SCIENTIFIC AMERICAN

SURFACE OF THE MOON

SIXTY CENTS

March 1967

16 ways a business machine company put First National City Bank to work in the last year

1

Long-term financing—The bank made a study of methods that could fill company's need for new financing through 1970. The possibilities were analyzed jointly by senior Citibank and company officers.

2

Invested pension fund—As the company's pension fund trustee, Citibank is responsible for the soundness of multimillion dollar investments—the source of retirement benefits for tens of thousands of employees.

3

Advice on foreign cash collections—The bank outlined to the company how payments of European customers in their own currencies at local Citibank branches can eliminate expenses for multiple money exchanges.

4

Credit lines around the world—Citibank maintains multimillion dollar credit lines in local currencies for the company in the U.S. and 20 foreign countries...used in more than two dozen ways, from financing imports to help in buying real estate abroad.

5

Stock transfer agent—As major transfer agent for the company, Citibank's data processing equipment keeps tabs on 26,000 shareholders, coding each one 11 ways—location, age, sex, type of ownership, etc. The bank also disburses stock dividends.

6

Services securities—The company maintains two safekeeping accounts at the bank for stocks, bonds, notes, C.D.'s, etc. Coupons are clipped, securities received, stored and forwarded from Citibank's vaults at 20 Exchange Place, New York.

7

Help at international conventions—When the company's Latin American branch managers convened in Puerto Rico, a bank officer was on hand to change their currencies into dollars. When the company displayed its equipment at a convention in Greece, Citibank's Athens branch issued a 4 million drachma credit to company's agent to cover customs duties.

8

Feedback on performance of new machines—The bank was the company's first customer for a new check sorting and encoding machine and gave company engineers an early report on performance. (It was excellent.) Company's product development people consult Citibank on banking problems new machines might help solve.

9

Voluntary restraint program—Company and Citibank officers discussed techniques for foreign financing that would meet the company's needs within guidelines set by the President. For example, Eurodollar financing, loans from foreign lenders backed by Citibank credit, foreign debentures, etc.

10

Invested foundation funds—The company funds a multimillion dollar foundation account from which contributions for educational and other worthy causes are drawn. Citibank acts as investment adviser.

11

Foreign exchange transactions—Citibank handled foreign remittances for the company, converted proceeds of foreign sales and dividends into dollars.

12 to 16 etc.

Important routine services—Citibank economists and senior officers discussed present and future business conditions both at the bank and at company headquarters . . . Citibank issues hundreds of letters of credit to the company...wires advice on remittances over $50,000 ...sends the "Monthly Summary" (confidential for customers) which gives a concise picture of economic conditions in 45 countries...buys commercial paper for company's accounts, etc.

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

FIRST NATIONAL CITY BANK

399 PARK AVENUE, NEW YORK, N.Y. 10022 • MEMBER FEDERAL DEPOSIT INSURANCE CORP.

Edward Forbes
(1815-1854)

Woodcarving by William Ransom
Photographed by Max Yavno

"Forbes was certainly the most brilliant and inspiring naturalist of his day – a day when it was still possible to make original contributions to knowledge in several departments of nature.... he held posts successively as Professor of Botany in London, as Palaeontologist to the Geological Survey, and as Professor of Natural History in Edinburgh; but to my mind the best description in brief form is that he was the pioneer of Oceanography – the science of the sea."[1]

"It must suffice to add that all the sciences concerned [in Oceanography] – Physics, Chemistry, Geology, Zoology, Botany, Physiology, and Geography – have problems for the oceanographer awaiting solution...."[2]

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[1] Sir William A. Herdman, *Founders of Oceanography and Their Work,* Edward Arnold and Company, London, 1923, p. 33.

[2] *Op. cit.,* p. 329.

INTERACTIONS OF DIVERSE DISCIPLINES

To those classical sciences which gave birth to oceanography are now added the sustaining disciplines of engineering, operations research, economic analysis, the computer sciences, and the new management sciences. All except botany are found on Planning Research Corporation's professional staff of five hundred scientists, engineers, and mathematicians. Interactions of their disciplines, on multidisciplined teams, form the most powerful calculus yet achieved for the solution of world-wide problems, including those related to ocean space.

Industry and governments are invited to inquire about Planning Research experience in planning the economic and organizational structure necessary for an undersea research operation and its land and sea facilities. Write or telephone Mr. Stanley L. Gendler, Vice President for Engineering.

PLANNING RESEARCH CORPORATION

Home office: 1100 Glendon Avenue, Los Angeles, California 90024

Established 1845 **SCIENTIFIC AMERICAN** March 1967 Volume 216 Number 3

ARTICLES

DEPARTMENTS

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THE COVER

The lurid photograph of the moon on the cover has a definite purpose: to provide information on the nature of the lunar surface (see "The Surface of the Moon," page 60). It is based on two pictures taken by Ewen Whittaker of the University of Arizona. First a photograph of the moon was made through a filter that transmitted ultraviolet radiation. Then a photograph was made through a filter that passed infrared radiation. Next a negative of the ultraviolet image was superposed on a positive of the infrared image. Finally a positive of this black-and-white sandwich was used to produce the red plate used in the cover illustration and a negative of the same image was used to produce the blue plate. The resulting picture separates those areas of the moon that reflect more ultraviolet and less infrared from those that reflect more infrared and less ultraviolet. There is as yet no satisfactory explanation of how the lunar surface material became differentiated to produce the result shown. The round blue spot at lower left is the crater Aristarchus; the larger blue spot at upper right, the crater Plato. The red streaks at lower right radiate from Copernicus, which does not appear.

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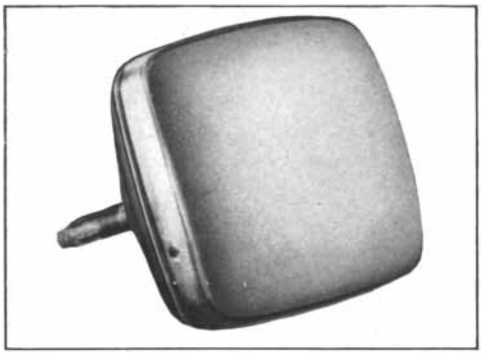
We crucible-tested over 50,000 phosphors last year. Any one of them might solve a problem for you.

Phosphors are an essential ingredient in solid-state electroluminescent displays.



Sylvania developed rare earth europium phosphors to add brightness to color television.

Sylvania is always testing phosphors. In a year's time, we examine more than 50,000 different kinds. They're formulated in small crucibles and studied for their emissions in ultraviolet, infra-red, cathode ray and daylight.

That's because we're always looking for better phosphors for TV, lighting, sorting, tracing and identifying. And other uses.

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We're always hard at work on new developments. How about *your* product development? Maybe our phosphors can help you solve a couple of problems. Write for free samples. Let us have an idea of your application and the information you need.

Sylvania Electric Products Inc., Chemical & Metallurgical Division, Towanda, Pennsylvania 18848.

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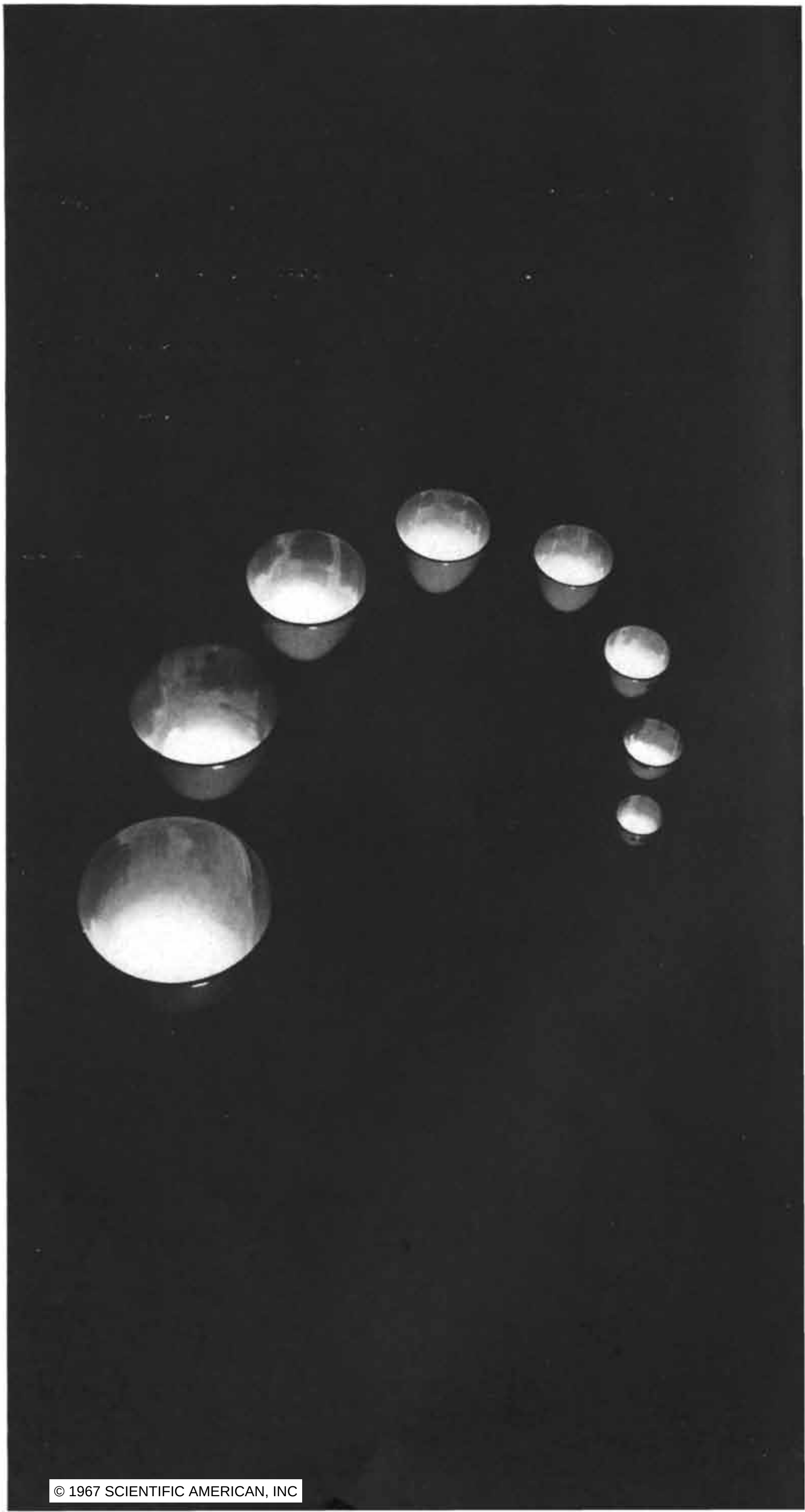

LETTERS

Sirs:

The article by Burke M. Smith on the polygraph in your January issue is one that more properly should have been published, if at all, in *Popular Mechanics* or *Reader's Digest*—certainly not in *Scientific American*.

This article is a rehash of the same biased criticisms of the polygraph as already put out by Dearman, Kubis *et al.*, and it further indicates that the psychiatrist-psychologist group has entered on a crusade to discredit the polygraph lie-detection technique. For some reason psychologists have felt themselves qualified to act as arbiters of the validity and reliability of this technique. They have done this with little or no reference to the actual techniques used by qualified and reputable polygraphists. Researches conducted by psychologists on the polygraph have been based primarily on the testing of college students in fictitious crime situations. Conspicuously absent have been searching inquiries as to the utility and accuracy of the polygraph technique in actual case applications. The psychologists have erroneously assumed that the psychophysiologic reactions in fictitious examinations occur in the same way as they do in actual criminal testing. Obviously such research will be misleading as to the actual validity and reliability of the polygraph technique.

It is immediately evident to any polygraphist that Dr. Smith is poorly informed as to actual polygraph procedures. He refers to "control" questions, and what he has to say about them indicates that he has no understanding of what they are. He refers to pitfalls in the interpretation of chart interpretation, implying that polygraphists are unaware of them. He has quite a bit to say about countermeasures, quoting statistics as to how easily the polygraphist can be "beaten," again based on testing college students in sham theft situations. But he and Dr. Kubis completely ignore the fact that persons who are telling the truth in actuality simply do not try to "beat the test." It is only the person who is concealing information in an actual case situation who will attempt countermeasures. From these and other inaccuracies in the article it could be said that Dr. Smith has not even read *Truth and Deception* by Reid and Inbau, the most definitive work on the subject.

Why must the polygraphist be saddled with the requirement that he be 100 percent accurate? Even if a tenth of the scare stories such as the *one* mentioned by Smith were true, there remains one indisputable fact: the polygraph examination given by a competent examiner is the most accurate system yet devised to determine whether or not a person is telling the truth. Errors in diagnostic techniques in other fields such as medicine and psychology are accepted as inevitable risks. But when a polygraphist makes one error in 1,000 examinations, he is branded as a charlatan and the whole technique is referred to as little better than tea-leaf reading. Can psychologists and psychiatrists bring forth proof that even one of their hundreds of procedures, techniques or tests is as valid and as reliable as properly conducted, actual polygraph examinations? The frequent contradictory opinions offered by psychiatrists in court, one against the other, has become a laughing matter. In the trial of Jack Ruby, psychiatrists, neurologists and one psychologist varied considerably about whether or not Ruby was a psychomotor epileptic variant. Five said he was and seven said he was not.

Polygraphists are not unmindful of the ethical and moral considerations involved in their work. The rules for standards of professional conduct of the American Polygraph Association are as strict as any to be found in any profession. The polygraphist is just as concerned with being able to exonerate an unjustly accused person as he is with detecting the criminal. In fact, far more people are cleared of suspicion and unjust accusation by the polygraph than are found to be untruthful. However, in considering the moral aspect of polygraph examinations a point can be reached where overconcern for the criminal and wrongdoer approaches the "bleeding heart" and "sob sister" stage. There is no absolute right to privacy. If the use of the polygraph is an invasion of privacy, then it can be said that every investigative step and every preemployment inquiry is an invasion of privacy. What about preemployment physical examinations, typing tests, dexterity tests, psychological personality tests and IQ tests? Are not these invasions of privacy? Does the right to work really mean that anyone who wants a particular job must be given it? If this were so, then every rapist, child-molester, alcoholic, narcotic addict or murderer who wants a sensitive job must be hired! It is the polygraph that so often is the only way to expose the unsuitable. No physical or mental test ever detected a thief or a traitor.

Admittedly there have been abuses in the use of polygraph examinations, and there are some polygraphists who are not competent. The proper answer to correcting this situation is through licensing and control of polygraphists, and all ethical polygraphists are seeking this. Other professions have had to correct some of their practices, but not by outlawing the profession.

GEORGE W. HARMAN

Director
John E. Reid and Associates,
Personnel Security Analysts
San Francisco, Calif.

Sirs:

Thank you for publishing the excellent article by Burke M. Smith on the polygraph. Objective analysis such as Smith's is sorely needed to contradict the claims of polygraph purveyors.

I should like to bring Dr. Smith's article up to date in reference to the number of states that have outlawed the use of "lie detectors" in employment relations. In addition to Massachusetts, Oregon, California and Alaska (which are listed by Smith), the following states have similar statutes: Rhode Island, New Jersey, Maryland, Delaware, Washington and Hawaii. The cities of Akron,

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Ohio, and Shively, Ky., and both the city and the county of Baltimore also have local statutes forbidding the use of polygraphs as "lie detectors" in employment relations. In addition, several other state legislatures have debated antipolygraph statutes. In both New York and Wisconsin statutes were passed by both houses of the respective legislatures but were vetoed by Governor Rockefeller and Governor Knowles. In several other state legislatures (including Connecticut, Illinois, Michigan, Missouri and Ohio) antipolygraph statutes were passed in at least one house.

I should also like to expand on one other area of the Smith article. Only two paragraphs of this article relate specifically to the ethical problems involved in the use of the polygraph as a "lie detector." No reference is made to what I believe is the fundamental question. The use of the polygraph in employment relations reverses the basic Anglo-Saxon tenet that a person is innocent until proved guilty.

When all employees in an establishment are required to take a "lie detector" test to prove their individual innocence, then workers are put in the position of being guilty until proved innocent. To say that the taking of a test is voluntary is a clear evasion. Unfortunately the unsubstantiated claims of those with vested interests in the polygraph have led to a generally misinformed public and therefore an employee who refuses a test is under suspicion by his fellow employees as well as by his employer.

The only sure protection for a worker is not to gamble on the "lie box" game. A worker who refuses the gamble joins such distinguished Americans as former Assistant Secretary of Defense Arthur Sylvester, former Director of Naval Intelligence Rear Admiral Rufus Taylor and Representative John E. Moss. Secretary Sylvester refused a "lie detector" test when a suggestion was made during an investigation of an information leak that all defense officials be tested. In his article Dr. Smith referred to the Moss committee hearings. The following exchange took place between Congressman Moss and Admiral Taylor during those hearings:

Moss: "Of course, Admiral, I have since April of last year been directing a staff study of polygraphs. We have been attempting to get together a great deal of information so that we would be in a position to understand the full subject and prepare for these hearings.

"I started this assignment with no definite opinion on polygraphs. I had never given them much thought, but as a result of the experience of the past 12 months I would refuse most emphatically to take one, unless perhaps I had my personal physician, a psychiatrist, and my lawyer with me and had their evaluation of what was going on."

Admiral Taylor: "I really can hardly blame you for taking that view, particularly in view of some of the things I have heard in sitting in this hearing on the sidelines.... I have misgivings about this thing, too. What I feel to be a lot of pseudo-scientific nonsense that has been discussed here.... But if you want my considered opinion as someone advising you to what your rights [are] and where your best interests lie, I would say don't take a polygraph examination."

I am hopeful that articles such as Dr. Smith's will assist in the campaign to add to the number of states that have outlawed "lie detectors" in employment relations.

BERTRAM GOTTLIEB

College of Business Administration
University of Iowa
Iowa City, Iowa

Sirs:

Geoffrey Burbidge and Fred Hoyle incorrectly attribute the discovery of quasars to me alone ["The Problem of the Quasi-stellar Objects," by Geoffrey Burbidge and Fred Hoyle; SCIENTIFIC AMERICAN, December, 1966]. The 1960 work that led to the identification of the first three objects of the class (3*C* 48, 3*C* 196 and 3*C* 286), and to the discovery of their peculiar spectrum, ultraviolet excess and light variation, was done jointly with Thomas A. Matthews, then at the Owens Valley Radio Astronomy Observatory and now at the University of Maryland.

ALLAN R. SANDAGE

Mount Wilson and Palomar Observatories
Pasadena, Calif.

ERRATUM

On page 42 of the article "The Repair of DNA" (SCIENTIFIC AMERICAN, February) reference is made to John M. Clark, Jr., of the University of California at Berkeley. The correct name is Alvin John Clark.

50 AND 100 YEARS AGO

SCIENTIFIC AMERICAN

MARCH, 1917: "A few weeks ago, before even the rumors of the great Russian revolution had reached us, we suggested that if we wished to strike a decisive blow on the battlefields of Europe, we could do so most effectively by arming and supplying the many millions of reserve troops in the Russian army, which cannot be used at the front because they are lacking in munitions and equipment. Russia has now become, like us, a democracy. Hence there are compelling reasons of sentiment and mutual aspirations that would render our munitionment of Russia particularly appropriate. There is no finer fighting material in Europe today than the stalwart Russian peasant. Now that the army has been purged of the poison of Prussian intrigue and relieved of the burden of bureaucratic incompetency, we believe that if its millions were amply equipped, it would move forward to an overwhelming victory. The Pacific Ocean is not infested with submarines, and shipment of munitions by way of Vladivostok and the Trans-Siberian Railway would be unimpeded. Moreover, our munition ships, under convoy of our own and the Allied fleets, would be able to make deliveries through the ports of northern Russia."

"There are more than 100 aeroplanes in flight service in the United States to-day, as compared with 12 a year ago. Five hundred will be in service, it is understood, at a relatively early date. There are 50 rated military aviators to-day, in addition to 50 officer-students at San Diego. There are 50 reserve corps aviators in various stages of advancement. About 650 elementary licenses have been issued to aviators in this country since the beginning of the art. A goodly number of men to whom these licenses were issued are not now available for service."

"Since the preliminary announcement that he had found an apparent relation between the sunspot period and the behavior of the polar caps of Mars, M. Antoniadi has published detailed observations that appear to establish this relation in a striking manner. Except in two years, 1862 and 1877, when local conditions on Mars may have disturbed the effects of solar radiation, he finds that whenever sunspots are large and numerous the melting of the Martian polar caps is rapid, and that whenever sunspots are small and few the melting of the caps takes place slowly."

"A steel that does not stain or tarnish is one of the latest new materials and will be welcomed by the housewife as a real boon. It is called 'stainless steel' and from it table cutlery is being made that not only takes a beautiful polish but also preserves this appearance under all circumstances. The new chromium-alloy steel was discovered in England but is now being made in the United States and sold as table cutlery. Its possibilities, however, are by no means limited to cutlery. One can readily imagine to what countless uses a stainless and rustless metal can be put."

SCIENTIFIC AMERICAN

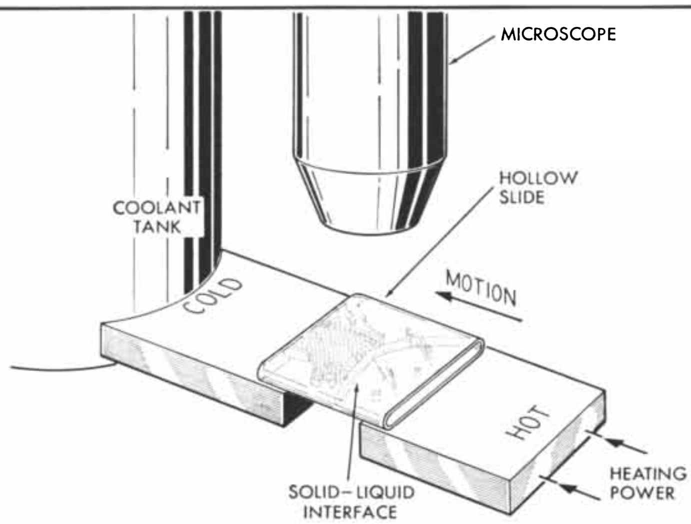
MARCH, 1867: "M. Jean Dollfus, a large manufacturer in France, finding upon investigation that the women employed in his factories lost 40 per cent of their children in the first year, whereas the average mortality at that age in France is only 18 per cent, determined with a princely philanthropy to go to the root of the evil by paying every recent mother six weeks' wages without work. The result has been the reduction of infant mortality in the district from 40 to 25 per cent in three years. Other manufacturers have introduced a similar plan, by inducing the employees to contribute to a fund. The subject is of importance everywhere, and some provision of the kind is demanded by humanity for both mothers and children."

"Prof. Tyndall has recently unfolded in a lecture at the Royal Institution the result of his investigations of the effect of sounds upon flames. He exhibited a most wonderful set of experiments on flames or gas jets thrown through glass tubes. These tubes were of all varieties of length and size, and by singing to them, reciting lines of poetry to them and sounding tuning-forks at them the lecturer exhibited from each flame a distinct note or song, and the room was

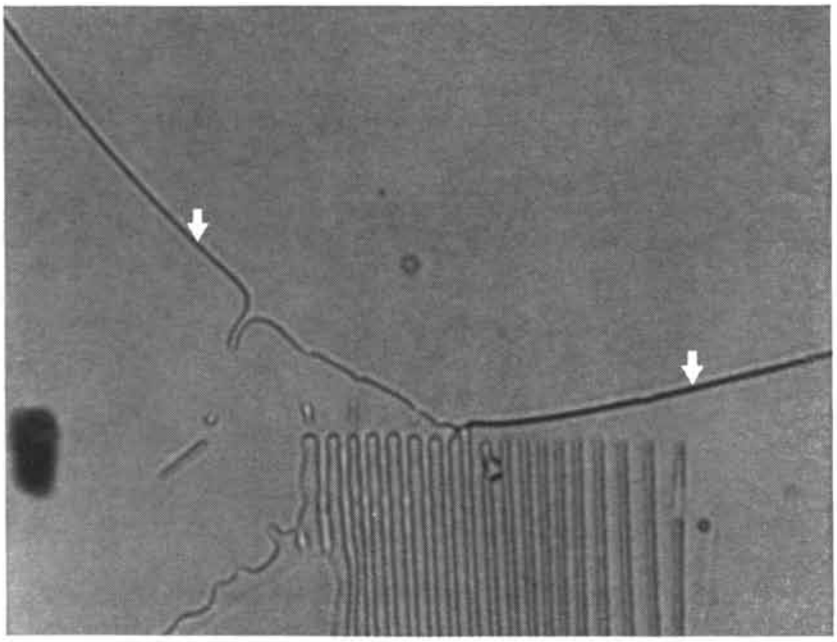
Report from

BELL LABORATORIES

Inside Solidifying Metals



Experimental setup in which photographs such as that below were taken. The glass slide or cell—containing a liquid which freezes like a metal—is placed between hot and cold blocks of brass. This produces a temperature difference along the slide. A solid-liquid interface then forms between the two blocks. By moving the slide toward the cold block at a constant rate, one can observe the steady growth of the crystal under the microscope.



Bell Laboratories' model (200x) permits physical simulation of a eutectic phase diagram for an alloy such as lead-tin. Diagram relates liquid proportions (horizontal scale) to temperature (vertical).

Two different liquids were put into a single slide . . . hexachloroethane on the left and carbon tetrabromide on the right. After a brief period, the liquids formed a graded mixture, from 100% of one at the left to 100% of the other at the right. The mixture was partially frozen, then photographed with the slide stationary. The solid-liquid interface (arrows) then showed the freezing point for every possible composition.

The "grid" under the solid-liquid interface is made up of alternate solid layers of the two chemicals (the eutectic region).

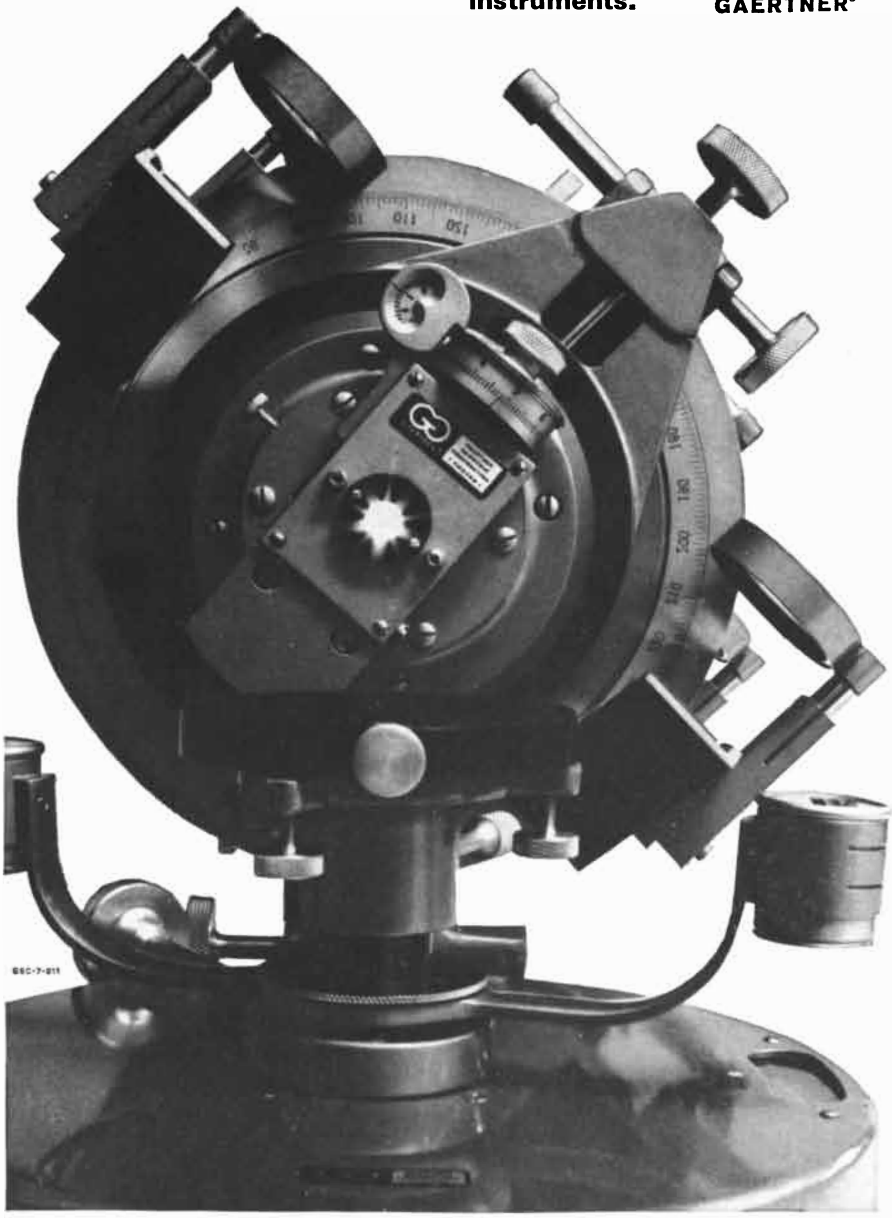
At Bell Telephone Laboratories, metallurgist Kenneth A. Jackson has devised transparent models of solidifying molten metals. With these models, we can now study what happens inside a metal as it freezes. This gives us a tool which promises to improve existing alloys and will perhaps help us find new and better ones.

The models are hollow microscope slides (diagram) containing such organic liquids as camphor or carbon tetrabromide. These compounds are among the few transparent substances whose molecules freeze without having to rotate into a specific orientation. Metal atoms act the same way, hence the similarity in freezing behavior.

Various modes of metal-crystal growth—planar, dendritic (tree-like branching) and cellular—have been studied in detail with this technique. Also, the solidification of alloys has been simulated (photo). To do this, liquids with freezing characteristics corresponding to those of two metals are mixed and cooled. With this procedure, Jackson and J. D. Hunt (now at the University of Oxford) observed, for the first time, the process by which the "equiaxed" zone forms in alloy castings. This is a zone of relatively small crystals, usually found in the center of an alloy casting. The new technique shows that the equiaxed zone results from "branches" melted from dendritic crystals. As the alloy cools, freezing begins at the outer surface, producing dendrites which project inward toward the hotter, liquid center. Branches, melted from these growing dendrites, are carried to the center of the casting to form the crystals of the equiaxed zone.

Until now, the only methods for studying metal freezing were laborious . . . cutting, polishing and etching, for instance. The new technique is not only simpler but also reveals hitherto unknown details of crystal growth.

Bell Telephone Laboratories
Research and Development Unit of the Bell System



at times filled with harmonies as of many aeolian harps. One flame was so sensitive that, although it was 20 inches long, the slightest tap on a distant anvil knocked it down to eight inches, and the dropping of a sixpence threw it into a violent commotion. Another flame could not tolerate the utterance of a letter S, and a hiss from some one, which the Professor invited, made it flare and shiver in the most ludicrous way."

"M. Niepce de St. Victor has recently communicated to the French Académie des Sciences the results of his latest researches, having for their object to obtain and fix the colors of nature by means of photography. His paper is full of important new facts, proving that the fixation of natural colors on the photographic tablet as a practical and available result, which for a long time has been considered as a dream, is perhaps not so far from being fully realized—not as a mere scientific experiment but as the completion of the splendid discovery of photography."

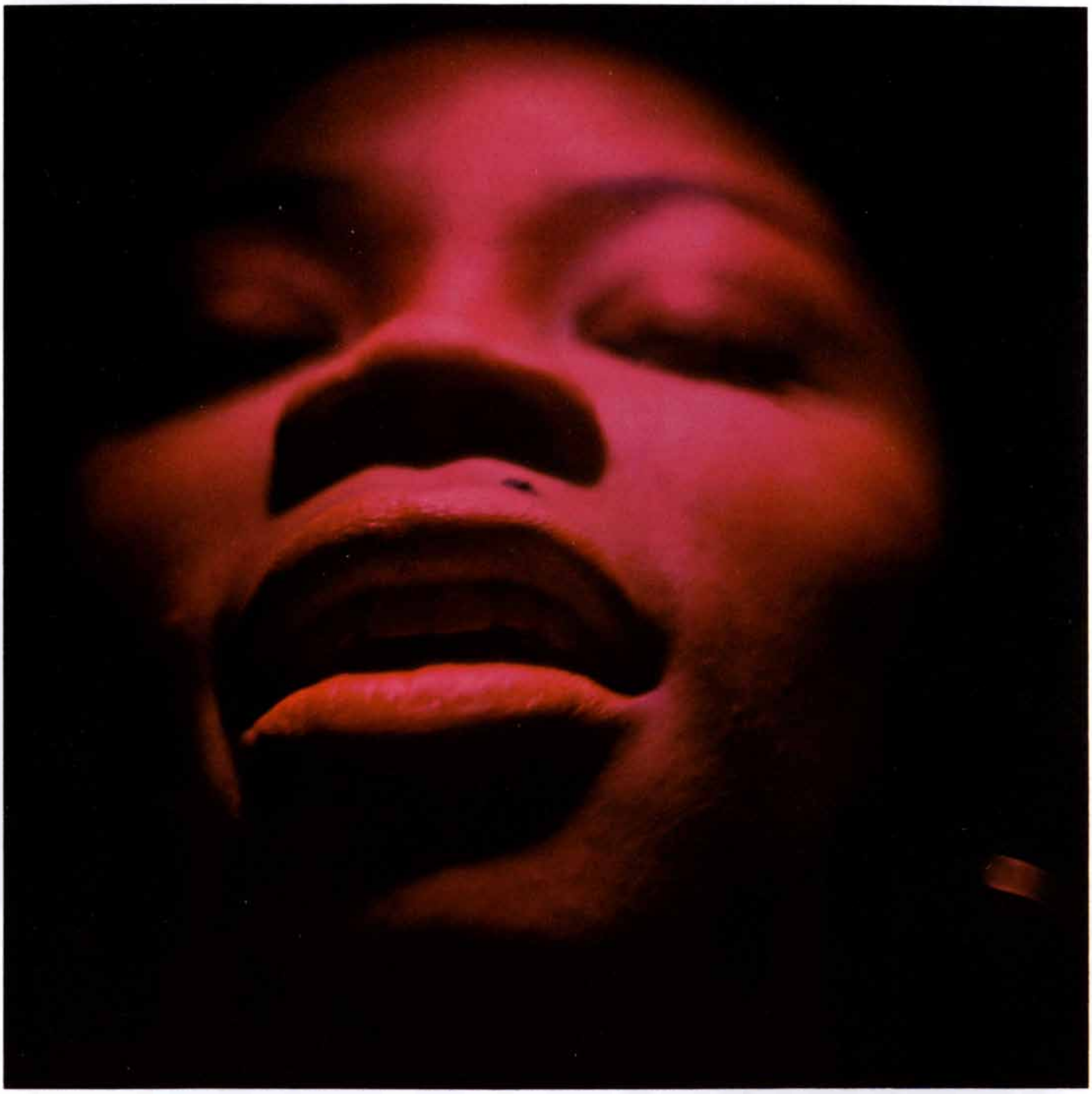
"As a result of the late strike in the iron trade in England, a scheme has been started at Darlington, which appears to have the sanction of the ironworkers of the district and is principally under their management, to erect rolling mills on the co-operative principle."

"M. Bazin has obtained clear submarine photographs at a depth of 300 feet in his diving studio by means of the electric light thrown through water-tight lens windows upon the objects that are to be photographed. The value of this invention in submarine surveying is obvious."

"The latest report to the Atlantic Telegraph Company states that its profits from the time of the opening of the line, July 28, 1866, have been at the rate of 25 per cent per annum on its capital ($3,000,000), although the business is said to be only about one-twelfth of the capacity of the two cables, in consequence of the exorbitant rate charged. With a view to still greater profits, the rate was reduced to $1.25 per word on the 1st of March. One hundred words per minute can be sent through each cable."

"A volcano in the moon is said to be in active eruption. The crater called Linné has been lately observed to be obscured, and it is said that the same darkness was observed on this spot in 1788."

Moving air is easy... controlling it takes an expert



The truly great blues singer is a marvel of complex simplicity. She stamps a simple song as her own by adding subtle variations in tempo, dynamics or timbre. Or she reduces a complex composition to a straight-from-the-heart ballad that is remembered by millions as "our song." This is what makes a pro. In the business of moving air, our Design Engineers are pros, whose latest development is the Crossflo® blower. This compact, quiet unit works against high pressures, and produces a ribbon of air. The Crossflo's straight through principle allows a limitless width of air, too. Data and samples readily available.
The Torrington Manufacturing Company.

TORRINGTON

United States: Torrington, Conn./Van Nuys, Calif./Rochester, Ind. **Canada:** Oakville, Ont. **England:** Swindon, Wilts. **Belgium:** Nivelles **Australia:** Sydney

Watching the Oceans: A report from General Dynamics

Wouldn't it be nice if you could plan a vacation and *know* weeks ahead that the weather would be good?

Actually, 24-hour local forecasting is right almost 85 percent of the time. But longer range prediction—on which can depend anything from a vacation trip to the success of a year's wheat crop—is far less certain.

Even though information from hundreds of full-time land weather stations is supplemented by measurements in the upper atmosphere and reports from weather satellites, a vital link in the chain has been missing.

Weather is essentially born or modified as a result of the interaction of sun and air with the oceans that cover two-thirds of the earth's surface.

Oceanography and meteorology can be considered two faces of the same coin—the study of the total marine environment. And relatively little is known about it yet.

Seagoing "weather bureau":

What has been needed to fill the gap is an oceanographic "weather bureau."

It would have to stay in place in the deepest part of the sea, regardless of storm or current; collect environmental information from the atmosphere, the surface and the depths; send that information regularly and correctly back to land.

And it would have to do all these jobs without human presence for long periods of time.

With a network of such sea stations seeded throughout the world, oceanic information could be integrated with that obtained from land stations and from space. Meteorologists could determine the patterns that will create the weather next week, or perhaps months hence.

Oceanographers could analyze the subsurface currents, the levels of dissolved nutrients in the water, the migratory patterns of fish to anticipate their location for commercial fishing.

And with navigation lights, fog horns and radar beacons at known positions, such a network would provide invaluable navigation aid for ships.

Monster buoys:

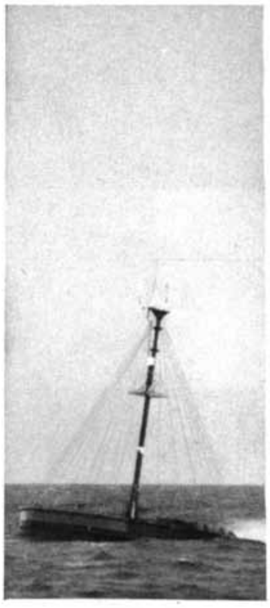
Today, the beginning of such a worldwide system may be at hand—an ocean data station, more commonly known as a monster buoy, developed and built by General Dynamics for the United States Navy's Office of Naval Research.

The first prototype has been undergoing sea trials since 1964, collecting and sending its information through calm and hurricane.

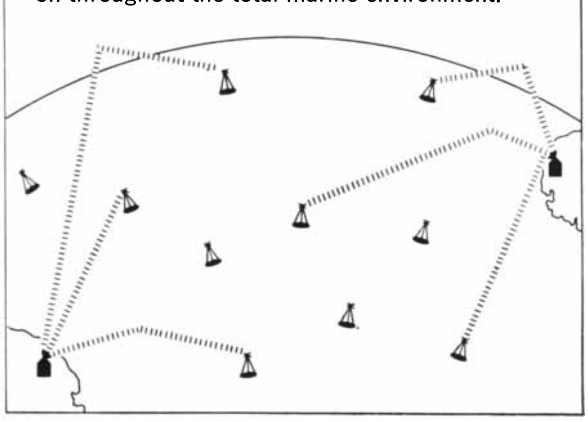
This ocean data system consists of a giant pieplate-shaped buoy, forty feet in diameter and seven and one-half feet deep, containing an assortment of environmental measuring devices and the electronic and power equipment to collect and transmit to shore the data acquired.

It can be "locked" in place, moored to an ocean floor as deep as 30,000 feet, by a plaited nylon cable only two inches thick. Although the buoys are presently designed to operate for a year at a time without human maintenance, the conventional propane-powered generator systems that provide electricity for the buoy's operation carry a two-year supply of fuel.

Unlike a traditional ship, which exaggerates the motion of waves, particularly in side-to-side pendulum-like rolling, the symmetrical, discus-shaped buoy hull follows the slope of the waves, reducing pitching and rolling to a minimum. Its stability keeps its omnidirectional antenna in proper position to radio information to a shore analysis station.



Someday a large network of ocean data stations could simultaneously supply information about weather and oceanographic factors throughout all the oceans. Land-based scientists could receive an almost minute-by-minute picture of what is going on throughout the total marine environment.



Defies hurricanes:

No one really knows just how rough the weather might get in a full-scale typhoon or hurricane—defined only as a cyclonic storm with winds of over 75 miles per hour—because of the obvious difficulty of humans taking accurate measurements under such conditions.

The General Dynamics/ONR ocean data station was designed to withstand winds of 160 miles per hour and waves 60 feet high.

Buoy Bravo, the first prototype, remained in place under winds of 110 miles per hour and waves 50 feet high during Hurricane Betsy in 1965, with no interruption in its flow of information. Its elastic nylon mooring line permits the buoy to drift slightly and then pull back to position without dragging its "anchor" of steel chain.

Typhoons and hurricanes, luckily occur only occasionally. But the intensely corrosive environment of the sea is constant. For protection, the buoy's steel hull, mast and antennae are coated with inorganic zinc and several layers of vinyl.

A hundred tests:

An assortment of sensors can be located on the 38-foot-high mast and on the radial spokes of the discone antenna to measure wind, humidity, precipitation, radiation (from the sky and reflected back from the sea), barometric pressure, and compass bearing.

Others inside and immediately under the hull will read water temperature at the surface, wave height, period and direction.

Clamped along the mooring line at regular intervals underwater, still others will measure temperature, pressure and salinity and determine the structure of subsurface layers of the depths.

Inside the hull, rugged electronic components and circuitry will acquire, store and transmit information from as many as 100 separate sensors.

These subsystems will be packaged

in containers purged with nitrogen and hermetically sealed to provide an inert, absolutely dry, environment. The buoy at sea will provide better conditions for electronic equipment than does a dust-temperature-humidity-controlled laboratory ashore.

The data acquisition system will look at every sensor once an hour (or it can be monitored more often; individual sensors can be checked continually). Measurements will go into both a magnetic core memory with a capacity of 24 hours of data and a recorder that will store a full year's information.

Every six hours a ground station will interrogate the buoy, commanding it to transmit all information accumulated during the past twenty-four hours. Each discharge of data will provide an eighteen-hour overlap, giving scientists a continuous record.

The ground station will also instruct the buoy to transmit data on the particular one of its three radio channels which will assure best reception on shore of long-distance "bounce" off the ionosphere.

Benefit for all nations:

A few prototype monster buoys do not, to be sure, constitute a full-scale oceanic environmental survey. They do provide a starting point for a truly international system—one in which all nations would share, and from which all would benefit.

But now that the practicality of an ocean data station has been proved, the many elements of a total system are already being worked out: the optimum number and locations of stations to provide simultaneous coverage throughout the seas; ways to integrate at central analysis stations the ocean data with that from land and space; techniques of maintenance and replenishment for the seaborne network; development of devices to measure many kinds of subsurface phenomena.

The day when data stations will be dotted throughout the oceans for a genuine oceanographic-meteorological environmental watch could come within a decade.

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GENERAL DYNAMICS

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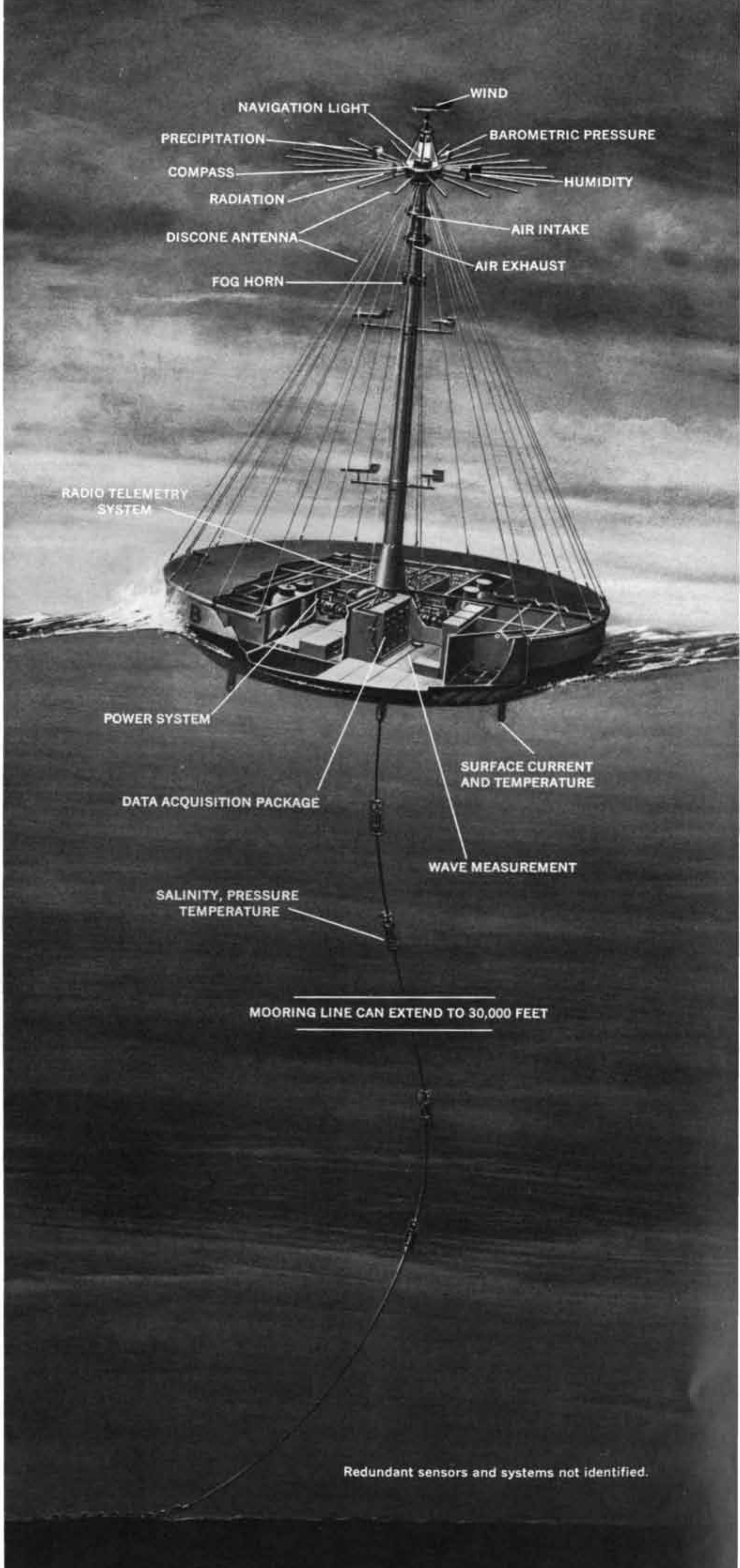
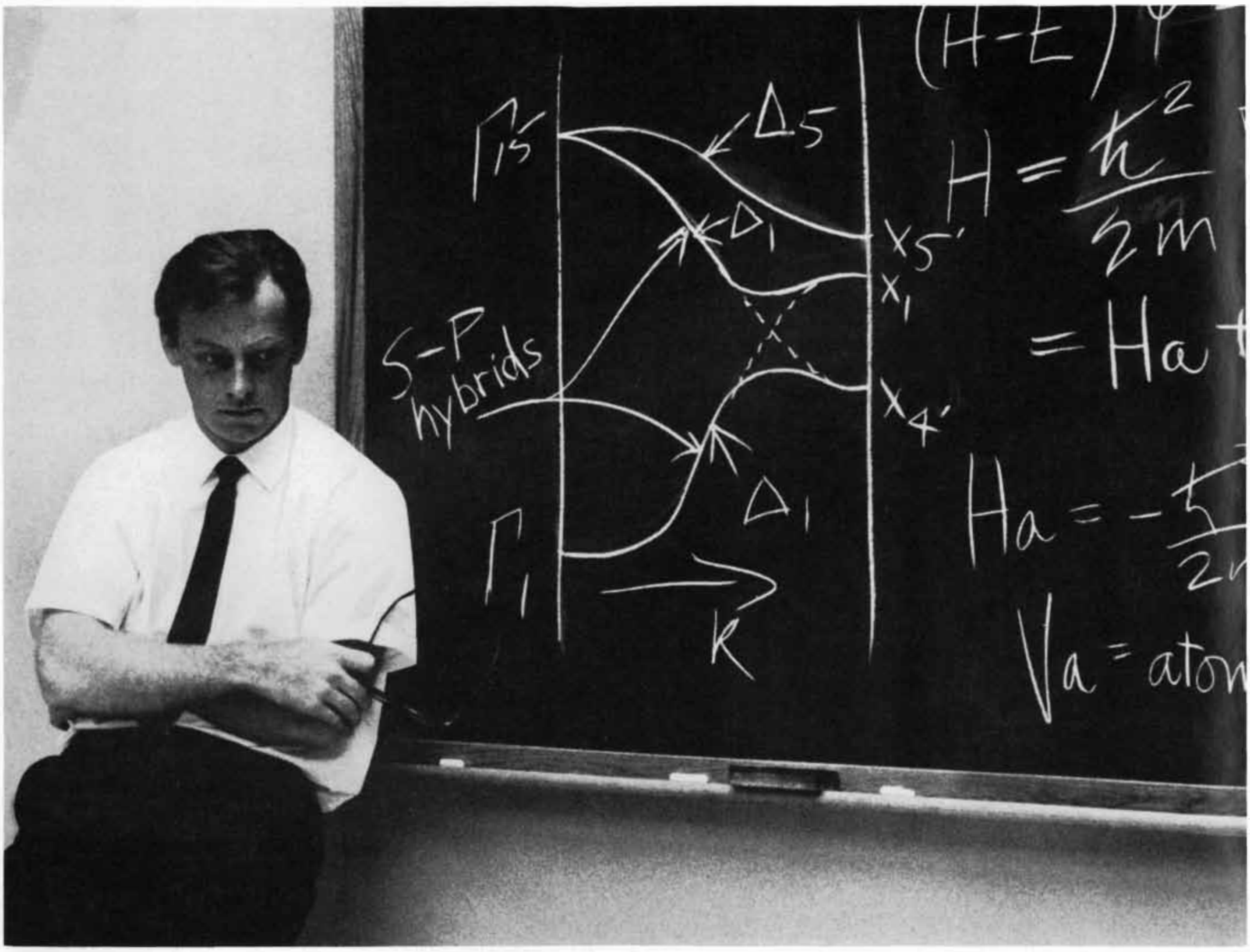
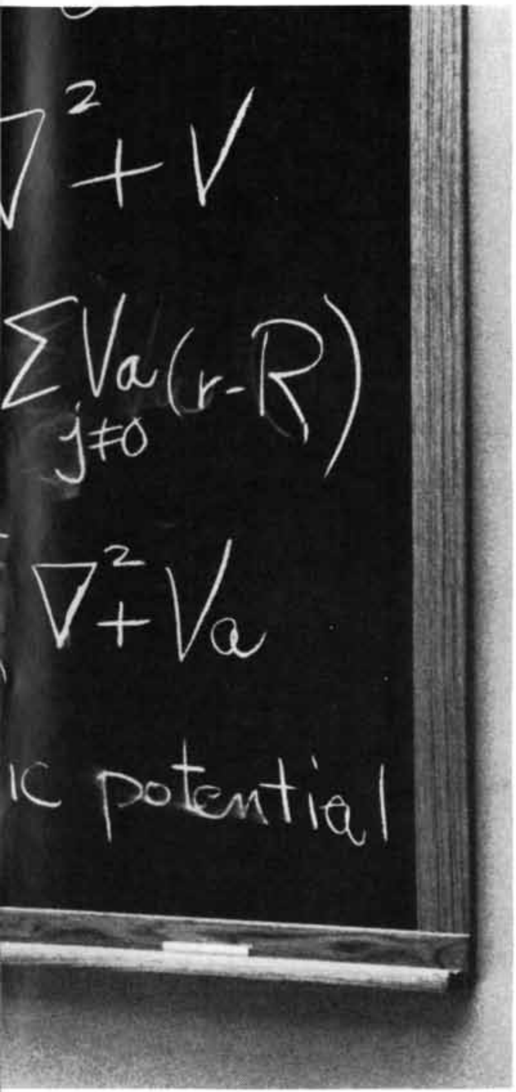


The loneliness of the long-distance thinker.





