resemble early stages in the development of language in the child.

One must allow for the fact that the particular elaboration on the ground plan for a given child depends on the language used by those around him. For this Lenneberg does not want to use the familiar term "learning," perhaps because the multitude of conflicting technical senses given that term by our two and seventy jarring sects of psychologists have spoiled it. Instead he proposes that the child's language behavior comes to "resonate" with that of his mentors. This is harmless, provided that we remember it is merely a new label, not an explanation.

These conclusions strike me as well reasoned and in some respects a genuine improvement over our earlier views, although in no sense revolutionary. But in order to dig this positive content out of Lenneberg's discussion I have had to apply more exegesis than should be required. Anyone doing multidisciplinary research is under the obligation to incorporate only the best and most carefully tested results of each discipline. Insofar as I can judge, Lenneberg does this for all the technical fields involved except the most important one: linguistics. This is an old, tiresome story. Time and again researchers without linguistic training have carefully drawn their chemistry from chemists, their physiology from physiologists, and so on, but have assumed that since language is the common possession of all human beings anyone can be his own expert. In this vein Lenneberg does a number of foolish things. Two examples will suffice: his handling of articulatory phonetics and of phonetic notation is amateurish, and he expresses at one point the peculiar opinion that proper names are not part of vocabulary. The results in cases such as these are merely laughable. What is truly tragic is that, when he sets aside the notion that anyone can invent linguistics for himself and seeks expert guidance, he turns not to our calm and quietly growing tradition of scientific linguistics (Bloomfield's name does not appear in the book!) but to the specu-

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On a piano bench it will help raise the youngest pianist to a more professional level; particularly since he'll find in its pages information about practically every composer, pre Bach to post Bernstein; about every musical instrument. He'll learn music terminology and symbols.

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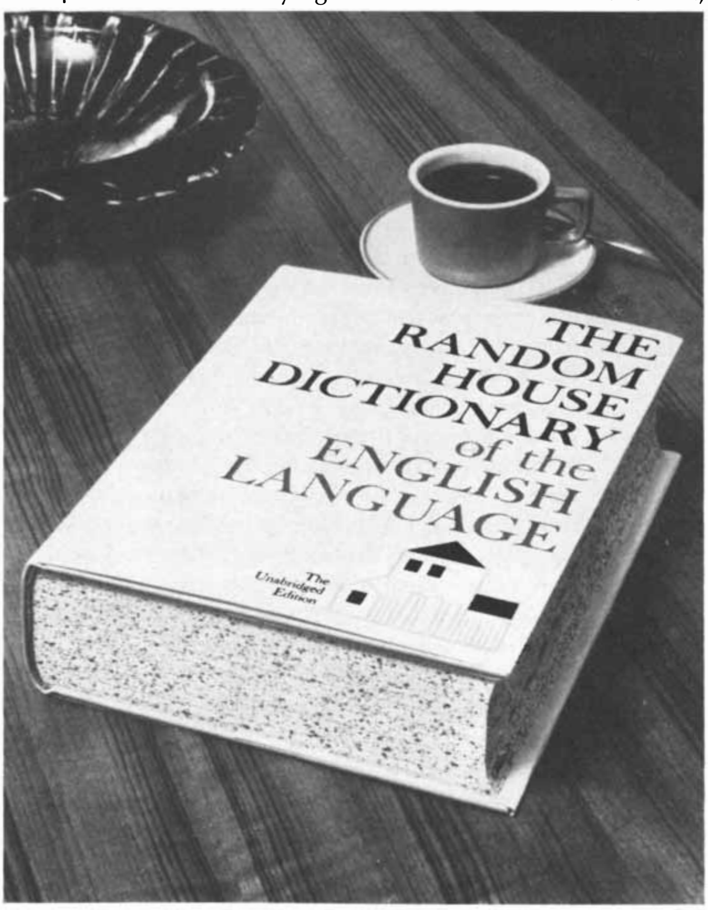

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And it's less likely you'll get caught cheating at the Times' Crossword Puzzle because the Random House Dictionary is so very quick and easy to use, so simply indexed. So keep it close: perhaps on your coffee table.
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The Random House Dictionary of the English Language. $25.00

lations of the neomedieval philosopher Noam Chomsky.