In the gently rolling countryside of Maryland, we maintain the Research Institute for Advanced Studies (RIAS). There, scientists spend long, patient hours in the laboratory. Or perhaps they merely sit alone and think. Their work is dedicated to solving problems that are beyond the limits of present scientific knowledge.

The sleepy Maryland countryside might seem an odd place for RIAS, where intellectual ferment and radical innovation are all part of a day's work.

The Institute itself is an airy modern building which nestles comfortably on the side of a hill. It occupies little more than an acre of the 29-acre site, much of it wooded.

There are usually some fifty scientists and their assistants at work on perhaps a dozen major programs.

Each project is aimed at a specific answer to one of the mysteries of aerospace and related technology. But the work is so advanced that the answers also increase the fundamental knowledge of our world and its universe.

That's a big order, and it may sound grandiose. In actuality, the research scientist's job is often a hard, lonely, grinding one. And it may take years of work before a theory can be proved —or disproved—by physical evidence.

RIAS projects are diverse. Presently, one project has physicists and metallurgists exploring the inmost structure of materials. Why do certain metals and minerals react the way they do to their environment? How can we modify the basic structure of materials to meet demands far beyond today's most advanced technology?

Another RIAS project is concerned with microbes that require no light for growth. They could be used in a system that efficiently meets food, oxygen and waste-disposal requirements on long space flights.

In a third project, physicists discovered a chemical mechanism that controls burning rate in primary explosives and solid rocket oxidizers.

RIAS was established in 1955, the first such research organization in the aerospace field. Since then, its scientists have explored scores of problems in many fields.

As to the value of such research, Dr. Homer E. Newell of NASA compares basic research to sowing seed, applied research to tending the crops, and development to reaping the harvest. We feel it makes good sense to do all three.

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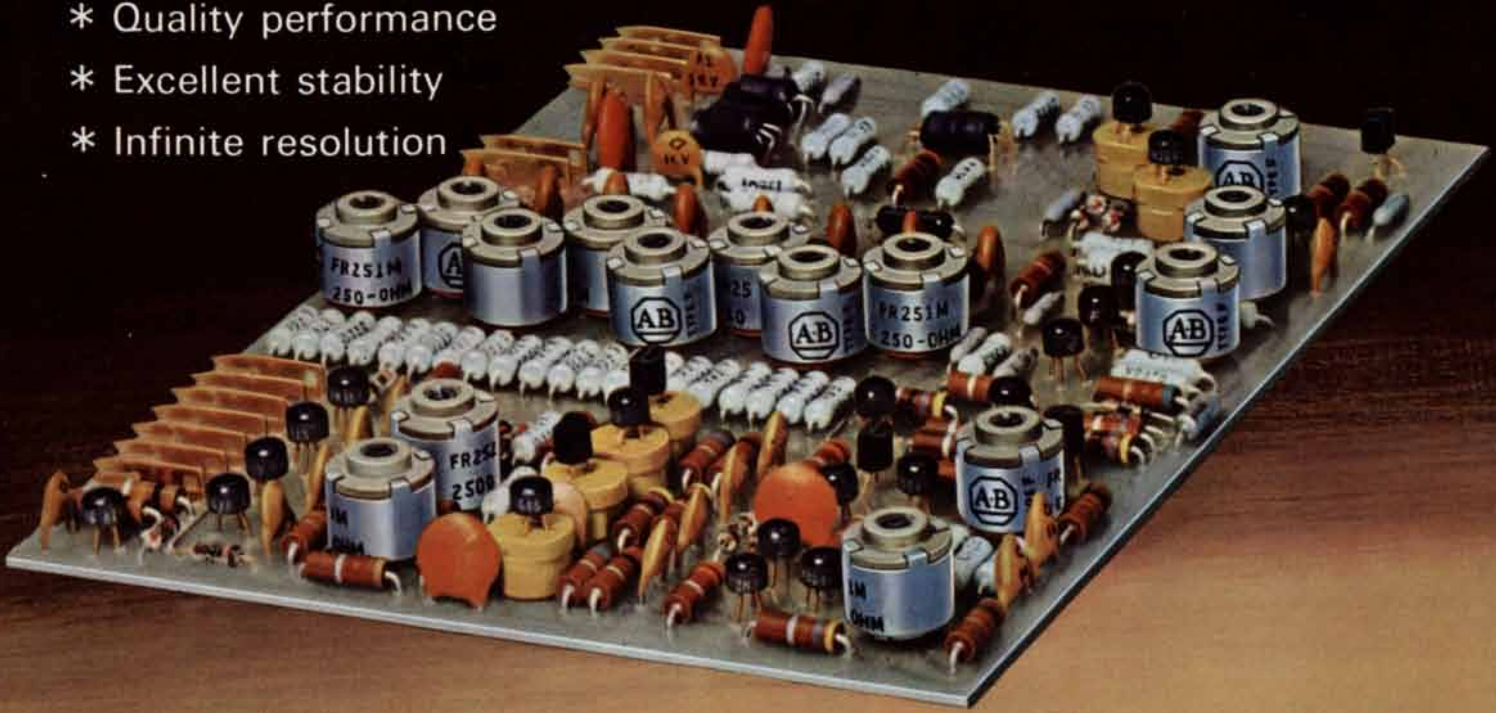

One of the 5-inch by 6½-inch Wavetek printed circuit cards, showing 15 of the 25 Allen-Bradley Type F hot molded variable resistors and numerous hot molded fixed resistors used in the Model 111 VCG function generator.

Type F variable resistor with pin type terminals for mounting directly on printed wiring boards. Rated ¼ watt at 70°C. Total resistance values from 100 ohms to 5 megohms.

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Wavetek Model 111 VCG generates sine, square, triangle, and ramp waves from 0.0015 Hz to 1 MHz, and offers precision control of the frequency of the waveforms by external voltage.

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THE AUTHORS

GEORGE M. WOODWELL ("Toxic Substances and Ecological Cycles") is an ecologist at the Brookhaven National Laboratory. His original field of study was botany; he received an undergraduate degree in that subject at Dartmouth College in 1950 and master's and doctor's degrees from Duke University in 1956 and 1958 respectively. From 1957 to 1962, when he joined the Brookhaven staff, he taught at the University of Maine. He notes that his article "in no way reflects an official attitude of the U.S. Atomic Energy Commission or Brookhaven National Laboratory."

E. F. ADOLPH ("The Heart's Pacemaker") is emeritus professor of physiology at the University of Rochester. He was graduated from Harvard College in 1916, obtained a Ph.D. from Harvard in 1920 and taught zoology at the University of Pittsburgh before going to the School of Medicine and Dentistry at the University of Rochester in 1925 as assistant professor of physiology. He has been interested in a number of regulatory processes in physiology, particularly the beginnings of such processes in the individual. In 1953 he was president of the American Physiological Society. Although he retired in 1960, he continues to work regularly in his laboratory at the university.

TAHSİN ÖZGÜÇ ("Ancient Ararat") is chairman of the department of Near Eastern archaeology at the University of Ankara. He describes himself as an "archaeologist, explorer and excavator." Özgüç received a Ph.D. from the University of Ankara in 1942. Four years earlier he had his first experience in field archaeology, accompanying a Turkish mission at work in various parts of Anatolia. In 1945 he was head of an expedition to Central Anatolia and made excavations at Sivas, Ankara and Karahüyük. In 1948 he began a dig at Kültepe (ancient Kanish); his work on the site he describes in his article began in 1959. Özgüç is a member of the Turkish Historical Foundation and the German Archaeological Association.

ALBERT R. HIBBS ("The Surface of the Moon") is senior staff scientist at the Jet Propulsion Laboratory of the California Institute of Technology and also science editor of the National Broadcasting Company. With a bachelor's degree in physics from Cal Tech, a master's degree in mathematics from the University of Chicago and a Ph.D. in physics from Cal Tech, he joined the laboratory 15 years ago and has been involved in various research projects on astronomy and engineering for space ventures. In broadcasting he has been host of the weekly television program "Exploring" and the weekly radio program "World of Science." He has also acted as consultant to several local boards of education in Southern California and to the state board of education on curriculum planning, programs for gifted children and the special training of science teachers.

ALBERT BANDURA ("Behavioral Psychotherapy") is professor of psychology at Stanford University. He was graduated from the University of British Columbia in 1949, received a Ph.D. from the State University of Iowa in 1952 and joined the Stanford faculty in 1953. He writes: "I am primarily interested in the development of social-learning theory and its applications to issues concerning personality development, psychopathology and psychotherapy. Most theories of learning rely heavily on a limited range of principles established on the basis of studies of animals or of human learning in one-person situations. In order to account adequately for social phenomena it is necessary to extend and revise these principles through studies of the acquisition and modification of human behavior in social situations."

HUGO BOYKO ("Salt-Water Agriculture") is president of the World Academy of Art and Science. An ecologist by training and experience, he retired in 1961 as ecological adviser to the government of Israel but has continued his activity in this area. While he was traveling recently an associate wrote: "When one mentions 'Dr. Boyko,' one usually thinks of 'the Boykos,' because they are a scientific husband-wife team. Elisabeth Boyko, a horticulturist, has been Hugo Boyko's co-worker since they met in Vienna back in the '20's." Of Hugo Boyko the associate wrote: "He is a very original thinker who never ceases to surprise me with the simplicity of his approach and the solutions he presents to problems. In fact, by his humanistic approach, his encyclopedic knowledge and his proficiency in so many fields outside his scientific work (in his younger years he used to be an excellent athlete and he still is an accomplished carpenter) he reminds me of the outstanding men of the Renaissance." Boyko received a doctorate in botany and zoology from the University of Vienna in 1930 and taught there for five years before moving to Palestine.

LYNWOOD BRYANT ("The Origin of the Automobile Engine") is associate professor of history at the Massachusetts Institute of Technology, where he teaches courses in American intellectual history, American economic history and the history of transportation in the U.S. Bryant was graduated from Harvard College in 1929 with a degree in English literature; in 1938 he obtained a master's degree in American civilization at Harvard. He writes: "My chief professional interest is in the history, philosophy and sociology of technology. In this area I have no academic training, but I have considerable experience." He is also interested in technical writing and publication, which was his major interest while he was director of the M.I.T. Press from 1957 to 1962. In addition to his other work Bryant serves as master of McCormick Hall at M.I.T.

WILLIAM B. SAMPSON, PAUL P. CRAIG and MYRON STRONGIN ("Advances in Superconducting Magnets") are physicists at the Brookhaven National Laboratory. Sampson, who is in the accelerator department, went to Brookhaven from the University of Toronto, where he received a Ph.D. in 1963. His major interest is the application of high-field superconductivity to high-energy physics, particularly in equipment for handling accelerator beams. Craig, who with Strongin is in the physics department at Brookhaven, was graduated from Haverford College in 1954 and obtained a Ph.D. from the California Institute of Technology in 1959. Since 1962 he has been leader of the cryogenics group at Brookhaven; his interests include the Mössbauer effect and the properties of matter at ultralow temperatures. Strongin, a member of the cryogenics group, was graduated from Rensselaer Polytechnic Institute in 1956 and received a Ph.D. from Yale University in 1962. His current research interests are thin films and the possibility of obtaining high-temperature superconductors.

JOHN C. KENDREW, who in this issue reviews *Phage and the Origins of Molecular Biology*, edited by John Cairns, Gunther S. Stent and James D. Watson, is deputy chairman of the Medical Research Council's Laboratory of Molecular Biology in Cambridge, England.


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Toxic Substances and Ecological Cycles

Radioactive elements or pesticides such as DDT that are released in the environment may enter meteorological and biological cycles that distribute them and can concentrate them to dangerous levels

by George M. Woodwell

The vastness of the earth has fostered a tradition of unconcern about the release of toxic wastes into the environment. Billowing clouds of smoke are diluted to apparent nothingness; discarded chemicals are flushed away in rivers; insecticides "disappear" after they have done their job; even the massive quantities of radioactive debris of nuclear explosions are diluted in the apparently infinite volume of the environment. Such pollutants are indeed diluted to traces—to levels infinitesimal by ordinary standards, measured as parts per billion or less in air, soil and water. Some pollutants do disappear; they are immobilized or decay to harmless substances. Others last, sometimes in toxic form, for long periods. We have learned in recent years that dilution of persistent pollutants even to trace levels detectable only by refined techniques is no guarantee of safety. Nature has ways of concentrating substances that are frequently surprising and occasionally disastrous.

We have had dramatic examples of one of the hazards in the dense smogs that blanket our cities with increasing frequency. What is less widely realized is that there are global, long-term ecological processes that concentrate toxic substances, sometimes hundreds of thousands of times above levels in the environment. These processes include not only patterns of air and water circulation but also a complex series of biological mechanisms. Over the past decade detailed studies of the distribution of both radioactive debris and pesticides have revealed patterns that have surprised even biologists long familiar with the unpredictability of nature.

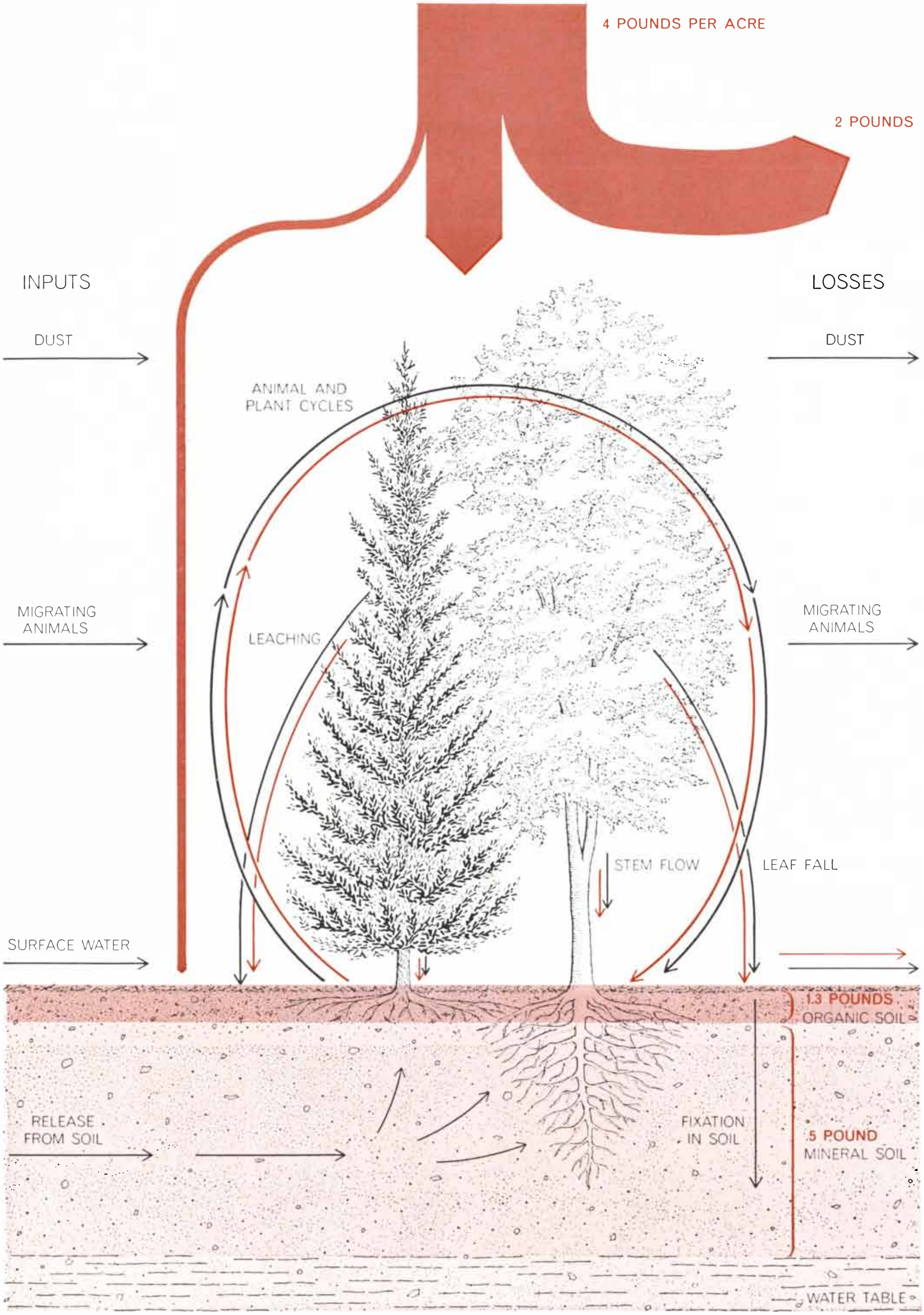
Major contributions to knowledge of these patterns have come from studies of radioactive fallout. The incident that triggered worldwide interest in large-scale radioactive pollution was the hydrogen-bomb test at Bikini in 1954 known as "Project Bravo." This was the test that inadvertently dropped radioactive fallout on several Pacific islands and on the Japanese fishing vessel *Lucky Dragon*. Several thousand square miles of the Pacific were contaminated with fallout radiation that would have been lethal to man. Japanese and U.S. oceanographic vessels surveying the region found that the radioactive debris had been spread by wind and water, and, more disturbing, it was being passed rapidly along food chains from small plants to small marine organisms that ate them to larger animals (including the tuna, a staple of the Japanese diet).

The U.S. Atomic Energy Commission and agencies of other nations, particularly Britain and the U.S.S.R., mounted a large international research program, costing many millions of dollars, to learn the details of the movement of such debris over the earth and to explore its hazards. Although these studies have been focused primarily on radioactive materials, they have produced a great deal of basic information about pollutants in general. The radioactive substances serve as tracers to show the transport and concentration of materials by wind and water and the biological mechanisms that are characteristic of natural communities.

One series of investigations traced the worldwide movement of particles in the air. The tracer in this case was strontium 90, a fission product released into the earth's atmosphere in large quantities by nuclear-bomb tests. Two reports in 1962—one by S. Laurence Kulp and Arthur R. Schulert of Columbia University and the other by a United Nations committee—furnished a detailed picture of the travels of strontium 90. The isotope was concentrated on the ground between the latitudes of 30 and 60 degrees in both hemispheres, but concentrations were five to 10 times greater in the Northern Hemisphere, where most of the bomb tests were conducted.

It is apparently in the middle latitudes

FOREST COMMUNITY is an integrated array of plants and animals that accumulates and reuses nutrients in stable cycles, as indicated schematically in black. DDT participates in parallel cycles (*color*). The author measured DDT residues in a New Brunswick forest in which four pounds per acre of DDT had been applied over seven years. (Studies have shown about half of this landed in the forest, the remainder dispersing in the atmosphere.) Three years after the spraying, residues of DDT were as shown (in pounds per acre).


4 POUNDS PER ACRE
2 POUNDS
INPUTS
LOSSES
DUST
DUST
ANIMAL AND PLANT CYCLES
MIGRATING ANIMALS
LEACHING
MIGRATING ANIMALS
STEM FLOW
LEAF FALL
SURFACE WATER
1.3 POUNDS
ORGANIC SOIL
RELEASE FROM SOIL
FIXATION IN SOIL
.5 POUND
MINERAL SOIL
WATER TABLE

that exchanges occur between the air of upper elevations (the stratosphere) and that of lower elevations (the troposphere). The larger tests have injected debris into the stratosphere; there it remains for relatively long periods, being carried back into the troposphere and to the ground in the middle latitudes in late winter or spring. The mean "half-time" of the particles' residence in the stratosphere (that is, the time for half of a given injection to fall out) is from three months to five years, depending on many factors, including the height of the injection, the size of the particles, the latitude of injection and the time of year. Debris injected into the troposphere has a mean half-time of residence ranging from a few days to about a month. Once airborne, the particles may travel rapidly and far. The time for one circuit around the earth in the middle latitudes varies from 25 days to less than 15. (Following two recent bomb tests in China fallout was detected at the Brookhaven National Laboratory on Long Island respectively nine and 14 days after the tests.)

Numerous studies have shown further that precipitation (rain and snowfall) plays an important role in determining where fallout will be deposited. Lyle T. Alexander of the Soil Conservation Service and Edward P. Hardy, Jr., of the AEC found in an extensive study in Clallam County, Washington, that the amount of fallout was directly proportional to the total annual rainfall.

It is reasonable to assume that the findings about the movement and fallout of radioactive debris also apply to other particles of similar size in the air. This conclusion is supported by a recent report by Donald F. Gatz and A. Nelson Dingle of the University of Michigan, who showed that the concentration of pollen in precipitation follows the same pattern as that of radioactive fallout. This observation is particularly meaningful because pollen is not injected into the troposphere by a nuclear explosion; it is picked up in air currents from plants close to the ground. There is little question that dust and other particles, including small crystals of pesticides, also follow these patterns.

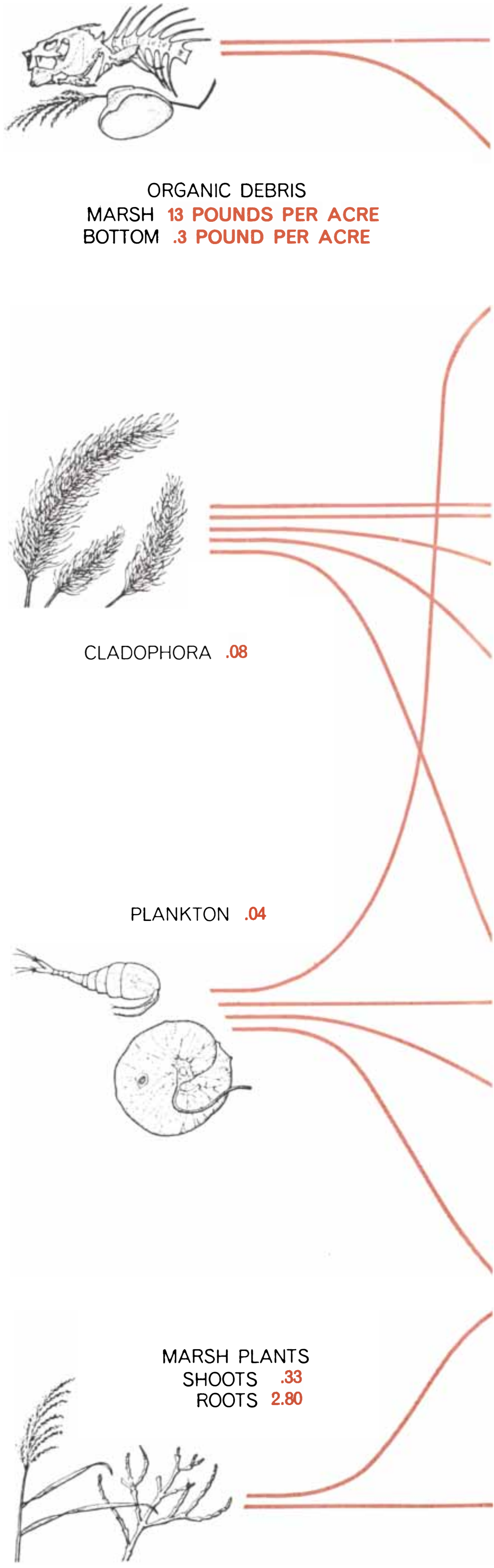
From these and other studies it is clear that various substances released into the air are carried widely around the world and may be deposited in concentrated form far from the original source. Similarly, most bodies of water—especially the oceans—have surface currents that may move materials five to 10 miles a day. Much higher rates, of course, are found in such major oceanic currents as the Gulf Stream. These currents are one more physical mechanism that can distribute pollutants widely over the earth.

The research programs of the AEC and other organizations have explored not only the pathways of air and water transport but also the pathways along which pollutants are distributed in plant and animal communities. In this connection we must examine what we mean by a "community."

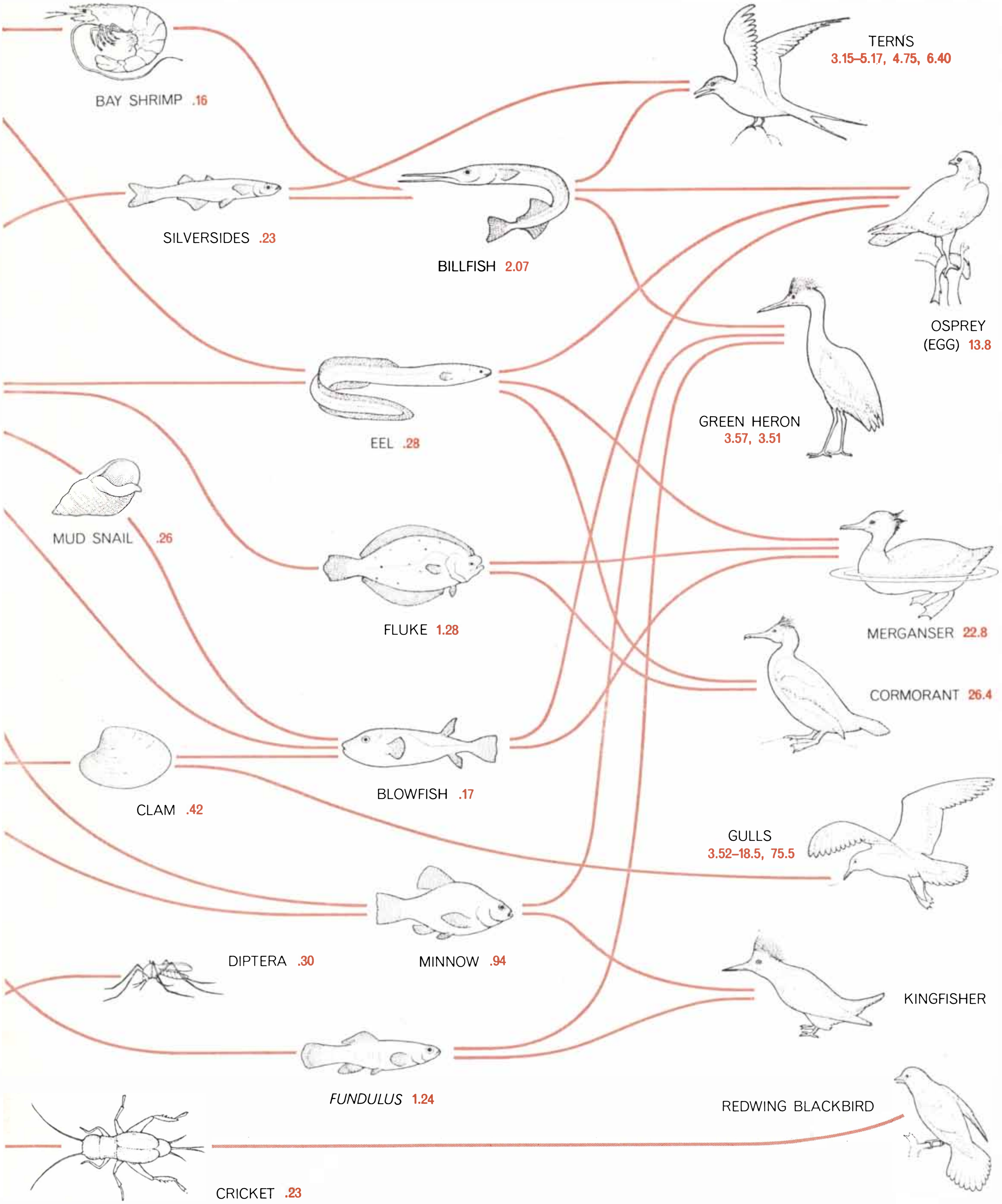
Biologists define communities broadly to include all species, not just man. A natural community is an aggregation of a great many different kinds of organisms, all mutually interdependent. The basic conditions for the integration of a community are determined by physical characteristics of the environment such as climate and soil. Thus a sand dune supports one kind of community, a freshwater lake another, a high mountain still another. Within each type of environment there develops a complex of organisms that in the course of evolution becomes a balanced, self-sustaining biological system.

Such a system has a structure of interrelations that endows the entire community with a predictable developmental pattern, called "succession," that leads toward stability and enables the community to make the best use of its physical environment. This entails the development of cycles through which the community as a whole shares certain resources, such as mineral nutrients and energy. For example, there are a number of different inputs of nutrient elements into such a system. The principal input is from the decay of primary minerals in the soil. There are also certain losses, mainly through the leaching of substances into the underlying water table. Ecologists view the cycles in the system as mechanisms that have evolved to conserve the elements essential for the survival of the organisms making up the community.

One of the most important of these cycles is the movement of nutrients and energy from one organism to another along the pathways that are sometimes called food chains. Such chains start with plants, which use the sun's energy to synthesize organic matter; animals eat the plants; other animals eat these herbivores, and carnivores in turn may constitute additional levels feeding on the herbivores and on one another. If the lower orders in the chain are to survive and endure, there must be a feedback of nutrients. This is provided by decay organisms (mainly microorganisms) that break down organic debris



FOOD WEB is a complex network through which energy passes from plants to herbivores and on to carnivores within a biologi-



cal community. This web showing some of the plants and animals in a Long Island estuary and along the nearby shore was developed by Dennis Puleston of the Brookhaven National Laboratory. Numbers indicate residues of DDT and its derivatives (in parts per million, wet weight, whole-body basis) found in the course of a study made by the author with Charles F. Wurster, Jr., and Peter A. Isaacson.

into the substances used by plants. It is also obvious that the community will not survive if essential links in the chain are eliminated; therefore the preying of one level on another must be limited.

Ecologists estimate that such a food chain allows the transmission of roughly 10 percent of the energy entering one level to the next level above it, that is, each level can pass on 10 percent of the energy it receives from below without suffering a loss of population that would imperil its survival. The simplest version of a system of this kind takes the form of a pyramid, each successively higher population receiving about a tenth of the energy received at the level below it.

Actually nature seldom builds communities with so simple a structure. Almost invariably the energy is not passed along in a neatly ordered chain but is spread about to a great variety of organisms through a sprawling, complex web of pathways [*see illustration on preceding two pages*]. The more mature the community, the more diverse its makeup and the more complicated its web. In a natural ecosystem the network may consist of thousands of pathways.

This complexity is one of the principal factors we must consider in investigating how toxic substances may be distributed and concentrated in living communities. Other important basic factors lie in the nature of the metabolic process. For example, of the energy a population of organisms receives as food, usually less than 50 percent goes into the construction of new tissue, the rest being spent for respiration. This circumstance acts as a concentrating mechanism: a substance not involved in respiration and not excreted efficiently may be concentrated in the tissues twofold or more when passed from one population to another.

Let us consider three types of pathway for toxic substances that involve man as the ultimate consumer. The three examples, based on studies of radioactive substances, illustrate the complexity and variety of pollution problems.

The first and simplest case is that of strontium 90. Similar to calcium in chemical behavior, this element is concentrated in bone. It is a long-lived radioactive isotope and is a hazard because its energetic beta radiation can damage the mechanisms involved in the manufacture of blood cells in the bone marrow. In the long run the irradiation may produce certain types of cancer. The route of strontium 90 from air to man is rather direct: we ingest it in leafy vegetables, which absorbed it from the soil or received it as fallout from the air, or in milk and other dairy products from cows that have fed on contaminated vegetation. Fortunately strontium is not usually concentrated in man's food by an extensive food chain. Since it lodges chiefly in bone, it is not concentrated in passing from animal to animal in the same ways other radioactive substances may be (unless the predator eats bones!).

FALLOUT is distributed around the earth by meteorological processes. Deposits of strontium 90, for instance, are concentrated between 30 and 60 degrees north, as shown by depth of color on the map and by the curve (*right*). Points on the chart represent individual samples. The data are from a study made in 1963 and 1964 by Robert J. List and colleagues in several U.S. agencies. Such

Quite different is the case of the radioactive isotope cesium 137. This isotope, also a fission product, has a long-lived radioactivity (its half-life is about 30 years) and emits penetrating gamma rays. Because it behaves chemically like potassium, an essential constituent of all cells, it becomes widely distributed once it enters the body. Consequently it is passed along to meat-eating animals, and under certain circumstances it can accumulate in a chain of carnivores.

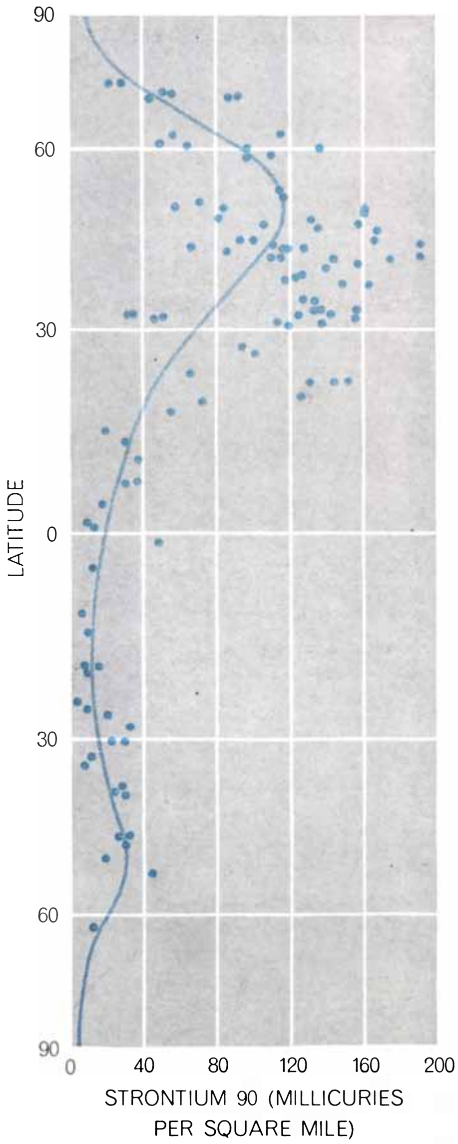
A study in Alaska by Wayne C. Hanson, H. E. Palmer and B. I. Griffin of the AEC's Pacific-Northwest Laboratory showed that the concentration factor for cesium 137 may be two or three for one step in a food chain. The first link of the chain in this case was lichens growing in the Alaskan forest and tundra. The lichens collected cesium 137 from fallout in rain. Certain caribou in Alaska live mainly on lichens during the winter, and caribou meat in turn is the principal diet of Eskimos in the same areas. The investigators found that caribou had accumulated about 15 micromicrocuries of cesium radioactivity per gram of tissue in their bodies. The Eskimos who fed on these caribou had a concentration twice as high (about 30 micromicrocuries per gram of tissue) after eating many pounds of caribou meat in the course of a season. Wolves and foxes that ate caribou sometimes contained three times the concentration in the flesh of the caribou. It is easy to see that in a longer chain, involving not just two animals but several, the concentration of a substance that was not excreted or metabolized could be increased to high levels.

A third case is that of iodine 131, another gamma ray emitter. Again the chain to man is short and simple: The contaminant (from fallout) comes to man mainly through cows' milk, and thus the chain involves only grass, cattle, milk and man. The danger of iodine 131 lies in the fact that iodine is concentrated in the thyroid gland. Although iodine 131 is short-lived (its half-life is only about eight days), its quick and localized concentration in the thyroid can cause damage. For instance, a research team from the Brookhaven National Laboratory headed by Robert Conard has discovered that children on Rongelap Atoll who were exposed to fallout from the 1954 bomb test later developed thyroid nodules.

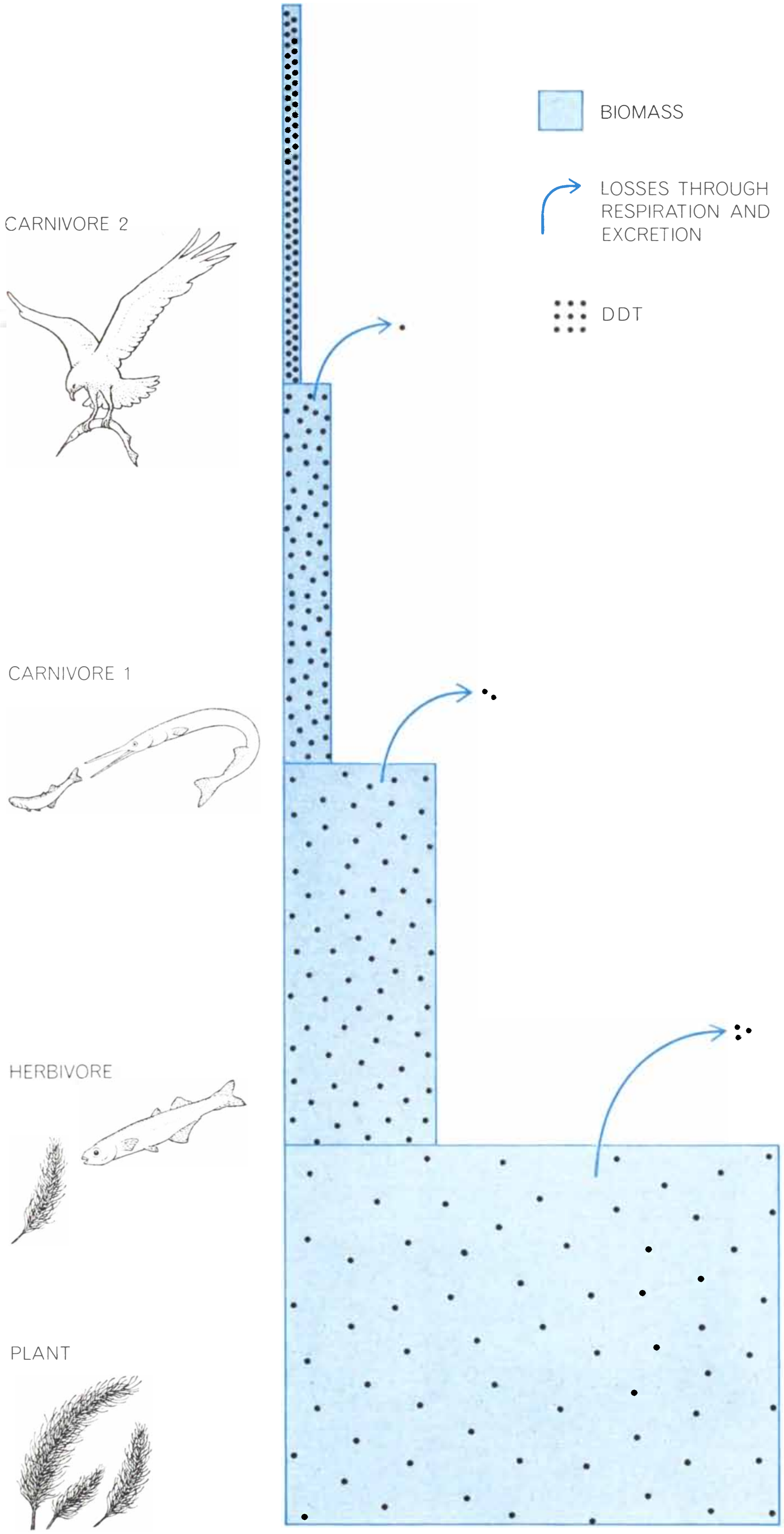
The investigations of the iodine 131 hazard yielded two lessons that have an important bearing on the problem of pesticides and other toxic substances released in the environment. In the first place we have had a demonstration that the hazard of the toxic substance itself often tends to be underestimated. This was shown to be true of the exposure of the thyroid to radiation. Thyroid tumors were found in children who had been treated years before for enlarged thymus glands with doses of X rays that had been considered safe. As a result of this discovery and studies of the effects of iodine 131, the Federal Radiation Council in 1961 issued a new guide reducing the permissible limit of exposure to ionizing radiation to less than a tenth of what had previously been accepted. Not the least significant aspect of this lesson is the fact that the toxic effects of such a hazard may not appear until long after the exposure; on Rongelap Atoll 10 years passed before the thyroid abnormalities showed up in the children who had been exposed.

The second lesson is that, even when the pathways are well understood, it is almost impossible to predict just where toxic substances released into the environment will reach dangerous levels. Even in the case of the simple pathway followed by iodine 131 the eventual destination of the substance and its effects on people are complicated by a great many variables: the area of the cow's pasture (the smaller the area, the less fallout the cow will pick up); the amount and timing of rains on the pasture (which on the one hand may bring down fallout but on the other may wash it off the forage); the extent to which the cow is given stored, uncontaminated feed; the amount of iodine the cow secretes in its milk; the amount of milk in the diet of the individual consumer, and so on.

If it is difficult to estimate the nature and extent of the hazards from radioactive fallout, which have been investigated in great detail for more than a decade by an international research program, it must be said that we are in a poor position indeed to estimate the hazards from pesticides. So far the



studies have not been made for pesticides but it appears that DDT may also be carried in air and deposited in precipitation.



CONCENTRATION of DDT residues being passed along a simple food chain is indicated schematically in this diagram. As "biomass," or living material, is transferred from one link to another along such a chain, usually more than half of it is consumed in respiration or is excreted (*arrows*); the remainder forms new biomass. The losses of DDT residues along the chain, on the other hand, are small in proportion to the amount that is transferred from one link to the next. For this reason high concentrations occur in the carnivores.

amount of research effort given to the ecological effects of these poisons has been comparatively small, although it is increasing rapidly. Much has been learned, however, about the movement and distribution of pesticides in the environment, thanks in part to the clues supplied by the studies of radioactive fallout.

Our chief tool in the pesticide inquiry is DDT. There are many reasons for focusing on DDT: it is long-lasting, it is now comparatively easy to detect, it is by far the most widely used pesticide and it is toxic to a broad spectrum of animals, including man. Introduced only a quarter-century ago and spectacularly successful during World War II in controlling body lice and therefore typhus, DDT quickly became a universal weapon in agriculture and in public health campaigns against disease-carriers. Not surprisingly, by this time DDT has thoroughly permeated our environment. It is found in the air of cities, in wildlife all over North America and in remote corners of the earth, even in Adélie penguins and skua gulls (both carnivores) in the Antarctic. It is also found the world over in the fatty tissue of man. It is fair to say that there are probably few populations in the world that are not contaminated to some extent with DDT.

We now have a considerable amount of evidence that DDT is spread over the earth by wind and water in much the same patterns as radioactive fallout. This seems to be true in spite of the fact that DDT is not injected high into the atmosphere by an explosion. When DDT is sprayed in the air, some fraction of it is picked up by air currents as pollen is, circulated through the lower troposphere and deposited on the ground by rainfall. I found in tests in Maine and New Brunswick, where DDT has been sprayed from airplanes to control the spruce budworm in forests, that even in the open, away from trees, about 50 percent of the DDT does not fall to the ground. Instead it is probably dispersed as small crystals in the air. This is true even on days when the air is still and when the low-flying planes release the spray only 50 to 100 feet above treetop level. Other mechanisms besides air movement can carry DDT for great distances around the world. Migrating fish and birds can transport it thousands of miles. So also do oceanic currents. DDT has only a low solubility in water (the upper limit is about one part per billion), but as algae and other organisms in the water absorb the substance in fats, where it is highly soluble, they make room for more DDT to be dissolved into the water. Accordingly water that never contains more than a trace of DDT can continuously transfer it from deposits on the bottom to organisms.

DDT is an extremely stable compound that breaks down very slowly in the environment. Hence with repeated spraying the residues in the soil or water basins accumulate. Working with Frederic T. Martin of the University of Maine, I found that in a New Brunswick forest where spraying had been discontinued in 1958 the DDT content of the soil increased from half a pound per acre to 1.8 pounds per acre in the three years between 1958 and 1961. Apparently the DDT residues were carried to the ground very slowly on foliage and decayed very little. The conclusion is that DDT has a long half-life in the trees and soil of a forest, certainly in the range of tens of years.

Doubtless there are many places in the world where reservoirs of DDT are accumulating. With my colleagues Charles F. Wurster, Jr., and Peter A. Isaacson of the State University of New York at Stony Brook, I recently sampled a marsh along the south shore of Long Island that had been sprayed with DDT for 20 years to control mosquitoes. We found that the DDT residues in the upper layer of mud in this marsh ranged up to 32 pounds per acre!

We learned further that plant and animal life in the area constituted a chain that concentrated the DDT in spectacular fashion. At the lowest level the plankton in the water contained .04 part per million of DDT; minnows contained one part per million, and a carnivorous scavenging bird (a ring-billed gull) contained about 75 parts per million in its tissues (on a whole-body, wet-weight basis). Some of the carnivorous animals in this community had concentrated DDT by a factor of more than 1,000 over the organisms at the base of the ladder.

A further tenfold increase in the concentrations along this food web would in all likelihood result in the death of many of the organisms in it. It would then be impossible to discover why they had disappeared. The damage from DDT concentration is particularly serious in the higher carnivores. The mere fact that conspicuous mortality is not observed is no assurance of safety. Comparatively low concentrations may inhibit reproduction and thus cause the species to fade away.

That DDT is a serious ecological hazard was recognized from the beginning of its use. In 1946 Clarence Cottam and Elmer Higgins of the U.S. Fish and Wildlife Service warned in the *Journal of Economic Entomology* that the pesticide was a potential menace to mammals, birds, fishes and other wildlife and that special care should be taken to avoid its application to streams, lakes and coastal bays because of the sensitivity of fishes and crabs. Because of the wide distribution of DDT the effects of the substance on a species of animal can be more damaging than hunting or the elimination of a habitat (through an operation such as dredging marshes). DDT affects the entire species rather than a single population and may well wipe out the species by eliminating reproduction.

Within the past five years, with the development of improved techniques for detecting the presence of pesticide residues in animals and the environment, ecologists have been able to measure the extent of the hazards presented by DDT and other persistent general poisons. The picture that is emerging is not a comforting one. Pesticide residues have now accumulated to levels that are catastrophic for certain animal populations, particularly carnivorous birds. Furthermore, it has been clear for many years that because of their shotgun effect these weapons not only attack the pests but also destroy predators and competitors that normally tend to limit proliferation of the pests. Under exposure to pesticides the pests tend to develop new strains that are resistant to the chemicals. The result is an escalating chemical warfare that is self-defeating and has secondary effects whose costs are only beginning to be measured. One of the costs is wildlife, notably carnivorous and scavenging birds such as hawks and eagles. There are others: destruction of food webs aggravates pollution problems, particularly in bodies of water that receive mineral nutrients in sewage or in water draining from heavily fertilized agricultural lands. The plant populations, no longer consumed by animals, fall to the bottom to decay anaerobically, producing hydrogen sulfide and other noxious gases, further degrading the environment.

The accumulation of persistent toxic substances in the ecological cycles of the earth is a problem to which mankind will have to pay increasing attention. It affects many elements of society, not only in the necessity for concern about the disposal of wastes but also in the need for a revolution in pest control. We must learn to use pesticides that have a short half-life in the environment—better yet, to use pest-control techniques that do not require applications of general poisons. What has been learned about the dangers in polluting ecological cycles is ample proof that there is no longer safety in the vastness of the earth.

LOCATION	ORGANISM	TISSUE	CONCENTRATION (PARTS PER MILLION)
U.S. (AVERAGE)	MAN	FAT	11
ALASKA (ESKIMO)			2.8
ENGLAND			2.2
WEST GERMANY			2.3
FRANCE			5.2
CANADA			5.3
HUNGARY			12.4
ISRAEL			19.2
INDIA			12.8-31.0
U.S. CALIFORNIA	PLANKTON		5.3
U.S. CALIFORNIA	BASS	EDIBLE FLESH	4-138
U.S. CALIFORNIA	GREBES	VISCERAL FAT	UP TO 1,600
U.S. MONTANA	ROBIN	WHOLE BODY	6.8-13.9
U.S. WISCONSIN	CRUSTACEA		.41
U.S. WISCONSIN	CHUB	WHOLE BODY	4.52
U.S. WISCONSIN	GULL	BRAIN	20.8
U.S. MISSOURI	BALD EAGLE	EGGS	1.1-5.6
U.S. CONNECTICUT	OSPREY	EGGS	6.5
U.S. FLORIDA	DOLPHIN	BLUBBER	ABOUT 220
CANADA	WOODCOCK	WHOLE BODY	1.7
ANTARCTICA	PENGUIN	FAT	.015-.18
ANTARCTICA	SEAL	FAT	.042-.12
SCOTLAND	EAGLE	EGGS	1.18
NEW ZEALAND	TROUT	WHOLE BODY	.6-.8

DDT RESIDUES, which include the derivatives DDD and DDE as well as DDT itself, have apparently entered most food webs. These data were selected from hundreds of reports that show DDT has a worldwide distribution, with the highest concentrations in carnivorous birds.

The Heart's Pacemaker

A group of specialized cells regulates the fundamental rhythm of an animal's heart. The pacemaker also limits the heart's range of responses to the influences of nerves and hormones

by E. F. Adolph

The heart of a mouse at rest beats about 500 times a minute; in contrast, the elephant's basal heart rate is only 35 beats a minute. In the mouse's lifetime of one to two years its heart totals as many beats as the elephant's does in 25 to 50 years. What governs an animal's heart rate? Obviously it is regulated in part from outside the heart in response to the demands of exercise or stress. But the heart itself has its own pacemaker, regulating its fundamental rhythm and setting limits on its range of rates. Recent experimental investigations in various animals, including observation of the beginnings of the heartbeat in the embryo, have done much to illuminate the operation and regulation of the pacemaker.

The embryonic heart starts beating at a certain age that is characteristic for each animal. In the chick, for instance, the first beats arise at about the 30th hour of the embryo's life [*see top illustration on pages 34 and 35*]. Rhythmic contractions of the heart muscle begin in the right ventricle. A number of hours later the right atrium, or auricle, which meanwhile has taken shape behind the ventricle, also starts to beat. Its beat is faster and it sets the pace, the ventricular cells falling in step with its timing. Finally the venous sinus, which eventually sets apart a group of cells known as the sinoatrial node, develops to the rear of the right atrium, and this structure, beating still faster, takes over the pacemaking function. The sinoatrial node remains the basic pacemaker throughout the animal's life. Other regions of the heart muscle contract rhythmically according to its lead, but most of them lose the capacity to initiate beats of their own accord.