Chomsky thinks of a language as an ideal rational schema hidden deep inside a human being and reflected only with great distortion in actual speech. Furthermore, this hidden schema is a system in the same sense as any well-defined algorithmic system of mathematics or mathematical logic. He is thus led to ignore empirical evidence, which is necessarily the observation of actual speech and of responses to it, and to reject, one by one, the various simple inferences that have been made from the empirical evidence by generations of linguists. The result is something like what would happen if a chemist should suddenly conclude that the electronic theory of valence cannot possibly be valid and that some totally different theory must be developed to explain how matter behaves. This is all we need say about Chomsky here. I have recently devoted a monograph to the dissection of his weird notions, and anyone really interested can read it. It seems more constructive to devote the final paragraphs of this review to a capsule summary of the design of human language as understood so far by science. What I shall say is at bottom what Bloomfield said. Some of the words (for instance "association" and "habit") have been claimed by various psychologists in various special senses, but I claim them back as part of everyday vocabulary—there is no psychological theory in this summary.

Any speaker of any human language, at any given time, speaks and understands in terms of a set of habits of articulation and hearing that constitute the *phonology* of his language. In speaking he aims his articulatory motions at a series of articulatory targets, although usually the aim is careless. In hearing the speech of others he identifies what is linguistically relevant in the incoming speech signal, when he needs to, in terms of the articulatory targets at which he himself would aim in order to match the signal. (The occasional individual who has been mute from birth but who understands the speech of others obviously cannot do this; we do not know how he manages.) The actual sound of speech in any language shows the widest and wildest variation, but the targets are discrete and finite in number. Functionally there is no such thing in any language as an "indefinitely small difference of sound." The number and location of the targets for any one language are specific to the language, as are the sequences in which they are aimed at and the relative timings of the aims. This is consonant with the fact that as time passes the phonology of any language changes, in ways and by mechanisms that are well understood.

Certain arrangements of targets are associated, sometimes precisely and sometimes very vaguely, with certain things or situations, or kinds of things or situations, in the experience of the speaker. Any such recurrent arrangement of targets is a linguistic *form*, and that with which it is associated is the *meaning* of the form.

People imitate each other, so that a form may spread from one speaker, or from one dialect, or even from one language, to another. When language habits are changed or enlarged in this way, the traditional term for the mechanism is "borrowing." Of course, this term is no more explanatory than "imitation" or Lenneberg's "resonance" is, but we are here merely stating facts, not accounting for them. The mechanism plays a constant role in the development of any one speaker's language habits, from their earliest appearance to his death.

Any speaker constantly faces situations, real or imagined, at least a little different from any he has encountered before. If he responds with speech (even silently, to himself), he may use a form already in his repertory, or he may coin a new linguistic form on the *analogy* of those he already knows. He may even follow two or more analogies at once. This creation of new forms goes on all the time: most of our utterances are new. It cannot in any way be distinguished from the mere use of language, although some coinages, it is true, are more strikingly novel than others. The longer and more complex a coinage, the more likely it is to be used just once and then forgotten. Nonetheless, a speaker may remember a new coinage—even a long one, say a poem—and utter it again, and others may borrow it, whereupon it may survive indefinitely. Contrariwise, any form may fall into disuse, forgotten by those who once knew it and never learned by others, and thus disappear.

The stock of forms a speaker controls at any one moment is his *vocabulary* (or *lexicon*). The order of magnitude of the vocabulary of any adult speaker of any language is in the tens of thousands; a more precise measurement is difficult because of constant change. The analogies by which new forms are coined are *grammar*. This too is constantly changing. In part these changes are kaleidoscopic, but for the most part they are sufficiently slow that the members of a speech community can usually understand one another, given a little trial and error, and that an investigator can prepare a description of a language that is not seriously out of date by the time it is published.

This is just about all we can say that is true of all human languages. There may be some universal features of a more specific nature. For example, it may be that all languages have something like the Latin or English contrast between noun and verb. Such a feature, however, could be universal without necessarily being part of the genetically controlled, species-specific ground plan. After all, if all the languages of the world except one were to die out, thereafter anything true of that one language would be a language "universal," but that would not change our genes.

Most of the foregoing is straightforward, but some people have trouble with analogy. There is nothing mysterious about it, and it is manifested in all phases of human behavior, not just in language. An exchange student from India went to lunch with an American friend and ordered tea. When the fixings arrived, he carefully tore open the bag and poured the tea leaves into his cup. The American explained that the whole bag could be immersed and that the water would filter through. Grateful for the counsel, the Indian took a paper packet of sugar and dropped it into the cup.