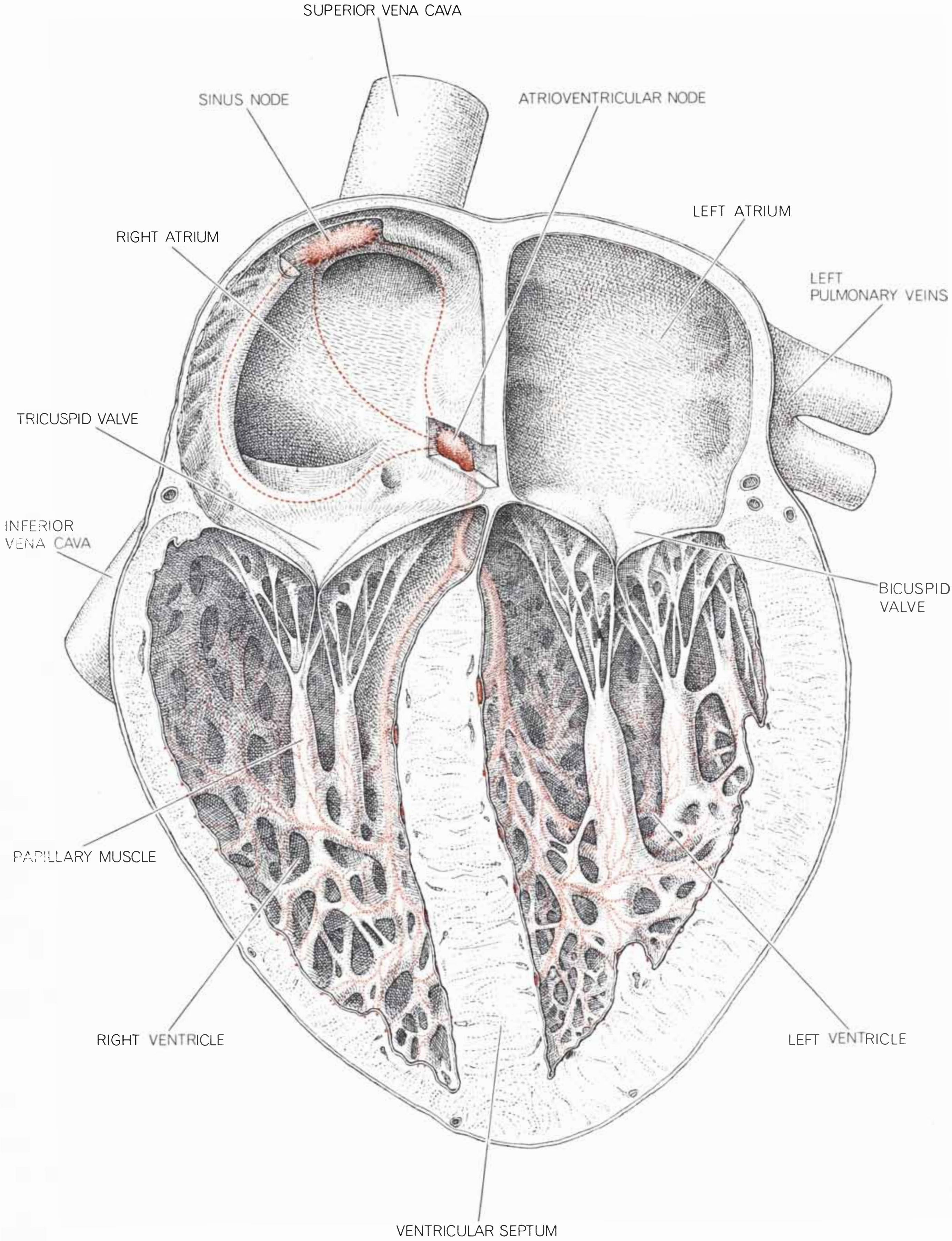
It is an interesting fact that the various muscle cells of the embryo heart differ in their intrinsic beating tempo, yet all are coordinated by the pacemaker. In the tubular heart of a salamander embryo, for example, W. M. Copenhaver of the Columbia University College of Physicians and Surgeons showed by cutting across the heart at various levels that at least eight different intrinsic beating rates can be detected along the length of the heart, each successive region rearward toward the sinus having a faster intrinsic rate. Indeed, when the cells of any embryo heart are separated from one another (by the use of the enzyme trypsin to break down the cement that holds them together), it is found that each cell beats with its own rhythm, depending mainly on the region of the heart from which it came. When, on the other hand, individual cells or fragments of heart tissue are brought together in intimate contact, they synchronize their contractions. Invariably the cell that has the fastest beat takes over the pacemaking. There are indications, however, that the pace is not entirely set by a single cell; the other cells seem to have some influence, and the actual beating rate possibly results from a consensus.

The sinoatrial pacemaker as a whole, consisting of hundreds or thousands of cells, has an intrinsic regulation. Whether in the embryo or maintained in an unchanging chemical medium at a constant temperature, it will beat at a constant rate hour after hour. A disturbance such as deprivation of oxygen can slow the rate, but as soon as normal conditions are restored the pacemaker resumes its basal rhythm. In each species of animal the pacemaker has a certain characteristic rate; for each species there is a "set point"—a standard rate—to which the heart adheres except during disturbing circumstances.

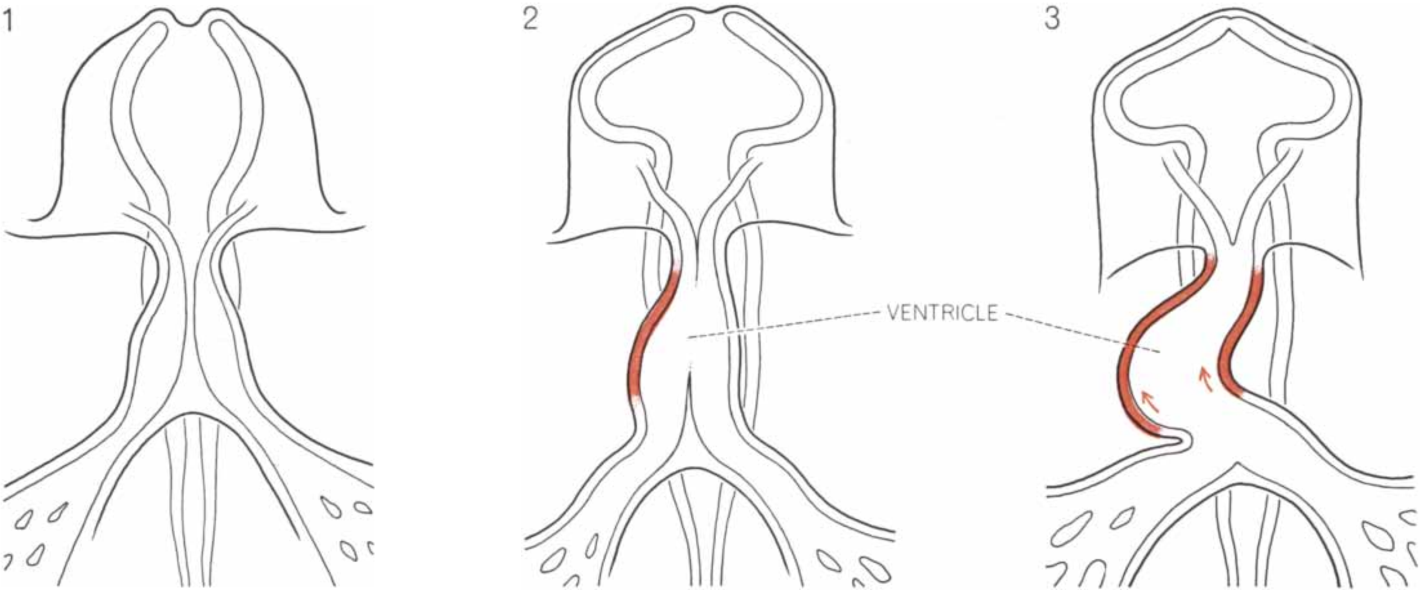
Copenhaver performed experiments with salamander embryos that dramatically tested the autonomy of the pacemaker. Using two different species—the tiger salamander and the spotted salamander—he transplanted the heart from one species to the other before the heart had begun to beat. Which beat would the transplanted heart take up, the donor animal's or the host's? In every case it beat at its own rate, not at that of the host, although in some cases it was pumping the host's blood, and it maintained its own beating pattern throughout the animal's life. The tiger salamander's heart normally beats more rapidly than the spotted salamander's during the first days of life and then slows to less than the spotted salamander's rate; it still showed the same pattern when it was transplanted into a spotted salamander, whether it was grafted in place of the animal's heart or was implanted in the abdomen or tail as a second heart.

The heart of any animal changes its rate with age, usually increasing in rate as the embryo grows and decreasing in later life. In Copenhaver's experiments the transplanted heart, whether it had belonged originally to a tiger salamander or to a spotted salamander, followed its own typical pattern of tempo changes with age. In short, the pacemaker of a given species is endowed not with a particular pace but with a whole program of paces that will develop during its lifetime. This program obviously is implanted in the future pacemaker tissue during the early development of the embryo, when the heart tissue is differentiating. Experiments in the culture of potential heart tissues have shown that such is indeed the case.

How does the pacemaker work? On this central question there are, unfor-

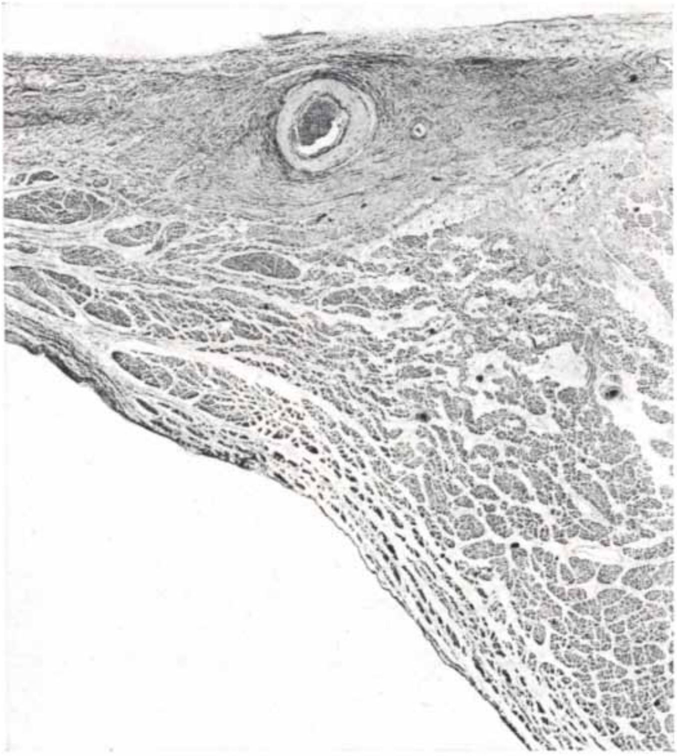


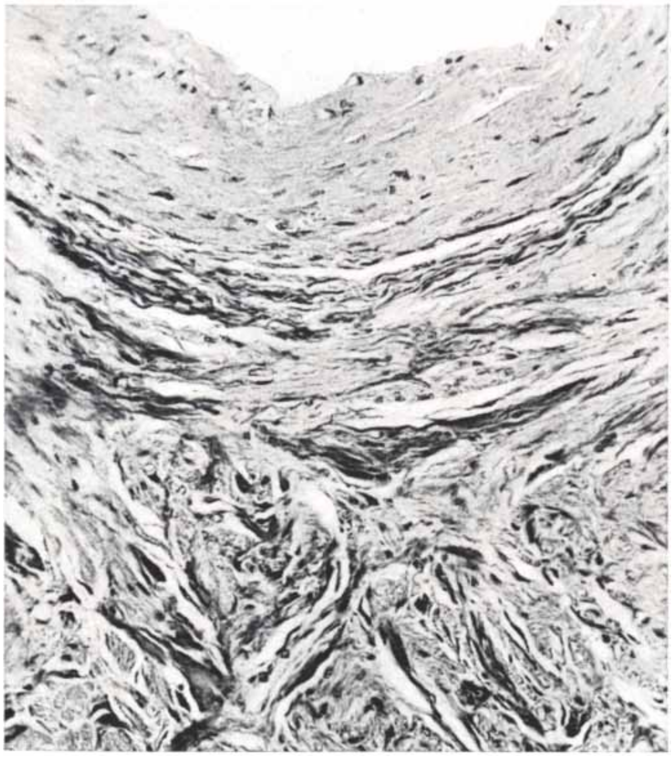
CUTAWAY VIEW of the human heart, showing the rear portion, depicts the pacemaker and the path of its impulses in color. The pacemaker is the structure near the top of the heart; it is variously called the sinus node and the sinoatrial node. Impulses from the pacemaker spread along the paths indicated by the broken lines to the atrioventricular node, from which they are transmitted to the ventricles. Pacemaker cells differ from both nerve cells and muscle cells; they are usually described as modified muscle cells.



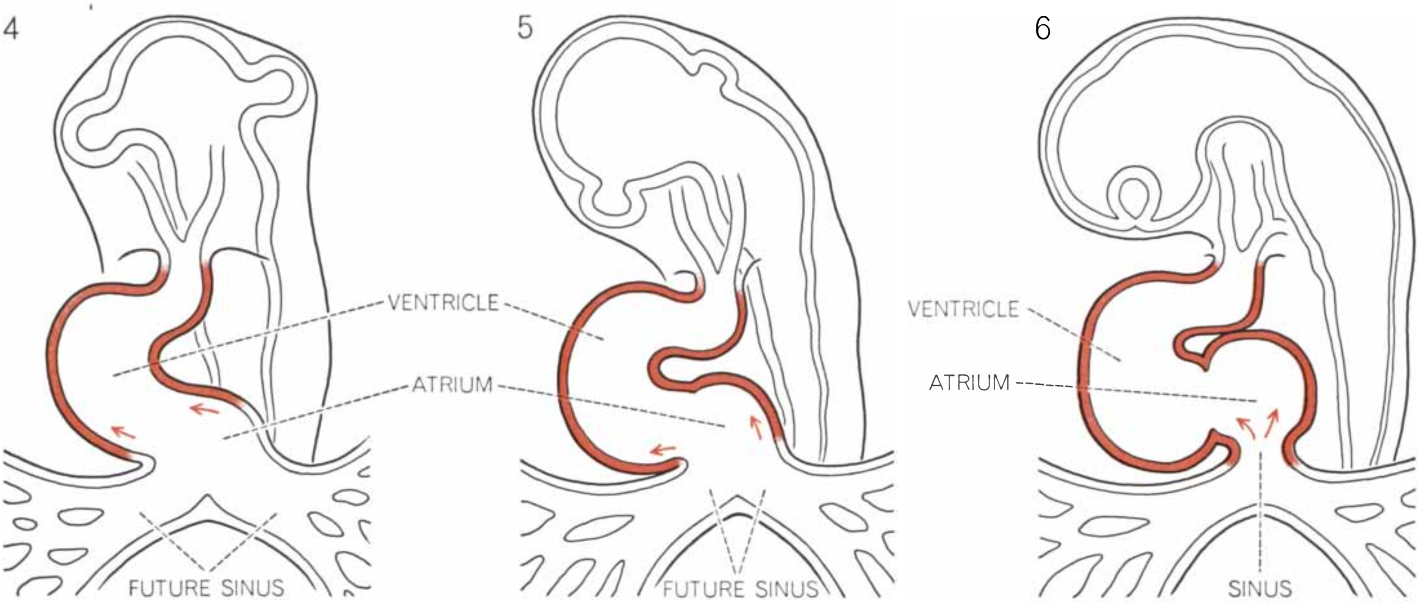
PACEMAKING CHANGES in an embryonic chicken heart are depicted in color; arrows show the direction of impulse conduction. At 27 hours (*1*) beating has not begun. The first contractions arise (*2*) in the ventricle. Gradually they originate farther to the rear,

tunately, very few clues so far. The pacemaking cells look distinctly different from other cells. Under the microscope we can see that the cells in the sinoatrial node are more widely separated from one another and have less contractile structure than the cells in other heart tissues. Electrical exploration of the pacemaking cells reveals another distinctive feature [*see upper illustration on page 37*]. By inserting a microelectrode in an individual cell one finds that during the diastolic, or passive, phase of the beat cycle the inside of the cell loses its negativity gradually until it reaches a transition point, after which it completes its depolarization rapidly (and actually becomes positive for an instant). This pattern of gradual depolarization is peculiar to pacemaker cells. One is tempted to compare these cells to an electric condenser, which discharges periodically after accumulating charge gradually. The condenser model does not, however, quite fit the process of the cell. Indeed, no model yet suggested has given us much enlightenment on how the pacemaker translates metabolic energy into its rhythmic beat, how it synchronizes the discharges of its many





HUMAN PACEMAKER appears in photomicrographs of two thin slices of heart. At left, in an enlargement of 12 diameters, the sinus node is the dense tissue organized around an artery. At right, in an enlargement of 260 diameters, the internal structure of the node is evident. The darker tissue is the framework of collagen. Within this frame bundles of sinus-node fibers interweave in all directions.



reaching the atrium (*5*) and finally the sinus (*6*). Drawings, which slowly turn the embryo from a frontal view at *1* to a view of the left side at *6*, were adapted from *Early Embryology of the Chick*, by Bradley M. Patten, published by the McGraw-Hill Book Company.

cells or how it changes the tempo of its beat as it ages.

Perhaps some enlightenment will come from studies of the pacemakers of invertebrate animals. In the lobster, for instance, the heartbeat is activated by a small group of nerve cells outside the heart. Donald M. Maynard of the University of Michigan studied a species of lobster in which the pacemaker consists of nine nerve cells—four small and five large. He found that any one of the small cells triggers a burst of impulses from all nine, and repetitive bursts from the group are responsible for the rhythmic beats of the heart. How are the discharges from the four small nerve cells regulated? If the interactions of these cells could be unraveled, one might find a clue to the coordinated action of the thousands of cells that constitute the pacemaker in the heart of a vertebrate.

We may well ask: Of what use are the vertebrate pacemaker's thousands of cells? It has been suggested that perhaps only a few of them are pacemaking at any given time and the rest act as reserves. In that case, however, what would prevent one uncontrolled cell from starting a beat of its own? A single cell that began to beat at a pace twice that of the others could throw the entire system into confusion. A more plausible hypothesis is that all the pacemaker cells are under mutual control. So far, however, only feeble evidence of communication among the pacemaker cells has been discovered.

Notwithstanding the lack of information about how natural pacemakers operate, artificial pacemakers have been devised, and they are serving today to keep alive many people with damaged hearts. The best solution to their problem would be the implantation of living pacemaker tissue from a human donor or an animal one. In the embryo of a salamander such a transplant takes beautifully, and the implanted tissue can drive the host's heart quite satisfactorily. Unfortunately in mammals implanted tissue does not wed itself to the heart but simply forms a scar. The only available artificial pacemaker for human use, therefore, is a mechanical one. It consists of a device that produces rhythmic electrical discharges, and wires from this device feed the discharges to the excitable tissues of the heart. The artificial pacemaker can maintain a steady heartbeat; it does not, however, respond to bodily needs that call for a speedup of the beat.

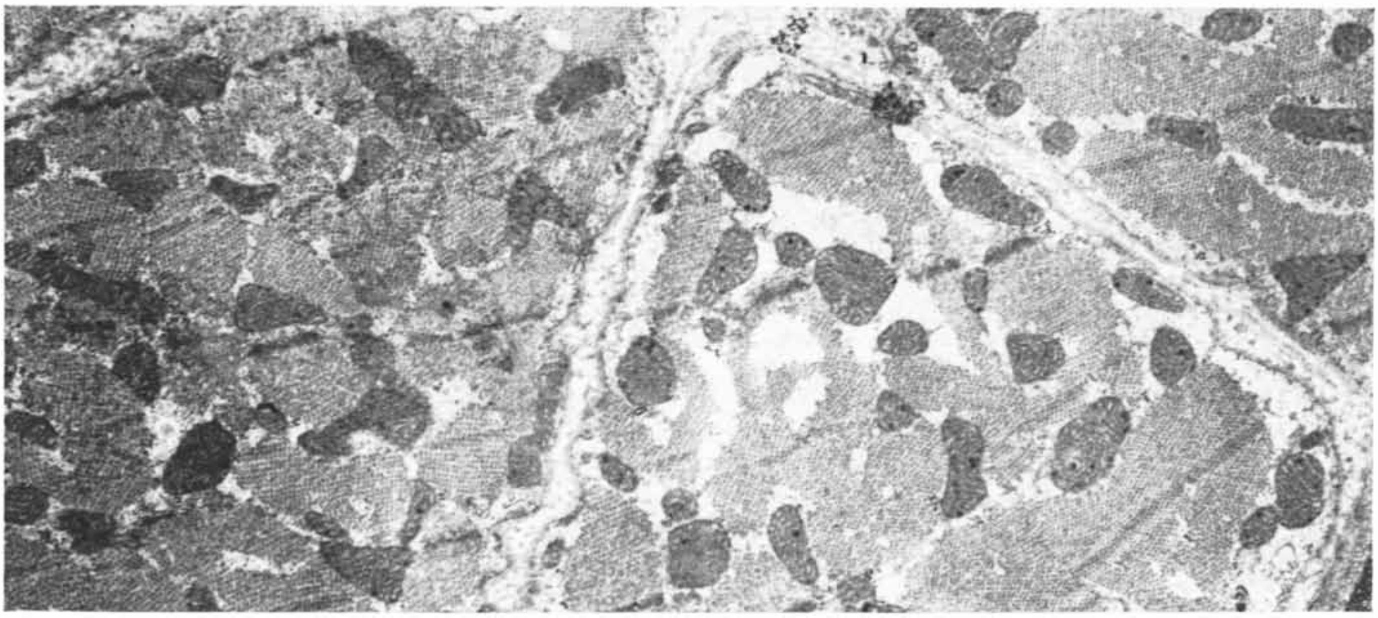
What are the extrinsic, or external, mechanisms that affect the natural pacemaker of the heart, and how do they act? In our laboratory at the University of Rochester School of Medicine and Dentistry we have explored these questions, along with those concerning the intrinsic beat itself, by studying the development of the heart's behavior in animals from the early fetal stage to adulthood.

In the fetus of a rat the heart begins to beat in the 10th day of life. At that stage the heart is still free of any stimulation from nerves, and about the only factors that can change its intrinsic beat are temperature, oxygen and blood supply. From day to day during the growth of the fetus the rate of the intrinsic beat increases. The pacemaker remains relatively insensitive to extrinsic influences, even after nerves grow into the heart on the 16th day, and the insensitivity continues until near birth (on the 22nd day).

By adulthood an animal's heartbeat has become subject to strong influences from the parasympathetic and sympathetic nervous systems. Several investigators, including Raymond C. Truex and David M. Long, then at Hahnemann Medical College, have measured the extent of these influences in the dog. The heart rate of a dog at rest is about 90 beats a minute. If the animal is given a dose of atropine, which blocks parasympathetic nerve impulses from reaching the heart, its rate jumps to 250 beats a minute. Evidently, then, under normal circumstances a flow of impulses from the parasympathetic nerves acts as a restraining influence on the heart rate. On the other hand, the sympathetic nerves have a prodding effect. If these nerves are cut so that no impulses reach the heart, the heartbeats slow to 65 a minute. In short, the sympathetic system acts as an accelerator and the parasympathetic system as a brake, and under normal conditions the two systems counteract each other. When the nerve supply to the heart is completely cut (blocking both systems), the dog's heart beats about 110 times a minute. Perhaps in an adult dog this is the intrinsic rate of the pacemaker itself.

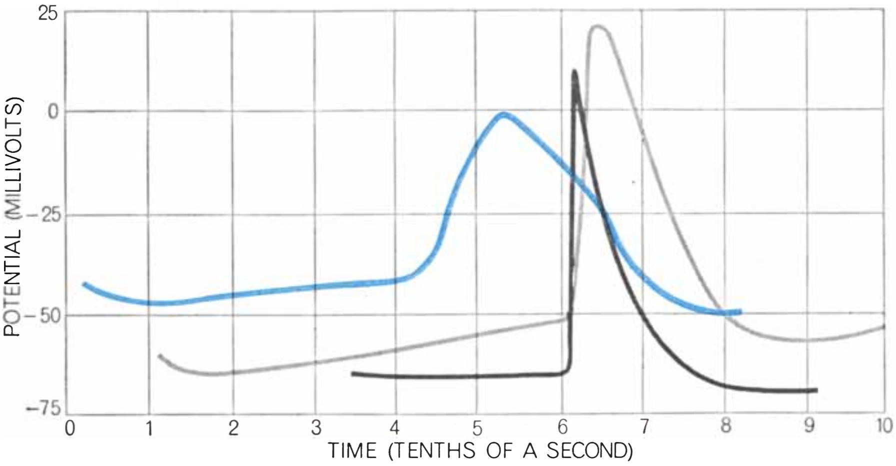
What the experiments show in general is that a continuous interplay normally goes on among the pacemaker and the two nervous systems controlling the heart, whose sources are centered

PACEMAKER CELLS appear at an enlargement of 18,000 diameters in this electron micrograph by Thomas N. James of the Henry Ford Hospital in Detroit. The cells, which are the lighter structures, are from the heart of a dog. The darker cells are working myocardial cells, which are not involved in pacemaking. The featureless area at bottom right is one of the capillaries of the heart.



MYOCARDIAL CELLS, which have a muscular function in the heartbeat, differ in structure from pacemaker cells. The latter predominate only in the sinus node. Electron micrograph by James shows parts of three dog myocardial cells enlarged 18,000 diameters.

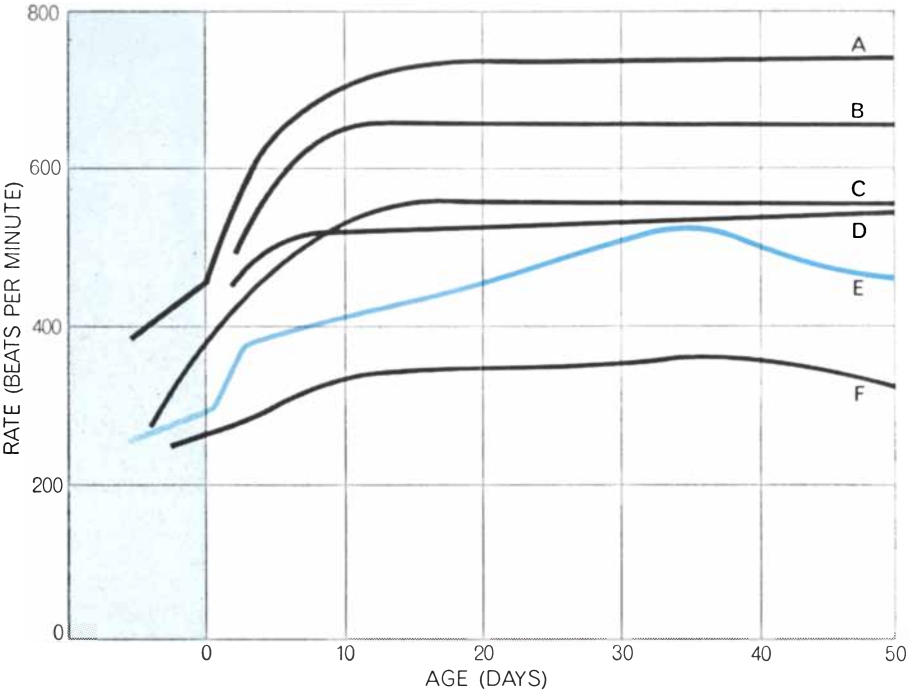
in the medulla oblongata of the brainstem. The pacemaker's pace is modified by rhythmic impulses from these nervous systems, and they in turn are guided by activities of the body that call for an increase or a decrease in the pumping action of the heart. Both types of nervous mechanism, however, and hormonal controls as well, work only within fixed limits, which depend on the animal's age and size. In a puppy, for example, the sympathetic nerves exert a much stronger effect on the pacemaker than the parasympathetic nerves do, whereas in the adult dog the reverse is true. Similarly, the pacemaker and the nervous controls combine to give the mouse a more rapid basal beat than the elephant, and an elephant's heart can never beat as fast as that of a mouse.



ELECTRICAL POTENTIALS in one pacemaker cell (*color*) and two nonpacemaker cells of a rabbit heart were measured by intracellular electrodes. Only cells capable of pacemaking show the gradual changes of polarization indicated by the colored curve for a single beat.

Precisely what is the ceiling for an animal's heart rate? We investigated the question in the rat by applying rhythmic electric shocks to drive the heart to its maximal capacity. The rats were anesthetized and the driving electric impulses were delivered through fine wire electrodes inserted in the chest. We found that in the fetus the heart's maximal rate was about 350 beats a minute; in a newborn rat, about 450 beats a minute, and in an adult rat, some 750 beats a minute. At these high rates the heart was very inefficient: it pumped little blood because it had no time to fill before each contraction. We can deduce that the limit of tempo set up in the pacemaker may serve as a protective mechanism; if the pacemaker drove the heart too fast, it might produce the uncoordinated, disorderly type of contraction known as fibrillation.

We found further that the hormones isopropyl noradrenalin and thyroxin, whose ability to speed up the heart has long been well known, raised the rats' heart rates to high levels but not to the limits of the heart's capacity. In each case the rate of the rat's heartbeat under maximal prodding rose with age until the animal reached the age of 10 days, after which it leveled off [*see lower illustration at right*].



VARIATIONS IN RATE of rats' hearts under different conditions are shown for ages beginning four days before birth and ending at maturity. The colored curve represents the normal rate after birth. Other curves are: *A*, maximal rate when the heart is driven by electric shocks; *B*, rate after administration of stimulating hormones thyroxin and isopropyl noradrenalin; *C*, rate under latter hormone alone; *D*, rate under thyroxin alone, and *F*, rate after administration of the drug propranolol, which blocks accelerating nerve impulses.

The normal heart rate at rest, on the other hand, presents a different picture as the animal ages. Instead of leveling off at the age of 10 days it continues to rise. This rise is attributed mainly to the influence of the maturing nervous system rather than to change in the intrinsic tempo of the pacemaker itself. It was found that administration of a drug that blocks the prodding action of the sympathetic impulses almost eliminated the heart rate increase with age. Our experiments show that the sympathetic nerves begin to affect the heart rate in rats a day or two before birth, whereas the parasympathetic system does not begin to act on the heart until about 16 days after birth. Thereafter the rate is under the control of the two systems acting competitively, with the sympathetic system apparently exerting slightly more influence than the parasympathetic.

To sum up, it appears that when the heart of the embryo begins to beat, it functions as an independent organ, driven only by its own inherent pacemaker. As it grows older it becomes receptive to one extrinsic influence after another and through them becomes the servant of many organs and activities of the body. In the adult animal it is capable of a wide range of responses to the body's needs. The full development of its responses and regulation does not come until long after birth, but we can see the beginnings of the arrangements even before the animal is born.

ANCIENT ARARAT

Sometimes called Urartu, it was a powerful nation of the region around Mount Ararat in 800 B.C. A mound in Turkey has yielded much information about this nation and its widespread influence

by Tahsin Özgüç

The Hebrew word *Ararat* is familiar as the name of the mountain where Noah's ark was stranded by the receding waters of the Biblical flood. Less well known is the fact that Mount Ararat, the summit of which is a 17,000-foot peak on the eastern frontier of Turkey, was the geographical center of a highland kingdom that was a major power of the ancient world. This kingdom disappeared soon after 600 B.C., yet it left a heritage of architecture and art that can be traced today in cultural remains as diverse as the public buildings of old Persia and the metallurgy of the Etruscans. It is known mainly through the writings of the Assyrians, who were its principal adversaries and in the end its allies. In their language both the kingdom and its central mountain had a name closely related to the Hebrew: *Uruatri.* Today the kingdom is generally called Urartu, a corruption of *Uruatri.*

Conquerors from the north crushed both Assyria and Urartu in the final years of the seventh century B.C. and put the highland kingdom's cities to the torch. Recent excavations, however, have uncovered one stronghold of western Urartu that was left untouched by the wave of conquest. Thanks to the remarkable findings at this site it is now possible to reconstruct the culture of the kingdom in considerable detail.

The site is called Altintepe: "the hill of gold." The hill, some 200 feet high and 600 feet long, rises abruptly from level farmland some 250 miles to the west of Mount Ararat near the modern Turkish city of Erzincan. Thirty years ago the accidental discovery of an ancient tomb at Altintepe yielded a number of Urartian treasures, the best of which found their way to the National Museum in Ankara. Thereafter Altintepe was not disturbed until 1956, when a second rich tomb was unearthed, again by accident.

The second find attracted the attention of the Turkish Historical Foundation and the Turkish government's Department of Antiquities and Museums. Each year since 1959 the two organizations have jointly sponsored diggings at Altintepe, directed by myself and staffed by my colleagues and students from the University of Ankara. In the course of eight seasons' work we have traced the massive walls that made Altintepe a formidable citadel of Urartu's western frontier, have uncovered a cemetery outside the walls and have cleared the citadel itself. Within the citadel we have found the remains of storerooms, of a building that was both palace and temple and of a great audience hall in which are preserved numerous fragments of a brightly colored mural that once decorated many square yards of wall [*see illustration on opposite page*]. In both the citadel and the cemetery we have found abundant examples of Urartian work in bronze, iron, precious metals, ivory, stone and wood that are testimony to the high artistic skills of Urartu's craftsmen.

The quantities of rich objects found in the tombs of the cemetery indicate that the people buried there were not ordinary subjects of Urartu but were nobles or at least local administrator-warriors of substantial wealth and power. Each tomb is a well-made small replica of a house. In the walls of the replica house are niches in which funeral goods were stored, and between its rooms (usually three in number) are doorways carefully closed with stone slabs. The entrance to each house was closed with several tons of boulders; the roof, made of large blocks of stone, was covered with a layer of boulders and then a layer of unfired bricks. It is evident that the people of Altintepe did their best to see that their tombs would be neither easily found nor easily robbed.

Within most of the tombs we found the remains of a single person lying in a handsome coffin of stone or wood and dressed in fine garments. (A few of the tombs held the remains of a man and a woman.) When the occupant was a woman, the tomb typically contained not only female clothing—often dresses decorated with large gold buttons—but also jewelry made of gold, silver and precious stones. A man's remains were usually accompanied by weapons made of bronze or iron. The tombs were also furnished with wooden chairs, couches and tables, decorated with gold and silver leaf and mounted on bronze legs cast in the shape of cattle's hoofs or lions' paws. The legs were frequently cross-braced with wooden bars decorated with spirals of bronze. In addition to the furniture, the rooms contained large bronze caldrons, resting on three legs and decorated with bulls' heads, and a variety of other objects made of gold, silver and iron and of stone, terra-cotta and ivory.

In one of the tombs we found a war

FRAGMENT OF MURAL, preserved for more than 2,600 years, is seen in its matrix of dried mud on the opposite page. The mural decorated the great audience hall in the Urartian frontier citadel of Altintepe in eastern Asia Minor. When Altintepe was abandoned, the hall, which was built of unbaked bricks, soon crumbled. Some bricks fell in such a way as to preserve bits of the mural; the author has now recovered more than 50 such fragments.

SITE OF CITADEL, an oval hill in eastern Asia Minor, is seen in the center of this aerial photograph. The citadel occupies the top of the hill. The pits visible on the slopes of the hill are where the author has uncovered a number of unplundered Urartian tombs.

ALTINTEPE rises abruptly from the level farmland that surrounds it: the hill is 200 feet high and 600 feet long. As a frontier post it commanded the main mountain passes leading from eastern to central Asia Minor. Altintepe is a Turkish word meaning "hill of gold."

chariot complete with horse trappings and harness, including jointed bronze bits decorated at the ends with the heads of bulls, horses or eagles. Along with the trappings were a number of disks and belts of bronze bearing geometric designs or the figures of animals, men and gods. One of the disks, about 3½ inches in diameter, is unique in the history of Urartian religious art and provides an important clue to the origin of an element in Greek mythology. A god wearing a long robe is shown mounted on a winged horse that is galloping at full speed. Some of the belts show winged horses without a rider [*see top illustration on page 43*]. It is difficult to avoid the conjecture that here, in Urartian metalwork of the eighth century B.C., is the original Pegasus, the winged horse Bellerophon rode in his adventures.

Just as the contents of the tombs testify to the wealth of Urartu, so the dimensions and contents of the citadel's storerooms are evidence of the kingdom's economic efficiency and military preparedness. Altintepe is situated so that it dominates two mountain passes that lead from eastern to central Asia Minor, and its control of east-west communications made it one of the kingdom's more important outposts. Accordingly it should have been prepared to withstand a siege. We were soon able to show that such had been the case. In two large storerooms we found rows of huge jars half-buried in the ground [*see bottom illustration at right*]; each jar was inscribed with hieroglyphs indicating the nature and amount of its contents. These inscriptions cannot yet be read, but if the storerooms of Altintepe resembled others in Urartu, some of the jars were filled with wheat, barley, sesame and beans and others with oil and wine. One storage depot that was unearthed at a site of northern Urartu contained 90 such jars capable of holding some 35,000 gallons of wine, and an inscription found in the Lake Van area states that the royal Urartian cellars alone had storage space for 55,000 gallons of wine. Indeed, when the Assyrians under Sargon II invaded Urartu in 714 B.C., a problem in military discipline faced by the invaders was the irresistible appeal the local wine had for the Assyrian troops.

The outer walls of the Altintepe citadel, 36 feet thick, are ample proof of Urartian skill in masonry. Some of the dressed stones that make up the wall weigh as much as 40 tons, yet the builders were able to raise them 200 feet above the level of the surrounding plain

KINGDOM OF URARTU, with Mount Ararat at its center, originally extended from the highlands between Lake Çildir and Lake Van (both in modern Turkey) eastward to Lake Sevan (in the U.S.S.R.) and Lake Urmia (in Iran). Its greatest expansion pushed its boundaries to the Mediterranean and the Black Sea. Altintepe was near the western frontier.

STOREROOM, one of two discovered at Altintepe, contains rows of huge jars half-buried in the floor of the room. The Urartians stored large quantities of foodstuffs in this way to support them during the long mountain winters and as provisions in the event of a siege.

STONE FOUNDATION of the temple shrine at Altintepe consists of three masonry courses on top of which the Urartian builders raised walls of mud brick. The rows of round stones are bases for the wooden pillars of a gallery that surrounded the courtyard.

SITTING LION made of ivory is one of the sculptures found in the temple gallery at Altintepe. A few flakes of the gold leaf that once covered the statuette's breast and neck still remain in place.

IVORY FIGURE of a supernatural being with a human body and a griffin's head and wings was also found in the temple. In style the statuette is much less stiff than its Assyrian counterparts are.

and to fit them neatly into place. The remains of the two main structures within the citadel demonstrate both the skill and the aesthetic capabilities of Urartian architects. One of the structures, the palace-temple, was divided into two parts. In one part were service areas, living quarters and the great hall. The other part was a temple courtyard 90 feet square in which stood the inner shrine. This structure housed the throne and statue of Haldi, the male deity who heads the Urartian pantheon. Around the courtyard, which was open to the sky, was a roofed gallery [*see illustration on page 46*].

When we excavated the courtyard, we found 20 smoothly finished stone disks that had served as pedestals for a series of 14-foot wooden posts supporting the gallery roof. We also found fragments of the posts themselves. At other Urartian temple sites such posts show traces of paint; at Altintepe the wood was too decayed to reveal if paint had once been applied to it.

The shrine was about 45 feet square and had walls 15 feet thick. Three of the walls were indented with a recess 15 feet long and a foot deep; the fourth had a door that opened on the shrine. The base of the walls consisted of three courses of stone about three feet high [*see top illustration on opposite page*]; above this base the walls were evidently made of unbaked brick.

Inside the shrine we found the stone base on which the throne and statue of Haldi had rested; the throne and statue themselves, which were probably made of precious metals and ivory, were gone. Mingled with the debris of the temple, however, were many offerings to the god: pottery vases and bronze and iron maces, arrowheads and spearheads (the last being Haldi's special symbol). A richer collection of offerings was found in the gallery area nearest the entrance to the courtyard. Here we unearthed a number of bronze shields, which must once have hung by the temple gates, and several ivory sculptures, some of which may originally have been inlays decorating Haldi's sacred furniture.

An ivory statuette of a seated lion is a masterpiece of Urartian workmanship [*see illustration at bottom left on opposite page*]. Its neck and breast still reveal traces of the gold leaf that once covered it; its head is turned toward the left and its mouth is open. Every detail of the brow, the eyes and even the wrinkles around the nose perfectly depict the animal's fierce temperament. Two ivory figures carved in low relief

WINGED HORSE, most familiar to the western world as Pegasus, a creature of Greek myth, appears as a decoration on bronze belts unearthed in the tombs at Altintepe; in this example the horse is riderless. It seems probable that the Greeks learned of the mythical animal, which was first represented in Assyrian art, as a result of trade in Urartian metalwork.

DEER AND TREE, made of ivory, represent a hitherto unknown form of Urartian craftsmanship. The hollows in the deer's body were once inlaid with gems or precious metal.

show supernatural beings with the bodies of men and the heads and wings of griffins. They wear short skirts covered by long coats; their wings and the borders of the coats are decorated with gold leaf. Winged human figures are common in Assyrian art, but this pair of figures is distinctively Urartian. They show the relation between the art of Urartu and the work of contemporaneous Assyrian artists to the south. Another ivory masterpiece uncovered in the temple gallery is a low relief showing a deer with its head turned toward a tree [*see bottom illustration on preceding page*]. Carved with grace and realism, it represents a form of Urartian craftsmanship hitherto unknown: the animal's ivory body was originally inlaid either with precious metal or with gems.

The interior of the shrine and the walls of one of the adjacent palace rooms were decorated with murals, and the yard outside one palace room was floored with a pebble mosaic. In every case, however, the surface is so poorly preserved that the designs can scarcely be identified. We can only be sure that, if the exterior of the palace-temple was monumental and severe, the interior—with its graceful pillars, airy galleries, mosaics and brightly painted walls—must have provided a marked contrast to it.

WINGED FIGURE, drawn stiffly in imitation of an Assyrian original, is one of several surviving fragments of the great mural that once decorated the audience hall at Altintepe. Pairs of such figures, standing on each side of a pomegranate tree, form two of the parallel rows of repeating motifs in the mural (*see illustration on opposite page*). Each figure holds a pail in one hand; the other hand is raised in the act of grafting the pomegranate tree.

Although the palace-temple shows no sign of ever having been razed, a portion of the palace section was torn down in the second half of the seventh century B.C. to make room for another building. At that time the lord of Altintepe ordered the construction of the great audience hall, 130 feet long and 75 feet wide, in an adjacent part of the citadel. Some sense of Urartian prosperity or self-regard during this period can be gained by bearing in mind that Altintepe was only a frontier outpost of Urartu and not one of the kingdom's main cities. Moreover, the rulers of the Phrygian and late Hittite kingdoms, Urartu's powerful neighbors to the west, were apparently quite content to receive ambassadors from abroad in buildings much more modest than the audience hall at Altintepe.

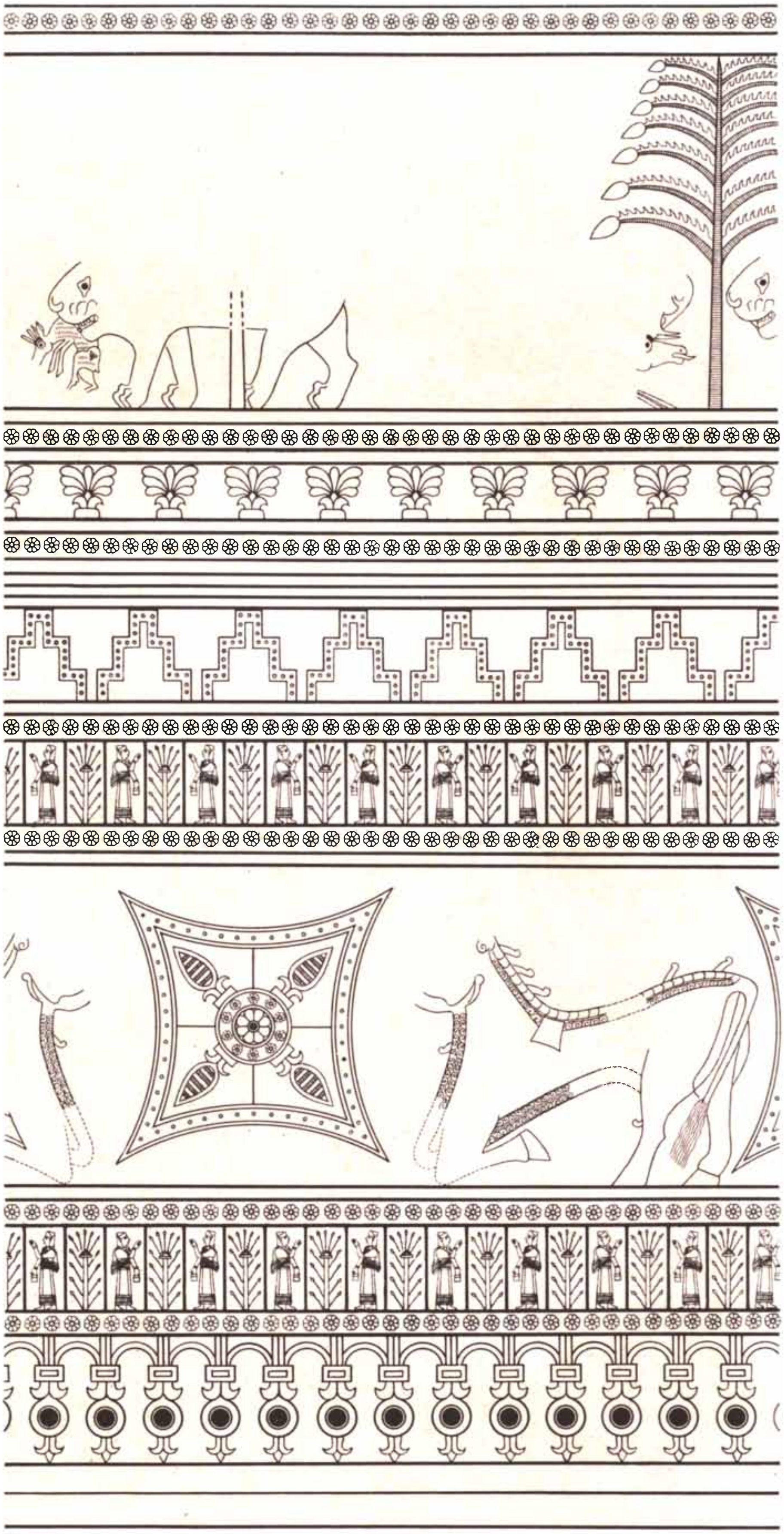
Eighteen columns, arranged in three rows, supported the flat roof of this great public building. The outstanding feature of the audience hall was an elaborate mural that covered its inner walls from top to bottom. We have been able to reconstruct this mural because of a fortunate accident of history. The walls of the building, nine feet thick and made of unfired brick, had been given a smooth coating of plaster on which the mural was then painted. If the audience hall had been sacked and burned, its bricks would have been at least partly baked and would better have withstood the ravages of time. As it was, the hall was not burned, and its bricks crumbled fairly soon. As the walls disintegrated, however, some of the bricks fell to the floor in such a way that bits of the mural on them were saved from obliteration. So far we have managed to retrieve and preserve more than 50 pieces of painted brick, and with the help of these fragments we have been able to reconstruct a large section of the mural [*see illustration at right*].

After the plaster applied to the walls of the audience hall had dried, the muralists painted the surface blue (except for a few selected areas that were left unpainted). Then they drew the outlines of their figures—geometric, plant, animal or divine—in black and added details in red, blue, light brown and occasionally green. In executing the geometric designs they made use of ruler and compass. Most of the design elements—rosettes, palmetto leaves, concave rectangles, sphinxes, kneeling bulls and winged supernatural figures—were borrowed by the Urartian painters from their Assyrian neighbors. Two of the fragments we have recovered, however, are characteristically Urartian. In one of them a lion peers from behind a tree at a deer. In the other a lion has in its jaws the limp body of a fawn. Both scenes are executed in a lively style that is in sharp contrast to the almost wooden formality of the Assyrian motifs.

Although the preservation of parts of the mural at Altintepe is a happy event in Near Eastern archaeology, the architecture of the audience hall is actually more significant than its art. The building is the prototype of the apadana, or great hall, that was a major feature of the royal palaces of ancient Persia. The most magnificent apadanas known to history are those built at Persepolis and at Pazargade by the Achaemenid kings of Persia (559 to 330 B.C.). It is clear that the Persians first learned the art of constructing monumental reception halls from the architects of Urartu.

The end of Altintepe, although evidently peaceful, is intimately connected with the last years of the Urartian kingdom. Prosperous under a succession of kings from Sarduri I (840 B.C.) to Rusa I (who committed suicide in 714 B.C. after the defeat by the Assyrians), Urartu attained its greatest geographical extent in the reign of Sarduri II (764–735 B.C.). The kingdom's heartland had been an area roughly 250 miles on a side bounded by the four lakes Çildir, Van, Urmia (in Iran) and Sevan (in the U.S.S.R.). Under Sarduri II the Urartians held sway from the Black Sea to the eastern Mediterranean and from the Caucasus to Mesopotamia.

During this period of expansion the Urartians maintained close contact with nations to the west of them. As an example, bulls' heads that decorate votive tripods found in Cyprus are virtually

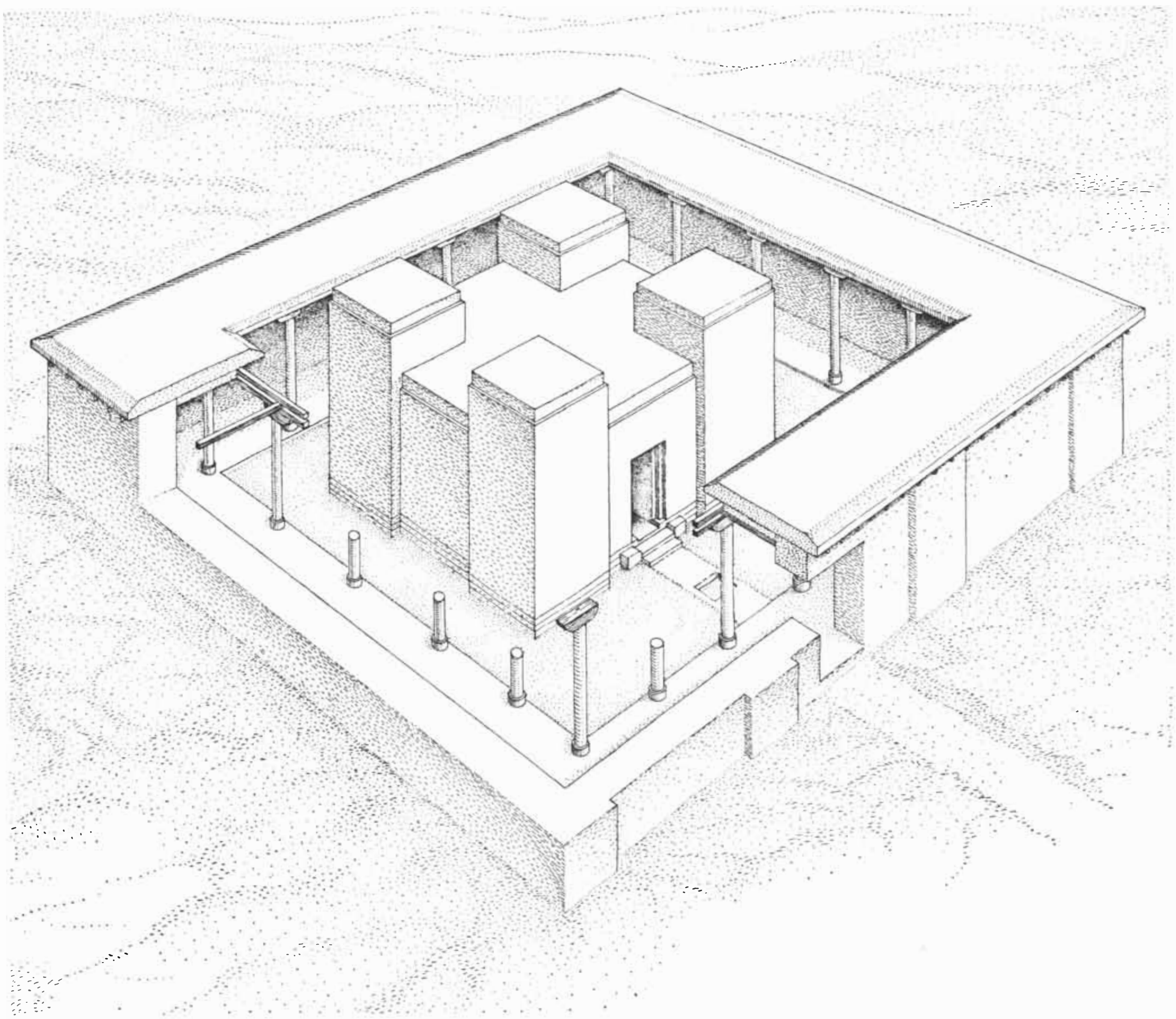


AUDIENCE-HALL MURAL at Altintepe has been reconstructed on the basis of salvaged fragments; one portion of the reconstruction is illustrated here. Assyrian motifs comprise most of the mural but two typically Urartian scenes appear. At top left a lion holds the carcass of a young deer in its jaws; at right a lion peers past a tree at a crouching buck. The lively animals contrast sharply with the stylized Assyrian bull shown kneeling below.

identical with those on the caldrons uncovered at Altintepe and at other Urartian sites. Other Urartian caldron ornaments—so much alike as to be almost certainly the product of a single workshop—have been found not only at the sites of neighboring Phrygia but also as far to the west as Greece and the Etruscan region of Italy. Indeed, the Etruscans, who were redoubtable metallurgists, seem to have learned some of their techniques from objects imported from Urartu.

Even after Urartu had been conquered by the Assyrians—an event that can be at least partly attributed to the erosion of Urartian power by Scythian raiders from the north—the highland kingdom enjoyed another century of prosperity and great public works. Rusa II (685–645 B.C.) made common cause with the Scythians and successfully raided for slaves—the essential foundation of the Urartian economy—along the Assyrian frontier. The kingdom continued to prosper under Sarduri III (645–635 B.C.) and briefly under Rusa III (625–609 B.C.), who engineered the alliance with the Assyrians to counter the Medes and the Babylonians. The Medes, however, crushed the Assyrians in 609 B.C., and in the same year the Scythians sacked the Urartian capital city on Lake Van. By 585 B.C. the Medes had reestablished order in this part of Asia Minor, but the kingdom of Urartu was no more.

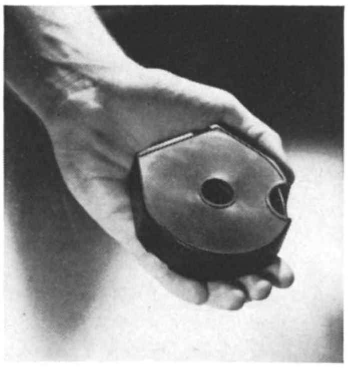
It may have been during these last days of Urartu that an unchallenged but outflanked garrison at Altintepe, deciding that abandonment of the citadel was the better part of valor, loaded Haldi's throne and statue on carts and marched away to disappear from history. Or it may be that, at the height of Rusa I's troubles with the Scythians and Assyrians a century earlier, the beleaguered king summoned the Altintepe garrison to serve him elsewhere. All that seems certain is that the Urartian outpost on the hill of gold came to a peaceful rather than a violent end, thereby preserving for us the splendid examples of art and architecture that reveal so much about ancient Ararat.



WALLED TEMPLE, shown in a reconstruction that omits the adjacent palace structure, had an unpaved courtyard, open to the sky and surrounded by a pillared gallery. The gallery's flat roof, made of timber and clay, was supported partly by 20 pillars and partly by the four temple walls. Dominating the courtyard was the temple shrine, the recesses in its walls giving it the appearance of having a tower at each corner. Weapons and other offerings to Haldi, the Urartians' chief god, were found in the shrine. Other examples of Urartian craftsmanship, including the ivory sculptures illustrated on pages 42 and 43, were unearthed in the temple gallery.

The hope of doing each other some good prompts these advertisements

Single concept



This, in some educators' jargon, is a single-concept film. From the armamentarium of up-to-date primary and secondary school techniques, we commend it to the attention of those who feel moved to scrutinize for reasonableness the traditional practices governing lab sections for college freshmen and sophomores.

A single-concept film is not supposed to be a very fancy affair. It is nothing at all like a movie that costs $60,000 to produce. It might run no more than 8 feet long, or it might run as long as 50 feet—whatever is required to show what needs to be shown and no more. The student consults it as he would a page in a lab manual. If he consulted it before performing an assigned lab exercise, just watching the film a few times could take the place of the part of the exercise that answers the questions already answered long ago by the founding fathers of the science. He could then use the precious actual lab time to answer some more profound questions that you might propound.

Now is the right time for college teachers—or any teachers, for that matter—to start thinking about what they would like to have happen in single-concept films. New standard formats are shaping up so that the same old tiresome operating problems need not be solved over and over again. We have worked out a cartridge design that other manufacturers can adopt. The new and higher-quality super 8 films that you will buy or make can be easily loaded into it for instant use on special study-type projectors, easily kept track of in school, and easily unloaded for showing on any of the vast numbers of super 8 projectors already waiting in private homes.

We have been out talking to publishers. We tell them our ideas about hardware, about how to bring films into existence and before the eyes and ears of the students at the lowest possible cost. We beg to be told where we are wrong, for we know we are only businessmen and engineers, not teachers.

To join the dialogue as a purveyor of curriculum materials, as an educator, or as a professor who would never be happy with material not of your own creation, address some questions to Eastman Kodak Company, Motion Picture and Education Division, Rochester, N.Y. 14650.

Mr. Fudge, the manganese man

Pressure is building up these days on Thomas S. Fudge, a sales executive of Eastman Chemical Products, Inc. (Subsidiary of Eastman Kodak Company). By 1975 his success in responding to it should be apparent from a map of the United States that plots the extent and severity of manganese deficiency in American soil. Tom Fudge is expected to make the Mn-deficient acreage shrink and shrink.

Manganese is the one and only trace element in soil that directly concerns Mr. Fudge. Zinc, copper, vanadium, and other trace elements are also important to agriculture but not in a business way important to Tom Fudge. Only manganese.

Will alleviation of manganese deficiency vastly improve the quality of human life in this land? It is probably too much to expect.

What, then, is putting the pressure on Mr. Fudge? You will find the answer quite difficult to believe, but here it is anyway: *the success of* KODAK INSTAMATIC® *Cameras.*

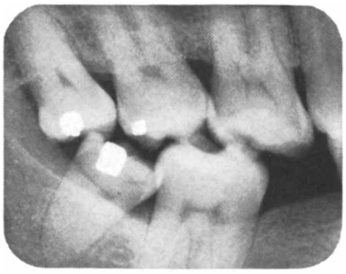
In point of fact, these cameras have made picture-taking so simple and rewarding that there has been a vast upsurge in the number of pictures taken and consequently in the demand for photofinishing service, for photographic developer, and ultimately for the hydroquinone that goes into most of it. We make hydroquinone by a process in which manganese dioxide enters and manganese sulfate comes out. Manganese sulfate is therefore coming out pretty fast at present. Would you have us dump it somewhere? You wouldn't like that one bit, and neither would we—particularly since our hydroquinone plant takes the same insoluble MnO_2 that some people try to use in fertilizer and changes it to a fully soluble source of those Mn^{++} ions without which, for example, citrus groves on impoverished soil languish in chlorosis.

And that is why, when Tom Fudge of Eastman Chemical Products, Inc., Kingsport, Tenn. 37662, goes about insisting on the importance of the trademark TECMANGAM *in soil improvement he is performing a reasonable, beneficial, and highly unusual role. It comes in 50-lb bags. Ask Tom for pertinent experiment station literature.*

The writer's favorite teeth

Writer's right molars gave this radiographic image on September 24, 1952.

Same writer's same molars gave this radiographic image on April 6, 1965, but with less than 1/25 the radiation dose required in 1952. Reason: writer's employer had increased the sensitivity of x-ray film.

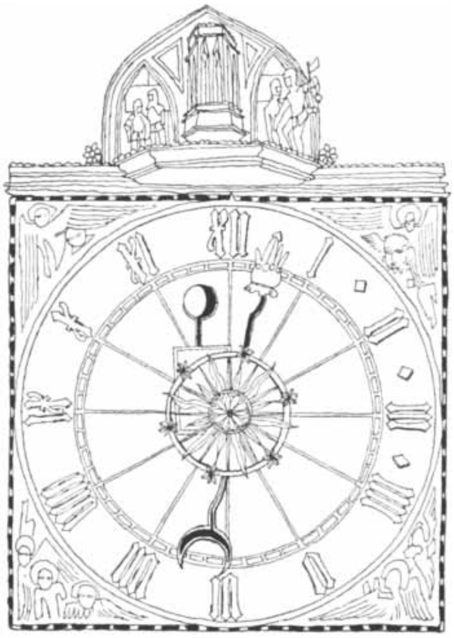


Same molars on August 22, 1966. This time it was even comfortable. No more of those wretched hard, sharp edges on the x-ray film packets that make the gums feel as though being cut to ribbons. Furthermore, the new film needed much less darkness for processing, so that the gal didn't have to spend time dark-adapting her eyes, which kept things moving more briskly in the waiting room. Improvements signified by additional trademarks "Poly-Soft" and "Morlite" after the basic trademark "Kodak" on dental x-ray film.

Never tell your dentist what kind of products to put in your mouth, but see him regularly and be friendly.

Kodak

SCIENCE AND



Flattened Star

A significant modification in Albert Einstein's general theory of relativity may be needed as a result of an experiment indicating that the sun is sufficiently flattened at the poles to affect the orbit of the planet Mercury. This flattening, said Robert H. Dicke of Princeton University in reporting his measurements at a January meeting on relativistic astrophysics held in New York, can account for about 8 percent of a component of Mercury's orbit that is explained by the general theory.

The orbital component is the slow advance of the perihelion, or closest point to the sun. The rate at which Mercury's perihelion advances has long been regarded as the best-verified prediction of the general theory. When the effects due to the gravitational attraction of other planets are calculated on the basis of Newtonian gravitational theory, one finds that there is an excess in the advance of Mercury's perihelion amounting to 43 seconds of arc per century. Einstein's theory accounts for an excess of 43.03 seconds.

In this prediction the general theory is inflexible. Dicke believes that if part of the advance of Mercury's perihelion can be attributed to the oblateness of the sun, it will be necessary to make a specific modification in the general theory within the framework of relativistic principles. In the general theory gravity is not a force but a consequence of the curvature of space. Gravity is associated with the presence of a "tensor field," which is the metric tensor of the Riemannian geometry of curved space. The metric tensor helps to define the distance between any two points in the four-dimensional space-time continuum of general relativity.

Believing that gravitation is more than a purely geometrical phenomenon, Dicke proposes to add a force component associated with a "scalar field," one in which each point in space has a specific physical quality to which a single value can be assigned. This theory, which Dicke developed several years ago in collaboration with Carl Brans, resembles other alternative theories of gravitation, such as the one devised by Pascual Jordan of Germany. It should be possible to choose among the theories by observational tests of the type Dicke has reported. In the Dicke-Brans theory the advance of Mercury's perihelion is less than in Einstein's theory by about 10 percent, or by the factor $1 - 4s/3$, where s is the fraction of a body's weight due to the scalar interaction.

To measure the oblateness of the sun Dicke, Henry Hill (now at Wesleyan University) and H. Mark Goldenberg designed an instrument that projects the image of the sun on a fixed disk that is slightly smaller than the image. The light that passes the rim of the disk strikes a rotating wheel, concentric with the sun, that has two apertures on opposite sides. A photodetector below the rotating disk samples the light that passes through the apertures. To the extent that the sun is not perfectly round, the recorded light will appear to flicker. The measurements had to be conducted over a long period because the shape of the sun as it is seen from the earth is continuously distorted by the earth's atmosphere.

Apart from their possible implications for Einstein's general theory, the results of Dicke and his colleagues indicate an interesting fact: The core of the sun must be rotating much faster than the sun's surface, which makes one revolution in about 28 days. Another colleague of Dicke's, P. J. E. Peebles, has calculated that to produce the observed flattening the core must be rotating once in about 1.8 days.

Ribonuclease in Three Dimensions

The three-dimensional structure of a fourth protein molecule has been determined. Up to now this feat had been performed (with various degrees of resolution) only for three proteins: myoglobin, the respiratory pigment of muscle cells; hemoglobin, the respiratory pigment of red blood cells, and the enzyme lysozyme. Now a team of investigators at the Roswell Park Memorial Institute in Buffalo has worked out the three-dimensional arrangement of the 124 amino acid units of the enzyme ribonuclease.

Ribonuclease breaks down ribonucleic acid, the substance that in various forms acts as an intermediary in translating the genetic information of deoxyribonucleic acid (DNA) into the sequences of amino acid units in proteins. Accordingly the enzyme plays an important role in the regulation of cellular processes. Since the way any enzyme works depends on its three-dimensional form and its "active sites," knowledge of that form is a necessary step toward understanding its exact mode of action.

The sequence of amino acid units in the ribonuclease molecule was determined some years ago by two groups of investigators, one at the Rockefeller Institute and the other at the National Institutes of Health [see "The Chemical Structure of Proteins," by William H. Stein and Stanford Moore; Scientific American, February, 1961]. At the Polytechnic Institute of Brooklyn and then at Roswell Park, David Harker, Gopinath Kartha and Jake Bello undertook to map the molecule in three dimensions. To this end they modified established X-ray crystallographic methods and adopted a technique developed by M. F. Perutz and his colleagues in Britain. This involves attaching heavy atoms to certain parts of protein molecules so that, when the molecules are arrayed in a crystal, the planes formed by the heavy atoms reflect X rays in a regular manner [see "The Hemoglobin Molecule," by M. F. Perutz; Scientific American, November, 1964]. After producing crystalline ribonuclease and finding the appropriate heavy atoms and a new way to diffuse them into the crystals, Harker's group placed the crystals in a computer-controlled X-ray device that oriented them at various angles and recorded the X-ray reflections. From these data the computer generated contour maps of various sections of the crystal, and a three-dimensional stack of these maps yielded a three-dimensional model of the molecule.

The model traces the convolutions and cross-linkages of the chain forming the backbone of the molecule. Its resolution (two angstrom units, or two hundred-millionths of a centimeter) is not fine enough, however, to show the exact position and orientation of each amino acid subunit as the models of myoglobin and lysozyme do. Harker and his colleagues are now working on a higher-resolution model.

No Superweak Force

Since 1964, when a group of workers from Princeton University discovered that certain weak interactions of subatomic particles violate the basic symmetry principle known as *CP* invariance, physicists have been searching for a way to interpret this finding without accepting one of its apparent implications: the idea that particle interactions in general exhibit a preference for a certain time direction. Now the preliminary results of a pair of experiments in progress—one at the European Organization for Nuclear Research (CERN) in Geneva and the other at the Princeton-Pennsylvania Accelerator (PPA) in Princeton—appear to rule out a particularly attractive class of explanations put forward to account for the observed violation of *CP* symmetry.

The principle of *CP* invariance states that, in those interactions that have been found to violate either the principle of the conservation of charge (*C*) or the principle of the conservation of parity (*P*), a combination of the two principles is obeyed. The interactions in question would then be indistinguishable from their oppositely charged, space-reflected mirror images. The 1964 experiment showed, however, that the *CP* rule does not always govern the decay of the long-lived neutral *K* meson; instead of the three pi mesons permitted by *CP* symmetry this decay was sometimes observed to produce only two particles, a positive pi meson and a negative pi meson—a result forbidden by *CP* symmetry.

The trouble with accepting *CP* asymmetry in this instance is that its implications go much further. If the principle of *CP* invariance is not universal (that is, if the laws governing some events in nature are not invariant when reflected in the "*CP* mirror"), then it can be demonstrated that the "*T* mirror"—the principle of time-reversal invariance—is also in jeopardy. This would leave only one universal symmetry principle: the combined "*CPT* mirror," in which all three basic symmetries (charge, parity and time) could be reversed together. To limit the implications of the observed violation of *CP* symmetry, theoretical physicists have proposed a number of alternative explanations, attributing the violation to previously undetected high-energy processes, called virtual processes, that are noticeable only in the decay of neutral *K* mesons. They have suggested that the virtual processes at work in *K*-meson decay represent either a subtle form of some known interaction (such as the weak force, the electromagnetic force or the nuclear force) or an entirely new interaction: the "superweak" force.

It is this last category of explanations that has now been eliminated as a possible explanation of *CP* nonconservation. The two experiments that contradicted the hypothesis of the superweak force were both designed to measure the rate of decay of the long-lived neutral *K* meson to form two neutral pi mesons. Although the experiments differ somewhat in technique, the measured decay rate in both departs significantly from the rate predicted by the superweak-force hypothesis. Moreover, the observation of two neutral pi mesons in itself constituted further proof that *CP* is not conserved. It appears likely that *CP* asymmetry is a much more general phenomenon than some physicists had supposed, and attempts to observe it in other particle interactions are now under way.

The PPA experiment was performed by four physicists from Princeton: James W. Cronin, Paul F. Kunz, Winthrop S. Risk and Paul C. Wheeler. The Geneva experiment was done by a group of 14 physicists from CERN, the Rutherford High-Energy Laboratory at Harwell in England and the Technische Hochschule at Aachen in Germany.

Biology Afloat

A ship designed as a floating laboratory for experimental biology departed from California on February 3 for an eight-month stay in the waters of the Amazon. The ship is the *Alpha Helix*, financed by the National Science Foundation and operated by the Scripps Institution of Oceanography. The name refers to one of the basic structures of the protein molecule and suggests the fundamental nature of the work for which the vessel is intended.

The 133-foot steel ship was designed to provide a fully equipped biological station in any part of the world. Its facilities include a biochemical laboratory, a "wet" laboratory with facilities for aquariums, an electrophysiological lab-

oratory (including a darkroom and a small room in which experiments can be performed in a cold environment or specimens can be quick-frozen), a machine shop and a scientific library. A hold astern contains a jeep and a prefabricated building that can be assembled ashore as a laboratory. The ship has quarters for 10 investigators and a crew of 12.

Per F. Scholander of the Scripps Institution had a major role in developing the concept and design of the vessel. According to Theodore H. Bullock of the University of California at San Diego, who is chairman of the national advisory board for the ship, one of the key concepts is that the ship provide a "24-hour symposium" for workers in different but related disciplines. He notes that the vessel also brings together workers from different institutions and different countries.

The concepts were tested last year on the ship's first cruise, which involved an investigation of the Great Barrier Reef of Australia. The participants were 44 workers from 11 institutions in the U.S. and eight abroad. This year's expedition to the Amazon will include four successive programs: neurobiology, with Bullock as leader; osmotic regulation, led by Knut Schmidt-Nielsen of Duke University; insect physiology, led by Carroll M. Williams of Harvard University, and plant physiology, with Jacob B. Biale of the University of California at Los Angeles as leader. On the return voyage the ship will spend about two weeks in work on deep-sea physiology under Malcolm S. Gordon of U.C.L.A.

Oldest Australopithecus

The known antiquity of man's immediate ancestor, *Australopithecus* of Africa, has been nearly doubled by the discovery of a 2.5-million-year-old fragment of arm bone near Lake Rudolf in Kenya. The fossil, the lower tip of a humerus, was found in August, 1965, by Bryan Patterson, a Harvard University paleontologist; its identity was announced in January of this year by Patterson and William W. Howells, a Harvard anthropologist. The sedimentary rocks from which the bone came are overlain by a lava flow that is dated by the potassium-argon method as 2.5 million (±200,000) years old. The oldest rocks at Olduvai Gorge in neighboring Tanzania, famous for their prehuman fossil remains, are about 750,000 years younger.

The Kenya find is particularly significant because it indicates the presence of a member of the human lineage in East Africa 750,000 years before the time when comparable hominids coexisted at Olduvai with representatives of the less human hominid *Paranthropus robustus.* Some students of human evolution have suspected that *Australopithecus* and *Paranthropus* had developed along separate lines long before Olduvai times; the new fossil points in the same direction.

Although Patterson's discovery pushes the antiquity of recent hominids back toward the beginning of the Pleistocene epoch, some 3.3 million years ago, a tremendous gap still exists between these hominids and their most probable ancestors of Miocene times: such forms as *Ramapithecus* and *Kenyapithecus,* which flourished in India and Africa between 20 million and 14 million years ago.

Coral Corral?

A proposal to raise plankton-eating whales in captivity for the dual purpose of providing food for the expanding human population and saving the whales from extinction has been advanced by Gifford B. Pinchot of Johns Hopkins University. Pinchot, a biochemist and a career investigator for the U.S. Public Health Service, writes in *Perspectives in Biology and Medicine* that the corrals for domesticated whales could be coral: the atolls of the Pacific. An important feature of the scheme would be to fertilize the water in the atolls artificially to increase the production of plankton.

Pinchot notes that since the oceans cover three-quarters of the earth's surface, they receive three times as much sunlight as the land and so "have the potential ability to produce much more food than the land." The problem is that "we still hunt the oceans rather than farm them." An atoll has a roughly circular "fence"—a coral reef—surrounding a central lagoon and "would provide an ideal preformed container" for experiments in fertilization. Pinchot proposes two ways of doing the fertilizing: adding commercial fertilizer or pumping in water from the depths around the atoll, which are rich in nutrients. He suggests that the pumping could be done with windmills, since the atolls are in the trade-wind belt of the Pacific and have winds averaging 12 to 18 miles per hour most of the time.

"We would expect," Pinchot argues, "that our fertilized atoll would grow phytoplankton, which in turn would be eaten by zooplankton, and then we should be ready to put some harvestable animals into our pasture. For the sake of

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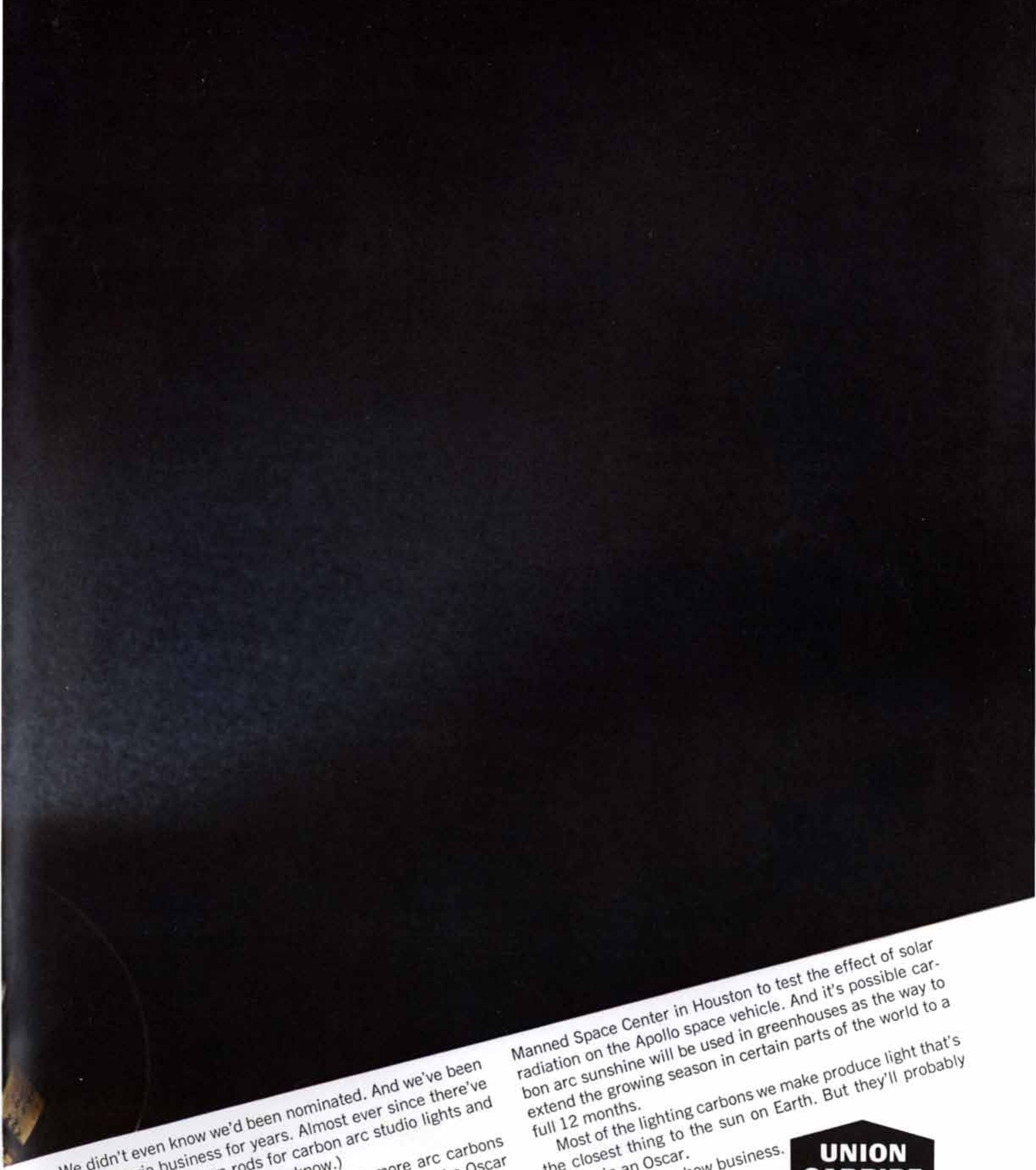

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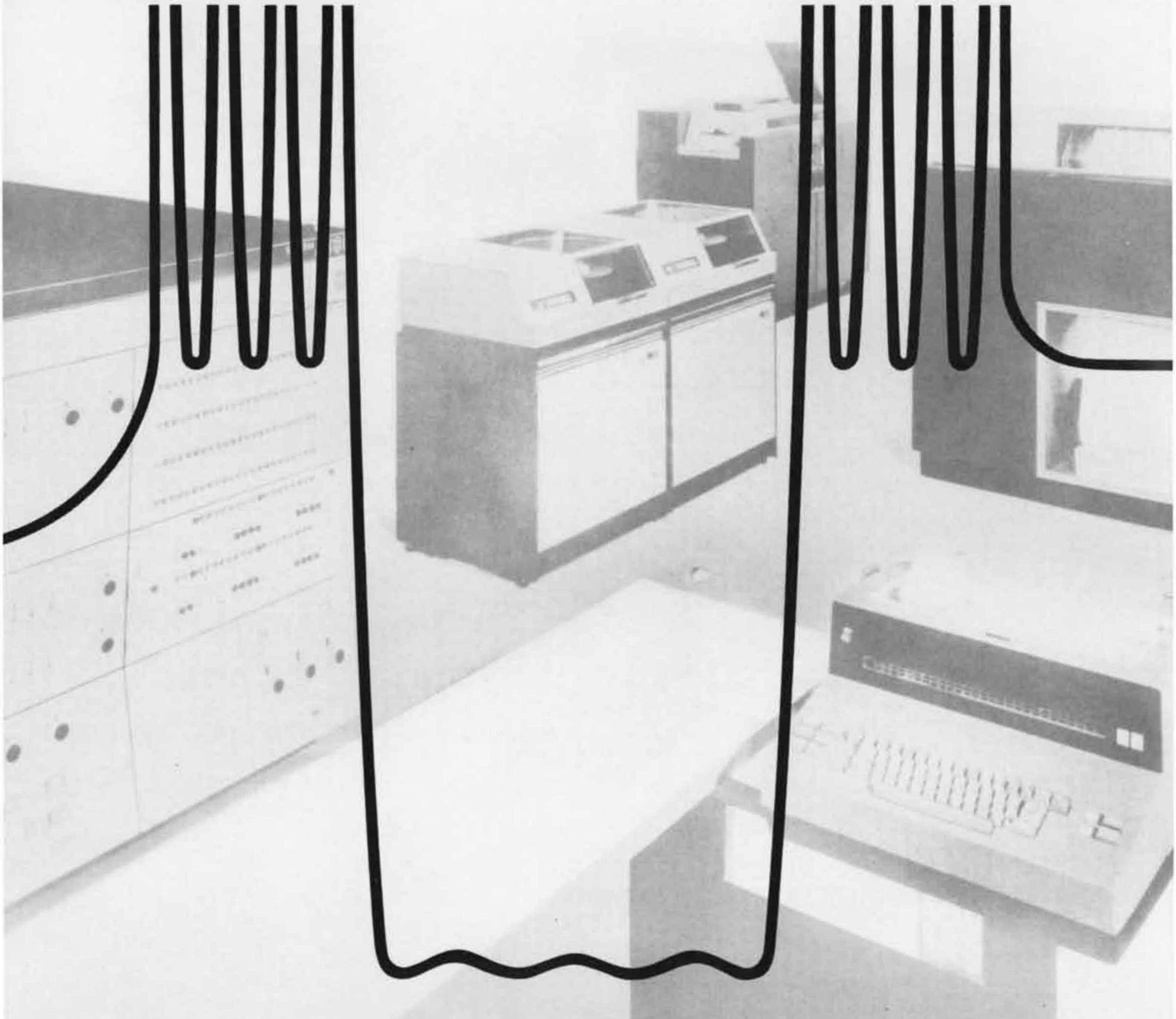

efficiency we should like to harvest animals that eat zooplankton rather than harvest fish that eat small fish that eat zooplankton." The filter-feeding whales, such as the blue whale, the humpback whale and the sei whale, eat zooplankton, and because of their size they would be relatively invulnerable to predation and easy to keep track of in an enclosed atoll.

Pinchot concludes: "It is a real tragedy that whales stand in danger of being completely exterminated by man, and the situation illustrates again the extreme shortsightedness of human beings. These filter-feeding whales are in an almost unique position in the food chain in the sea, since they are large and feed on zooplankton. If they are exterminated, this extremely efficient mechanism for converting plants into animal protein will be lost forever."

Jumping Sprinters

One of the two "kicks" in running—the leg thrust a runner uses to propel himself, rather than the term for a final burst of effort—has now been analyzed; the leg action proves to be far more complex than was supposed. Akira Tsujino of the Kobe University School of Medicine buried a concrete box with a loose wooden lid in one of the university's athletic fields. Volunteer sprinters then ran a 100-meter course, managing to step squarely on the box midway; the horizontal and vertical components of each impact were measured by means of strain gauges. Tsujino reports in the *Kobe Journal of Medical Sciences* that the dynamics of a runner's step are divisible into three parts: (1) a force that brakes forward motion as the foot first strikes the ground, (2) a downward pressure as the runner's body swings forward and (3) a rearward thrust—the kick—that counteracts the deceleration accompanying the first two events. At each stride the foot remains on the ground for about a tenth of a second, so that during the 12 seconds or so of a 100-meter run the runner is in contact with the ground for five seconds.

Contrary to widespread belief, Tsujino notes, it is not the kick that keeps a sprinter literally up in the air during more than half of every race. Instead the runner gets his lift from the conversion of forward momentum into a vertically directed force during the second part of the stride; a 125-pound sprinter exerts an average downward pressure of nearly 500 pounds at that instant. The force of the rearward kick is a modest 70 pounds. Tsujino concludes that sprinters spend most of a race jumping.

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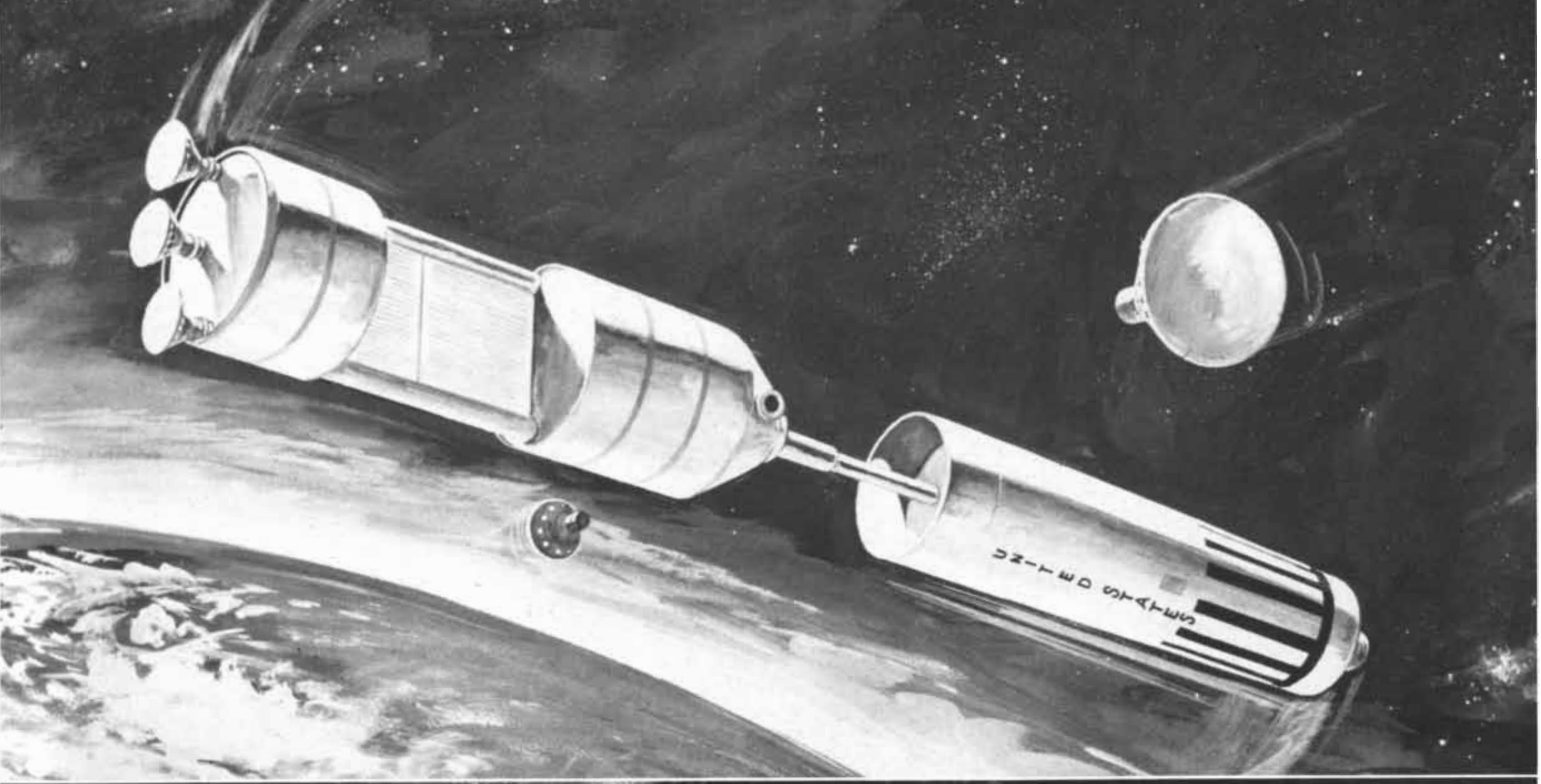

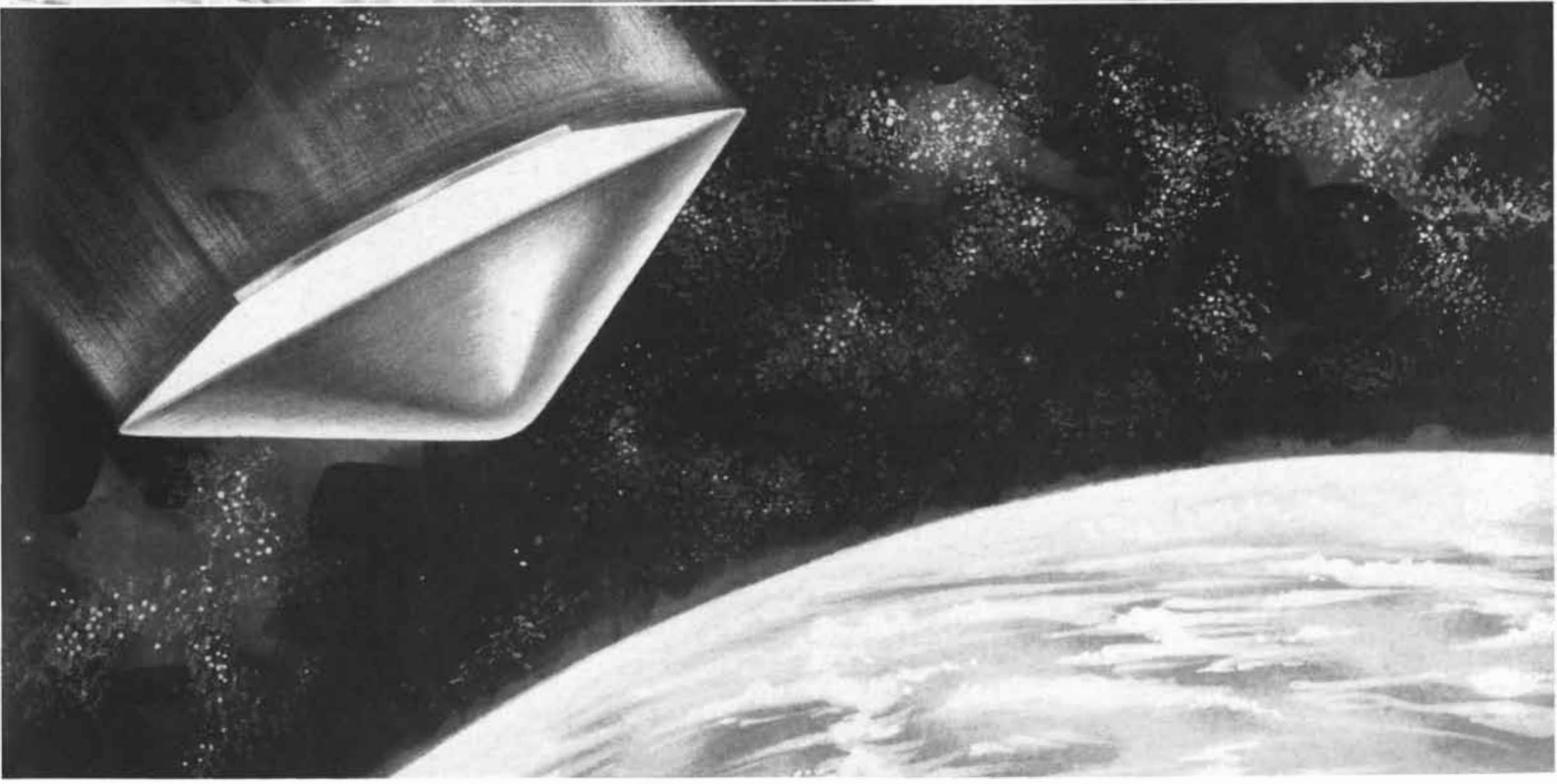

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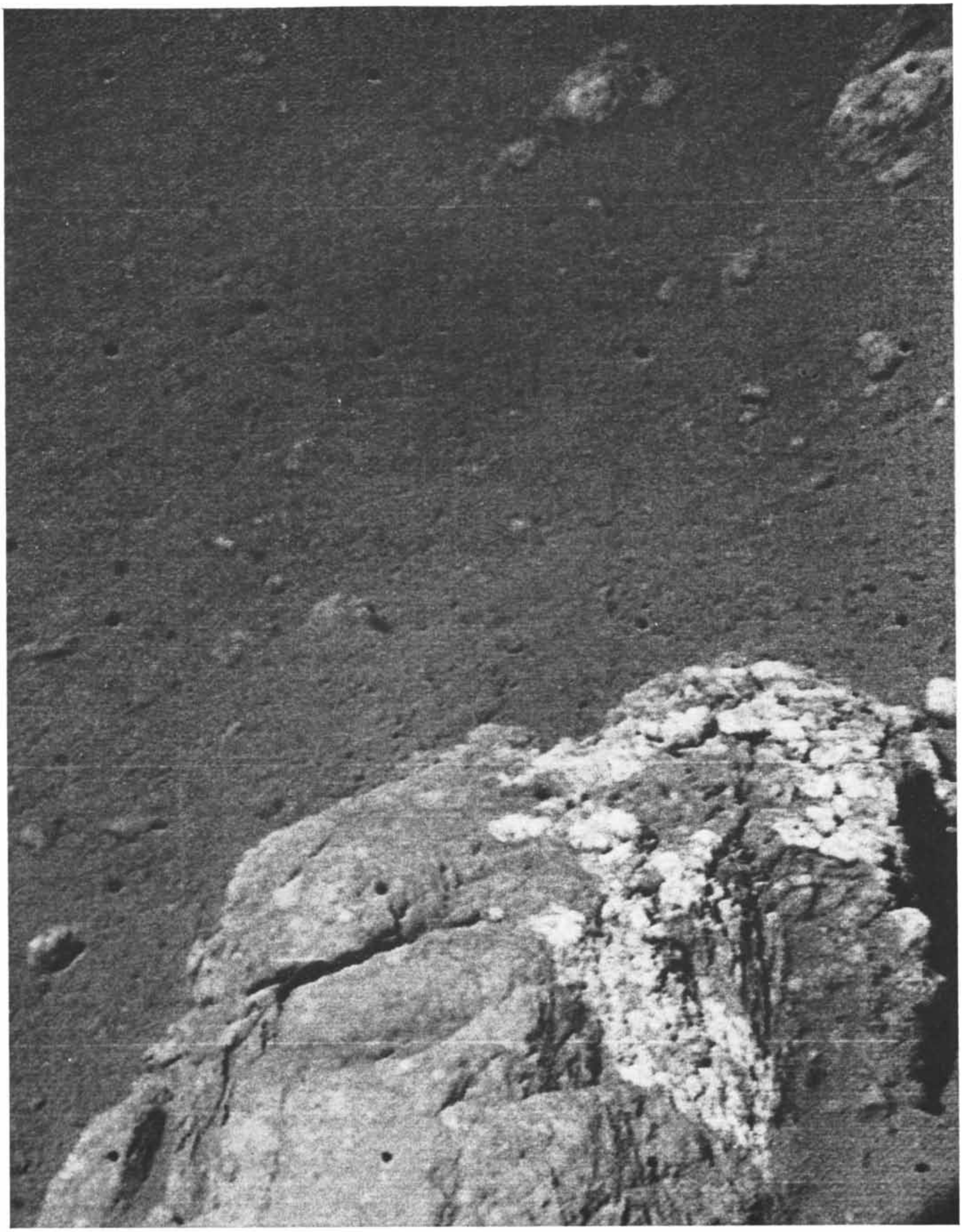


MOON ROCK was photographed by *Surveyor I* shortly after its successful landing last June. Approximately 12 feet from *Surveyor*'s television camera, the rock is about 18 inches long and six inches high. Although it looks like a typical terrestrial rock, one hypothesis suggests that it is an aggregate produced by the shock of a meteoritic impact. Such aggregates have been called "instant rocks." The quality of the picture has been enhanced by computer processing of the original signal. *Surveyor I* was designed and built by the Hughes Aircraft Company under the supervision of the Jet Propulsion Laboratory of the California Institute of Technology.

The Surface of the Moon

Nine spacecraft have provided thousands of closeup pictures of the moon. Although they have revealed much never seen before, they have not solved the riddle of the moon's nature and origin

by Albert R. Hibbs

Within the past three years astronomers have been presented with a wealth of photographic information about the moon, beginning with the 17,000 pictures sent back to the earth by the three Ranger spacecraft that crashed on the moon in 1964 and 1965. These pictures were followed early in 1966 by the first detailed views of the lunar surface provided by the Russian spacecraft *Luna 9* and soon afterward by the American *Surveyor I*. In succeeding months several hundred more photographs were received from the moon-circling spacecraft *Orbiter I, Orbiter II* and *Orbiter III*.

Now that we have seen the moon in greater detail than ever before, including views that reveal surface particles smaller than a millimeter, what conclusions can be reached about the nature of the lunar surface? Which hypotheses have been confirmed by the photographs and which eliminated? Have the pictures yielded any insight into the structure of the moon? Have they shed any light on the moon's origin?

It should be said at the outset that the American spacecraft lofted toward the moon—the Rangers, Surveyors and Orbiters—were designed with a single overriding objective in mind: to provide the information essential for achieving the national goal of landing a man safely on the moon before 1970. In other words, the spacecraft were not designed primarily as vehicles of scientific exploration. They were reconnaissance vehicles, built to gather technological information that would pave the way for the landing and operation of larger, more complex vehicles, particularly those carrying men. So when compromises had to be made, when some instruments had to be given priority over others in the early stages of the program, the decision was clear. In laying out plans that extended over several years, the first thing to be learned was the mechanical characteristics of the moon's surface at a few selected points, and the conditions that would govern a safe landing of the manned Apollo spacecraft. When the Apollo astronauts are easing the first landing module to the surface of the moon, they will know that the area selected for touchdown is both smooth enough and strong enough to make that landing safe.

Once this has been said, it remains true that information sent back by the various lunar vehicles has been of immense interest to investigators whose specialty is the moon: its surface features, its internal structure, its history and its origin. Until a few years ago it seemed reasonable to suppose if one could only get better pictures of the moon's surface, one might be able to resolve at least some of the arguments that had developed over the nature and history of the moon. Until July, 1964, our knowledge of the surface of the moon had changed very little over the past 100 years. The turbulence of the earth's atmosphere made it impossible to resolve, even with the best telescopes under the best seeing conditions, surface features of the moon that were smaller than several hundred meters across. The photographs made within the past three years have improved on this limit of resolution by a factor of at least 100,000.

The Lunar Hypotheses

Before considering the information that has been gleaned from both the American and the Russian lunar spacecraft, I shall describe some of the conflicting ideas about the moon that one might hope to test by placing cameras, as well as other instruments, aboard such spacecraft. Let me begin at the beginning, by describing three principal hypotheses that attempt to account for the formation of the moon.

According to one hypothesis the moon was once part of the earth and was thrown out into space when the earth was spinning considerably faster than it is now. The moon then moved out to its present orbit as a result of tidal interactions between the earth and the moon. According to a second hypothesis the moon was formed initially as a satellite of the earth by a process similar to the one that created the earth itself, that is, a gradual accumulation of matter out of a cloud of gas and dust. A third hypothesis of lunar origin suggests that the moon was originally an independent planet whose orbit brought it close enough to the earth for it to be captured as a satellite.

Each of these hypotheses presents difficulties. For the first the difficulty is dynamical. It is possible to calculate the changing shape of the original spinning body as it became distorted to the point of coming apart, at least up to the instant when the proto-moon would be torn free [*see illustration on page 63*]. This calculation gives figures for the total energy and angular momentum of the system at the moment of separation. The present energy and angular momentum of the earth-moon system, however, are much smaller than the calculated original ones. The energy is now only 6 percent of the original energy indicated by this hypothesis and the angular momentum about 27 percent. Although the energy of the system can be dissipated by such processes as friction due to tidal motions, it is difficult to imagine any process of dissipation that could account for the loss of 94 percent of the original amount, and it is almost impossible to account for the loss of angular momentum.

The second hypothesis supposes that the earth and the moon were both created from the same mass of dust and gas, part of which accumulated to form the earth and part to form the moon. The average density of the moon, however, is only 60 percent of the earth's density. This difference in density implies that some kind of differentiation process must have been at work while the two bodies were being formed. So far no one has been able to suggest an adequate process.

The first hypothesis avoids this difficulty because the part of the earth that broke away and formed the moon would have been composed largely of material in the earth's crust. Indeed, the average density of the earth's crust is only a little less than the average density of the entire moon.

The third hypothesis is again limited by dynamical arguments, but perhaps not so severely as the first. The difficulties lie in details of the capture process. Recently Gordon J. F. MacDonald of the University of California at Los Angeles, among others, has calculated dynamically possible orbits for the earth and the moon that would have led not only to the capture of the moon by the earth but also to the establishment of the moon's present orbit [*see illustrations on pages 64 and 65*]. The initial conditions for such capture are of course extremely limited. The likelihood of their being met are correspondingly small, but this does not rule out the possibility.

The History of the Moon

In addition to the three hypotheses of origin there are three points of view concerning the general conditions of the moon's subsequent history. These can be labeled the hot theory, the warm theory and the cold theory. Proponents of the hot theory believe a considerable amount of plutonic activity—activity involving molten rock—has taken place deep in the interior of the moon and on its surface. In fact, there are some who believe most of the craters on the moon are volcanic; they describe some of the larger ones as calderas: craters that have been made many times larger than the original volcanic vent by the collapse of the surrounding region. One of the principal conclusions of the hot-moon theory is that the large dark areas on the moon—the maria, or "seas"—are flows of either lava or ash.

There is some evidence to support the idea that material has spread over the lunar surface. The low hills in Mare Imbrium, for example, appear to have been formed by flowing material. Recently flowlike patterns on the lunar surface have been revealed by making separate images of the moon through filters that pass either ultraviolet or infrared radiation and viewing a negative of one plate against a positive of the other. If the resulting black-and-white picture is reprocessed to produce a colored version, one obtains the result shown on the cover of this issue of *Scientific American*. The photographs used in this demonstration were made by

TELESCOPIC VIEW OF MOON is typical of the best lunar photographs that were available before the space age. The crater in the center of this photograph is Tycho, which lies in the moon's southern hemisphere. It is believed to be one of the moon's most recently formed features. Infrared, radio and radar measurements show that some of the material around the edge of Tycho has properties quite different from those over most of the moon's surface. The photograph was made with the 100-inch telescope on Mount Wilson.