An analogical act may thus be a mistake. In one sense all analogical innovations could be characterized as errors of computation—breakdowns in what would otherwise be mechanically algorithmic, as so much of the communicative behavior of other animals seems to be. Some analogical coinages in speech, like most mutations in genetics, are failures; those that are successful differ from the failures not at all in what brings them about, only in their consequences.

Lenneberg's search for the biological foundations of language would have been easier, and his results a great deal more straightforward, if he had understood the foregoing rather simple facts about language itself. The reader who does not understand them can be badly misled by the book. It would be ungracious, however, to end on this note. My principal attitude is one of sincere appreciation to Lenneberg for the hard work he has done and for what he has taught us.

Short Reviews

World Climate from 8000 to 0 b.c., edited by J. S. Sawyer. Royal Meteorological Society ($8.80). In the spring of 1966 a symposium was held

Some day, all convertibles will have a roll bar.

At last. The basic problem of open car safety has been solved. With a roll bar fully integrated into the car's total design. The world's first production-series convertible to have it is now here.

That's the new Porsche Targa, the competition-bred car named for the Targa Florio (the punishing Sicilian mountain road race that's become one of Porsche's most successful proving grounds).

Like most Porsche innovations, the Targa's distinctive roll bar is a racing idea. That's why it's as logical and functional as a safety pin. It makes the Targa secure as a coupe, with race-track protection for everyday driving. The stainless-steel-covered roll bar also separates top and back, so they can be used independently as well as together:

Top and windows down: Fully open to sky and breeze.

Windows up: Airflow stays out. A woman's hairdo is safe at any speed.

Top up and rear window down: Cool enjoyment of open-air, daytime driving.

Top and windows up: Closed-car comfort, shielded against rain, snow or cold.

Porsche offers the Targa in three versions, the 912, 911 and 911L, with the same air-cooled, rear-mounted engines and equipment developed for Porsche's coupes. Common to all Targas are Porsche's famous four-wheel disc brakes, full-synchromesh transmission, and the trouble-free performance inherent in every Porsche.

Coupe prices start about $4950, East Coast POE. Targa convertibles, $400 more. For information, overseas delivery: Porsche of America Corporation, 107 Tryon Avenue West, Teaneck, N.J. 07666.

The new Targa by Porsche.

Permanent (tinted glass) rear window, optional at extra cost.

Teaching materials to carry bigger payloads.

New beryllium-aluminum alloys cut weight 50% over magnesium • Superplasticity is opening new avenues of high-strength metal fabrication • An advanced helicopter rotor hub gains performance from composite construction • A way to toughen ceramics may lead to structural applications • Graphite fibers can add greatly to strength of metals.

Knowledge being gained from Lockheed's search for ways to increase payloads—of air, space and even undersea vehicles—promises to produce "educated" new materials with higher strength- or stiffness-to-weight ratios.

Here are a few of the materials programs presently under way at Lockheed.

New lightweight beryllium-aluminum alloys. Solving a long-elusive problem, Lockheed scientists recently have succeeded in developing a practical beryllium-aluminum alloy suitable for aerospace applications. By carefully controlling microstructure, fine dispersions of aluminum in beryllium have been achieved, providing a series of workable, serviceable alloys. These possess extreme lightness without the brittleness characteristic of unalloyed beryllium. One, a 62%Be-38%Al material called Lockalloy, is now being produced commercially. It provides a 50% weight saving over commonly used magnesium alloys, while having three times the strength and four times the ductility of earlier developed beryllium-aluminum alloys.

Superplasticity. Generally, increases in strength of metals are obtained at the expense of ductility, making fabrication into complex shapes much more difficult.

To solve this problem, Lockheed is researching an unusual method of deformation called superplasticity. Both basic and applied studies are being conducted involving aluminum and titanium alloys. With one alloy, using the proper applications of thermal-mechanical treatment, elongations of 1400% have been achieved.