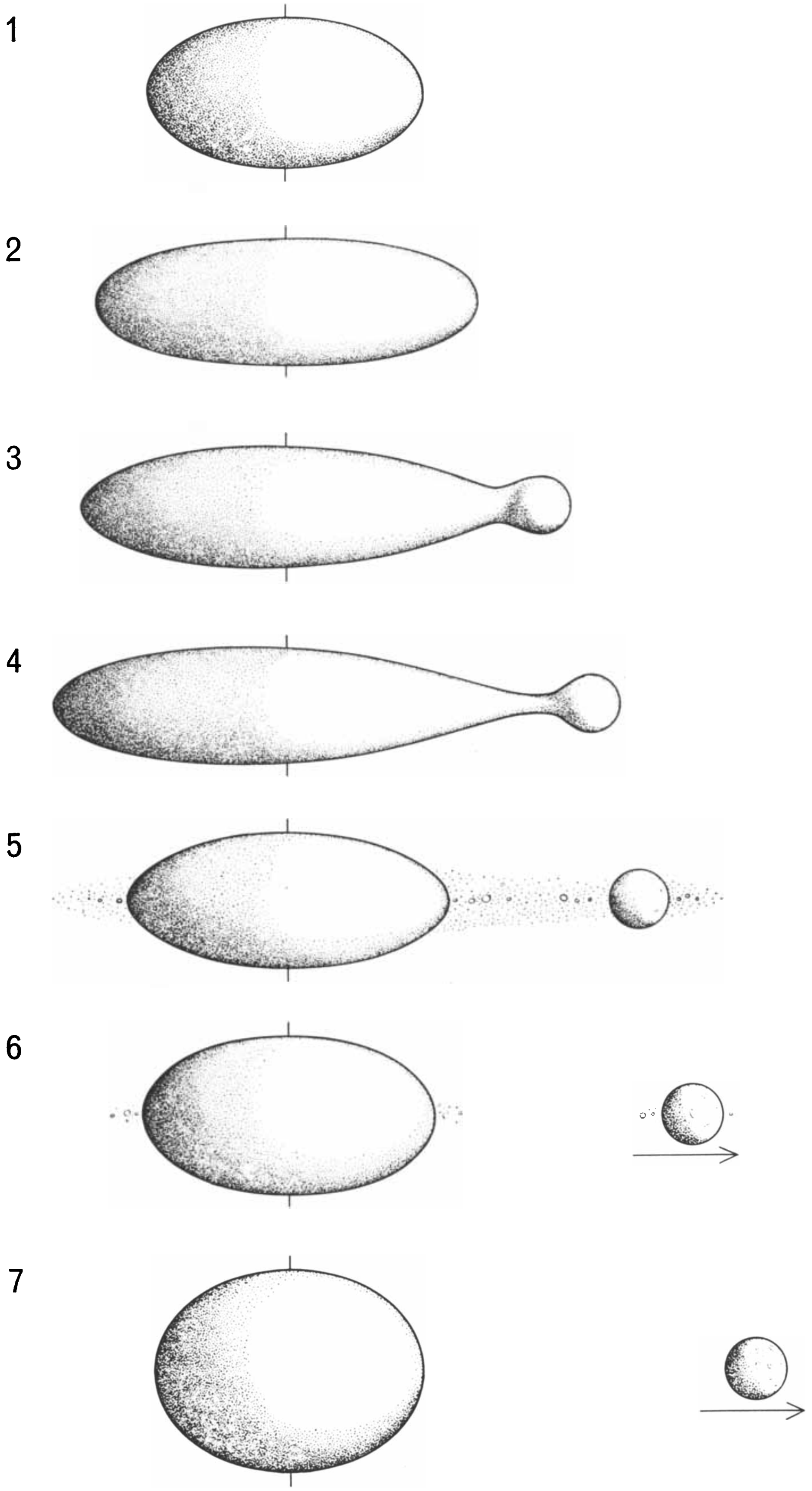
Ewen Whittaker of the Lunar and Planetary Laboratory of the University of Arizona.

Proponents of the cold theory hold that the moon has not had significant plutonic activity, at least near the surface. They argue that the appearance of the surface and the nature of the surface materials are determined by the impacts of bodies that participated in the moon's formation, and by objects that have been falling ever since. Some in this camp have even suggested that much of the subsurface material may be ice. The ice would be protected from solar radiation by an overlying blanket of dust, and at least some of it would escape being melted by the internal heat of the moon. Thus a layer of ice and dust would remain at a low enough temperature and a low enough vapor pressure to be preserved for the lifetime of the moon.

The warm theory lies between these extremes. Some members of the warm-moon school believe, for example, that a few features on the moon's surface are volcanic, such as the "dark halo" craters on the floor of the crater Alphonsus [*see bottom illustration on page 66*], and that perhaps lava has flowed over fairly large areas at some time, but that most of the craters are due to impact and most of the present surface material is the rubble resulting from such impacts.

Another hypothesis, more complex than any of those mentioned so far, relates both the origin and the history of the moon to the chemical and mineral characteristics of meteorites. This hypothesis, developed by Harold C. Urey of the University of California at San Diego, involves a three-step process for the formation of the solar system. He visualizes as a first step that a number of moon-sized bodies were formed by the accumulation of material at several points in a primordial dust cloud. This step was followed by collisions of the various bodies, leading to the destruction of most of them and the creation of at least some of the meteorites. The third step involved the recombination of most of the fragments into the planets as they exist now.

On this hypothesis Urey suggests that the moon is one of the primary bodies, and that it was captured by the earth in accordance with the hypothesis described earlier. This theory avoids the problem of specific gravity by suggesting that many of the small primary bodies originally in the general region of the earth's orbit had a density and composition similar to that of the present moon. The differentiation process that resulted



FORMATION OF MOON BY FISSION from the earth is one of three major hypotheses of moon's origin. At less than a critical spin rate (*1*) the earth is an oblate spheroid much flatter than that of the present planet. As the spin rate increases (*2*), perhaps as a result of the movement of heavier material to the core, the spheroid flattens. Then the motion is unstable and the earth assumes a shape resembling a bowling pin (*3* and *4*). Finally (*5*) the bulge separates from the earth. The earth and moon return to gravitationally stable ellipsoids (*6*). Thereafter (*7*) tidal friction reduces the energy of the system and causes the moon to move farther from the earth, while the earth's spin rate is steadily slowed. The diagram is based on calculations published by Sir James Jeans in 1929 and by Donald U. Wise in 1963.

in a heavier specific gravity for the earth took place during the second phase of the combination step.

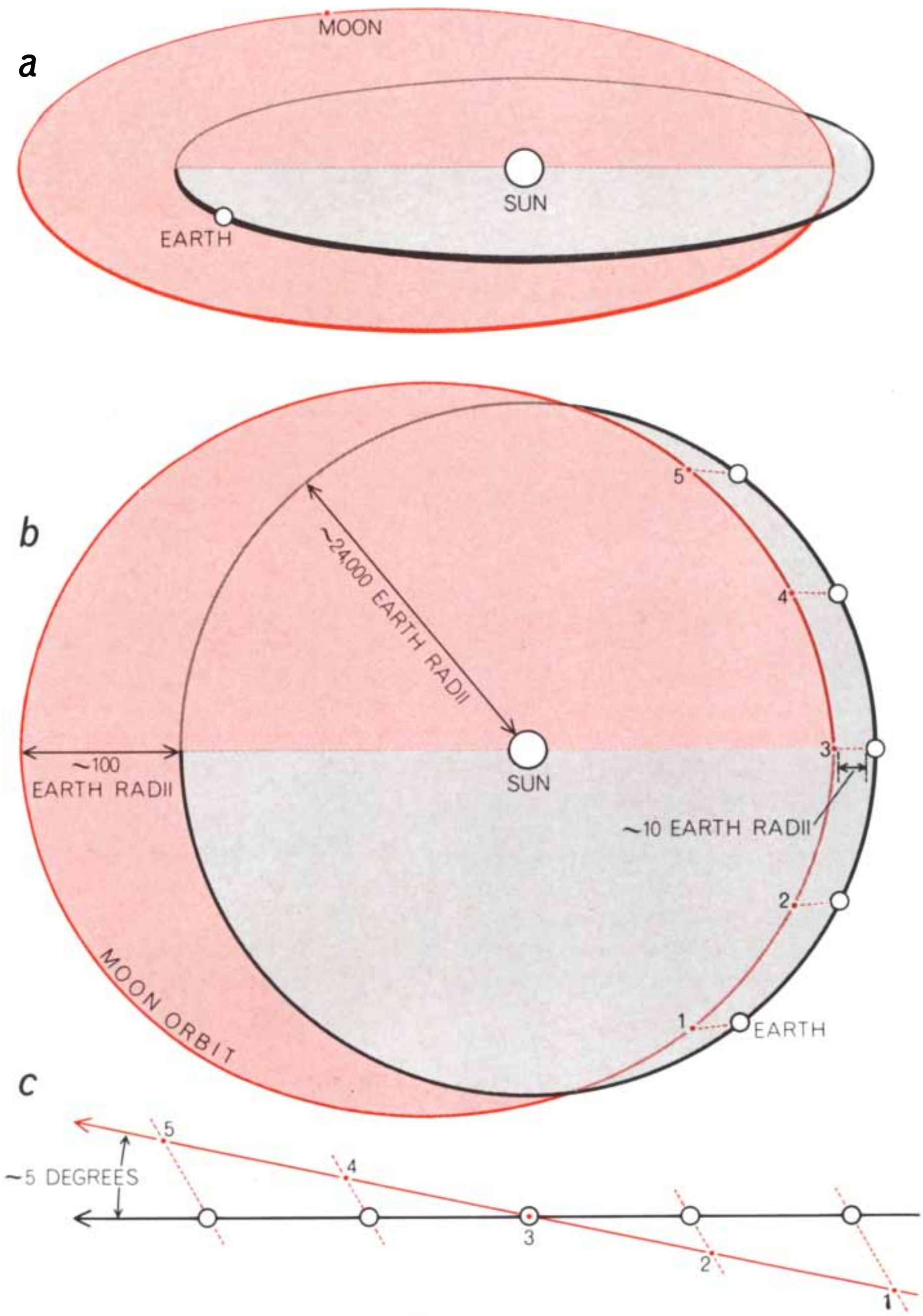
Dynamics and Temperature

Each proponent of one or another of these hypotheses has called attention to observations he feels cannot be explained by those who have put forward other hypotheses. For example, one problem concerns the three moments of inertia of the moon, one for each axis of a three-dimensional coordinate system. If the moon were not perfectly symmetrical but instead were somewhat ellipsoidal, it would wobble from side to side in its orbit. Such a wobble is called libration. If libration were observed, one could compute the three moments of inertia needed to produce it.

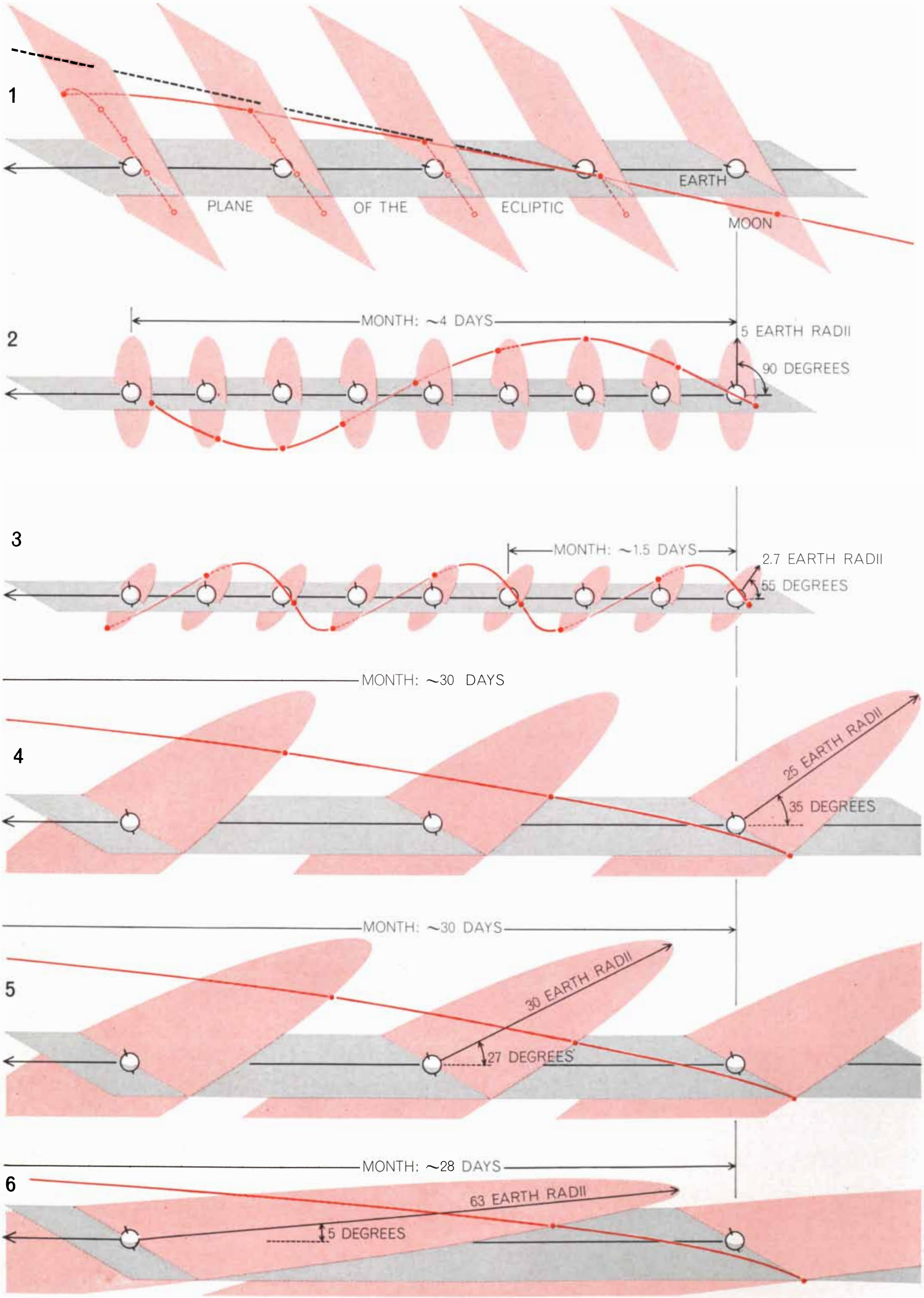
Unfortunately measurements of the moon's libration are difficult to make and are not very accurate. As they stand they give a picture of a quite unsymmetrical body, elongated both toward the earth and away from it, and flattened north and south. If these measurements are correct, and if the distribution of matter within the moon is homogeneous, then the moon is not in gravitational equilibrium in the earth-moon system. This lack of equilibrium means that a considerable gravitational stress exists at the moon's center—a stress that cannot be resisted by a liquid core. Such a conclusion would rule out hot models of the moon, and perhaps warm models as well.

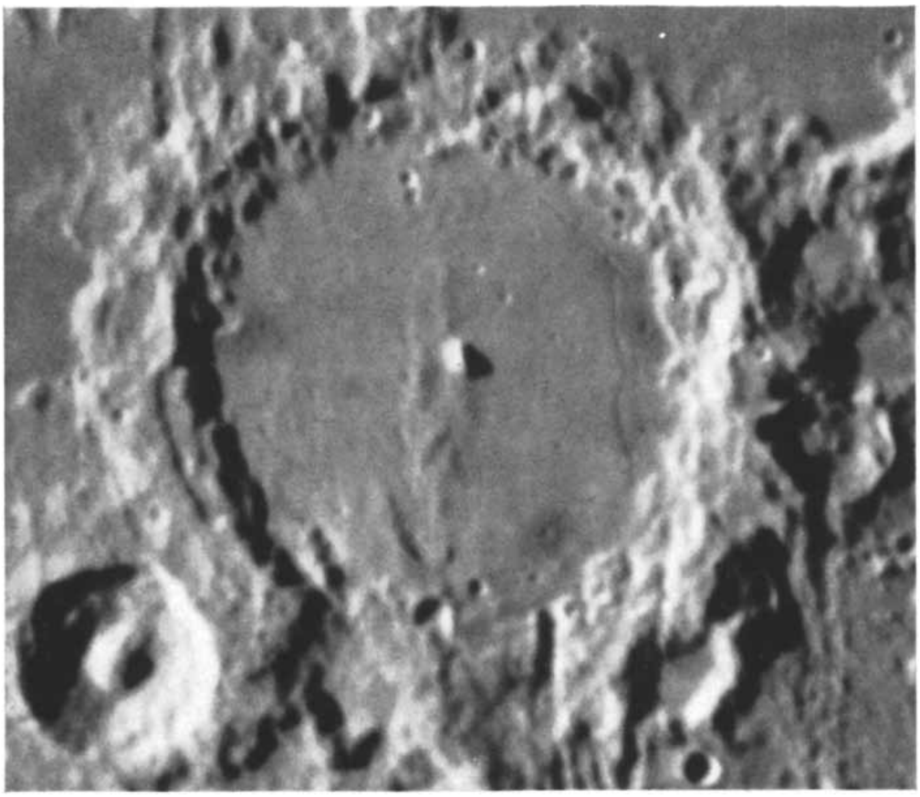
Of course the measurements could be in error, or the mass of the moon could be quite unsymmetrically distributed. There is enough uncertainty on both counts to limit the usefulness of the simple calculation. It is possible that the moon is gravitationally stable, even with a liquid core. A careful analysis of the paths around the moon followed by the lunar orbiters will provide more data on this point but will probably not resolve the problem.

One can also calculate theoretical values for the moon's internal temperature. Although the calculations themselves are straightforward, the results depend critically on the assumptions of the moon's initial temperature, its concentration of radioactive material and its thermal conductivity. If the initial temperature of the moon is assumed to have been about zero degrees centigrade, if the concentration of radioactive material is approximately the same as it is in the stony meteorites (which is less than the average for the earth's crust) and if the thermal conductivity is similar to the

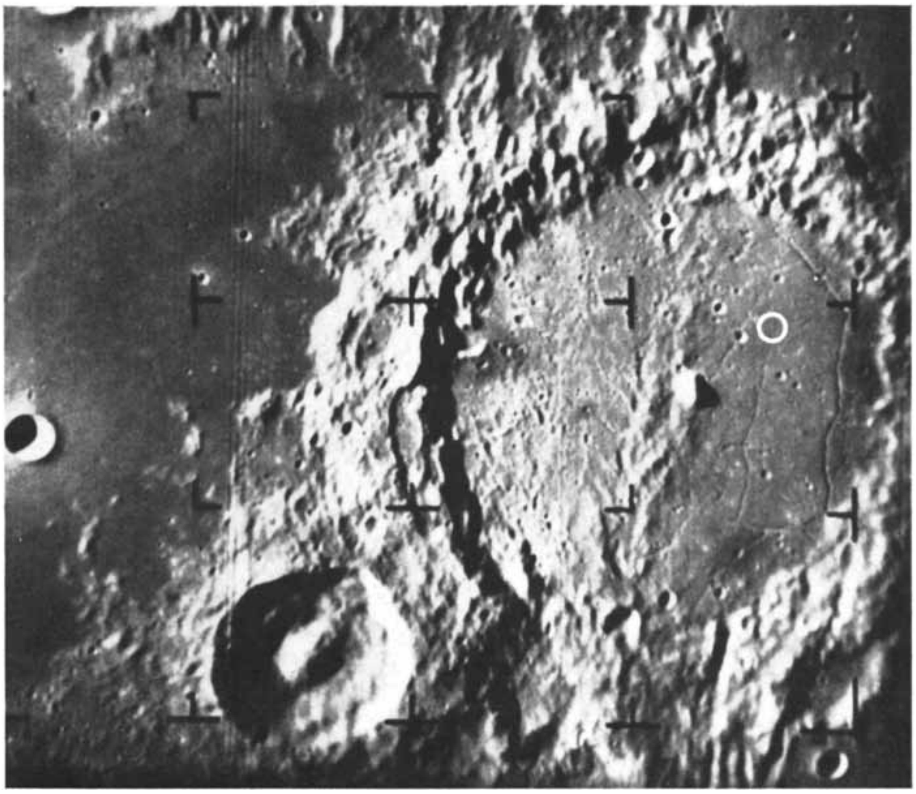


CAPTURE HYPOTHESIS assumes that the moon was originally a small planet in its own orbit around the sun. The paths of the earth and the moon before capture are shown from the side (*a*) and from above (*b*). The inclination of the two orbits, here exaggerated, was about five degrees. Capture conceivably occurred at a time when the moon passed within about 10 earth radii of the earth. The positions assigned to the earth and moon during this close approach (*b*) are repeated in diagram *c*, which shows how the two bodies would appear as viewed from the sun. To an observer on the earth, the moon would appear to pass through the plane of the earth's orbit at a steep angle (*broken colored line*). The diagrams on the opposite page show the hypothetical sequence of events if the moon were indeed captured during this close approach. The viewpoint is from a position slightly to the left of the sun and above the plane of the earth's orbit. The moon would be pulled out of its normal path (*broken black line in 1*) and would begin to circle the earth in a retrograde direction, that is, a clockwise direction as viewed from above. The capture may have occurred approximately 1.75 billion years ago, when the earth's axis may have been almost parallel to the plane of the earth's orbit. Following capture the moon would have rapidly moved closer to the earth (*2*), reaching a minimum distance of 2.7 earth radii (*3*) within a few million years. Tidal friction would then slow the earth's spin rate and drive the moon away, so that less than 10 million years after capture it would be about 25 earth radii from the earth (*4*) and 50 million years later 30 earth radii (*5*). The final diagram (*6*) shows the present relation of the orbits of the earth and the moon. The length of the day in each diagram corresponds to the actual length at the time. The diagrams follow calculations made by Gordon J. F. MacDonald of the University of California at Los Angeles.


1
PLANE
OF THE
ECLIPTIC
EARTH
MOON
2
MONTH: ~4 DAYS
5 EARTH RADII
90 DEGREES
3
MONTH: ~1.5 DAYS
2.7 EARTH RADII
55 DEGREES
MONTH: ~30 DAYS
4
25 EARTH RADII
35 DEGREES
MONTH: ~30 DAYS
5
30 EARTH RADII
27 DEGREES
MONTH: ~28 DAYS
6
63 EARTH RADII
5 DEGREES



CRATER ALPHONSUS, shown in this enlarged portion of a photograph made with the 100-inch telescope on Mount Wilson, was the target of the last of the Ranger lunar vehicles, *Ranger IX*. One reason for selecting Alphonsus as the target was to get a closer look at the central peak to see if it showed any evidence of having been created by volcanic activity.



RANGER IX VIEW OF ALPHONSUS was made from an altitude of 258 miles as the spacecraft was plunging toward its target at 5,600 miles per hour. The circle shows where *Ranger IX* hit the moon, having missed the aiming point by only three miles. Subsequent pictures revealed no evidence that the central peak was volcanic in origin. However, the dark "halos" around several small craters near the walls of Alphonsus itself (roughly at three o'clock, five o'clock and nine o'clock) look as if they were produced by subsurface activity.

conductivity of silicate rock, then the temperature at the center of the moon should have risen over a period of three billion years to the point at which iron would melt. If one assumption is changed, namely if the initial temperature is set at 600 degrees C., then 1.5 billion years after the moon's formation iron would be melted at depths greater than 300 miles. (The radius of the moon is 1,080 miles.)

Another result of these temperature calculations is an estimate of the internal stress that would build up in the moon, leading to moonquakes and possible surface effects. If the moon is either expanding or shrinking, it should carry the marks of this adjustment on its surface, and they should be easy to see. The craters of the moon are excellent reference marks for finding evidence of lateral motion. No such evidence has been found.

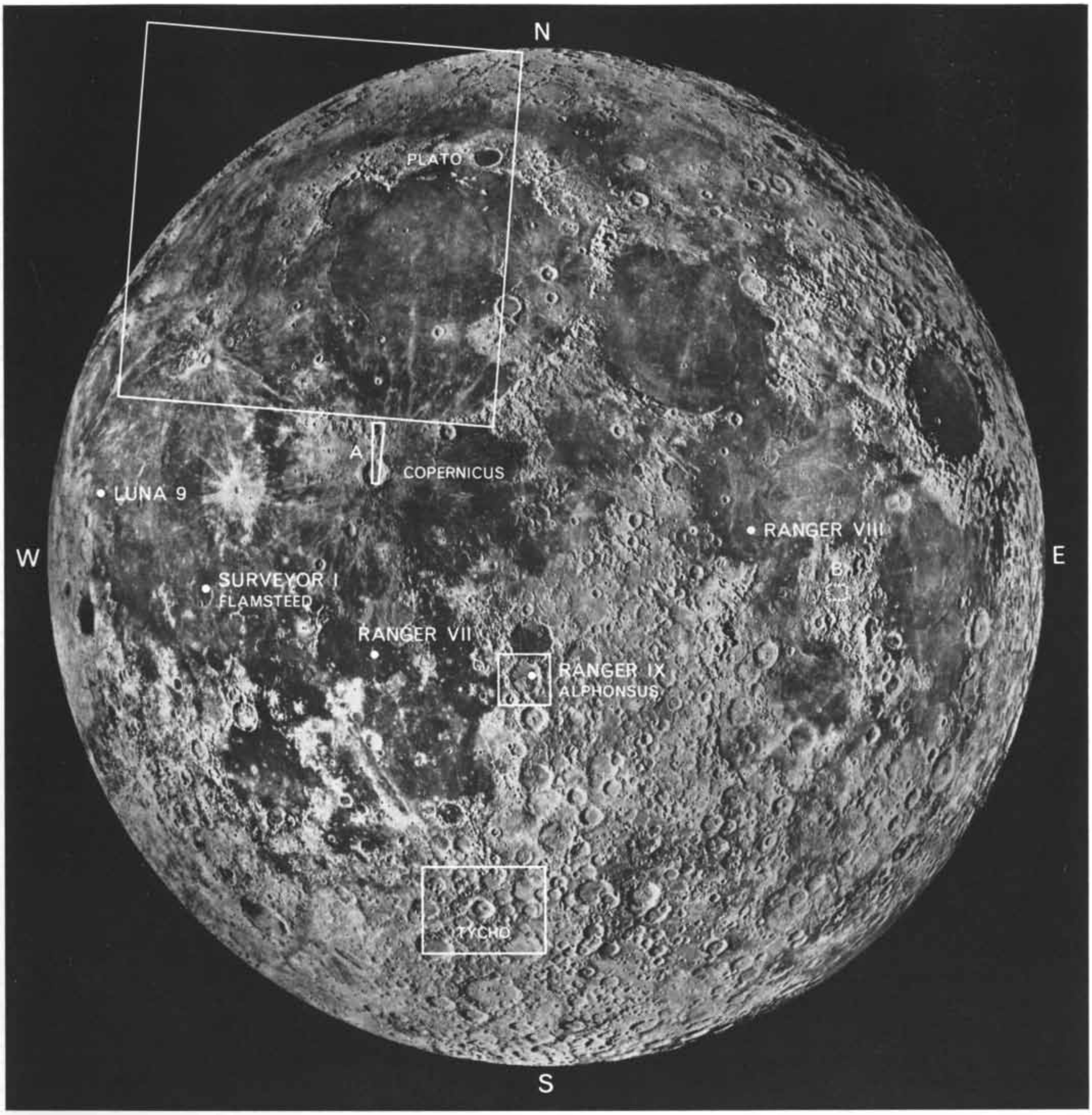
The result of the temperature calculation described above is that the moon should have expanded during the first three billion years of its existence, but should have stayed nearly the same size for the past 1.5 billion years (assuming that the moon is the same age as the earth, about 4.5 billion years). Nevertheless, heat would still be generated internally, and internal stresses would still build up and cause deep moonquakes.

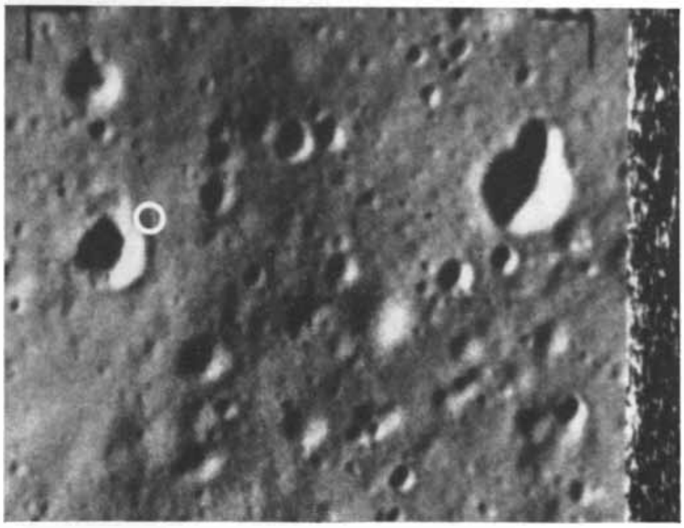
If the moon had a much higher concentration of radioactivity than is found in stony meteorites, a considerably greater degree of melting—not only of iron but also of silicate rock—would have taken place in its interior. The surface would display the effects, showing extensive volcanism and other plutonic activity. It is unlikely that under such conditions many large impact craters would remain. Instead the moon's surface would have been folded and warped into extensive mountain ranges similar to those on the earth. This conclusion presents a difficulty for the hot-moon theory.

Optical and Radio Measurements

Another source of information about the moon's surface is measurements of optical and radio properties. For example, the sunlight reflected from the moon's surface is polarized, and the degree of polarization depends on the microstructure of the surface material. Polarization measurements indicate that at least the very top of the surface is covered with a fine powder.

It has also been known for many years that the moon reflects more sunlight per unit area when it is full than it does at other times. This measurement





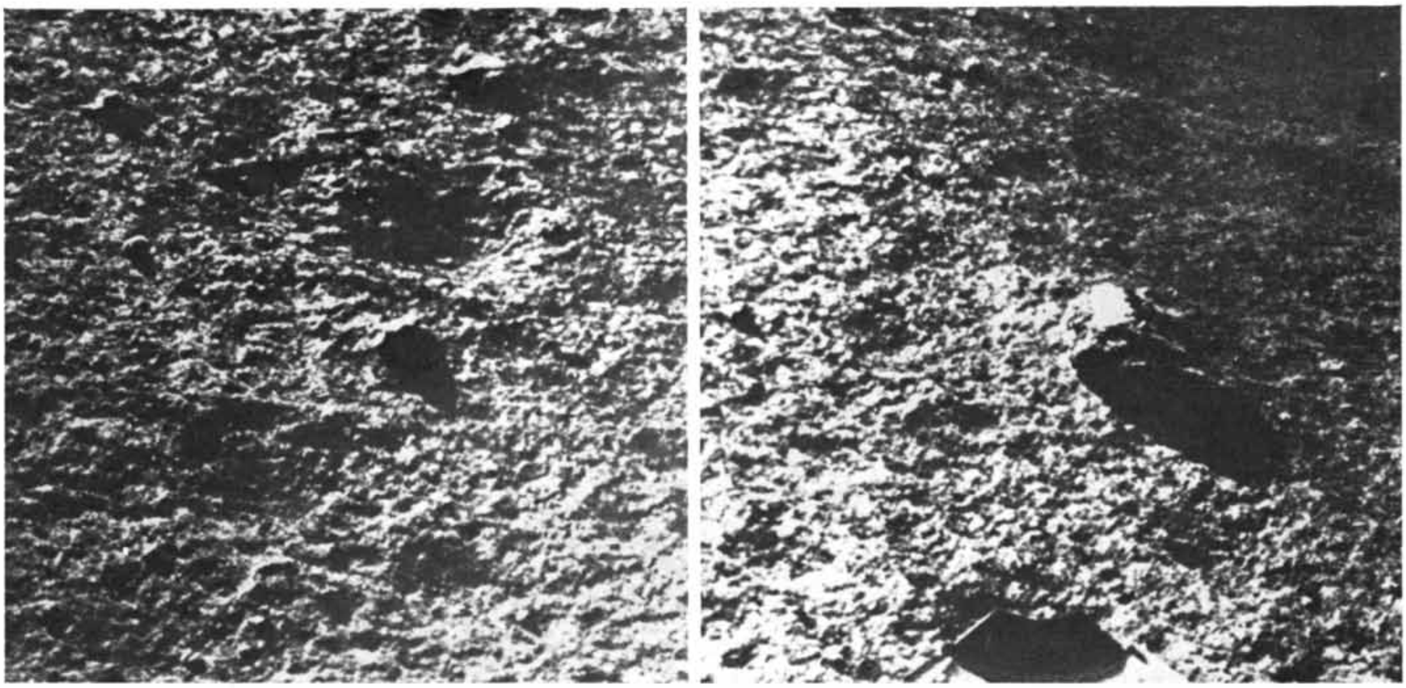
LUNAR TARGETS are identified in composite photograph of the moon (*above*). White dots show impact points of three Ranger spacecraft and the sites where *Luna 9* and *Surveyor I* landed safely on the surface. The large square at upper left outlines the region shown on the cover of this issue of SCIENTIFIC AMERICAN. The large rectangle outlines the area containing the crater Tycho, shown in the photograph on page 62. The areas labeled *A* and *B* identify two regions that appear respectively in photographs made by *Orbiter II* and *Orbiter I*; area *B* is on the far side of the moon. The Orbiter photographs appear on pages 71 and 72. The close-up of the lunar surface at the left was the last photograph taken by one of the four telescopic cameras on *Ranger IX*. Made from an altitude of .37 mile, it shows an area 253 feet across and 226 feet from top to bottom. Craters as small as 18 inches in diameter are visible.

implies that the moon's surface is highly porous or even filamentary in structure. When sunlight strikes such a surface at an angle, the porosities make tiny shadows that have the effect of reducing the surface brightness. Only when the source of light is nearly parallel to the line of vision will these deep areas be illuminated and the entire surface appear brighter.

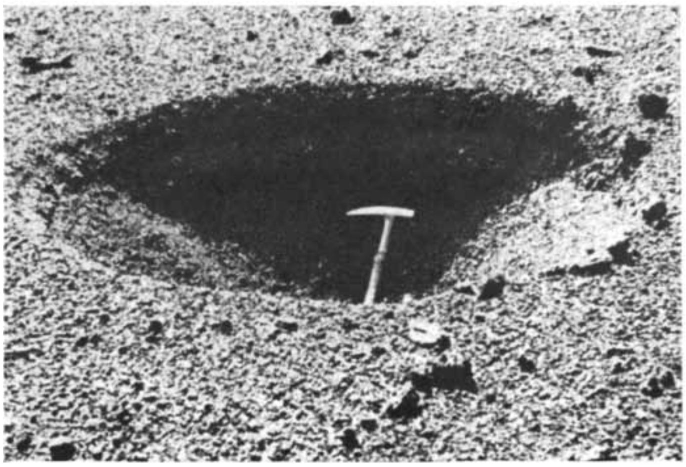
Measurements of the thermal radiation emitted by the moon at both infrared and radio frequencies show that the surface material is a good insulator and has a low density; it is thus quite different from solid rock. The depth of material that contributes to these measurements is roughly the same as the wavelength of the radiation involved. At the radio frequency used the measurements indicate the structure down to an inch or two below the surface. Radar measurements involve longer wavelengths and can probe still deeper into the moon's surface; such measurements also indicate a porous, low-density material down to a depth of one or two meters.

There are a few special areas on the moon where the material, at least at depths of more than an inch, seems different from the rest. Some of these areas can be clearly identified with sharp-edged craters such as Tycho [*see illustration on page 62*]. Approximately 95 percent of the surface, however, is surprisingly uniform. It is apparently covered to a depth of several feet with material that is both porous and low in density.

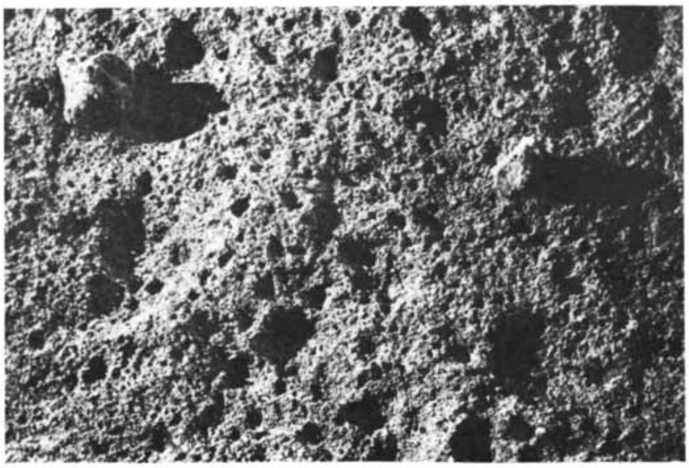
This kind of surface would appear to favor the cold-moon hypothesis, but advocates of the hot-moon hypothesis have suggested that the fluffy surface material may consist of ash flows and deposits of cinders. Another proposal is



VIEW FROM *LUNA 9*, the first device to be landed successfully on an extraterrestrial body, shows a rubble-strewn surface whose appearance is quite different from the one that can be seen in the most detailed pictures taken by the Rangers. *Luna 9* finally set to rest the fears of some that a spacecraft might sink out of sight in a bed of loose dust. Part of *Luna 9* is visible at the lower right.



TERRESTRIAL CRATER, in a site resembling that in the *Luna 9* pictures, was formed by drainage of material into an underground cavity. The crater, on the slope of the Hawaiian volcano Laimana, was photographed by Ewen Whittaker of the University of Arizona.



SIMULATED LUNAR SURFACE was created by Thomas Gold and B. W. Hapke of Cornell University. To show that fine powders can mimic the surface structure seen in *Luna 9* pictures they threw handfuls of portland cement into a bed of the same material.

that the surface may be a rock froth formed when gas bubbled out of lava in the vacuum that exists at the surface of the moon.

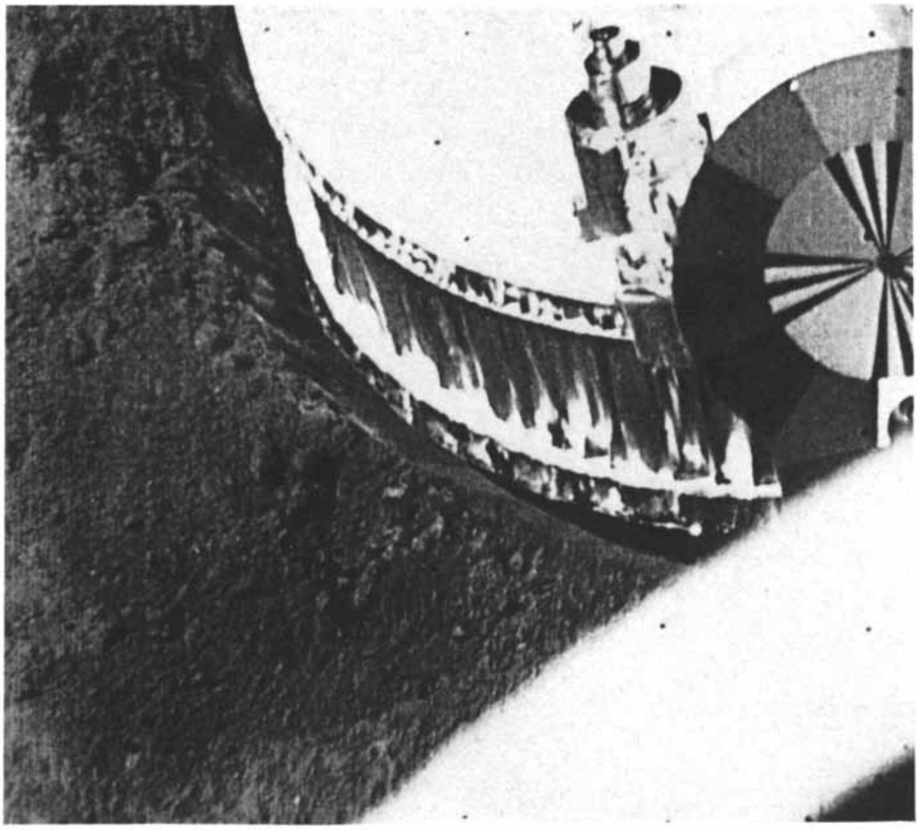
One can see from the foregoing how the notion gained currency that the moon might be covered with a thick layer of dust that would swallow up any spacecraft that landed on the moon's surface. Students of the lunar surface clearly understood, however, that moon dust, if it was indeed there, would not display the dustiness with which we are familiar in everyday experience. In the presence of an atmosphere the particles of dust slide past each other easily, lubricated by the thin layer of air between them. In the absence of an atmosphere the particles stick together to form a spongy structure that has been compared to newly fallen wet snow.

The Ranger Pictures

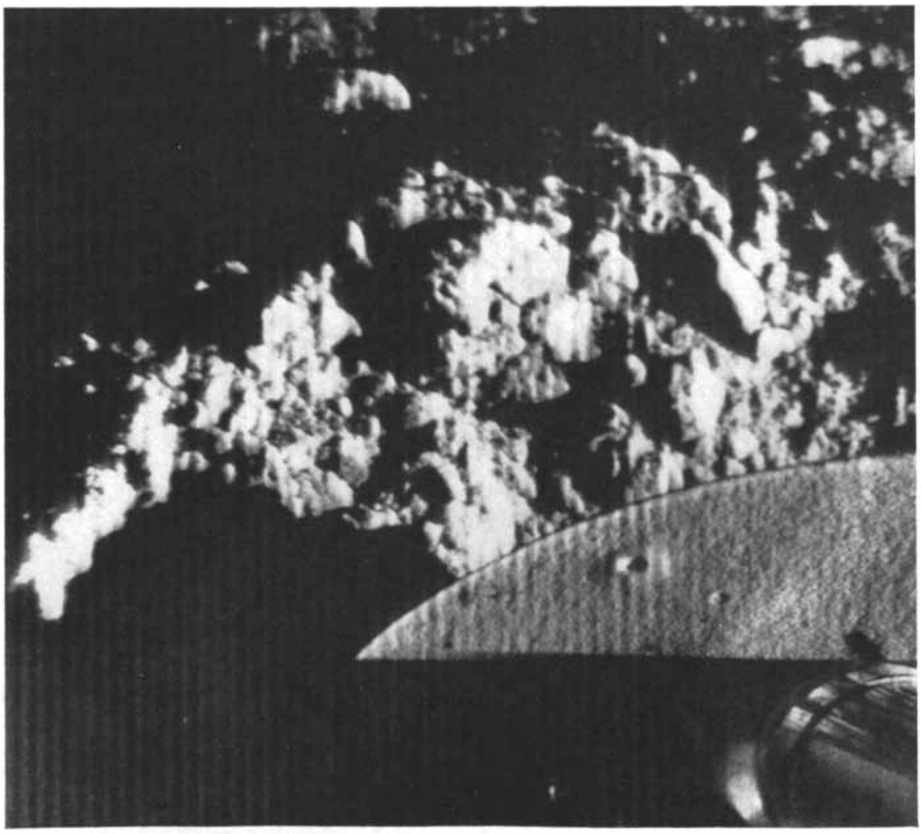
One can imagine how eagerly the proponents of the various lunar hypotheses awaited the pictures from the Ranger spacecraft. They recognized, of course, that resolving their disagreements was not the primary objective of the Ranger program. The failure of the first of the camera-carrying Rangers, *Ranger VI*, after a perfect flight to the Sea of Tranquillity was a bitter disappointment.

Then within a period of eight months *Ranger VII*, *Ranger VIII* and *Ranger IX* sent back a flood of excellent photographs showing surface features as small as 18 inches in diameter [*see bottom illustration on page* 67]. After the original excitement had subsided it was clear that the disagreements over the nature of the lunar surface, and their implications, remained unresolved. Those who believed the lunar surface was covered with lava and ash continued to think so after inspecting the Ranger photographs. Those who thought there was no lava on the moon held to their belief. And those who thought the moon was covered with fragmented material, with perhaps a few volcanoes here and there, found nothing in the pictures to disprove their ideas. As one lunar investigator remarked: "The Ranger photographs are like a mirror in which each one sees his own theories reflected back at him."

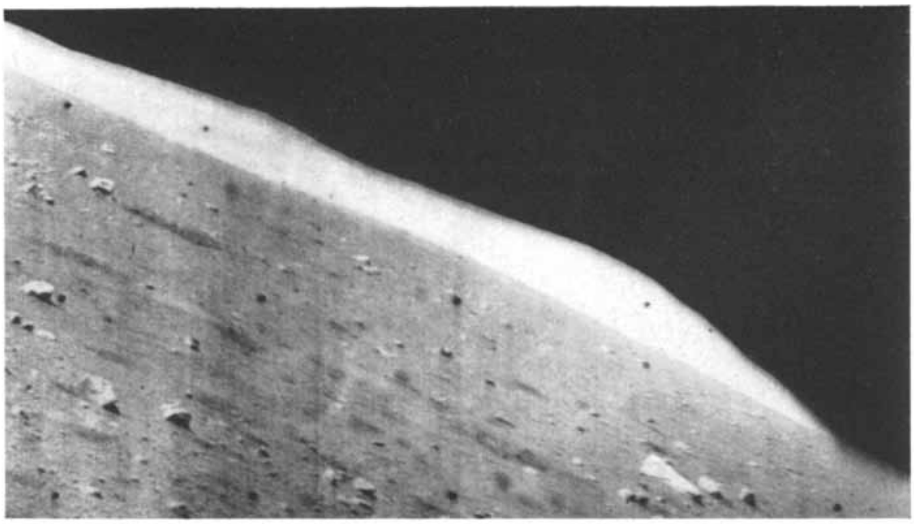
The difficulty was not in the Ranger spacecraft or the photographs they returned. The last three Rangers performed perfectly, and the thousands of pictures they transmitted revealed as much detail as the camera designers



DEPRESSION IN LUNAR SURFACE was formed by a crushable block attached to one of the three legs of *Surveyor I*, the second vehicle to land safely on the moon. This and other pictures clearly show that the surface is made up of granules that tend to stick together.

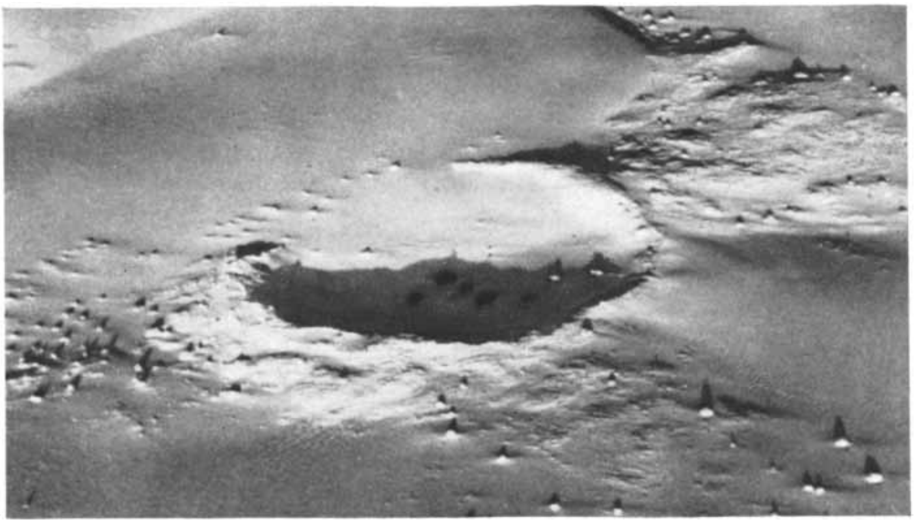


MARKED CHANGE IN SURFACE OF LANDING FOOT, as yet unexplained, took place during the 14-day lunar night between the time *Surveyor I* made the picture at the top of the page and this one. First-day pictures showed the surface as smooth and glossy. In this photograph it appears to have acquired a matte surface in which two crater pits are visible.



ROCK-STREWN MOONSCAPE is depicted in this *Surveyor I* view looking toward the northeast. The wall of the crater Flamsteed, about 12 miles away, appears on the horizon.

ROCKET CRATER at White Sands Proving Ground shows how rocklike lumps (instant rocks) are produced when a high-speed projectile lands in unconsolidated sandy soil.



METEORITE CRATER IN ARABIA may provide another example of instant rocks. Nicholas M. Short of the University of Houston, who has examined them, believes they were indeed produced by shock lithification. The crater, 97 meters in diameter, is the larger of the al-Halida (Wabar) pair of craters in the Rub' al-Khali desert of southeastern Arabia.

had hoped for. The problem was simply that, looking down on the moon's surface from above, it was impossible to judge surface hardness or composition, even from the close-ups. The Rangers did, however, satisfy their primary objective. They demonstrated that there were areas on the moon's surface smooth enough to permit the safe landing of the manned Apollo spacecraft.

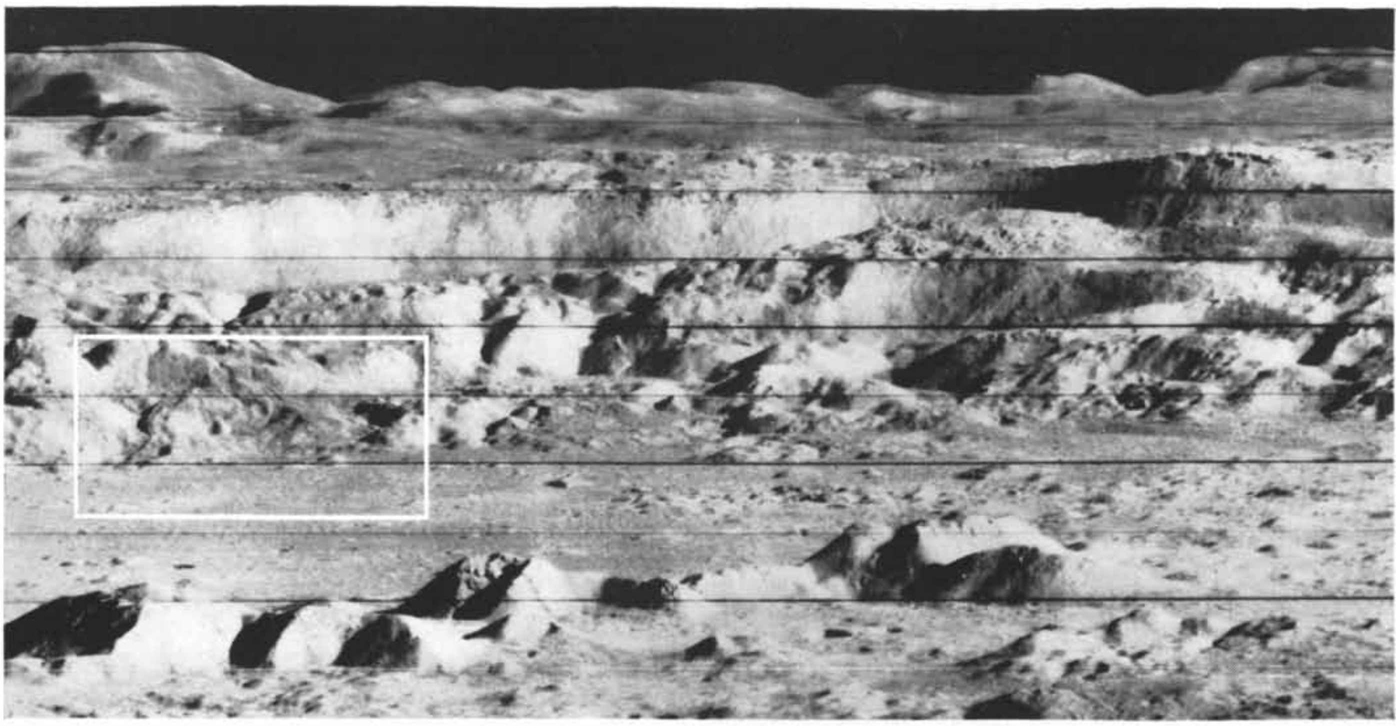
The next opportunity to determine the nature of the moon's surface came with the successful landing of the Russian *Luna 9* near the small crater Reiner (toward the western side of the moon's face) on February 3 of last year. The photographs from this spacecraft show many details of the surface in its immediate vicinity [*see upper illustration on page 68*]. They reveal considerable small-scale roughness, characterized by undulations a few centimeters high that may be the rims of tiny craters. On a larger scale the surroundings look rather smooth; one fairly big crater is visible near the horizon and a few rocks are scattered about. Nevertheless, there is no way to tell from the *Luna 9* pictures, or from any other data provided by the Russians from this flight, whether the surface is hard rock or granular material. One thing was certain: *Luna 9* had not sunk out of sight in a deep layer of loose dust. Although this fact did not solve any fundamental problems, it at least alleviated the fears of some who believed the moon's surface might not be able to support a load.