Defined as "an enhanced ductility associated with a microstructural change during application of stress," superplasticity, as far as the actual mechanism of deformation is concerned, is not yet fully understood. It appears to be associated with a fine, interlocked 2-phase microstructure where there is pronounced curvature of the interphase boundaries. Surprisingly, even when certain alloys are elongated enormously, there is no evidence

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of directionality in the microstructure. Transmission electron microscopy reveals it to be remarkably free of dislocations. None of the usual dislocation networks or tangles in plastically deformed metals can be detected. These results suggest that diffusional processes operate during superplastic deformation. Possibly, the key to the mechanism involved lies in a unique process of vacancy formation and migration inside the metal during stress.

This schematic representation shows the types of phase changes associated with superplastic effects.

Current investigations include commercial titanium alloys. Some, for example, Ti-8Al-1Mo-1V, can be elongated 400% at very low loads when kept within narrow temperature ranges.

Methods of deformation such as superplasticity may see extensive use in the next generation of aircraft.

Composites for Rigid Rotor helicopter hub. The recently developed Lockheed Rigid Rotor helicopter, because of its unique design, also presents some unique materials requirements. For example, the rotor hub. The hub arms must be flexible enough to provide proper dynamic characteristics, yet flexibility must be confined within narrow limits to avoid degrading the Rigid Rotor's outstanding stability and control qualities.

Today, titanium meets these exacting design conditions. But within a few years, composite materials now under development by Lockheed may offer signal advantages over metals in fulfilling the needs of new generations of rotary-wing vehicles. This is because a composite construction made with large-filament glass or metal fibers in a nonmetallic matrix permits superior control of flexibility due to a directionality of stiffness. A rotor hub made of such composites also meets fatigue life specifications while affording a high level of damage tolerance. A material of this type resists small nicks or scratches and is almost completely corrosion-resistant, providing long, safe, trouble-free service life. In addition, it is substantially lighter than a metal hub material and would further increase the helicopter's performance.

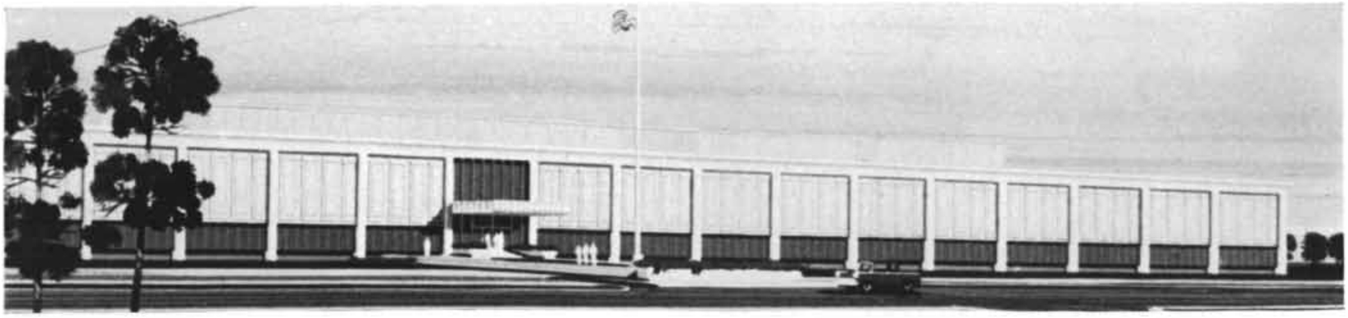
Ceramic composites. Ceramics have been tempting as materials to meet high strength-to-weight, temperature-resistance and corrosion-resistance requirements. But the inherent brittleness of ceramics has led to their rejection in previous investigations. New research at Lockheed, however, promises a solution. Using an unusual process involving special techniques and equipment, composite ceramics are being grown from the melt. The resulting laboratory product is a conventional ceramic matrix in which ultra-high-strength single-crystal fibers of either metal or ceramic material are imbedded. Presence of these fibers considerably toughens ceramics—to where they may find application as vehicle fabrication materials.

Graphite fibers in metal matrices. Graphite fibers recently have been developed with tensile strengths over 250,000 psi and moduli over 60 x 10^6 psi. Lockheed currently is investigating the compatibility of these high-modulus carbon fibers with metal matrices. Studies involve the temperatures and times required for composite preparation as well as potential fabrication applications. Compatibility is being tested by determining the wetting behavior of liquid-state metal matrix materials on the graphite substrate. Also, kinetic parameters are being established corresponding to possible interface reactions between fiber and matrix.

Because of their low density, graphite fibers are expected to play a significant role in developing lightweight, high-strength composites for many aerospace applications.