Once again those who believed the surface was solid lava could point to examples of terrestrial lava whose surface characteristics were similar to those photographed by *Luna 9* [*see illustration at lower left on page 68*]. Those who believed the lunar surface was composed of a fine granular material conducted laboratory demonstrations in which powdered rock (actually portland cement) thrown into the same material closely reproduced the surface texture shown in the *Luna 9* pictures [*see illustration at lower right on page 68*].

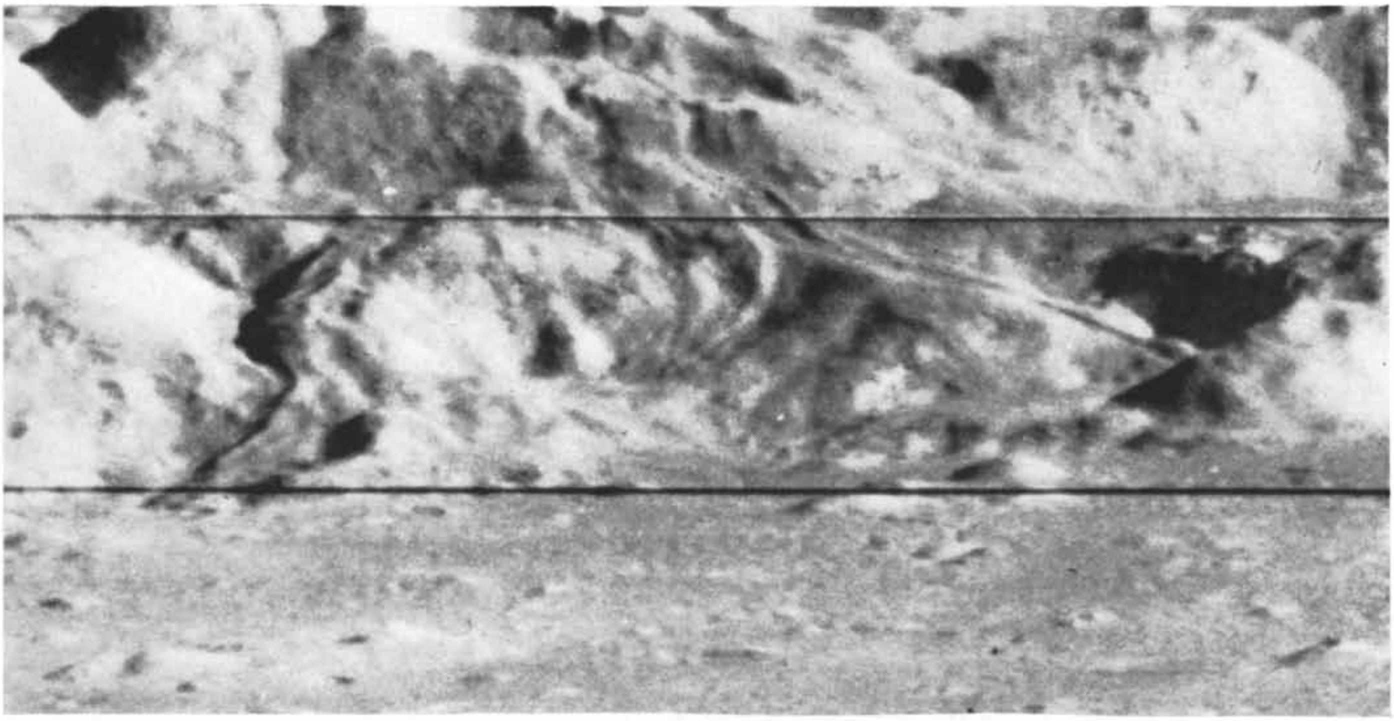
The Surveyor Pictures

The next opportunity to examine the lunar surface was to be the landing of *Surveyor I*, designed to carry instruments safely to the surface of the moon and to send back pictures of its landing site. On June 2 of last year *Surveyor I* touched down safely inside the crater Flamsteed. This site was selected for two principal reasons. First, it allowed a nearly vertical landing, which made things easier for this first use of the spacecraft's soft-landing system. Second, it was in one of the apparently smooth areas marked out as a potential landing site for the Apollo. The primary mission for *Surveyor*, as for its Ranger predecessors, was the scouting of potential landing sites for the manned Apollo mission.

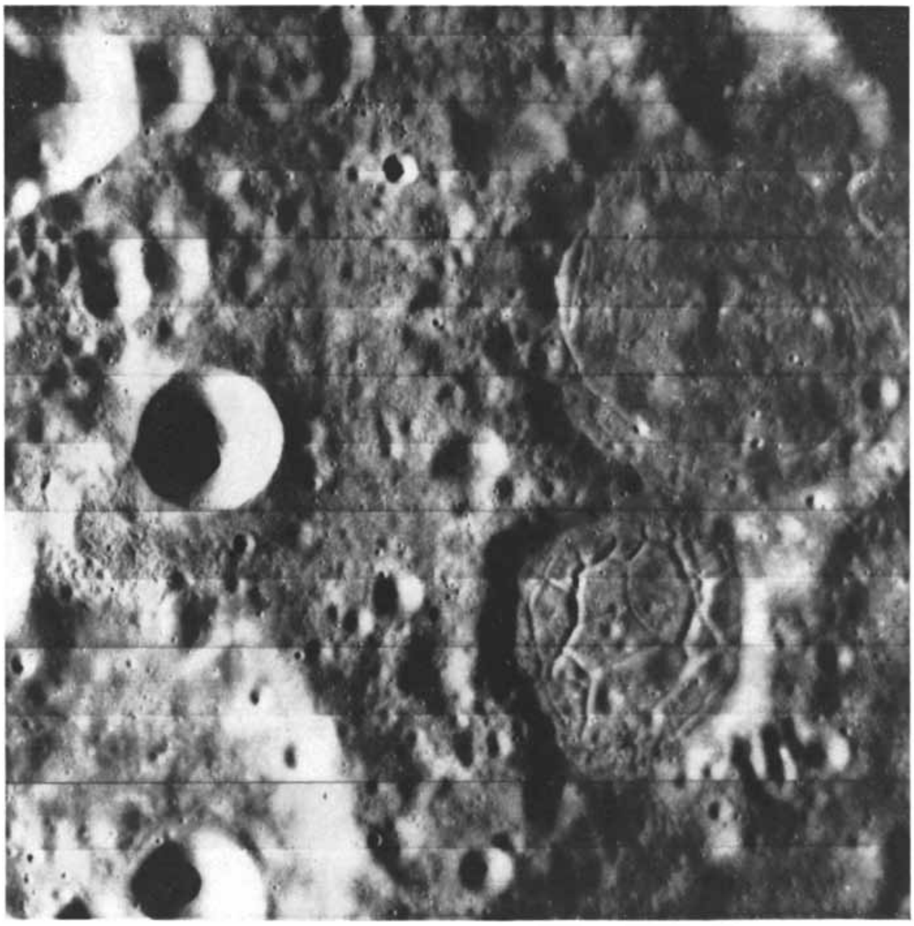
Surveyor's television camera sent back thousands of pictures of the surrounding moonscape under a wide variety of lighting conditions as the lunar day (equivalent to 14 terrestrial days) went through its cycle into darkness. Another set of pictures was taken during the next lunar day. In some of these pictures one can see details of the surface immediately around two of *Surveyor's* three landing feet [*see top illustration on page 69*] and also a bit of the surface under the spacecraft's hull where a shock-



LOW-LEVEL VIEW OF COPERNICUS, one of the larger lunar craters, was made by *Orbiter II* in November. The sharply shadowed hills, located in the middle of the crater, are about 1,000 feet high. The crater itself is about 60 miles across and two miles deep.



DETAIL OF COPERNICUS, enlarged from a region at the left of the photograph above, shows evidence that material has moved down the sides of the crater wall in glacier-like fashion. Proponents of the hot-moon theory believe the material was molten rock. Other theorists believe it was something else that moved, perhaps buried ice. The effect can be described generally as mass wasting.



FAR SIDE OF MOON was photographed by *Orbiter I*. The two large craters show a number of cracks, similar to those visible in the crater Alphonsus (*see illustrations on page 66*), that strongly suggest subsurface activity. The smaller crater of the two is about 15 miles across.

absorbing block of metal had briefly touched down. The message of these pictures was that the surface material was granular, at least to the depth penetrated by *Surveyor's* structure.

As the second lunar day drew toward evening, a photograph of the top of one of the landing pads showed the surface to be strangely mottled [*see bottom illustration on page 69*]. The reason for this appearance is a mystery. It may be some kind of corrosion of the surface resulting from temperature changes during the day-night cycle, or perhaps a layer of dust deposited on the surface by some unknown process.

At first these photographs seemed to present a serious blow to the hot-moon hypothesis, but the proponents of a volcanic moon have no thought of surrendering. They are willing to accept the idea that bombardment by small meteorites has pulverized the surface of the lava to some unknown but supposedly small depth. Under the surface, they predict, solid lava will be found. They point to the many rocks in the *Surveyor* photographs as evidence of some kind of plutonic activity; one rock in particular—"Rock A"—was close enough to be photographed in remarkable detail [*see illustration on page 60*].

Those who held to the dust theory were naturally pleased at the granular appearance of the surface, which coincides with their prediction of the behavior of dust particles in a vacuum. The many rocks strewn about the moonscape, however, seemed to present as much of a problem for them as the granular material did for the lava proponents. Undaunted, they have come up with an ingenious explanation: "instant rock."

This refers to a type of rock made out of powdery material by shock, in the process called shock lithification. Such lumps have been found at the sites where rockets have crashed on the White Sands Proving Ground [*see middle illustration on page 70*] and have been produced artificially by explosions in beds of quartz. Recently Nicholas M. Short of the University of Houston has tentatively identified instant rocks around meteorite craters in the Arabian desert [*see bottom illustration on page 70*].

At least one explanation coincides well with the *Surveyor* photographs. If one carefully measures the sizes of particles and rocks in these pictures, one finds that the distribution is similar to that resulting from any process that breaks down large solid objects. Presumably, then, the particles on the lunar surface have been produced by the kind of breakdown that would result from the impact of meteorites. This, however, does nothing to prove the existence or nonexistence of buried lava and so cannot solve the problem of the moon's thermal history.

If *Surveyor* had carried the complement of instruments originally intended for it, it could have performed a remote chemical and mineralogical analysis of the material. Unfortunately the launching rocket, the Atlas Centaur, did not give the performance hoped for in the early days of its development. As a result some 200 pounds of equipment had to be taken off *Surveyor* in order to get it to the moon at all, and this lost equipment represented all the scientific instruments except a single camera. An earlier group of three Rangers, all of which failed, carried gamma ray spectrometers to measure the relative abundance of radioactive potassium, uranium and thorium and thus might have provided some information on the chemical nature of the moon's surface. Such measurements might have indicated whether the surface material is similar to meteorites or to the crust of the earth, since the relative abundance of potassium, uranium and thorium is quite different for these two classes of rock. Because of weight restrictions gamma ray spectrographs were not carried on the final group of Rangers that succeeded in photographing the moon's surface.

The Orbiters

The Russian *Luna 10*, placed in orbit around the moon in the spring of 1966, carried as one of its family of instruments a gamma ray spectrometer similar to one designed for the early Rangers but less sensitive. The *Luna 10* instrument indicated that the radioactivity of the surface material was less than the radioactivity typical of granite, which together with basalt comprises the plutonic material of the earth's crust. Because of the high level of background radiation it was not possible to determine how much less radioactivity there was. Although the instrument had a 32-channel analyzer for the purpose of detecting individual spectrum lines of gamma radiation, no lines characteristic of the three critical elements could be seen in the data. The general radiation level detected appears to exclude granite but not basalt, which is less radioactive. If the detected radia-

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tion is mostly background radiation, then material with still less radioactivity, such as meteoritic rock, is also not excluded.

A few months after *Luna 10* had been placed in orbit around the moon the U.S. succeeded in doing the same with *Orbiter I.* The spacecraft spent several weeks circling the moon and making detailed photographs of a number of areas, concentrating on those considered most likely to be Apollo landing sites. These photographs were taken on film and then relayed to the earth with the help of a scanning system that operated for several weeks after the actual photographic mission was finished.

The photographs are remarkable in their detail. Most of the areas appear quite similar to those photographed by the Rangers and *Surveyor:* more or less level areas with a scattering of craters of all sizes. A few areas are more rugged, and some craters appearing in photographs of the far side of the moon have floors crisscrossed by rills, or cracks, strongly suggestive of subsurface activity [*see illustration on page 72*]. The rills are similar to those *Ranger IX* photographed on the floor of the crater Alphonsus. These pictures are welcomed by those who believe extensive lava formations lie just below the moon's surface. On the other hand, the cold-moon advocates are not to be shaken; they have suggested that the rills have resulted from the slow movement of a buried ice layer.

Several of the pictures made by *Orbiter I* and a few months later by *Orbiter II* provide strong indications that material has moved down the sides of craters [*see illustrations on page 71*]. Eugene M. Shoemaker of the U.S. Geological Survey has called attention to many such examples as clear evidence of "mass wasting," a term used to describe the redistribution of material from high places to lower ones. This is a typical erosion process on the earth, and it is not surprising to find it on the moon. The lunar erosion processes must be quite different, however, since there is neither air nor water on the surface of the moon.

Luna 13, the second Soviet moonlander, sent back pictures much like those taken by its predecessor, *Luna 9,* but it carried some additional equipment. A probe to test surface hardness verified conclusions based on the photographs of *Surveyor I*'s footprints. A density-measuring device reported that the surface material has a density of about one gram per cubic centimeter, according to preliminary reports. This checks well with the radar measurements made from the earth.

The Orbiters, like *Surveyor* and the Rangers, have done an excellent job with their primary task—to pave the way for Apollo. The determination of the nature of the moon's surface material and the implications of this information for the understanding of the origin and history of the moon must now wait until something more than photographic data is available. Two types of instrument are the best candidates for providing preliminary data. One type would be an improved version of the gamma ray spectrometer carried by the early Rangers. It is possible that such a device will be carried on one or more of the remaining Orbiters.

Later Surveyors may be able to carry added equipment, and one instrument high on the list of possibilities is an alpha ray spectrometer. This device carries an emitter and detector of alpha rays. It conducts a chemical analysis of the material around it by measuring the momentum of the alpha particles that come bouncing back to the detector after interacting with the nuclei of nearby atoms.

Future Investigations

Most investigators concerned with lunar exploration feel that even if these comparatively simple instruments are used and work to perfection, they can supply no more than preliminary data. The problem of establishing the moon's nature and history will be a long, hard job that will involve many flights of both manned and unmanned spacecraft. Some crucial investigations, such as the dating of samples by isotope analysis, will undoubtedly require the return of samples to earth-based laboratories. Eventually the moon's subsurface structure must be probed by seismometers and geophones, gravimeters and drills.

It was the prospect of a long and complex exploratory program that lay behind the decisions to concentrate on photographic missions during the early phase of the program. It was recognized that the cameras of the Rangers, Surveyors and Orbiters would probably not resolve any problems about the chemical constitution of the moon's surface material. It was also recognized that a thorough understanding of the nature and history of the moon would require considerably more information than could be returned from a few automatic spacecraft, regardless of what instruments they carried. After all, we are asking questions about the origin and history of the moon that we have yet to answer about the earth, where the task of investigation is considerably simpler.

STEEL RESEARCH AIDS PRODUCT DESIGN

Special division makes Youngstown's complete research facilities available to the steel customer. It gives direct assistance in the design and methods of using steel in the customer's products.

by R. H. Frazier, Manager, Research Services

Normally, research for the steel industry has two purposes:

(1) To develop new processes within the mills or to improve existing processes. For example, research in this area has led to a 50% rise in blast furnace iron production in the past ten years, and a 30% reduction in coke consumed per ton of iron production. Quality has risen, too. And all this effort has helped maintain stable, nominally low prices for iron and steel.

(2) To develop new steel products to meet more sophisticated requirements in both old and new markets. For example, new petroleum drill pipe with yield strength of more than 100,000 psi has been developed and proven. Increased depth of newer wells has seen pipe used at higher stresses, thus increasing the chance of corrosion fatigue. And the yield strength level is being increased to 135,000 psi and 150,000 psi with the expectation of equally good performance.

But at The Youngstown Sheet and Tube Company, research has a third distinct purpose – perhaps the most important one of all: to be of direct assistance to the customer.

Youngstown Steel has organized a separate division of the Research Department for the specific purpose of providing customer assistance. This division makes available to the customer the complete services of the Youngstown Research facility, not just a part.

A typical example of this service concerned the redesign of a water tank. A customer was manufacturing low-pressure water tanks by welding two drawn heads to a roll-formed body section with a welded side seam. The entire assembly was galvanized by dipping the tank into molten zinc.

The manufacturer decided to try simplifying construction by making two deep drawn sections from galvanized steel sheets and joining two sections with one circumferential weld.

Youngstown's design team played a major role in designing the tank, calculated the size and thickness of the required blank and assured a satisfactory and economical solution. Many thousands of the redesigned tanks have been made, and the customer is getting ready to make another tank, newly designed with aid from Youngstown.

If desired, Youngstown researchers make studies to suggest ways to improve the product's appearance as well as its function. And it is noteworthy that a customer's size and the size of his problems do not necessarily correlate. All companies, large or small, are served on an equal basis.

While remaining in close contact with the customer to insure that all possible assistance is always available, great care is also taken to guard against intrusion. In many cases only the customer himself knows what design characteristics best fit his entire product line. In still other cases, absolute styling secrecy is imperative. The rule is this: Youngstown research facilities are ready when needed. Proof testing or prototype copies of the product are perhaps the best methods of exactly determining the customer's needs.

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Value Analysis, a method of determining the total cost of putting a product on the market, is used by Youngstown to help the customer reduce overall costs. For often most of the cost of a finished product is contained, not in the raw material, but in the many processes along the line.

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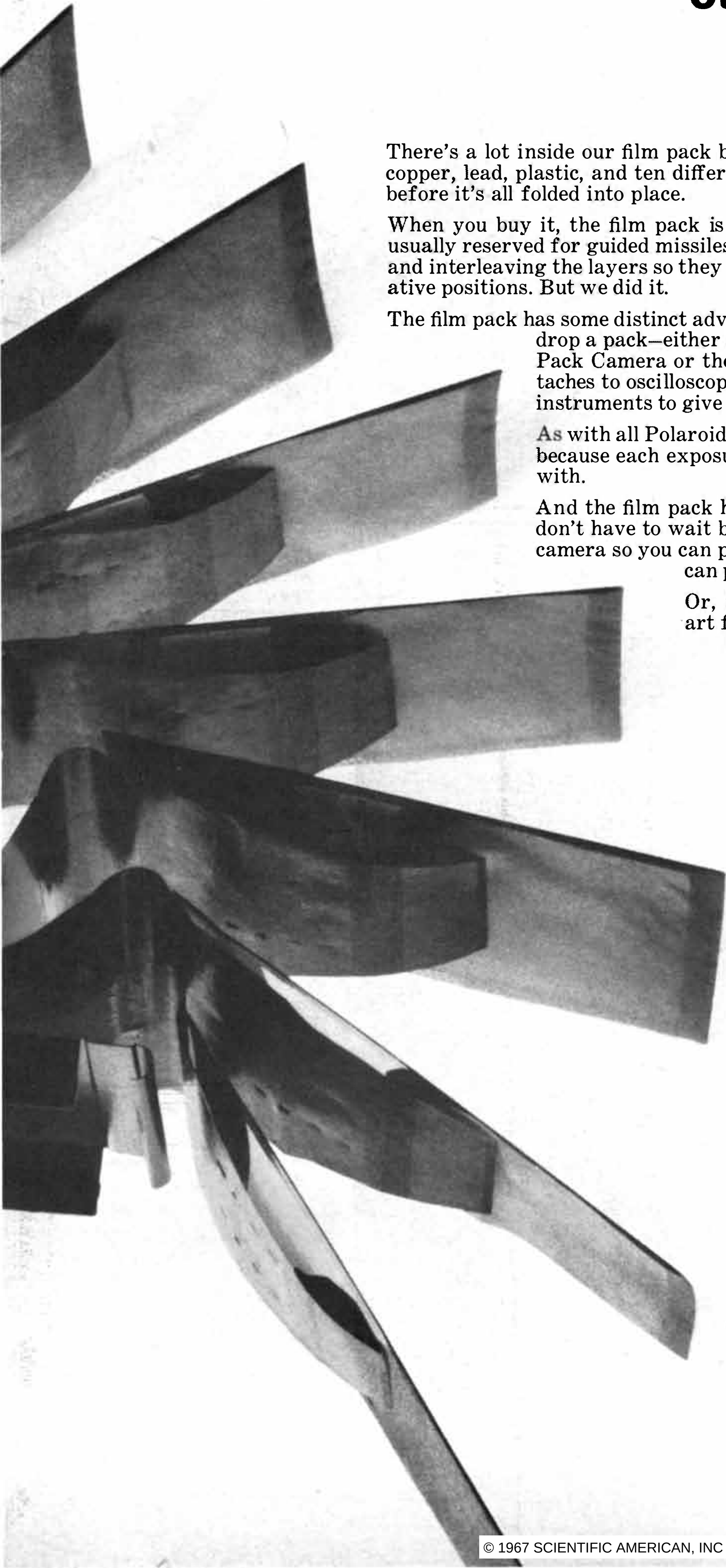

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BEHAVIORAL PSYCHOTHERAPY

Abnormal behavior can be thought of not as a symptom of a hidden illness but as a problem of "social learning," and can be treated directly by methods that are derived from principles of learning

by Albert Bandura

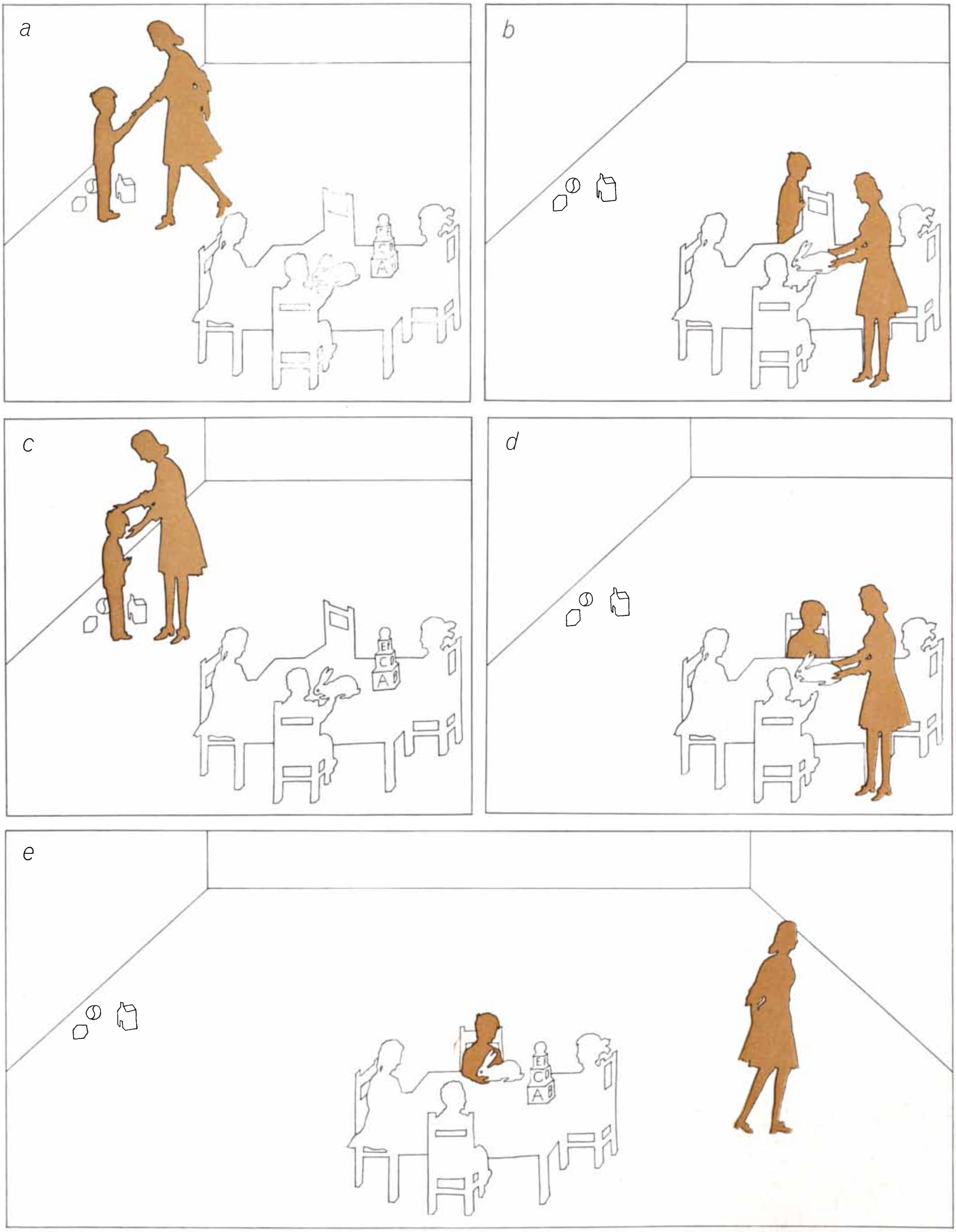
In recent years there has been a fundamental departure from conventional views regarding the nature, causes and treatment of psychological disorders. Most theories of maladaptive behavior are based on the disease concept, according to which abnormalities in behavior are considered to be symptoms of an underlying neurosis or psychic illness. Today many psychotherapists are advancing the view that behavior that is harmful to the individual or departs widely from accepted social and ethical norms should be viewed not as some kind of disease but as a way—which the person has learned—of coping with environmental demands. Treatment then becomes a problem in "social learning." The abnormal behavior can be dealt with directly, and in seeking to modify it the therapist can call on principles of learning that are based on experimentation and are subject to testing and verification.

The concepts of symptom and disease are quite appropriate in physical disorders. Changes in tissues or in their functioning do in fact occur, and they can be verified whether or not there are external manifestations. Where psychological problems are concerned, however, analogy with physical disease can be misleading. The psychic conditions that are assumed to underlie behavioral malfunctioning are merely abstractions from the behavior that are given substance and often endowed with powerful motivating properties. Each of the many conventional theories of psychopathology has its own favored set of hypothetical internal agents. Psychotherapists of differing theoretical background and affiliation tend to find evidence for their own preferred psychodynamic agents but not for those cited by other schools. Freudians unearth Oedipus complexes, Adlerians discover inferiority feelings with compensatory power-strivings, Rogerians find inappropriate self-concepts and existentialists are likely to diagnose existential crises and anxieties.

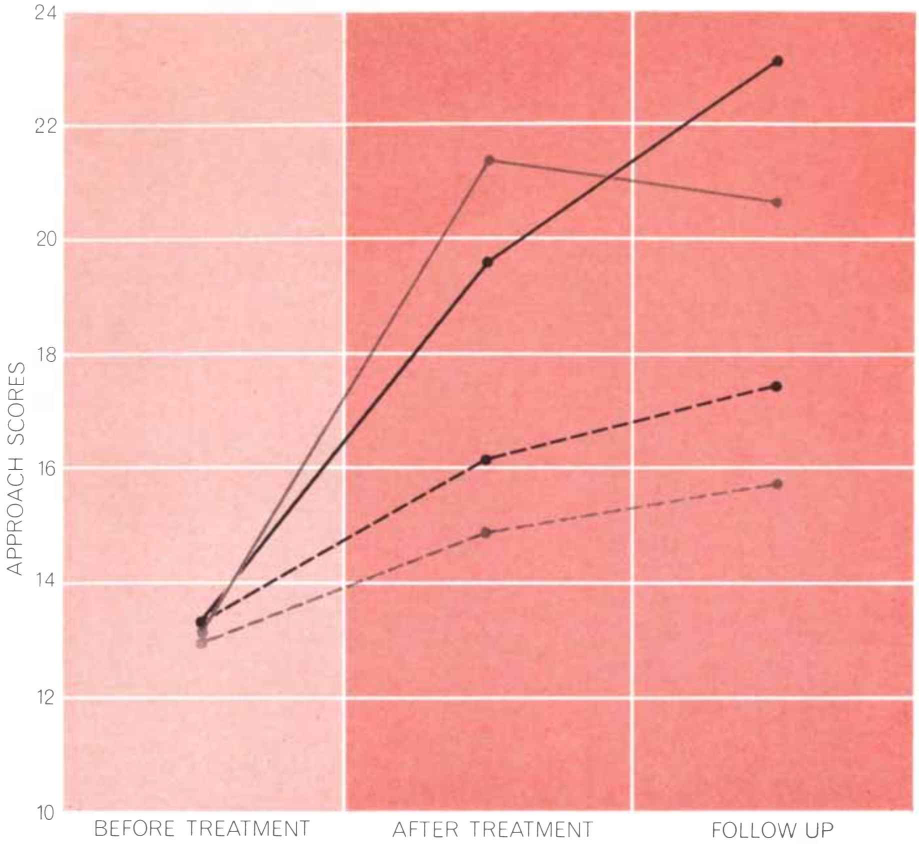
A correlate of the disease approach is the assumption that in order to gain lasting benefits from psychotherapy the client must achieve awareness of the concealed forces causing his actions, and the development of this insight is usually one of the primary goals of conventional therapy. A study of the results of psychotherapy made by Ralph W. Heine at the University of Chicago School of Medicine suggested, however, that a client's insights and emergent "unconscious" could be predicted more accurately from knowledge of his therapist's theoretical system than from the client's actual developmental history. It would seem from this finding and others that insight may primarily represent a conversion to the therapist's point of view rather than a process of self-discovery. It is therefore not surprising that insight can be achieved without any real effect on the difficulties for which the patient originally sought help. A chronic stutterer converted to Freudianism or Jungianism—or to any other theoretical system—will not necessarily begin to speak fluently. His stuttering behavior is more likely to be eliminated by the necessary relearning experiences than by the gradual discovery of predetermined insights.

Stuttering is a well-defined motor behavior, but I should make it clear that what are called behavioral therapies apply to the full range of psychological events: attitudinal and emotional as well as motor. Some forms of behavioral therapy bring about major changes in people's actions by modifying their emotional responses; on the other hand, enduring changes in attitude can be most successfully effected through modifications in overt behavior. In the final analysis all modes of psychotherapy are behavioral, since the client's behavior—broadly defined to include conceptual, emotional and motor expression—is the only reality the psychotherapist can deal with and modify. Indeed, while conventional therapists are promoting insights, they may simultaneously (if inadvertently) reward desirable patterns of behavior and show disapproval of abnormal behavior; they may reduce anxieties through their supportive reactions to a client's statements; they exhibit attitudes, values and patterns of behavior that a client is inclined to emulate. Many of the therapeutic changes that occur in conventional psychotherapy may therefore arise primarily from the unwitting application of social-learning principles. The point is that these beneficial results can be obtained more readily when the principles are applied in a more considered and systematic way. I shall describe a number of different approaches to treatment based on learning principles and review some studies, many of them controlled investigations, in which such procedures have been tested.

In our research at Stanford University we have found that almost any learning outcome that results from direct experience can also come about on a vicarious basis through observation of other people's behavior and its consequences for them. Indeed, providing an appropriate "model" may accelerate the learning process, and one method of social-learning therapy is therefore based on modeling the desired behavior. This is particularly suitable in the treatment of gross deficits in behavior, as in the case of a child (usually diagnosed as



PRINCIPLES OF LEARNING are utilized in the simple course of therapy suggested by these drawings. An extremely withdrawn prekindergarten boy whose solitary play is usually "reinforced" by the teacher's solicitude (*a*) is instead rewarded for joining a group by the teacher's devoting her full attention to him and the group (*b*). When the original reinforcement is resumed as a check on the treatment, he reverts to his former behavior (*c*). Then the therapeutic reinforcement is reinstituted and the desired behavior is well established (*d*). In time the child's enjoyment of his new behavior maintains his sociable interaction without special attention (*e*).



FEAR OF DOGS, as measured by an "approach score," abated most for children who watched displays in which "models" played with dogs in a party atmosphere (*solid black curve*) or in a neutral context (*solid gray*). The change was less for children who were merely in the party atmosphere (*broken black*) or who saw no child models (*broken gray*).

schizophrenic or autistic) who does not speak, interact with other people or even respond to their presence.

O. Ivar Lovaas of the University of California at Los Angeles has recently devised modeling procedures that hold promise of developing the intellectual and interpersonal capabilities of schizophrenic children. In teaching a mute child to talk, for example, the therapist first rewards any visual attentiveness and even random sounds made by the child. When vocalization has been increased, the rewards are limited to occasions on which sounds are made in response to a sound uttered by the therapist, and then to precise verbal reproduction of specific sounds, words and phrases modeled by the therapist. When the child has acquired a vocabulary and can imitate new words easily, the therapist goes on to teach the meaning of words, grammatical structure and even abstract verbal concepts by the modeling procedures. Lovaas has also taught schizophrenic children a variety of skills and social patterns of behavior by modeling the desired behavior and rewarding the child when he emulates it. The most impressive thing about this form of treatment is that it can be conducted under the supervision of nurses, students and parents, to whom the methods are easily taught.

In a very different application of modeling principles, George A. Kelly of Brandeis University conceived a role-enactment form of therapy for adults who want to develop new personality characteristics. The client is provided with a personality sketch and given demonstrations of the desired behavior; he then has opportunities to practice the new patterns in a protected therapeutic situation before being encouraged to apply them as he goes about his everyday life.

Often therapists, instead of having to fill a behavioral vacuum, have the problem of eliminating strongly established abnormal behavior. In an early study at the University of Iowa, Gertrude E. Chittenden tested the efficacy of a symbolic modeling procedure for dealing with children's hyperaggressive reactions to frustration. It has been widely assumed that either witnessing or participating in aggressive behavior serves to reduce, at least temporarily, the incidence of such behavior. The overall evidence from studies conducted in our laboratory and elsewhere strongly indicates that psychotherapies employing these conventional "cathartic" procedures may actually be increasing aggressive tendencies rather than reducing them. In contrast, therapy based on social-learning principles concentrates at the outset on developing constructive alternative modes of behavior. Chittenden had domineering and hyperaggressive children watch a series of scenes in which dolls representing preschool children exhibited first aggressive reactions to common frustrating situations and then cooperative reactions; the consequences of the aggressive reactions were shown as being unpleasant and those of the cooperative ones as being rewarding. Children for whom the different reactions and consequences were modeled showed a lasting decrease in aggressive, domineering behavior compared with a group of similarly hyperaggressive children who received no treatment.

We have found that phobias and inhibitions can be eliminated by having the fearful person observe a graduated sequence of modeled activities beginning with presentations that are easily tolerated. In a controlled test of this therapy, nursery school children who were afraid of dogs (according to their parents' statements and tests of "dog avoidance" behavior) were assigned to one of four groups. Children in the first group participated in eight brief sessions in which they watched a child without fear interact more and more closely with a dog—approaching it, playing with it, petting it and so on—with the entire procedure taking place in a "positive" party setting designed to counteract anxiety reactions. The second group saw the same sequence but in a neutral context. In order for us to assess the effects of exposure to the dog alone the third group saw the dog in a party setting but without the child model; the fourth joined the party activities but was not exposed to either the model or the dog.

The tests for avoidance behavior were readministered after the completion of treatment and again a month later. The tests were quite severe, requiring the child not only to touch, pet and walk a dog but also to remain alone in a room with it, to hand-feed it and finally to climb into a playpen with the animal. The test scores showed that most of the children who had received the modeling treatment had essentially lost their fear of dogs [*see illustration on this page*]. The favorable results were largely confirmed by a second experiment in which the same modeled behavior was presented to some children in filmed performances while children in a control group watched a different motion picture. Finally the control children, whose fear of dogs had remained unchanged, were shown the therapeutic movies, after which their fear was in turn substantially diminished. One of the obvious advantages of the modeling technique in psychotherapy is that it lends itself to the treatment of groups of people. Moreover, the success of the filmed version of the modeling suggests that it may be possible to develop therapeutic films to be used in preventive programs directed against certain common fears and anxieties before they became strongly established.

There is increasing evidence that behavior commonly attributed to internal psychic conditions is in fact largely regulated by its own external, environmental consequences. Positive reinforcement—the modification of behavior through alteration of its rewarding outcomes—is therefore an important procedure in behavioral therapy. The techniques are those of operant conditioning, which was developed largely by B. F. Skinner and his colleagues at Harvard University.

Three elements are necessary to the proper implementation of operant conditioning in psychotherapy. The first is that the reinforcement, or incentive, system must be capable of maintaining the client's motivation and responsiveness; the system can involve tangible rewards, opportunities to engage in enjoyable activities, praise and attention or the satisfaction of a job well done. The second is that the reinforcement must be made conditional on the occurrence of the desired behavior, correctly timed and applied on a regular basis. The third is that there must be a dependable way to elicit the desired behavior either by demonstrating it or by rewarding small improvements in the direction of more complex forms of behavior.

The application of these elements is illustrated by a case reported by Arthur W. Staats, then at Arizona State University, and William H. Butterfield. They treated a 14-year-old delinquent boy who, in addition to having a long history of aggressive, destructive behavior, had never received a passing grade in eight and a half years of school and who read at the second-grade level. He was considered to be uneducable, incorrigible and mentally retarded.

The therapists undertook to teach him to read—first single words, then sentences and finally brief stories. For each word the boy learned he received points that he saved and "exchanged" for phonograph records and other things he wanted or for sums of money. In four and a half months he made notable advances in reading-test scores [*see illustration below*]. Moreover, the brief treatment program produced generalized educational and psychological effects: he received passing grades in all his subjects for the first time and his aggressively defiant behavior ceased. The entire program, which was administered by a probation officer, involved a total expenditure of $20.31 for the exchange items!

The effectiveness of operant conditioning was demonstrated most convincingly by Florence R. Harris, Montrose M. Wolf and Donald M. Baer at the University of Washington. In their method grossly abnormal behavior in children is successively eliminated, reinstated and eliminated again by varying its social consequences.

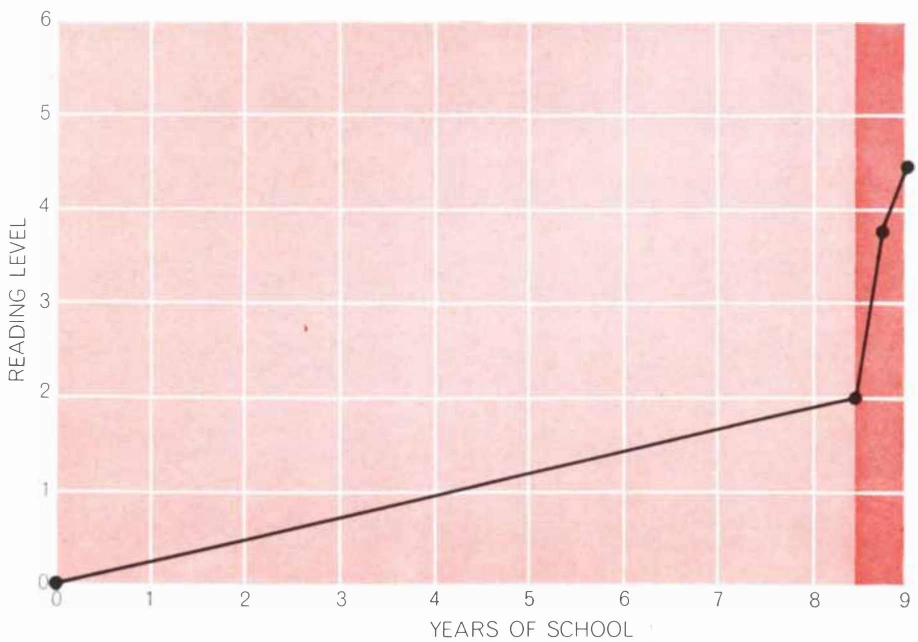
First the psychologists observe the child in question to note the frequency of the behavior disorder, the context in which it occurs and the reaction of the teacher. In one case an extremely withdrawn little boy in nursery school spent about 80 percent of the time in solitary activities. Observation revealed that the teacher unwittingly "reinforced" his solitary behavior by paying a great deal of attention to him, consoling him and encouraging him to play with the other children. When he did happen to join the others, the teacher took no particular notice.

In the second phase of the program a new set of reinforcement practices is substituted. In the case of the solitary little boy, for example, the teacher stopped rewarding solitary play with attention and support. Instead, whenever the child sought out other children, the teacher immediately joined the group and gave it her full attention. Soon the boy was spending about 60 percent of his time playing with the other children.

After the desired change in behavior has been produced, the original reinforcement practices are reinstated to determine if the original behavior was in fact maintained by its social consequences. In this third stage, for example, the teacher again paid no attention to the child's sociability but instead responded with comforting ministrations and concern whenever he was alone. The effect of this traditional "mental hygiene" treatment was to increase the child's withdrawal to the original high level.

Finally the therapeutic activity is reintroduced, the abnormal behavior is eliminated and the desired behavior pattern is generously reinforced until it is well enough established to be maintained by its own implicit satisfactions. Once the little boy was again playing with other children the teacher was able to reduce her direct involvement with the group; the child derived increasing enjoyment from his new behavior pattern and eventually maintained it without any special attention.

Children with a wide variety of be-



DELINQUENT ADOLESCENT BOY was reading at the second-grade level after more than eight years in school. In half a year of therapy his reading level had more than doubled.

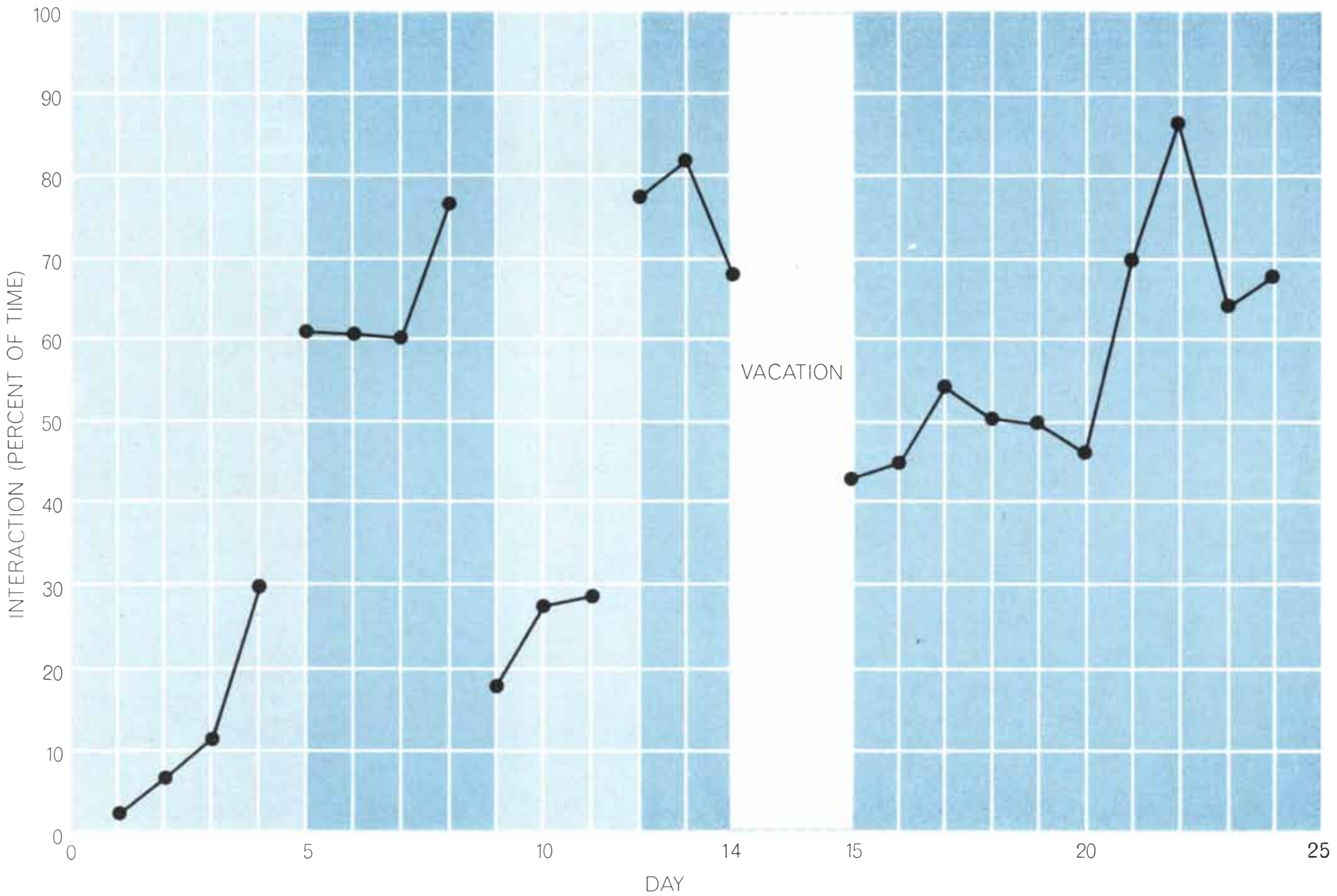
havior disorders have participated in this form of treatment, and in each case their maladaptive behavior was eliminated, reinstated and removed a second time by alterations in the teacher's "social responsiveness." Clearly child-rearing and therapeutic practices should be evaluated carefully in terms of the effects they have on their recipients rather than in terms of the humanitarian intent of teachers or psychotherapists.

Certain widespread psychological problems must be treated primarily at the social rather than the individual level. By altering the reinforcement contingencies of a social group it may be possible to affect the behavior of each member in beneficial ways, whereas working with individuals would yield trifling results. Recently incentive programs have been applied on a group basis in psychiatric hospitals and in institutions for retarded children and for delinquent adolescents. Operant conditioning therapies have, for example, restored some social competence and self-reliance in severely impaired psychiatric patients. The traditional hospital routine tends to reinforce docile behavior and dependence; the therapy rewards self-sufficiency, social relations and progress in vocational training. At the Anna State Hospital in Illinois, Teodoro Ayllon and Nathan H. Azrin found that psychotic patients would work productively in the rehabilitation program if activities and material comforts they wanted were made dependent on the completion of their assignments; the patients quickly lapsed into their customary lethargy when the incentives were discontinued and the privileges were made available routinely as before [*see illustration on page 84*].

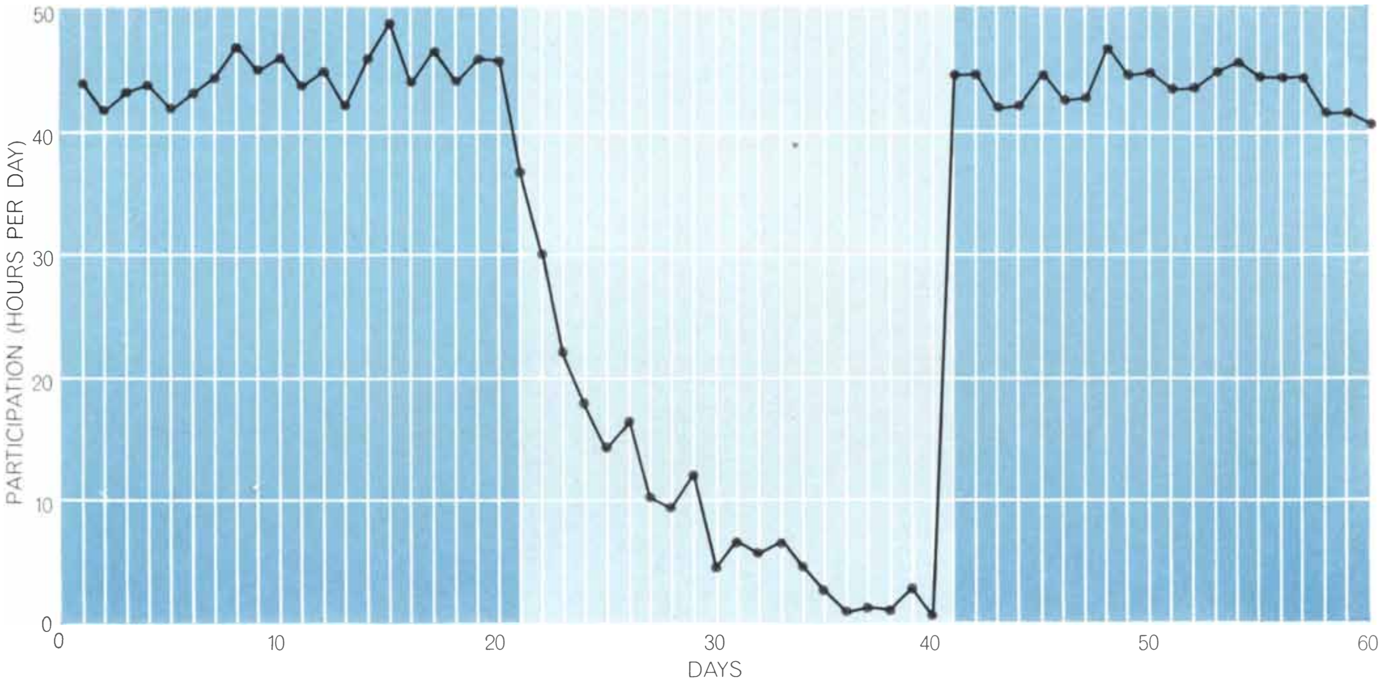
There is an obverse side to the positive-reinforcement method. Abnormal behavior that persists because it leads to rewarding outcomes can often be eliminated simply by withholding the usual positive reinforcement. Tantrums, hyperaggressive behavior, chronic eating problems, psychosomatic and hypochondriacal complaints, psychotic talk and even the bizarre behavior of autistic children have been found to abate gradually when the solicitous concern they usually evoke is not forthcoming. This process is greatly facilitated if alternative behavior patterns are rewarded at the same time.