A longitudinal section of sapphire fibers in an aluminum titanate matrix. This section was produced by electron beam zone melting.

The activities described here are only a few of Lockheed's current R&D projects in materials. If you are an engineer or scientist interested in this field of work, either in California or Georgia, Lockheed invites your inquiry. Write: K. R. Kiddoo, Lockheed Aircraft Corporation, Burbank, California. An equal opportunity employer.



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GENERAL DYNAMICS

Fort Worth Division

in London at which 15 specialists from four continents spoke to the topic. The dates chosen were not arbitrary; they were set to include in detail the time of the postglacial maximum in world temperature, and to exclude the epoch when documentation becomes the main source of climatic evidence. It is now more than a century since Louis Agassiz first read the record written in erratic boulders and U-shaped valleys to establish the work of the ice ages; the date of the last glacial maximum is well established. Now comes the richness of fine analysis; these men seek a detailed global pattern of climatic change over the span of time when civilization was born. Their master clock is the radioactive decay of carbon 14, and the troubles of that clock—its calibration, its confusion by nuclear bombs and the waste gases of industry, its dependence on intelligent sampling—are not overlooked. The radiocarbon content of the atmosphere is not constant but fluctuates by a few percent for a variety of reasons, among which solar activity and ocean temperature can be taken as examples.

The radiocarbon clock is compared with sequoia and pine rings and with the best dates of Egyptian history. It is found to be losing time steadily, by as much as 1,000 years in 6,000 or 8,000. The analysis of pollen, dating back to World War I, is highly refined, the cataloguing of pine, elm and oak pollen from layers deep in peat bogs showing clearly the shifting flora of the land as the weather changes. The pollen deposits of Chile and Puget Sound yield evidence that both hemispheres have shown parallel changes during postglacial times. In the few centuries of direct records this result continues; for instance, glaciers in Patagonia, in the State of Washington and in the Alps all grew in A.D. 1810–1820.

Glaciers reveal their own economy by the burial of logs and the shearing off of stumps at their edges and walls as the ice sheet grows or shrinks; radiocarbon can then date these local ice ages. In the quiet of the deep sea the diatoms fall like snow, and species by species their layers give evidence of temperature change, and even of actual temperatures (in their isotope ratios). Here too there are troubles. The silence of the sea bottom is a metaphor. Currents and slumps stir the sea ooze from time to time, and require careful control by microscopic search for debris, which may include material rafted from the polar regions by floating ice. The careful study of ancient shorelines can reveal the meltwater from the continental ice sheet, but the level of the land is not constant, so that unraveling the effect of sea rise from uplift or downwarping caused by mountain-building and by readjustment under the shifting load of ice is not unambiguous. Caves from the deep layers of the antarctic ice cap are now thought to record the mean temperature in annual layers.

Tentatively, but with increasing certainty, the history of climate is becoming clear. The high summer temperature of central England in 8500 B.C. was seven or eight degrees below today's cool 60 degrees Fahrenheit; it rose to a plateau of some 65 degrees between 5000 and 3000 B.C.; it fell in a step or two to the present value. While England was warm the central Sahara was a pastoral savanna. The evidence is there in Neolithic rock paintings of giraffe and rhinoceros, with lake shells, bones, dung and pollen to corroborate it, all rather vaguely dated by radiocarbon. A smaller temperature wave affects us now; the two centuries around A.D. 1200 were warm ones by a couple of degrees, just as the 20th century has been. Why? No one is yet sure. Small variations in the earth's orbit and inclination, and hence in the sunshine input, appear to show a plausible, although long delayed, correlation with the data. Variations in the sun itself also seem implicated. There is no doubt that the matter is complex. The atmospheric pattern has a many-lobed shape as we look down on weather maps around the pole; those changing lobes make the weather, if not the whole climate. Not the great north-south differences, which seem quite stable, but the circumpolar lobes and their anomalies are the vehicle of climate change. Perhaps the ocean temperature, affected by meltwater, solar-input changes and shifts in currents, will turn out to be the significant cause, at least for the Atlantic lands. So the book ends, with model weather maps of 8000 B.C. The last word has not been written.

COSMIC RAYS II, edited by K. Sitte. Volume XLVI/2 of *Encyclopedia of Physics*. Springer-Verlag ($44.50). Sixty-odd substantial volumes, mostly in English but with a strong admixture of German, this specialized *Handbuch* has grown across the shelves of every physics research library over the past decade. Here is one of its latest volumes, a good specimen of the genus. It is not at all an alphabetized list of brief articles covering the field; in this respect the English rendering is misleading. Yet calling it a handbook—the English cognate to its German name—is no better, because the work is not a compact collection of data and skeletal articles. No, it is nothing less than a *Handbuch*, echoing its great predecessor of pre-Hitler years, some of whose volumes are still useful 40 years after they were written.

A *Handbuch* is a collection of monographic articles, each more or less self-contained, each summarizing at research depth a special field of physics, grouped with related pieces to form a volume. The entire set spans all physics. The volume reviewed here (its partner XLVI/1 came out in 1961) holds eight papers in its nearly 700 pages. They are all of high quality, written by men whose names carry real weight in the fields of their interest. Here you can learn about the energy and charge spectrum of the cosmic rays, some from far outside our galaxy. You can study the elaborate transport theory of the cosmic ray cascade, which is able to follow the passage of a ray through the atmospheric shield equivalent to 10 yards of water, statistically counting its millions of proliferating secondary particles. You can read about the numerous time variations at low energy that bespeak the magnetic weather of the solar system, about the production of carbon 14 by cosmic rays and the effect on it of the earth's field and the solar cycle, about the remarkable mesonic explosions, when nucleons collide at effective energies tens or hundreds of times greater than those available in our largest accelerators, even those of the future using storage rings and clashing beams. You can read about the study of the isotopes manufactured in meteorites and the atmosphere, in the ocean and the rocks by the incessant bombardment of cosmic rays over the span of geologic time.

None of these papers, except perhaps the brief one on meteorite studies, is accessible without considerable background in physics; they are authoritative and up-to-date reviews, generally quite clear in the pedagogic sense, but all draw on the full mathematical and conceptual arsenal of research. The *Handbuch* is a place of comfort for the new research worker, the graduate student and the lecturer but not for the casual or general reader.

A review is given of the flux of high-energy neutrinos and gamma rays (not the charged particles of ordinary cosmic rays) that one expects and searches for in the cosmos. This is a subject of very recent growth; the year-and-a-half delay between writing and publishing makes a bigger difference here than in any of the other papers. The review (by Robert Gould and Geoffrey Burbidge of the University of California at San Diego) is nonetheless valuable for its conceptual and theoretical content.

The heroic years of the founders, men such as Wolfgang Pauli and Arnold Sommerfeld, are behind us; this volume on a kind of applied physics will not retain its freshness for a generation. The set is nevertheless an indispensable tool, a true monument and a demonstration of the vigor and quality of research and of technical publishing today. It is worth noting that the authors presented here work in Tokyo, Nagoya, London, Frankfurt, Bombay, Copenhagen, California and Minnesota. Physics remains genuinely international.

SOURCES FOR HISTORY OF QUANTUM PHYSICS: AN INVENTORY AND REPORT, by Thomas S. Kuhn, John L. Heilbron, Paul L. Forman and Lini Allen. The American Philosophical Society ($5). SOURCES OF QUANTUM MECHANICS, edited with a historical introduction by B. L. van der Waerden. North-Holland Publishing Company ($14). In Copenhagen and Göttingen, in Paris, Zurich, Leiden and Cambridge, the years between the end of World War I and the early 1930's saw the birth and transfiguration of the most powerful and perhaps the most novel fundamental theory physics has ever had: quantum mechanics. Still intact, still extending its sway to other phenomena, this theory was made by men of whom the majority are living today. "Many a young scientist," writes John Wheeler in a preface to the first book above, "lacks conviction about important points . . . because he does not know the debates that settled these issues firmly for the fathers of quantum theory." These two books, neither of them a proper history, represent contemporary concern for the historian of ideas, in physics or outside it. The first book is a detailed account of the fruit of a project that has accumulated tape recordings of knowing interviews with a hundred physicists, from Edoardo Amaldi to Hideki Yukawa, who played a role in the rise of quantum physics. On the evidence given, the questions that were asked and answered, built on preparation and study by historians of science, must make splendid listening. The tapes are not here, nor the manuscripts, nor the microfilms; what we have is a list of all the materials by each man now available. Niels Bohr was last interviewed the day before his death. His entry runs to eight pages of the dates and titles of the letters and manuscripts available somewhere for study! The Minute Books of the $\nabla^2 V$ Club and of the Kapitza Club of Cambridge are also inventoried here, with Munich and Copenhagen records and much else. This is the place for any would-be historian of the subject to start; he must be a brave man who would confront this treasury and attic heap.