A third major category of therapeutic methods derived from learning theory is based on the principle of "counterconditioning." These methods are appropriate for treating the conditions most frequently seen in a conventional interview-therapy practice: anxiety reactions, chronic tensions, inhibitions, phobias and psychosomatic reactions. The objective in counterconditioning is to induce strong positive responses in the presence of stimuli that ordinarily arouse fear or other unfavorable reactions in the client. As positive responses are repeatedly associated with the threatening events, the anxiety is gradually eliminated. Although psychotherapeutic applications of this principle were reported by Mary Cover Jones as long ago as 1924, the approach received little attention until some 30 years later, when Joseph Wolpe, now at the Temple University School of Medicine, worked out procedures that increased the range of disorders subject to treatment by counterconditioning.

In Wolpe's "desensitization" method



IMPROVEMENT in the behavior of the withdrawn child (*see illustration on page 79*) is indicated by the increasing time spent in social interaction. Before treatment began and during the time when his solitary play was rewarded with attention he was usually alone (*light colored areas*), but he played with others when such behavior was reinforced by the teacher's responses (*dark areas*).



PARTICIPATION in rehabilitation activities increased for a group of 44 schizophrenic patients when privileges were made conditional on their successful completion of assignments (*dark colored areas*), and decreased when the same rewards were provided whether or not they took part in the activities (*light area*). The colored spots indicate the total number of hours of participation each day.

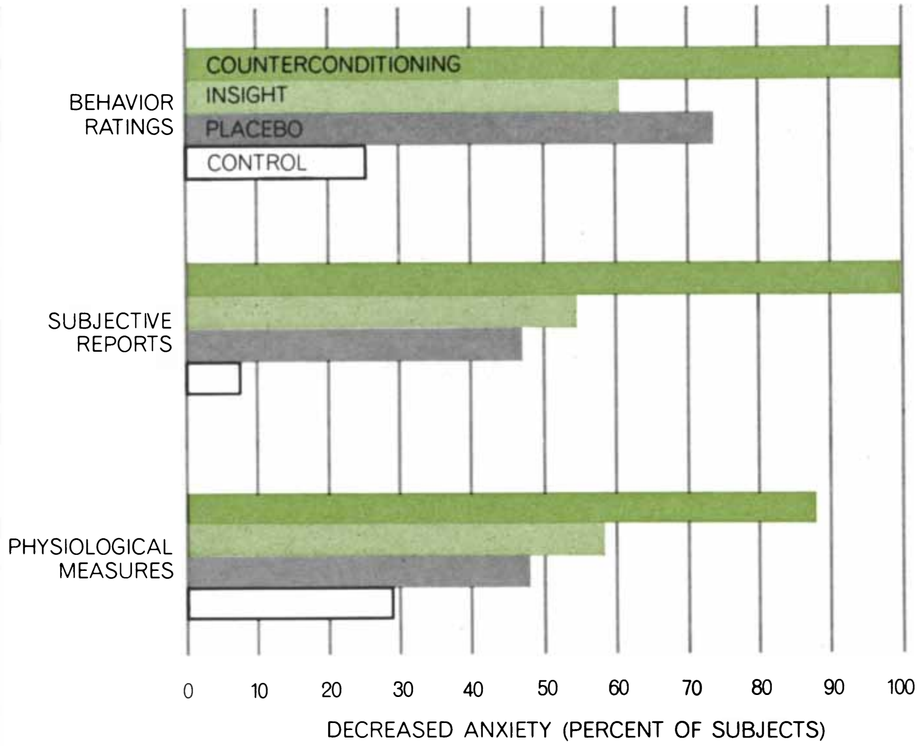
the therapist—working with information obtained from interviews and psychological tests—first constructs a "hierarchy," or ranked list, of situations to which the client reacts with increasing degrees of anxiety (or avoidance or inhibition, as the case may be). Then the therapist induces in the client a state of deep muscular relaxation—a state incompatible with anxiety—and asks the client to visualize the weakest item in the hierarchy of anxiety-arousing stimuli. If any tension results, the client is told to stop imagining the threatening situation and the relaxation process is resumed; if the relaxation remains unimpaired in the imagined presence of the stimulus, the patient is presented with the next item in the hierarchy. So it goes throughout the graduated series, with the intensity of the disturbing situations being increased from session to session until the most threatening situations have been completely neutralized.

Favorable clinical reports on counterconditioning have recently been borne out by a number of experimental studies in which changes in behavior were assessed objectively. Arnold A. Lazarus, now at Temple University, evaluated clients afflicted with acrophobia (fear of heights), claustrophobia or impotence after they had been treated either by conventional group psychotherapy or by group desensitization. Of the 18 clients treated by desensitization, 13 completely recovered from their phobias. The conventional treatment was successful in only two out of 17 cases, and of the 15 people whose phobias were essentially unmodified 10 were thereupon treated successfully by group desensitization. A follow-up study indicated that 80 percent of the clients for whom desensitization had been successful maintained their recovery as measured by a stringent criterion: the recurrence of even weak phobic responses was rated as a failure.

At the University of Illinois, Gordon L. Paul studied the relative efficacy of counterconditioning and conventional methods in treating college students who suffered from extreme anxiety about public speaking. One group received interview therapy intended to produce insight. A second group underwent desensitization treatments in which relaxation was associated with imagined public-speaking situations of a progressively more threatening nature. A third group was given a form of placebo treatment, and a control group had no treatment at all.

After six weeks the students' response to a stressful public-speaking test was evaluated according to three sets of criteria: their own reports as to just how disturbed they felt, physiological indicators of anxiety and an objective judgment of the extent to which their speaking behavior was disrupted. Students in all three of the treatment conditions showed less behavior indicative of anxiety, and reported less distress, than the untreated control group. Only the students in the counterconditioned group achieved a significant reduction in physiological arousal compared with the controls, however. In each case the counterconditioned group showed greater improvement than the insight group and the placebo group, which did not differ significantly from each other [*see illustration on page 86*]. In a follow-up period the counterconditioned students reported experiencing less anxiety about speaking than the other three groups. An interesting aspect of this study was that the therapists, who in their regular practice favored insight-directed methods, rated the students treated by desensitization as most improved and also indicated a better prognosis for them. A subsequent study by Paul and Donald Shannon indicated that desensitization administered on a group basis can be similarly effective in eliminating disabling anxieties.

A number of current investigations are directed at identifying the specific components of counterconditioning therapy that account for its success. In these experiments Gerald C. Davison and Earl D. Schubot of Stanford and Peter J. Lang of the University of Wisconsin devise treatment procedures with well-defined differences and then make objective measurements of behavioral changes. The preliminary results of their studies suggest that the critical factor is the close association of relaxation with



PUBLIC-SPEAKING phobia was treated by counterconditioning, by an "insight" method and by a placebo treatment. There was also an untreated control group. The chart gives the percent of subjects who showed decreased anxiety (according to three different criteria).

the stimuli that arouse anxiety, particularly in the treatment of severe anxiety disorders.

I have been discussing specific kinds of procedures for rather specific psychological problems. Many people seeking psychotherapy present multiple problems, and these call for combinations of procedures. (The developments in behavioral therapy in some respects parallel those in medicine, where all-purpose therapies of limited efficacy were eventually replaced by powerful specific procedures designed to treat particular physical disorders.) The treatment process is not piecemeal, since favorable changes in one area of behavior tend to produce beneficial modifications in other areas. In many instances a circumscribed problem has wide social consequences, and a change in such an area can have pervasive psychological effects.

Psychotherapists who think in terms of diseases often assume that the direct modification of abnormal behavior may result in what they call "symptom substitution." The available evidence reveals, however, that induced behavioral changes at least persist in themselves and often have favorable effects on other areas of psychological functioning. To be sure, a poorly designed course of therapy aimed only at eliminating maladaptive behavior patterns does not in itself guarantee that desired modes of response will take their place. The client may revert to alternative and equally unsatisfactory courses of action, and the therapist may be faced with the task of eliminating a succession of ineffective patterns of behavior. This problem can be forestalled by including procedures in the original treatment that are designed to foster desirable alternative modes of behavior.

Preliminary applications of social-learning approaches to psychotherapy indicate that these methods hold considerable promise; they need to be developed further, extended to the treatment of multiple problems and evaluated after a sufficient period has elapsed. Many new methods of psychotherapy have been introduced enthusiastically and then have been retired by controlled studies. The fact that social-learning therapies are based on established principles of behavior and are subjected to experimental study at each stage of development gives us reason to expect them to weather the test of time. The day may not be far off when psychological disorders will be treated not in hospitals or mental hygiene clinics but in comprehensive "learning centers," when clients will be considered not patients suffering from hidden psychic pathologies but responsible people who participate actively in developing their own potentialities.

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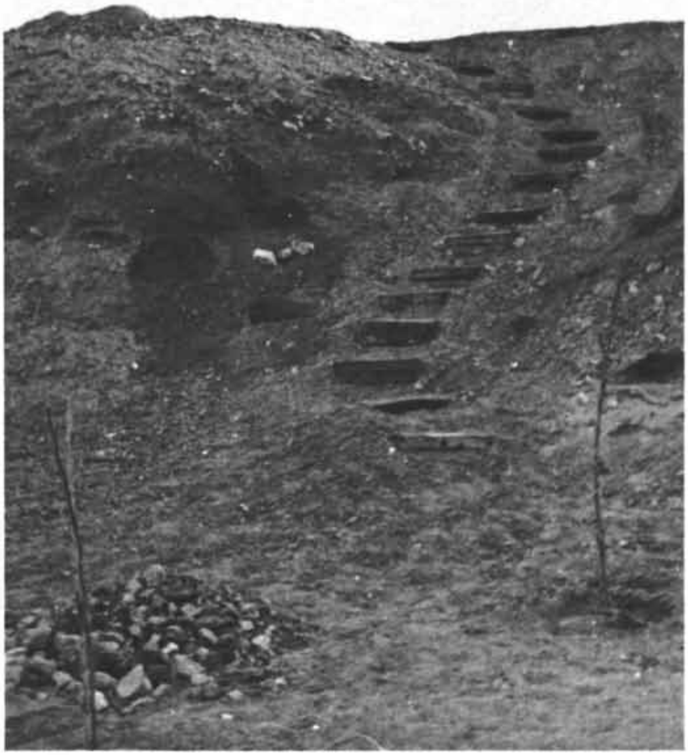
Salt-Water Agriculture

Experiments in Israel indicate that many plants can be irrigated with salty water, even at oceanic strength, if they are in sandy soil. The technique might open much barren land to agriculture

by Hugo Boyko

Arid and semiarid areas occupy fully a third of the earth's land surface. Within them are extensive regions of sand dunes, largely in deserts and along the coasts. The dune lands have a total area about twice the size of the U.S. Much of the sandy soil in arid areas could be made agriculturally productive with irrigation, but relatively little irrigation has been undertaken in such regions because the importation of fresh water is usually too expensive and the use of local water, which is often salty, has been avoided in the belief that few land plants can tolerate much salt. Experiments have demonstrated, however, that many plants can thrive in sandy soil even when they are irrigated with water that is quite salty. Indeed, under the right conditions irrigation can be done with seawater.



"DESERT GARDEN OF EILAT" in Israel was created on previously barren sandy soil with salt-water irrigation. The photograph at left shows one of the slopes in the six-acre tract just after it had been planted in 1949. At right is the same slope 10 years later. The planting was designed and supervised by the author and his wife. Water used for irrigation had a salt content of .2 to .6 percent.

One of the experiments I shall describe has transformed six acres of land in the Negev desert of Israel from a barren waste into a flourishing garden. As a result of the experiment other parts of the Negev, irrigated solely with saline water, have been made to produce such crops as melons and tomatoes, and the crops have become valuable articles of export for the desert settlements. Experiments in India with wheat, in West Germany with a fodder crop and in Italy with cereals, vegetables and flowers have similarly yielded encouraging results.

I need scarcely dwell on the potential significance of the work with sandy soil and salty water. Any advance in making sandy soils productive adds to the resources available for the production of food. And any such addition can be a factor in the effort to keep the production of food abreast of the growth of population.

In September, 1965, 104 investigators representing 23 nations and a wide spectrum of disciplines attended a symposium in Rome titled "Irrigation with Highly Saline Water and Seawater with and without Desalination." The symposium was organized by the World Academy of Art and Science in cooperation with the United Nations Educational, Scientific and Cultural Organization, the National Research Council of Italy and the Italian Academy of Agriculture. UNESCO also contributed to the financing of the symposium.

A few weeks later another international symposium was held in Washington. The problem was the same: how to use the saline waters of the oceans. The approach, however, was just the opposite of the one taken in Rome. The participants in Rome were interested in the direct use of saline water and seawater in agriculture; the main subject in Washington was desalination.

Both approaches will doubtless be needed in the campaign against hunger. The water won expensively by desalination will most likely be used in large cities, in industry and in the cultivation of particularly valuable plants. In any case, the production of desalinated seawater can be expected to save large amounts of fresh water for agriculture.

The direct use of saline water will find its application in converting sandy areas into rich agricultural lands, pastures and forests. It is with this approach that I shall be concerned here. For more than 30 years, in ecological work in the sandy regions of many nations, I have made it my task to develop the geophysical and biological principles underlying the use of salty water in agriculture. Practical experiments to test the principles were first undertaken in 1949, when I was ecological adviser to the Ministry of Agriculture of Israel and my wife, Elisabeth Boyko, was horticulturist for the ministry.

The basic principle of saline agriculture is that salty water can be used only on sand and sandy or gravelly soil if the objective is to grow plants on an economic basis. In other kinds of soil the salt soon accumulates, destroying the plants and making the soil unfit for agriculture. In sand, however, such accumulation does not occur. Moreover, one can help the sand rid itself of salt by growing plants that tend to accumulate salt. In this way one achieves what could be called biological desalination.

Underlying the basic postulate that saline agriculture is restricted to a sandy or gravelly environment are a number of other principles. Four of them have long been known, but their applicability to irrigation with highly saline water and seawater has been overlooked because the other principles were not obvious. The four familiar principles arise from the permeability of a soil consisting mainly of sand or gravel compared to the permeability of the more usual type of

ARID AND SEMIARID REGIONS cover a third of the earth's land surface. Within them are extensive areas of sand dunes, amounting in all to an area larger than the U.S. Many of agricultural soil, which contains a fairly high percentage of clay and silt particles.

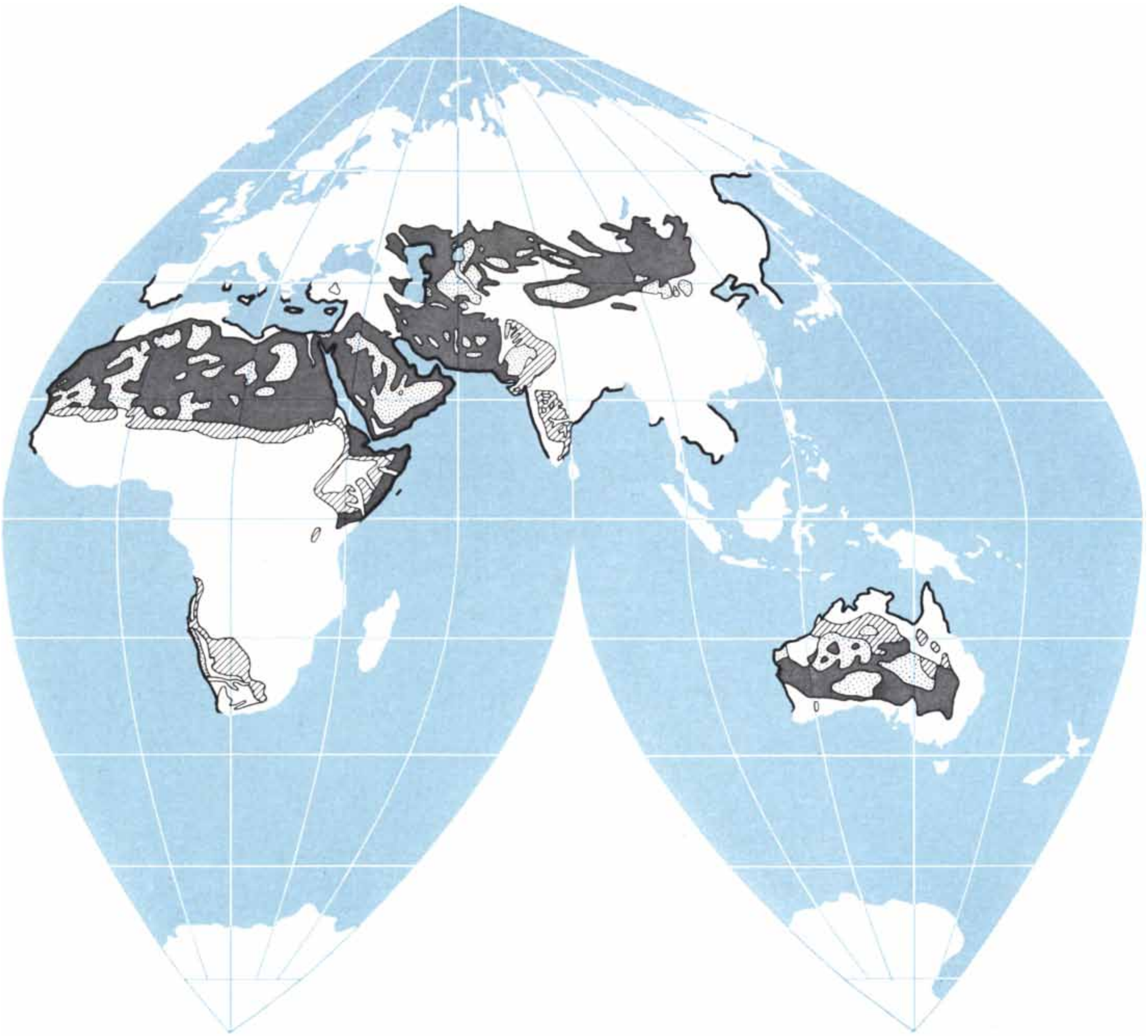
The first principle is that water percolates quickly through sand and gravel. The second is that the root systems of plants are well aerated in such an environment. The reason is that sand and gravel afford more space between particles of soil than clay and silt do.

The third principle is that sodium chloride and magnesium chloride—the components of salt water that are most harmful to plants—have little opportunity to affect plants in sand or gravel. Both are easily soluble, and in addition they are among the first components of salt water to be washed down into deeper layers when soil is watered. If the movement of the solution is upward because of evaporation or capillary action, sodium chloride and magnesium chloride tend to form crystals on the surface of sand or gravel rather than to remain below the surface, where they can harm plants. In either case the sodium chloride and magnesium chloride are not taken up in dangerous amounts by the selective feeder roots, or root hairs, of plants in sand and gravel.

The fourth principle is that the sodium ion is not adsorbed on particles of sand, whereas it is easily adsorbed on particles of clay. The adsorption of sodium on particles of clay is the main cause of salination in normal agricultural soils. Clay particles swell when they adsorb sodium. As a result the soil becomes impermeable, salts accumulate and plants die.

Of the newer principles, the first is what I call partial root contact. It is based on the fact that in sand the space between particles is usually many times larger than the feeder root of a plant can occupy. The concept can best be explained by following the events that occur when plants on a sandy plot are irrigated with salty water.

Immediately after irrigation the tiny feeder roots of the plant—200 to 500 of



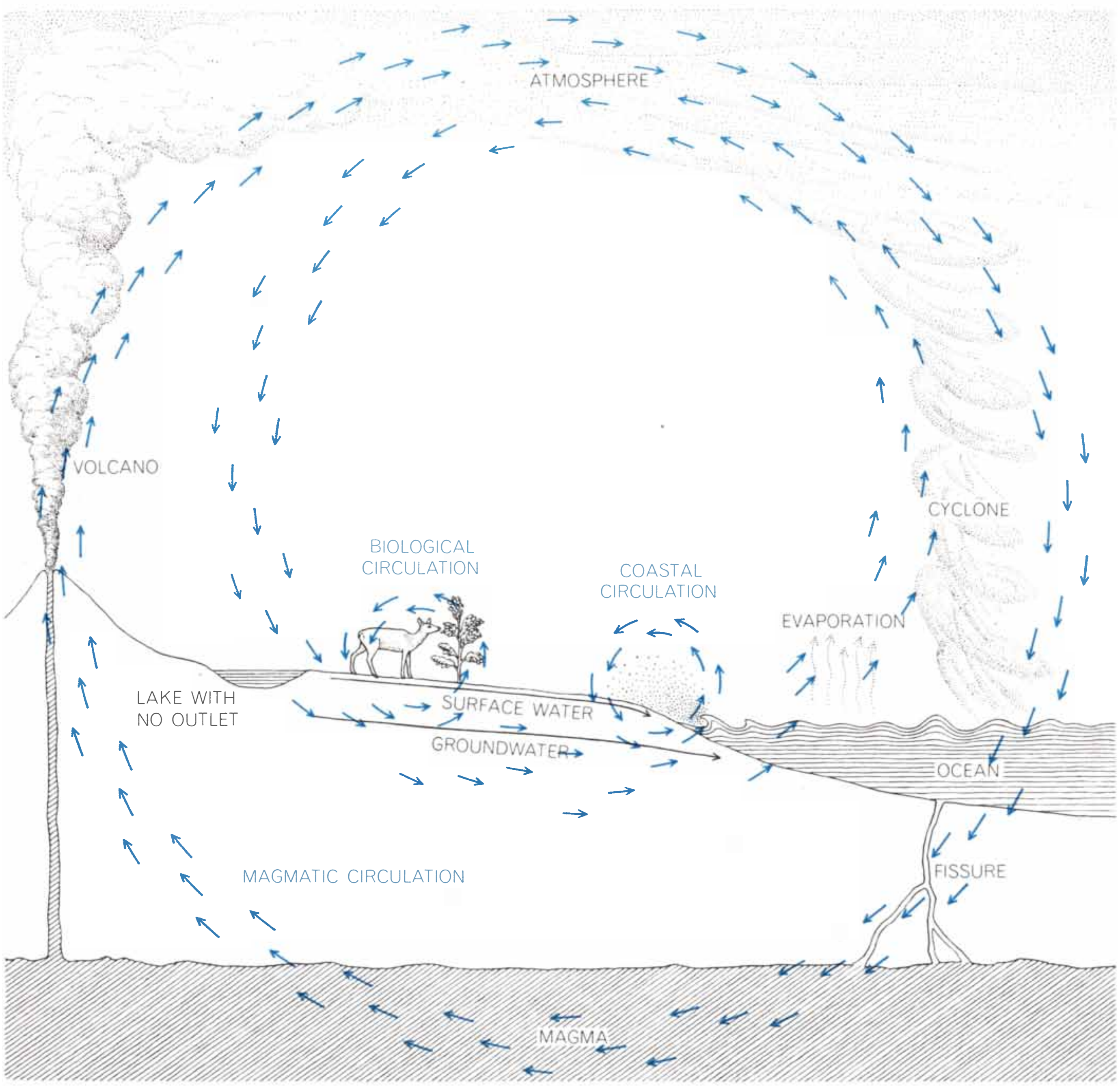
the sandy regions could be made productive with salt-water irrigation, according to experiments in Israel indicating that the salt tolerance of most plant species is raised if they are grown in sandy or gravelly soil that has a low content of clay or no clay.

them per square millimeter of root—are entirely immersed in the water. Most plants can stand only a brief immersion in salty water. In sand, however, the water percolates quickly, so that soon the surface of the feeder roots is only partly in contact with the salty water. By then the feeder roots are also partly in contact with air. The oxygen in the air considerably increases the plant's activity and available energy, so that the plant is more able to be selective in the uptake of the nutrient components of the seawater.

The air surrounding the feeder roots remains moist even after percolation. From time to time the moisture condenses, mostly in the cool morning hours. Condensation occurs particularly in continental deserts, where the temperature differences both between night and day and between different layers of sand are substantial [*see illustration on opposite page*].

The condensation is decisive in saline agriculture, because it produces a subterranean dew. The dew, of course, is fresh water. Hence the roots can have a source of fresh water even when chemical analysis of the soil reveals the presence of considerable salt. Any salt thus revealed is adhering to the particles of sand, and the feeder roots are either not in contact with it or only in partial contact. The next irrigation, whether it is done the following day or several months later, washes away any possible accumulation of sodium chloride and magnesium chloride.

This, then, is the second of the newer principles, which I call the principle of subterranean dew. The third principle is closely related to the second and is called the viscosity principle. The film of brine remaining on the surface of



GLOBAL SALT CYCLES work to prevent excessive accumulations of salt on land, even adjacent to bodies of salty water. In coastal circulation, for example, salt blown onto the shore in spray from the sea is returned to the sea by means of surface water and water flowing deeper in the ground. Similar cycles eventually return to the seas the salts that reach land by other means such as storms.

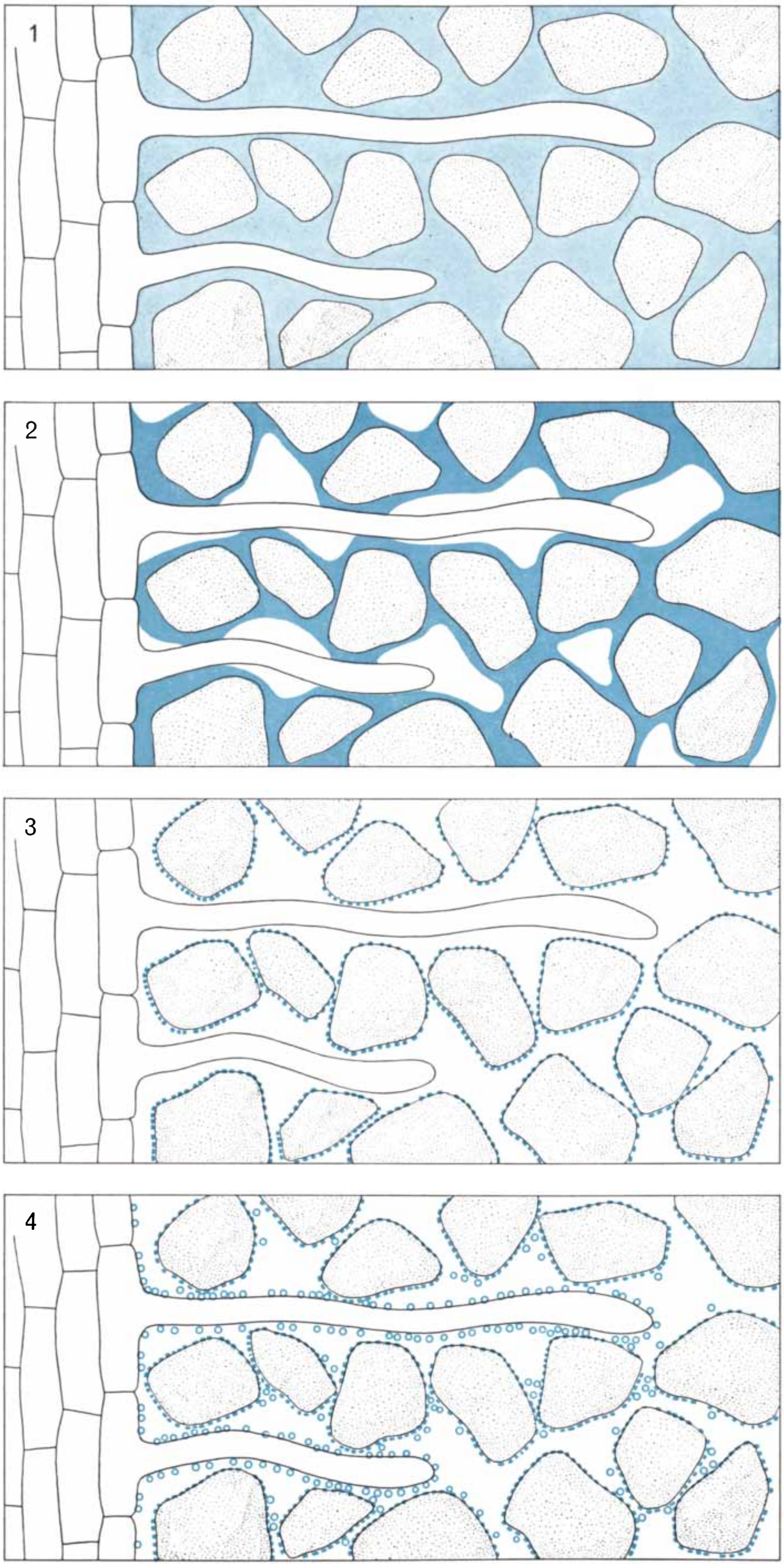
feeder roots and the surface of sand particles after the percolation of saline irrigation water is about .000001 millimeter thick. The viscosity of saline water is such that a film so thin is readily broken. Hence the film on the sand particles and the feeder roots cannot be coherent and leaves enough space for aeration.

I have already touched on the fourth principle, which is biological desalination. It lies in the ability of certain plants to accumulate salt in their green parts. With each harvest of the crops the salt content of the soil is diminished. Many investigators have been skeptical of this process. I had long suspected that biological desalination would be effective, and eventually I was able to demonstrate its effectiveness in an experiment my wife and I conducted south of the Dead Sea. The experiment showed that the soil's content of both sodium and chlorine was reduced significantly by two harvests of *Juncus maritimus*, a rush plant, grown on a sandy field and irrigated with saline water.

For the next principle I am indebted to Hugo Heimann of the Israel Institute of Technology. Heimann became curious about contradictions between farming experience and the widely held view that the damage to plants from salt arises from the excessive osmotic pressure connected with high concentrations of salt. The view is evidently attributable to the experimental procedures followed by investigators in this field. They grew plants in a culture solution, adding salts one at a time. The concentrations and the correlated osmotic pressures were noted at the point where the plants began to show damage. The damage always appeared at about the same osmotic pressure, regardless of the type of salt used. The experimenters concluded that it resulted from high osmotic pressure, which made it difficult for the plants to take up water.

Heimann pointed out that such experiments failed to duplicate conditions in nature. All organized systems of living cells in an aqueous environment charged with the ions characteristic of salts owe their well-being to a balanced ratio between the ions. Plants in physiologically balanced solutions can stand much higher osmotic pressures than plants in a solution of a single salt or in unbalanced mixtures.

Such findings led Heimann to the principle he has termed the balance of the ionic environment. It holds that with the proper ratio of ions plants can be grown at surprisingly high levels of sa-



FOUR STEPS show how a plant can grow in sandy soil with salt-water irrigation. After irrigation (*1*) the tiny root hairs are immersed in water (*color*). As the water percolates into the sand, air pockets are formed (*2*) and soon (*3*) the root hairs have only partial contact with salt. Changes of temperature cause condensation (*4*), which provides fresh water.

TOLERANCE FOR SALT	CEREALS	LEGUMES	OILSEEDS	SUGARS	FIBERS	GRASSES AND FODDERS
GOOD	BARLEY, RYE, ITALIAN MILLET	ALFALFA, LADINO CLOVER	FIELD MUSTARD (VAR. *TARAMIRA*)	SUGARCANE	VARIOUS REEDS AND RUSHES	BERMUDA GRASS, DROPSEED, SALT GRASS
MODERATE	WHEAT, OATS, SORGHUM	STRAWBERRY CLOVER, SWEET CLOVERS, BROAD BEAN	FIELD MUSTARD (VAR. *SARSON*)	SUGAR BEET	SUNN HEMP	RHODES GRASS, FODDER SORGHUM, BLUESTEM WHEAT-GRASS, SEASHORE PASPALUM
POOR	CORN, FINGER MILLET	VARIOUS BEANS AND PEAS	FIELD MUSTARD (VAR. *TORIA*) CASTOR, LINSEED, SESAME NIGER		COTTON, JUTE	GIANT STAR GRASS, NAPIER GRASS, SUDAN GRASS

SALT TOLERANCE of various crops is charted. The arrangement is based on the observations of a number of investigators and relates to a variety of conditions of soil and water. The author believes many of the crops could be grown commercially with salt-water irrigation in suitable conditions. The principal condition is that the soil be sandy so as to provide high permeability.

linity. Indeed, seawater has a singularly well-balanced ratio of salts, to which all forms of life were once adapted. It is hardly surprising that plants irrigated with seawater in sand show a higher tolerance for salt than plants irrigated with any other water of the same salt concentration.

Another principle I have called enhanced vitality. A better term, "enhanced vigor," has been suggested to me by Pierre Dansereau, curator of ecology at the New York Botanical Garden. In German, my native language, I would say *lebenskraft,* which is literally translated as "life strength." At any rate, the principle suggested itself after some experiments we carried out at the Negev Institute for Arid Zone Research in Beersheba. Five species of plants that had been irrigated with various kinds of water were withdrawn from irrigation and left untended in that arid region. Plants that had been irrigated with seawater and various dilutions of seawater survived two long dry periods of about nine months each better than control plants that had been irrigated with fresh water. The most vigorous were those irrigated with seawater of the Caspian Sea type, containing between 1 percent and 1.3 percent total dissolved solids, and of the North Sea type, containing between 2 and 2.7 percent. The reason for enhanced vigor may be that the salty waters provided a larger quantity of nutrients than the fresh water.

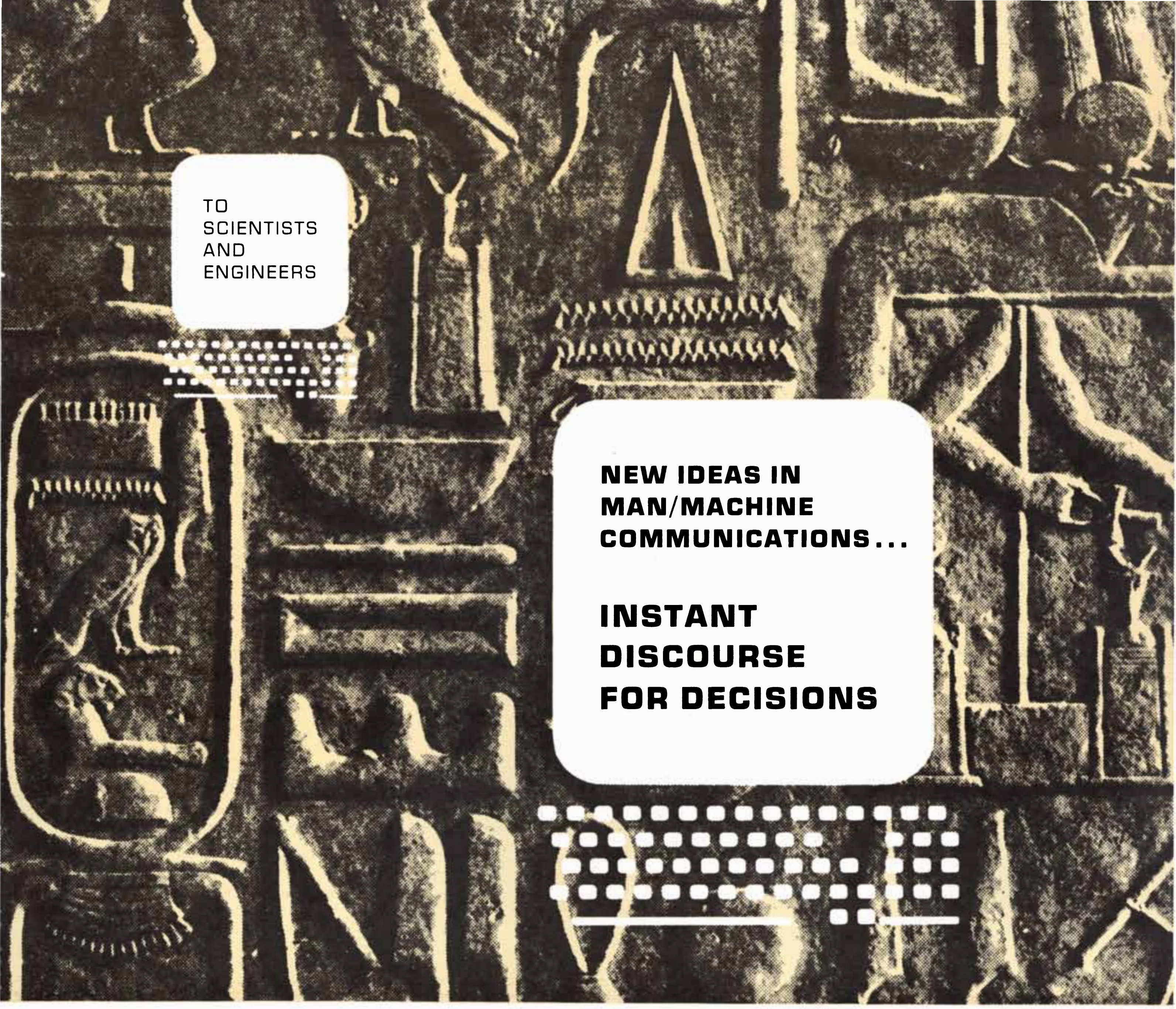
The final principle I shall put forward is the principle of global salt circulation [*see illustration on page 92*]. One can perceive this principle most readily by considering the state of affairs along a seacoast. There large quantities of salt are constantly being deposited on the land by wind blowing in from the sea. At the same time rainfall, runoff, percolation and the flow of water underground work to carry the salt back to the sea. The result is that coastal regions do not accumulate deposits of salt.

The same factors are at work, although more slowly, in inland areas. The principle indicates that no dangerous accumulation of salt is to be feared on sandy soil irrigated with saline water. Indeed, the principle accounts for the fact that salinization of normal agricultural soils can be overcome in regions of regular rainfall by occasionally letting land lie fallow and by providing appropriate drainage. The Jewish religion's *smittah* year, which is a fallow year every seven years, was probably introduced to allow a season's rains to wash away the salts deposited by irrigation.

All these principles figure in the success of the various experiments that have been conducted in saline agriculture. The first was "The Desert Garden of Eilat," laid out and planted by my wife starting in 1949 [*see illustration on page 89*]. This is the six-acre tract in the Negev desert to which I have referred. We were given the task of introducing vegetation in this barren area, where the building of a Red Sea port under the ancient name of Eilat was planned because the Suez Canal was closed to Israel.

The climatic features of the area include meager rain (about an inch a year, falling erratically during the winter), strong winds and high temperatures. At first the only water available for irrigation was highly saline water from a well 11 miles to the north; we had to bring the water to the garden by command car over the roadless desert. Later we were able to use other water, also saline, which was brought to Eilat by pipeline from an oasis 26 miles to the north. The water from the oasis had a total salt content fluctuating between .2 and .6 percent; the latter percentage corresponds to that of brackish water from the Baltic Sea.

We deliberately chose the gravel hills of the region because of the good percolation there. The soil had a composition of 96.3 percent stones and sand, 2.7 percent silt and 1 percent clay. In this soil and with such water we have successfully grown some 180 species of plants. Most of them are not halophytic, or salt-tolerant, under normal condi-



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tions. Among them are a blue-leaved acacia, potentially useful as wood or fodder; a sisal that could yield fiber; a silk oak capable of producing hardwood; mulberry, which yields both fruit and leaves to feed silkworms; an oleander that is ornamental and has medicinal uses, and a pomegranate that yields fruit and is also useful in tanning and medicine.

Another of the species is the *Juncus maritimus* that I mentioned in connection with biological desalination. This wild rush, which we cultivated for the first time, could be developed as a raw material for a printing paper of high quality. After the material had been used successfully by a paper mill in Scotland, an American group undertook to produce the crop commercially on a 2,000-acre tract in the sandy desert of Wadi Araba in Israel. The project, in which saline irrigation will be used, is now in the planting stage.

Our results in the garden at Eilat led us to undertake some experiments in direct irrigation with seawater. Our objectives were to ascertain the limits of salt tolerance in certain plants and to test experimentally the principles I have described. Our technique was to grow plants in bottomless barrels placed on sand and filled with sand. We irrigated with four types of seawater: the Caspian Sea type, the North Sea type, an oceanic concentration containing between a 3 and a 4 percent total of dissolved solids, and an eastern Mediterranean or Red Sea type with a 4 to 5 percent total of dissolved solids. For control plants we used fresh water.

The experiments involved 10 species of plants. Four of them survived irrigation with seawater of the oceanic type, containing more than a 3 percent total of dissolved solids. One was *Agropyrum junceum*, a dune grass that is sometimes called wheat grass. It is excellent for holding sand in place and also for animal fodder. Moreover, it is suitable for hybridization with wheat and hence opens up the possibility of breeding salt-tolerant cereals. Another plant was *Calotropis procera*, a desert succulent with many possible uses in the textile and chemical industries. The third was *Hordeum vulgare*, a barley. We used a strongly drought-resistant Bedouin strain, planting seeds from plants we had grown ourselves in highly saline water. The fourth was *Juncus maritimus*.

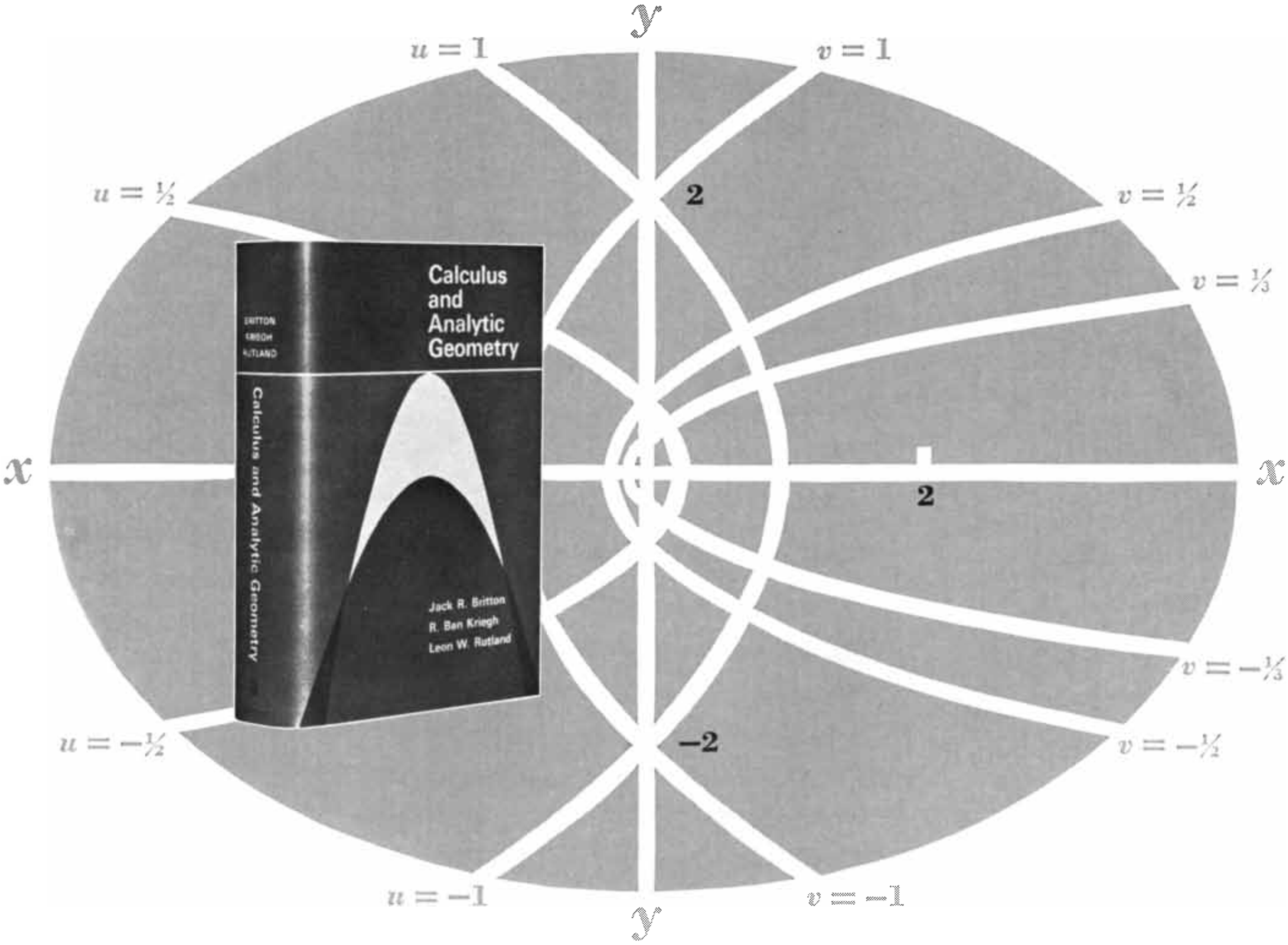
Our results indicated that the other six species would succeed economically only if they were irrigated with saline water no more concentrated than the Caspian Sea type (1 to 1.3 percent). The six included two species of *Agava*, known on the world market as a source of rope fiber; *Rottboellia fasciculata*, a fodder grass; *Ammophila arenaria*, a beach grass used in many countries to prevent the shifting of dunes; another species of *Juncus*, and finally *Beta vulgaris*, the sugar beet, which is known to be salt-tolerant but which had not been grown in water as salty as the water we used for irrigating it.

After obtaining these results I asked a number of investigators in other countries if they would be interested in undertaking such experiments. Similar projects have been successfully started with seawater in India, Spain and West Germany and with brackish water in Israel, Italy, Spain, Tunisia, Morocco, Sweden, the U.S. and the U.S.S.R. The number of species of plants grown in highly saline water from the sea or from underground sources runs to many dozens.

We have taken only the first tentative steps in this new direction. An extensive international effort will be needed if deserts are to be transformed into agricultural areas by saline irrigation. The participants in the symposium in Rome formulated an appeal for such an effort, adopting a resolution declaring their firm belief "that results already achieved by irrigation with highly saline water indicate clearly that those areas at least where such a water supply is available can be rendered capable of crop production."

I foresee the possibility that the efforts now under way to achieve economical and large-scale desalination of seawater will contribute significantly to the success of saline agriculture. Pumping water from the sea to inland deserts for irrigation will require large amounts of energy. Big nuclear reactors installed for desalination might serve a dual purpose: supplying fresh water for cities and industries and at the same time generating electricity to pump salt water from the sea or from desert aquifers for use in saline agriculture.

Another possibility lies in the use of electrolytic methods of desalination. Using only a fraction of the energy required for other methods, this technique can yield water of a concentration too salty for drinking but excellent for growing plants. Whatever the approach to saline agriculture, success on a large scale will be achieved only if research in this new field is adequately supported.



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The Origin of the Automobile Engine

The first internal-combustion engine to operate successfully on the four-stroke cycle was built in 1876 by Nicolaus August Otto. His "Silent Otto" was a good machine with a poor theory

by Lynwood Bryant

The modern automobile is driven by a heat engine whose basic principle was first demonstrated 91 years ago. The principle is the Otto cycle, named after Nicolaus August Otto, a self-taught German engineer who stumbled on a way to burn a compressed mixture of gas and air in the cylinder of an engine without producing destructive explosions. The "Silent Otto," as the engine was somewhat extravagantly called, employed a scheme in which the piston required four strokes to complete one cycle: an inward (toward the crankshaft) fuel-and-air-intake stroke, an outward (away from the crankshaft) compression stroke, an inward power stroke and an outward exhaust stroke.

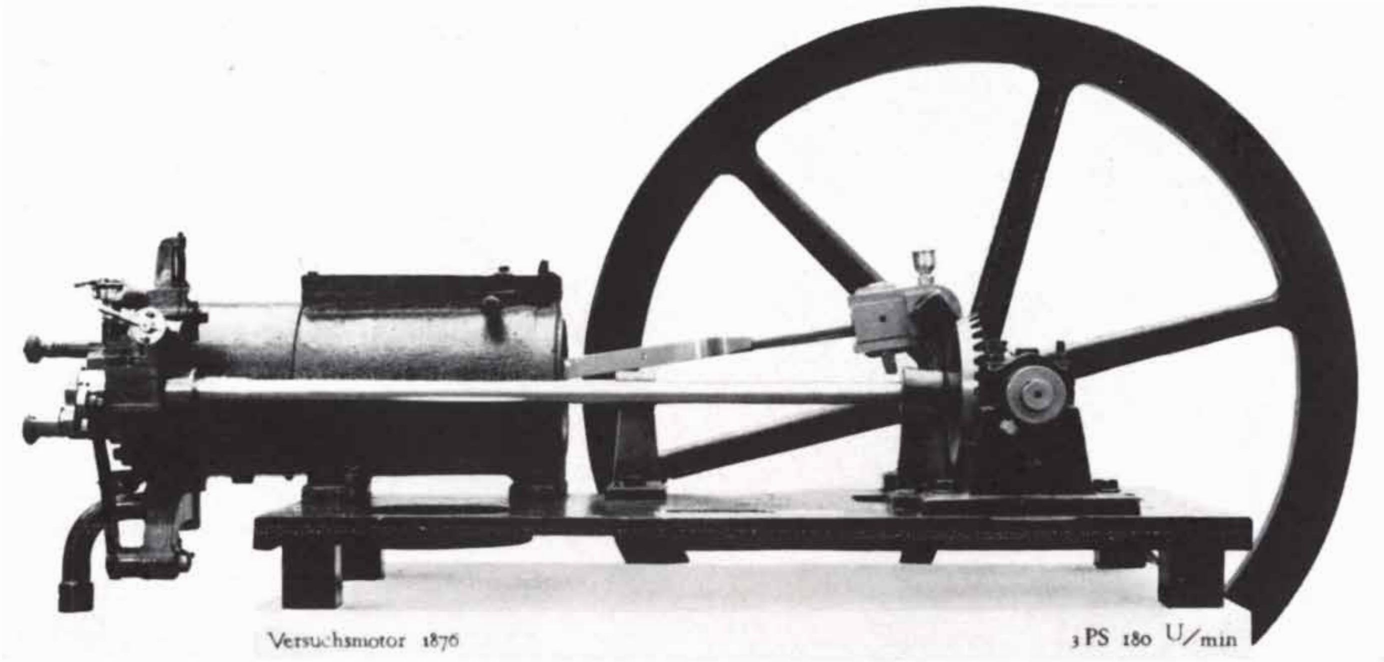
The term "Otto cycle" is sometimes used loosely to denote this four-stroke mode of operation, but actually an engine of the Otto type can be either two-stroke or four-stroke (or for that matter six-stroke, as some of the early ones were). The four functions of intake, compression, expansion and exhaust must be performed in any Otto engine, but they do not have to be performed in four distinct strokes. Strictly speaking, what distinguishes the Otto cycle from other cycles that can be used in piston engines is that an engine of the Otto type takes in a controlled mixture of fuel and air, compresses it to a moderate pressure and ignites it by some kind of ignition device, nowadays a spark plug.