Professor van der Waerden, historian and witness, gives us more meat and less promise. He reprints (all done into English as needed) 15 key papers, from Einstein's in 1917 on induced and spontaneous photon emission to the papers of January, 1926, in which Wolfgang Pauli and P. A. M. Dirac independently carry out the new matrix program of the Göttingen experts as applied to the hydrogen spectrum, even in external fields. ("Pauli's paper convinced most physicists that Quantum Mechanics is correct.") In a brief but original and knowing introduction, studded with letters from Werner Heisenberg written to Professor van der Waerden in reply to explicit questions, and with much other published and unpublished testimony, a first effort at a history is presented. The more personal tales are not neglected. Pauli, as usual, spoke caustically to the experts at Göttingen, who wanted "to spoil Heisenberg's physical ideas by your futile mathematics." Heisenberg had his 1925 idea for the matrix mechanics while on vacation, spent on the grassless isle of Helgoland in order to escape the pollen of Göttingen in June. "It was very late at night. I calculated it out painfully," he writes, "and it agreed. Then I climbed onto a rock and saw the sunrise and I was happy."

IFE IN THE HISTORY OF WEST AFRICAN SCULPTURE, by Frank Willett. McGraw-Hill Book Company ($9.95). When Picasso was a student in Paris, abstract African figures in wood opened the eyes of artists to a new vision. One came to expect the image out of black Africa to carry the grotesque intensity of those first surprises. In 1938, however, workers digging the foundation for a house in the western Nigerian city of Ife unearthed a group of life-size bronze heads of classical beauty and individuality, representing men and women recognizably African, cast by a masterly lost-wax technique that is clear evidence of a long history.

These were not even the first wonders out of Ife. The ethnologist Leo Frobenius had brought home from an illicit visit in 1910 a set of terra-cotta heads that he quite egregiously contended were the product of a Greek colony lost for a millennium! Nobody much listened, and not many looked at his finds. Now, however, the pits and shrines in the dark temple groves of Ife have yielded an entire corpus of art in clay and metal. This fresh and exciting book, by a man who has dug at Ife and who spent five years there as curator of its rich museum, illuminates the mystery. The painstaking stratigraphy of the Middle East works poorly in West Africa: the soil of house floors is always stirred up in the making of new ones. Carbon-14 dating is similarly confused, although some charcoal can be dated. Written records go back only a few centuries. Still, by careful study of the artifacts themselves, by serious and skeptical comparison of oral traditions, by a cautious and sensible typology of styles and techniques and above all by an imaginative evolutionary reconstruction of the rise of contemporary usage and ritual—the history of the art of Ife becomes clear.

These are funerary portraits, made in a time of courtly wealth for a funeral rite in which effigies of the dead ruler were paraded formally to establish the succession. The Benin bronzes, plainly related but newer and much more formal, provide a kind of dating; they were seen by Portuguese travelers in the 15th century. The work of Ife thus covered a century or two around the 14th century and itself carried on the tradition of sculpture found in the tin fields of Nok to the north (where some of the stylized terra-cotta portraits look like the Yorubas of today), dated by carbon 14 as being about 2,000 years old.

Thoughtless people have asked how Africans living in grass-roofed huts could make such magnificent art in bronze. (The metal used was often, in fact, a relatively pure copper with less than 1 percent of alloying metal.) The answer is easy. First, was the medieval England of Ely Cathedral, say, much less a land of grass roof and mud wall? Second, one need only look in Yorubaland today to see artists working in clay, wood and bronze with great success in a hundred villages and towns.

This book is an early step in the great enterprise of reconstituting the history of sub-Saharan Africa, a history of innovation and tradition as rich as any land's, as old as predynastic Egypt, still largely hidden in the unexamined and unfamiliar speeches and soils of rain forest and savanna. The plates in this book, many in color, witness the greatness of that still unshared history.

FOSSIL BIRDS, by W. E. Swinton. Trustees of the British Museum (Natural History). British Information Service, New York ($1.50). Next best to a visit to the galleries of the British Museum to see the original specimen of the first fossil bird *Archeopteryx* (three are known in all) is this handsomely illustrated little guide. One learns that the feathery fossil in lithographic stone, a sensation even among the Bavarian quarrymen who found it a century ago, was sold with other fossils to the museum by the medical officer of the district for 700 pounds, which he gave his daughter for her dowry.

The insects were the first organisms to fly, and in the Carboniferous they were big flying fellows, playing the part of "forest birds." Next to fly genuinely—not merely as gliders—were the reptiles, who evolved during 200 million years of flight to a wingspan of nine yards. *Archeopteryx* is the first known bird, fossilized in the fine mud of a vast inland sea. Seabirds are far more commonly fossilized than land birds, the rarest of fossils. The next bird fossils do not appear until 50 million years later; by that time there were many kinds of birds. *Archeopteryx*, about the size of a crow, was already a plausible-looking bird except for the claws on its wings. The next known birds could pass for loons or terns or for big roadrunners (although one Cretaceous form still had teeth). The biggest fossil bird is *Dinornis maximus,* a moa of New Zealand, standing 12 feet high, living on ferns and probably known to, and ended by, the earliest Maoris. A painting of moas done on rock by old Maori artists closes the book, whose many illustrations and reconstructions, mainly by Maurice Wilson, are full of interest.

TOUCH, HEAT AND PAIN, edited by A. V. S. De Reuck and Julie Knight. Little, Brown and Company ($14). PRINCIPLES OF BIOMOLECULAR ORGANIZATION, edited by G. E. W. Wolstenholme and Maeve O'Connor. Little, Brown and Company ($15). Call together a couple of dozen articulate and experienced research workers, set them a subject, allow the most energetic to deliver papers on their own recent work, ask a lot of questions and publish the entire proceedings. That is the design of these two books, recent members (both discussions were held in the summer of 1965) of a long series of general symposia on topics in medicine, biology and psychology sponsored by the Ciba Foundation in London. The two books differ sharply but both are fascinating. The first volume is expert and lively, whether showing signals from the cat's pad or discussing S. S. Stevens' power law of sensed intensity versus stimulus; it is mainly neurophysiology plus a dose of information theory and some psychophysics. It is a first-class survey. The second one is a tour de force. The meeting included such wits as N. W. Pirie ("A group of *émigré* physicists is now moving into biology. . . . The intrusion has been immensely valuable. In the first place it has released large new sources of money. . . .") and fruitful inventors such as John Kendrew, Francis Crick, Donald Caspar and J. D. Bernal. The discussions are genuinely brilliant. The central questions turn out to be the causes of orderly structure on the level of the protein shell of virus particles, spreading down to protein helixes and up to cell membranes and to muscle fibers. The marvelous icosahedrons of the virus shells, the cane weaving of scorpion leg muscle and the book pages of retinal rod membranes are all pictured and discussed with verve. A final session considered the economy of what is the smallest fully free-living form, one of the pleuropneumonia-like organisms, or PPLO's, so small a beast that it owns only a couple of hydrogen ions at a time and has a DNA tape holding the information content of a thin paperback.

FROM FREGE TO GÖDEL: A SOURCE BOOK IN MATHEMATICAL LOGIC, 1879–1931, by Jean van Heijenoort. Harvard University Press ($18.50). A thick volume containing 45 documents on this embattled subject, with learned introductions and a useful apparatus of notes and bibliography. There are four personal letters in the collection, surely a remarkable circumstance, emphasizing the air of controversy and insecurity that besets the search for logical certainty over two generations. The 1902 interchange between Bertrand Russell and Gottlob Frege is here; it is not easy to forget the noble picture of Frege "responding with intellectual pleasure" to the one-page letter from a young stranger that demonstrated to Frege that the fundamental assumption of almost a life's work was in error. Here are the paradoxes and their resolution, from Cesare Burali-Forti to L. E. J. Brouwer, David Hilbert and Hermann Weyl. The last papers center on Kurt Gödel's great proof. Its consequences mark the modern period, the rise of Turing machines and of the theory of recursive functions. Gödel writes in a 1963 note to his famous 1930 paper: "Due to A. M. Turing's work . . . it can be proved rigorously that in *every* consistent formal system that contains a certain amount of finitary number theory there exist undecidable arithmetic propositions."

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