NICOLAUS AUGUST OTTO (1832–1891) **was a traveling salesman for a wholesale grocer in the Rhineland in the early 1860's when he began his experiments with internal-combustion engines. He later was a partner in the firm of Gasmotorenfabrik Deutz near Cologne, for many years the largest manufacturer of internal-combustion engines in the world.**

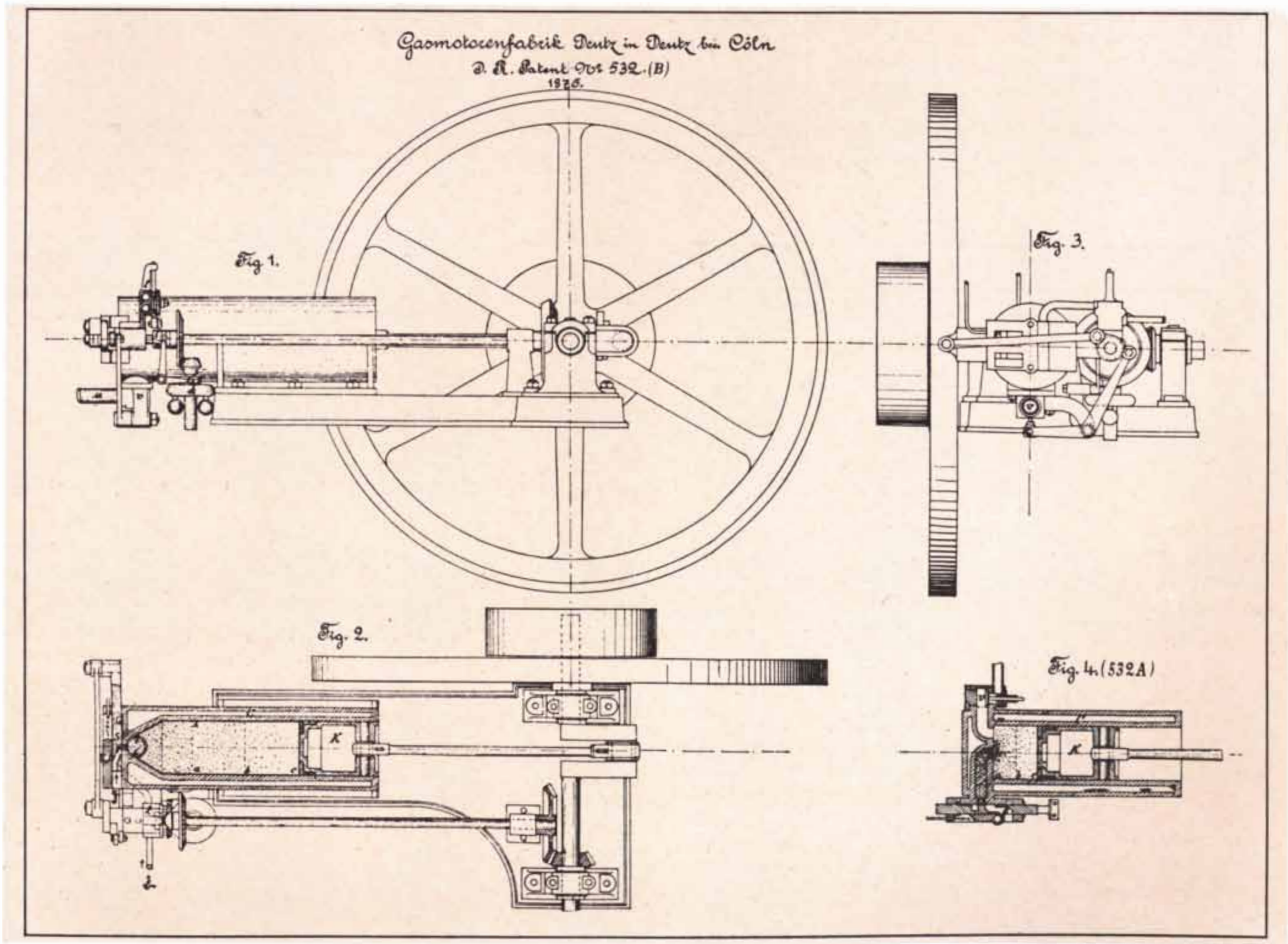
The original Otto engine achieved an efficiency three or four times greater than the steam engines of the day, with the result that Otto's factory near Cologne became a world-famous source of stationary power plants. Two of his associates in this enterprise were Gottlieb Daimler, who later became a pioneer in the automobile business, and Wilhelm Maybach, who designed most of the early Daimler automobiles and went on to make excellent engines for aircraft.

Otto's engine would be important if only because it was the ancestor of the automobile power plant. It has a special appeal for the historian of technology because it was a good machine built on a bad theory. In the early days of the gas engine (and it was gas, not gasoline) the central problem was how to get a smooth flow of power out of a series of explosions. Otto solved the problem—or thought he did—by mixing fuel and air in a special way that yielded what he described as a stratified charge. This was supposed to cushion the shock of the explosions. Otto was wrong in attributing the success of his engine to the distribution of the gases in the cylinder, but his error led him to a mode of operation that is still employed in more than 10 million new engines a year.

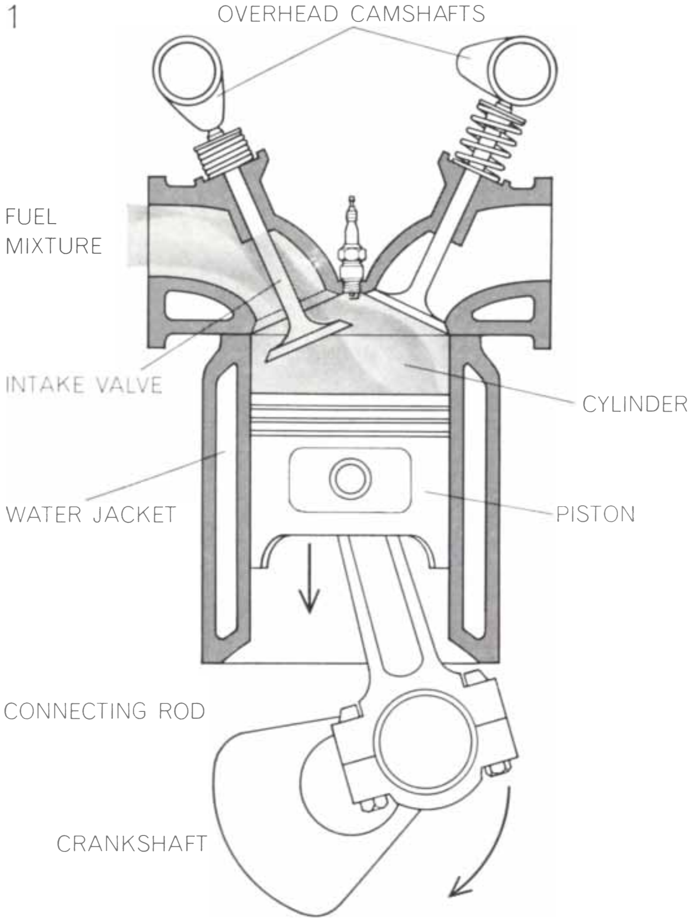
The Silent Otto looks more like a

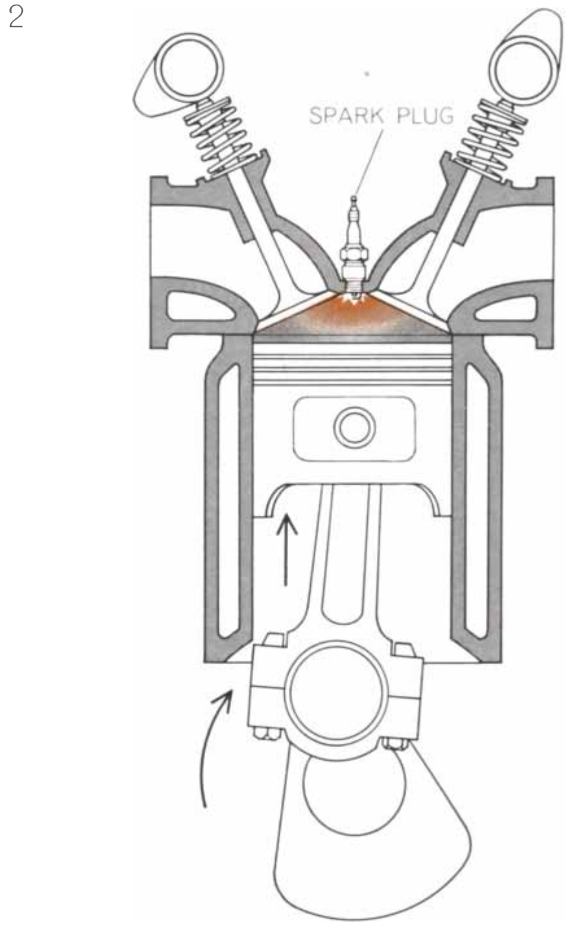


EXPERIMENTAL MODEL of the original Silent Otto gas engine was built by Otto at the Gasmotorenfabrik Deutz in 1876. The single cylinder (*left*) is a converted steam-engine cylinder. The large flywheel is needed because only one out of four strokes is a power stroke. The Silent Otto developed three horsepower (in German *Pferdstarke,* abbreviated *PS*) at 180 revolutions per minute (*Umdrehungen in der Minute,* or *U/min.*). It was photographed at the museum of Klöckner-Humboldt-Deutz near Cologne.



PATENT DRAWINGS of the Silent Otto accompanied Otto's original application for a German patent. The stippling in the cutaway view of the combustion chamber (*Fig. 2*) represents what Otto mistakenly believed was the reason for the smooth operation of his engine: a special mixture of illuminating gas and air that he described as a stratified charge (*see illustration on page 108*). A modified combustion chamber is shown in Fig. 4. An enlarged illustration of the slide-valve mechanism appears on page 110.





MODERN AUTOMOBILE ENGINE utilizes the four-stroke cycle first demonstrated by Otto, which consists of a downward fuel-and-air-intake stroke (*1*), an upward compression stroke (*2*), a downward power stroke (*3*) and an upward exhaust stroke (*4*). Ignition

steam engine than an automobile engine [*see illustrations on preceding page*]. This is not surprising, because it was the steam engine that provided the theory, the experience and even the hardware used by early workers on gas engines. The cylinder in Otto's single-cylinder engine was in fact a converted steam-engine cylinder. It incorporated a slide valve like the valve of a steam engine, except that it had a more complicated system of passages because it had to control three fluids—fuel, air and the ignition flame—rather than steam alone. The Silent Otto developed about three horsepower at 180 revolutions per minute.

The Otto engine, demonstrated in 1876, was the first to use the four-stroke cycle. To observers brought up on the steam engine this must have seemed a wasteful way to run an engine because it yielded only one power stroke for every two revolutions of the crankshaft. The steam engine not only had a two-stroke cycle but also was usually double-acting; this meant the piston was pushed by steam in both directions, so that there were two power strokes for each revolution of the crankshaft—four times as many as in the single-acting four-stroke gas engine. Otto seems to have adopted this mode of operation reluctantly and temporarily for lack of a better way to compress the charge. Such a drastic reduction in the frequency of power strokes must have seemed a high price to pay for the advantages of compression. Otto claimed the four-stroke cycle in his patent, but only incidentally. He promptly set to work to improve his engine by developing a two-stroke process, and so did a dozen other inventors. He was never able to improve on the four-stroke process, nor has anyone else been able to for engines of a size appropriate to automobiles.

Otto's fuel was illuminating gas. Although gasoline was known, it was regarded as being extremely dangerous. The problem of mixing gasoline vapor and air in the exact proportions required by an engine proved to be an intractable one that was not solved until the carburetor was devised in its present form in the 1890's. Gas, on the other hand, was a convenient and reliable fuel that was already in wide use for lighting. Usually produced by heating coal in the absence of air, it consisted chiefly of hydrogen, methane and carbon monoxide. Gas technology had been evolving for some 50 years, and whenever a city installed a gas system someone was likely to get the idea that this new source of energy could be used for power as well as light.

Early inventors therefore envisioned a small gas engine the user could turn on whenever he needed power (as we now plug in an electric motor) and turn off when he was through. They hoped that such an engine might compete with the steam engine, particularly in small sizes, because of its convenience and adaptability to intermittent use. The more enthusiastic promoters dreamed of supplanting the steam engine entirely, but a more realistic goal was to provide stationary power plants for small enterprises—pumping stations, breweries, printing shops and the like—that could not afford a steam engine or did not use power continuously.

Otto and others naturally considered using a gas engine to drive a vehicle, but that was not a practical objective in the 1870's. The Silent Otto and the first generation of its rivals were much too heavy (they weighed about a ton per

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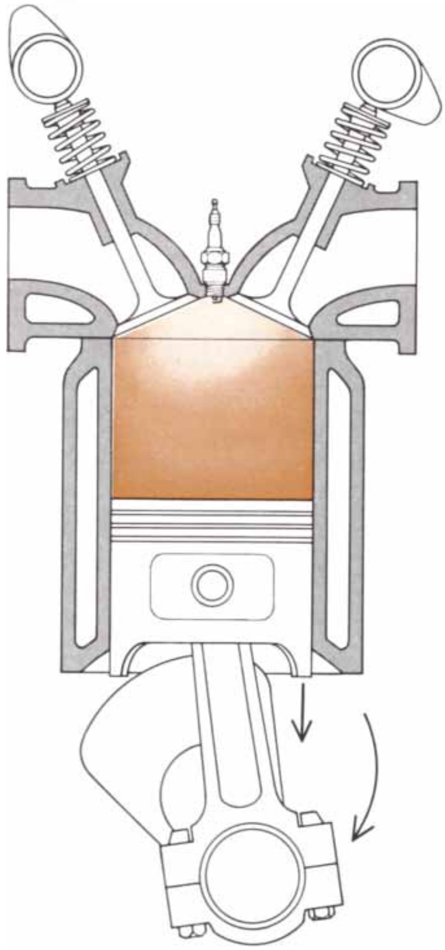

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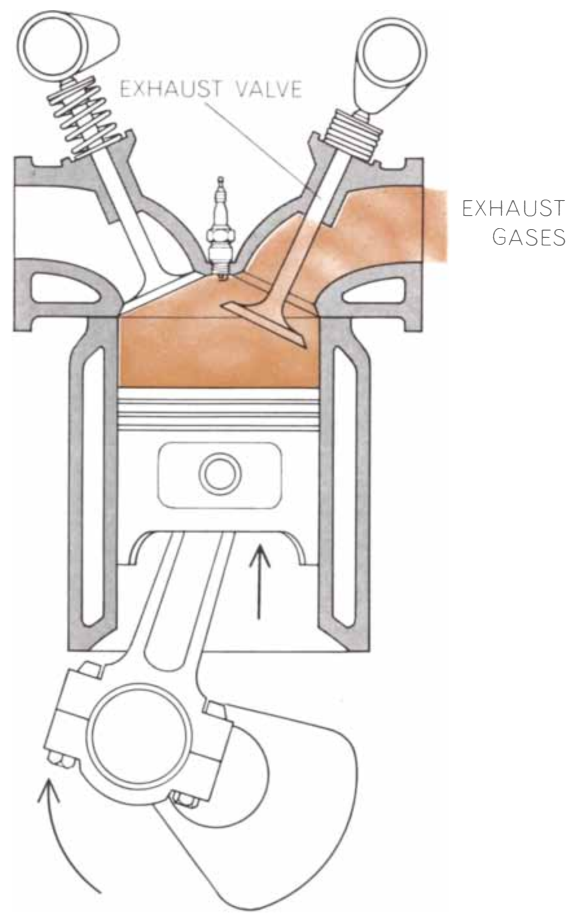


occurs just before the end of the compression stroke. More than 10 million new engines a year employ this mode of operation. The arrangement of the valves and camshafts varies from one engine to the next; dual overhead cams are shown here for the sake of clarity.

horsepower) and they were tied to a stationary gas system. Nonetheless, Otto's engine of 1876 embodied the essential concepts that later made the automobile engine possible, after much refinement of detail, chiefly reduction of weight and adaptation to liquid fuel.

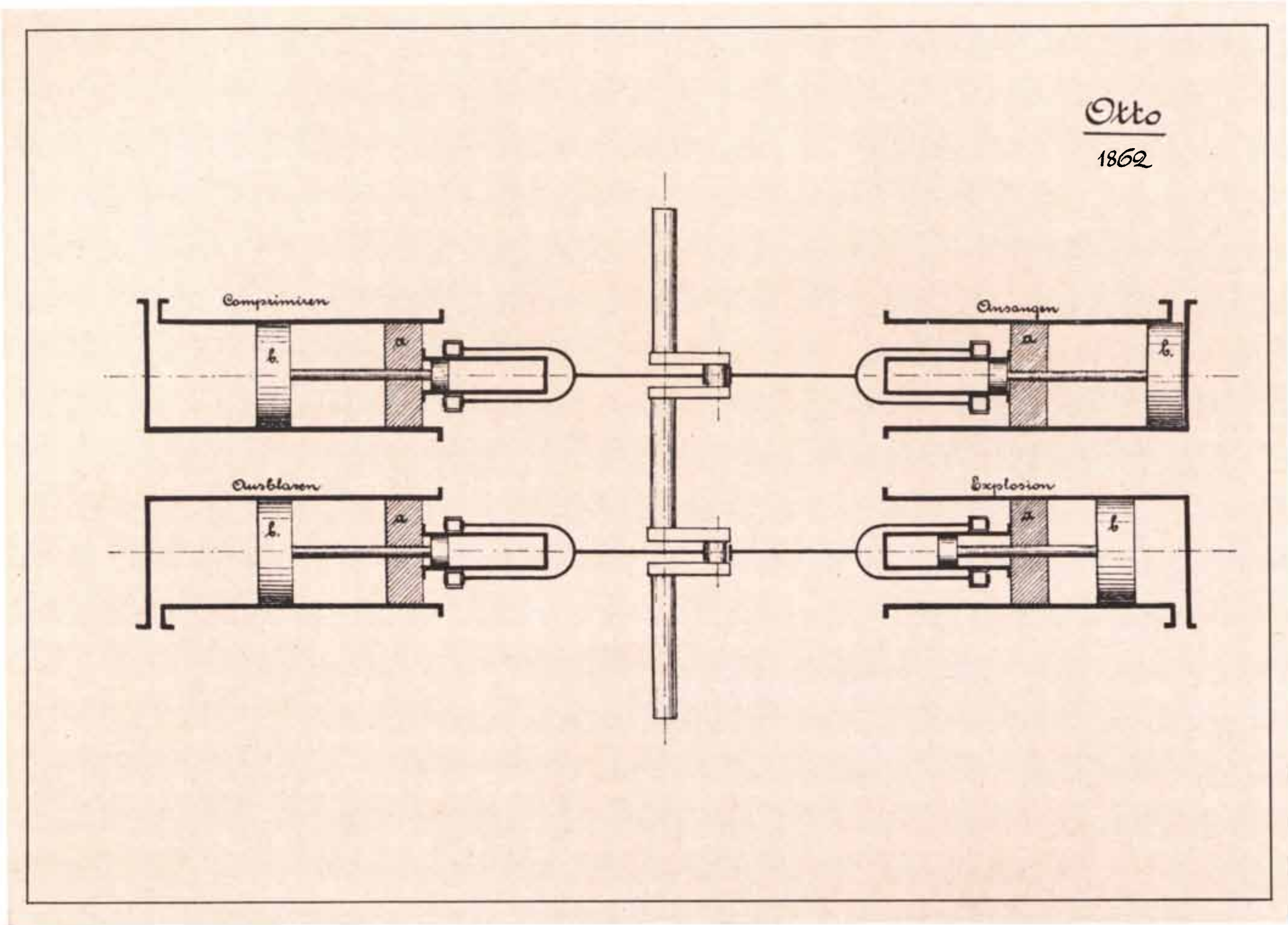
The concept of internal combustion—that is, the notion of burning the fuel inside the working cylinder of an engine and dispensing with firebox and boiler—was an attractive one in Otto's time, and scores of inventors were working on it. Practical engineers knew little thermodynamics in those days, but some knew enough to measure the thermal efficiency of the steam engine. They found it scandalously low, usually well under 5 percent. The internal-combustion approach seemed a promising one because it offered an opportunity to avoid the heat losses, not to mention the weight and expense, associated with firebox, smokestack and boiler. The heat would be generated at the face of the piston, so that it could immediately be converted into work without losses in transmission and storage.

At the time engineers also talked about another kind of economy: the saving of latent heat. The trouble with the steam engine, they said, is that much energy has to be spent in converting water into steam before any work is done, and that this investment in "latent" heat is not recovered if the exhaust steam is discharged into the atmosphere, as it usually is. The key advantage they saw in the internal-combustion process was that it utilized the products of combustion to drive the piston directly, without wasting energy in generating an intermediate working fluid such as steam. Actually the essential advantage, as more sophisticated engineers eventually learned, was that the internal-combustion engine was able to operate through a wider range of temperatures than the steam engine could; the nature of the working fluid made no essential difference.

Otto was not the first to try internal combustion. His most famous predecessor was Étienne Lenoir of France, who like Otto had no technical training. In 1860 Lenoir built a two-stroke engine much like a steam engine. It drew in a mixture of gas and air for the first half of each intake stroke and then ignited it with an electric spark. The second half of the stroke was used for expansion, and there was no compression of charge. The engine was double-acting: it used both sides of the piston like a steam engine.

The Lenoir engine created a flurry of excitement in the early 1860's. *Scientific American* quoted French journals as saying that it marked the end of the age of steam. "Watt and Fulton will soon be forgotten," the article said. "This is the way they do such things in France." Then professional engineers who knew some thermodynamics ran tests on the engine and published discouraging reports. It used large quantities of oil and cooling water, it overheated badly and it was hardly better than a steam engine in efficiency. Several hundred Lenoir engines were made, but within a few years they were mostly scrapped or converted to steam.

One of the suggestions offered for improving the efficiency of the Lenoir engine was to try compressing the charge. The idea of compression is a simple and obvious one that came up frequently in the 15 years before the Silent Otto. A commonsense engineer



OTTO'S FIRST SOLUTION to the shock problem involved an extra free piston (*b*) that would act as a spring to absorb the shock of the explosion. Otto said that he had incorporated such an arrangement in a four-cylinder engine built in 1862. This drawing was prepared from memory in 1885 in the course of a patent litigation to support Otto's doubtful claim that the engine used the four-stroke cycle. The big defect of such an engine is that the instant of ignition cannot be fixed in relation to the instant of maximum compression, which is determined by the position of the free piston. Otto reported that the engine was ruined by destructive shocks.

would see compression as a way of increasing the power of an engine by packing in more fuel, or as a way of reducing the size of the engine by simply packing the same amount of fuel into a smaller volume. One of the advantages of gas as an engine fuel is that the designer can choose a convenient density.

Otto discovered the value of compression as he was experimenting with a model of the Lenoir engine. While working as a traveling salesman for a wholesale grocer in the Rhineland he read about Lenoir in a newspaper and had a mechanic build the model engine for him according to the newspaper description so that he could try it out. Once in the course of testing various mixtures and sizes of charge and times of ignition he drew in a full cylinder of gas and air and then compressed it on the next stroke of the piston. (Indeed, one could scarcely do anything else with a full charge.) When he set off the compressed charge, he got a surprisingly violent explosion that drove the flywheel through several revolutions. He later said that this was the starting point of the four-stroke cycle.

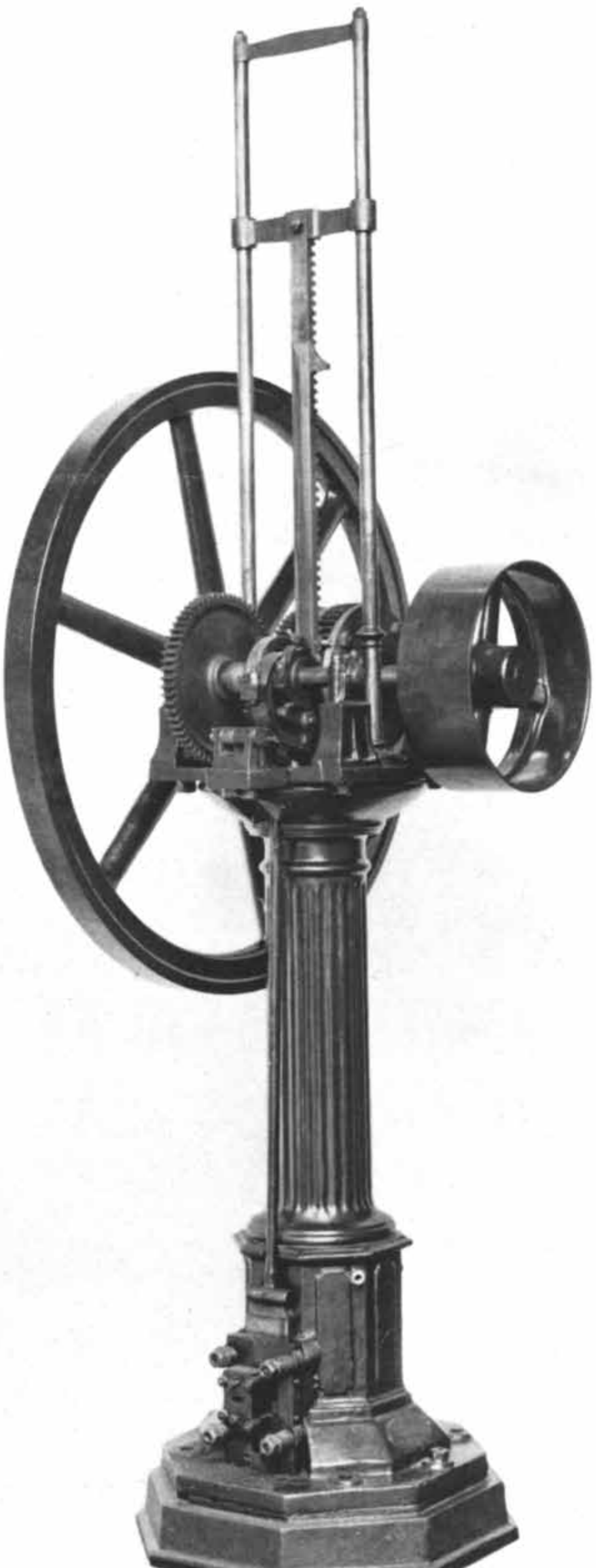
Otto probably did not follow up this discovery at the time because a violent explosion was the last thing he wanted. His problem was to reduce the violence of the explosions. He was not looking for ways to increase the power of his engine but rather for ways of controlling the power he had. A worker on gas engines in the 1860's had two models to use in his thinking. One was the steam engine, in which the steam delivered an easy, steady pressure to the cylinder that could be turned on and off at will and also could be easily transferred to the other side of the piston. This was the ideal to be achieved in a gas engine.

The other model was the gun, which provided experience with the behavior of explosions in cylinders. The gun was the first internal-combustion engine, and it delivered energy in spectacular bursts. The problem of developing a practical gas engine was like the problem of getting useful work out of a gun. One objective is to generate a series of explosions—to make it a machine gun. The other, the critical objective for Otto, was somehow to convert the series of explosive impulses into a smooth flow of power. A flywheel would obviously smooth out the impulses, but Otto still had the problem, or thought he did, of moderating or cushioning the explosions so that they would not destroy the engine.

Otto tried three different solutions to this problem. The first was to use an extra free piston in the cylinder that would act as a spring to absorb the shock of the explosion. Otto later said he had tried such an arrangement in 1862 [*see illustration above*]. It was incorporated in a four-cylinder engine (very surprising for 1862) that compressed the charge and was said to employ the four-stroke cycle. The drawing was prepared from memory by a mechanic in 1885 in the course of patent litigation to support Otto's doubtful contention that he had used the four-stroke cycle in 1862; its purpose here is only to illustrate Otto's first solution to the shock problem. Each cylinder had a working piston connected to the crankshaft in the usual way, and between this main piston and the end of the cylinder was a free piston mounted on a plunger that was free to move back and forth in a hollow passage in the connecting rod of the main piston. The free piston would act as a shock absorber; when the explosion came, it would be driven back against the main piston, and the air trapped between the two pistons and the air in the hollow passage of the connecting rod would cushion the shock. The main piston would therefore be driven back more smoothly and gradually than the free piston.

This double-piston arrangement had another function: it helped to drive out the exhaust gases. In an ordinary four-stroke engine the piston does not reach the end of the cylinder because it has to leave room for the compressed charge to be burned. Thus the space occupied by the charge at the end of the compression stroke is still there at the end of the exhaust stroke, and it contains unexpelled gases that remain to contaminate the next charge. At first engineers were concerned about this contamination. Nowadays they do not have to worry so much about it because they work with much higher compression ratios, say 10 to 1 (a tenfold increase in pressure). This means that the space not swept out by the piston is much smaller than it was, for example, in the Silent Otto, which had a compression ratio of 2.5 to 1. The free piston shown in Otto's 1862 arrangement would have been gradually forced back against the main piston by the increasing pressure of the charge being compressed, thereby leaving room for the charge at the end of the stroke. On the exhaust stroke the compressed air that had cushioned the explosion would have driven the free piston to the end wall of the cylinder and so have pushed out the exhaust completely.

It is doubtful that Otto actually ran such an engine, but he did try the idea of a shock-absorbing device. So did a number of others, including Lenoir. In 1893 Frank Duryea used a free piston like Otto's in the first American horseless-carriage engine. These engines were all failures. At that time engineers worried too much about expelling exhaust and not enough about properly timing the ignition of the charge. In a free-piston engine of this kind the instant of ignition could not be precisely fixed in relation to the instant of maximum compression. One could never tell from the



ATMOSPHERIC ENGINE, patented by Otto and his business partner Eugen Langen in 1866, was the first genuinely successful internal-combustion engine. Some 5,000 Otto & Langen engines were sold. An explosion drove a heavy free piston up the vertical cylinder as far as it would go. The gases then cooled and contracted to form a partial vacuum; atmospheric pressure, assisted by the weight of the piston, did the work on the way down. A clutch allowed the piston to rise freely but caused it to engage the output shaft on the downward power stroke. Atmospheric pressure placed a limit on the engine's performance, and it turned out to be a dead-end branch in the evolution of the internal-combustion engine.

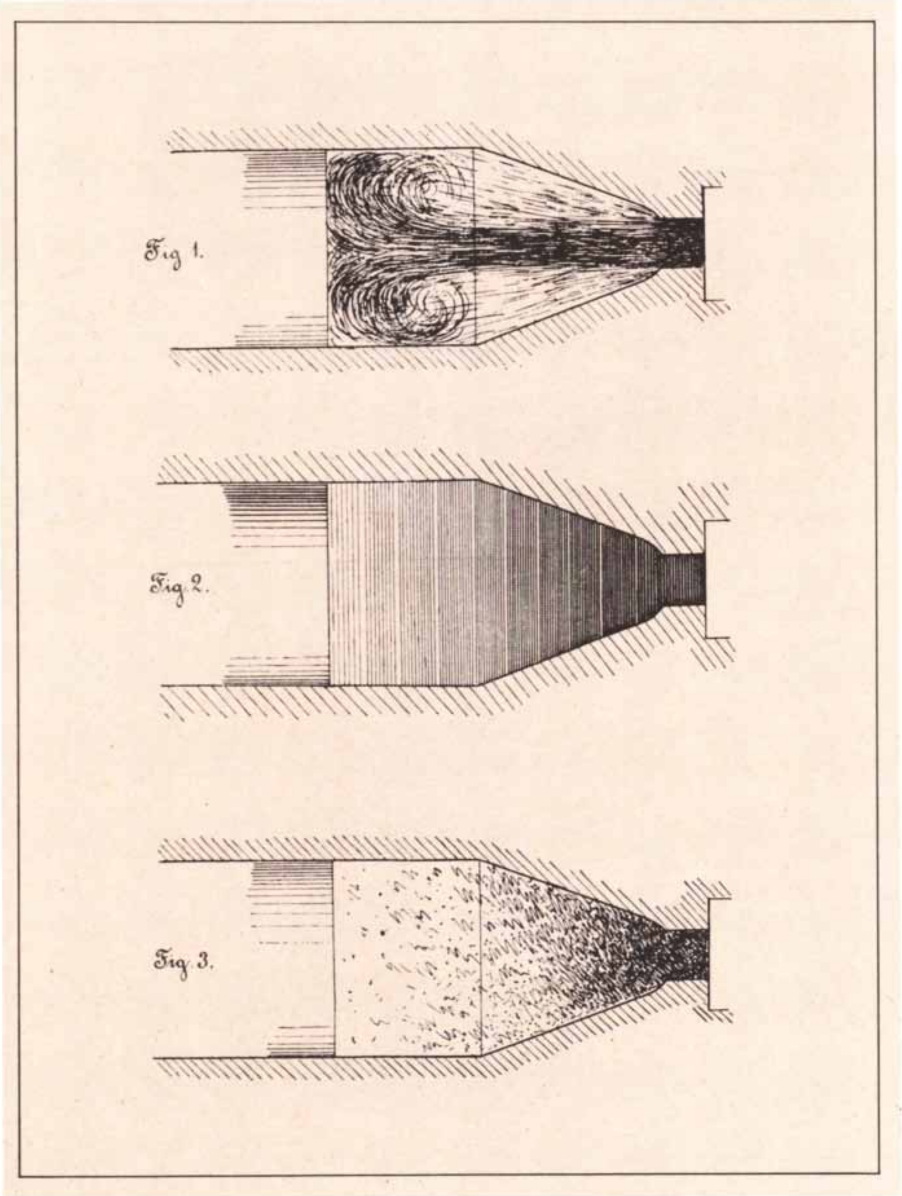
outside where the free piston was at any given time, and it was the free piston that determined the instant of maximum compression. Premature explosions must have been common. Otto said that this engine was ruined by destructive shocks and that he despaired of ever getting a gas engine to work on the direct-acting principle, that is, with the expanding gases driving the output shaft directly.

Otto now turned to a second kind of solution to the shock problem. He gave up trying to moderate or absorb the shock of the explosion and instead disconnected the piston from the output shaft during the explosion. He had found in his early work on the Lenoir engine that the hot gases in a cylinder would cool quickly and form a partial vacuum, so that atmospheric pressure would drive the piston back. In the "atmospheric engine" he developed over the next five years the explosion drove a heavy free piston up a vertical cylinder as far as it would go [*see illustration on preceding page*]. The gases then cooled and contracted to form a partial vacuum, and atmospheric pressure, assisted by the weight of the piston, did the work on the way down. A clutch allowed the piston to rise freely but caused it to engage the output shaft on the way down.

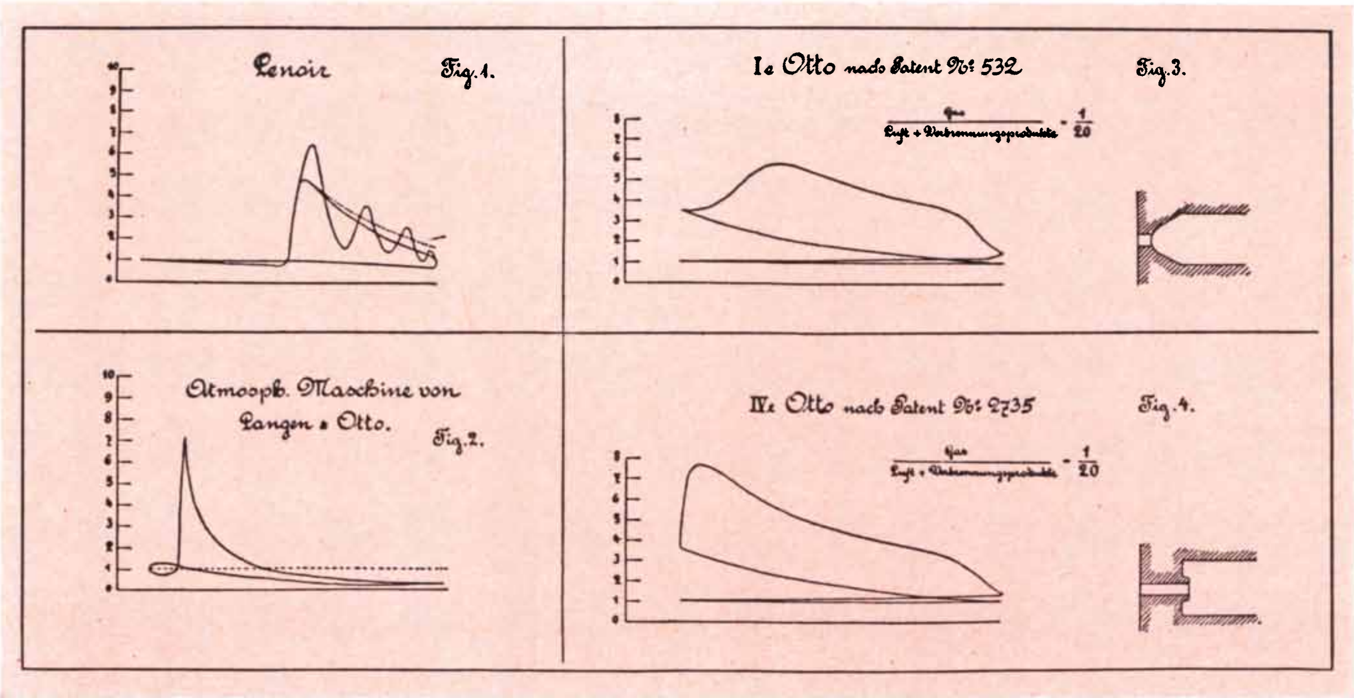
The atmospheric engine was an ingenious and perfectly workable solution to the problem of getting useful power from a series of explosions. To someone accustomed to steam engines it was noisy and queer-looking, but it was more efficient than Lenoir's imitation steam engine (chiefly because it allowed more expansion of the hot gases). The principle of the atmospheric engine was not new, although Otto said he had got the idea from his own experience. The Newcomen steam engine, known for 150 years, created a vacuum by causing steam to condense and letting atmospheric pressure do the useful work, and the same principle had been applied to the gas engine in the 1850's. Otto's engine, however, went beyond earlier atmospheric engines in efficiency and reliability; it was the first genuinely successful internal-combustion engine. It was also the foundation of a successful business in which the guiding spirit was Eugen Langen, whose name appears with Otto's on the nameplate of the engine. Langen made the same kind of contribution to Otto's progress that Matthew Boulton made to James Watt's.

About 5,000 of these engines were built in various countries, but the Otto & Langen turned out to be a dead-end branch in the evolution of the internal-combustion engine. The reason was that atmospheric pressure placed a ceiling on its performance. The Otto & Langen came at a time of increasing demand for more powerful engines, and it seemed impractical to make an engine of more than about three horsepower. Since the working pressure could not be increased, the only way to increase the power was to enlarge the cylinder, and it was already so large that in the three-horsepower size it needed about 12 feet of headroom. Otto and his associates tried all kinds of ideas for improving the atmospheric engine, but the basic design proved to be inflexible and not easily adapted to further development. Nevertheless, they learned much from the engine. It was a good experimental tool for Otto's continuing work on combustion because it gave him an easy way to estimate the explosive force of different fuels and mixtures: he could see how far the piston was driven up by different charges. Otto continued to study combustion in cylinders, to test competing engines and to try various ideas for new types of engines, including at least one involving compression.

In 1876, with sales of the Otto & Langen dropping, the need for some kind of radical improvement became urgent. At this time Otto suddenly thought of a third solution to his key



STRATIFIED CHARGE was Otto's third solution to the shock problem. He believed that at the moment of ignition the combustion chamber of the Silent Otto contained a layer of old exhaust gases nearest the piston (*left*), then a layer of air, then layers of fuel-air mixture of increasing richness, with the richest mixture nearest the point of ignition (*right*). It was not necessary to Otto's theory that there be distinct layers; he conceived of several possible charge structures, three of which he portrayed in these sketches, published in 1886.



INDICATOR DIAGRAMS give the relation between the volume (*horizontal scales*) and the pressure (*vertical scales*) inside the cylinders of various engines Otto tested. The oscillations in the expansion curve of the Lenoir engine (*Fig. 1*) reflect the kind of shock waves Otto professed to find in engines operating without a stratified charge. In contrast the expansion curves in the diagrams of the three Otto engines decline smoothly. The sketches attached to the diagrams of two versions of the Silent Otto (*Fig. 3 and Fig. 4*) show a change in the shape of the combustion chamber that was supposed to improve the combustion of lean mixtures.

problem: cushioning the shock of the gas explosions. It sent him back to the direct-acting gas engine he had abandoned as being hopeless in 1862, and persuaded him to try a compressed charge without the shock-absorbing piston. Guided by this idea, he quickly built the Silent Otto of 1876 and worked out the details of the four-stroke cycle as a way of compressing the charge in the working cylinder. The engine was a great success, and it proved to be a flexible design that could be used for many purposes and was susceptible to evolution into a wide variety of forms.

The idea that led Otto to his third solution was the concept of stratified charge—the concept that the gases inside the cylinder could themselves perform the shock-absorbing function if they were mixed properly. The idea came to him, Otto said, as he was idly watching smoke rise from a factory smokestack and thinking about combustion problems. The smoke billowed and swirled into the air and then gradually disappeared. A combustible mixture might enter a cylinder in the same fashion, he thought, and then it occurred to him that if a combustible mixture spread itself out into an inert medium like smoke rising in air, the inert medium might somehow slow down the burning or moderate the explosion.

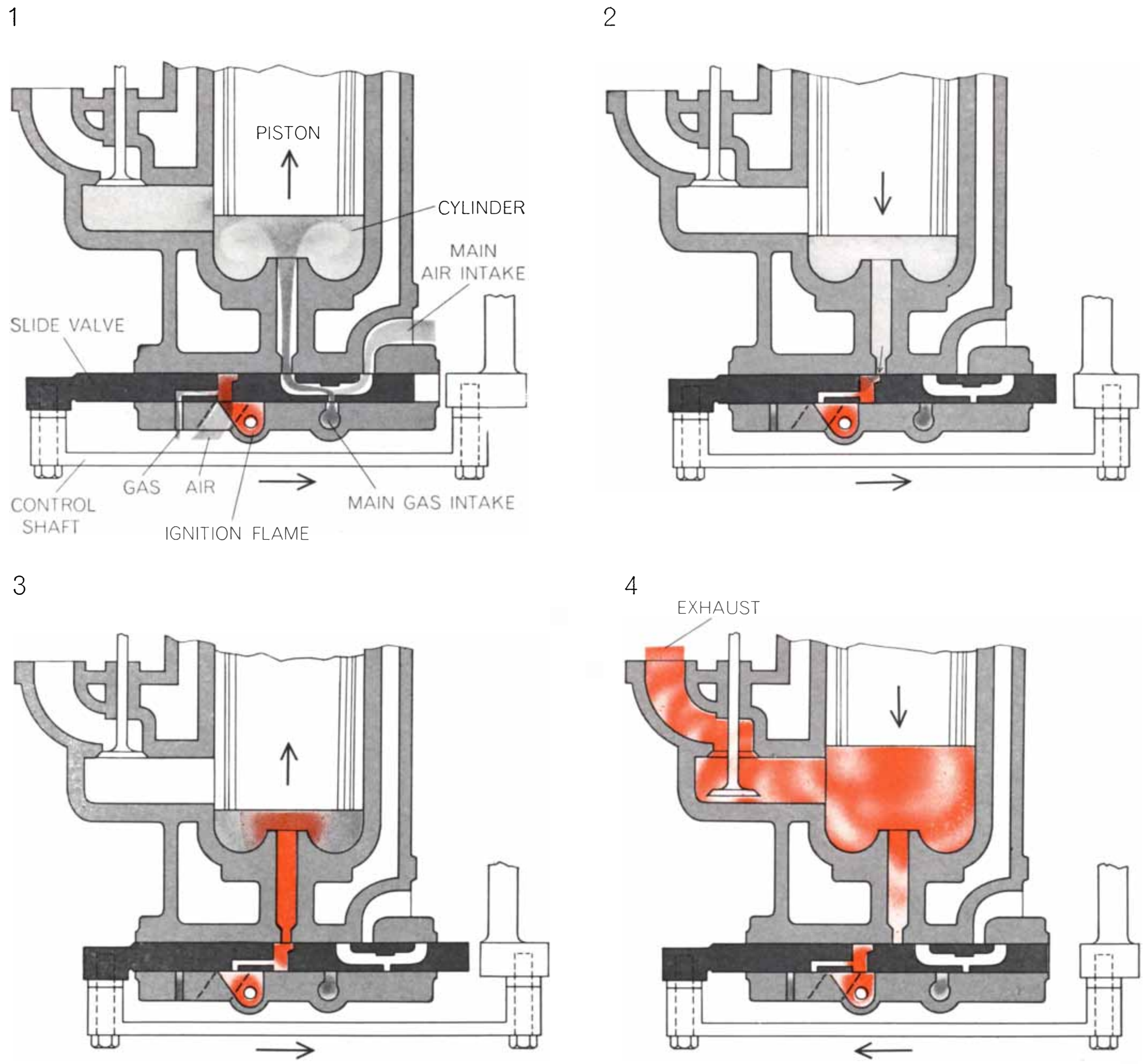
Otto had been studying combustion for 15 years. Back in 1860 his work on the Lenoir engine had taught him that the ratio of fuel to air was critically important. If a mixture of illuminating gas and air was too rich or too lean, he found, it would not burn at all. Within the rather narrow range of combustibility a mixture too rich would ignite easily, but the shock of the explosion would be too strong for the engine; a mixture too lean would burn more gently, but ignition was difficult. Accordingly Otto's problem in the 1860's was how to get both reliable ignition and slow burning. The idea suggested by the smokestack episode was that he could have both if he controlled the intake of the gas and air in such a way that he had a mixture rich enough near the point of ignition for the ignition to occur reliably, and lean enough near the piston for the combustion to occur slowly. On this basis the exhaust gases from the last cycle, which would not burn at all, suddenly became a positive good; they might remain in a layer near the piston and help to protect it from shocks. The extra free piston shown in Otto's 1862 plan would no longer be required to absorb the shock, nor would it be needed to expel the exhaust.

To produce this special kind of charge Otto used a slide valve that was driven back and forth across the entrance to the cylinder by a half-speed control shaft [*see illustration on next page*]. The valve was a brass block with an elaborate system of passages that admitted plain air for the first half of the intake stroke and a fuel-air mixture of increasing richness for the second half of the stroke. To ignite the stratified charge at the end of the compression stroke the slide valve picked up a bit of burning gas from an external standing flame and inserted it in the combustion chamber at just the right moment. This was quite a trick, because the pressure inside was higher than it was outside. What Otto thought he had in his combustion chamber at the time of ignition was a layer of old exhaust gases nearest the piston, then a layer of air, then layers of a fuel-air mixture of increasing richness, with the richest mixture nearest the point of ignition.

Otto got into trouble with the concept of the stratified charge. In fact, he lost his patent protection in some countries when his opponents were able to persuade the courts that the charge in Otto's engine was not stratified and that an engine with a homogeneous charge would also run smoothly. Otto continued to insist that no compression engine could run smoothly unless the charge was stratified in some sense. He did not really mean, he said later, that different kinds of gas had to be in sharply defined layers. They could be in irregular swirls, like the smoke from the smokestack, but the fuel-air particles would still have to be distributed in such a way that the combustion was propagated from one fuel-air particle to another through an inert medium that did not participate in the combustion and had the function of softening the shock or slowing the burning [*see illustration on page 108*].

In those days nobody could tell exactly what was happening inside the cylinder. Even in a slow engine such as Otto's a complete four-stroke cycle took less than a second. There was plenty of room for argument, and there *was* plenty of argument. One instrument used at that time to measure the performance of an engine and diagnose its ills was the indicator mechanism designed by James Watt for the steam engine; it recorded pressures within the cylinder as the piston went back and forth, in the form of a pressure-volume diagram.

Such an indicator diagram gives the engineer information he can use in the way the physician uses the pulse rate as evidence of what is happening inside the body. There was one important item of information, however, that in those days could only be inferred: temperature. Here the uncertainties were so large that the most respectable experts could differ widely about what was going on in an engine. In the illustration on the preceding page are indicator diagrams Otto recorded for a Lenoir, an Otto & Langen and a Silent Otto. The oscillations in the expansion curve of the Lenoir diagram reflect the kind of shock waves Otto professed to find in competing engines without stratified charge, and the smoothly declining pressure in the expansion curves of the



SLIDE VALVE used in the Silent Otto was driven back and forth across the entrance to the cylinder by a half-speed control shaft. A complicated system of passages admitted plain air for the first half of the intake stroke and a fuel-air mixture of increasing richness for the second half of the stroke. To ignite the stratified charge in the combustion chamber the slide valve picked up a bit of burning gas from an external flame (*1*) and, after equalizing the pressure in the valve and the chamber (*2*), inserted the flame into the chamber at the end of the compression stroke (*3*). A conventional poppet valve was used to release the exhaust gases (*4*).

diagrams of his own engines indicates the special kind of burning due to the structure of the gases that Otto claimed as the essence of his invention.

Otto never abandoned his theory of the stratified charge, but by the time of his death most experts had turned against it. It was generally agreed that the fuel-air mixture in an engine should be as homogeneous and as free of exhaust gases as possible, and that smooth running was achieved by the proper mixture and the timing of ignition. Still, not everyone was convinced, and it is curious to see how the concept of the stratified charge, or something very much like it, keeps reappearing in the history of the internal-combustion engine. Harry Ricardo, for example, reinvented the stratified charge in 1922 as a means of achieving fuel economy through improved combustion. He proposed igniting a particularly rich mixture in a small antechamber so that a hot flame would shoot out into the main combustion chamber and set fire to a mixture so lean that it ordinarily would not burn at all. (A contemporary version of the same concept appeared in a British automobile magazine as recently as last November.) Although Otto had begun by thinking of the stratified charge as a shock-absorbing device, he also saw in it a means of achieving more complete combustion. In 1877 he patented a modified shape of the combustion chamber of the Silent Otto that would concentrate the richest mixture in a narrow channel so that a hot flame would shoot out into the main charge and ignite its leanest parts.

The possibility of greater fuel economy makes such an idea interesting to automobile and oil companies today. Public awareness of air pollution has also helped to revive interest in the stratified charge as a potential way to get cleaner automobile exhaust through more complete combustion. A number of experimental programs have been launched in the past 15 years in the U.S. and abroad for the purpose of trying new shapes of combustion chambers and changes in fuel injection and ignition, all involving some kind of separation of rich and lean mixtures with the rich mixture near the point of ignition. These programs usually reflect an interest in turbulence within the cylinder that brings to mind Otto's original concept of a combustible mixture swirling about like smoke from a smokestack. One variation of the stratified charge, the Texaco Combustion Process, is said to eliminate knock, which would have been very interesting to Otto. Knock is the premature detonation of a part of the charge that is heard when low-octane gasoline is used in a high-compression engine. It was a different kind of shock that troubled Otto; he probably never tried a high enough compression to detect combustion knock as we know it. Nonetheless, he felt the same need to control combustion within his cylinder, and he tried to control it in the same way: by concentrating a rich mixture in the region of ignition.

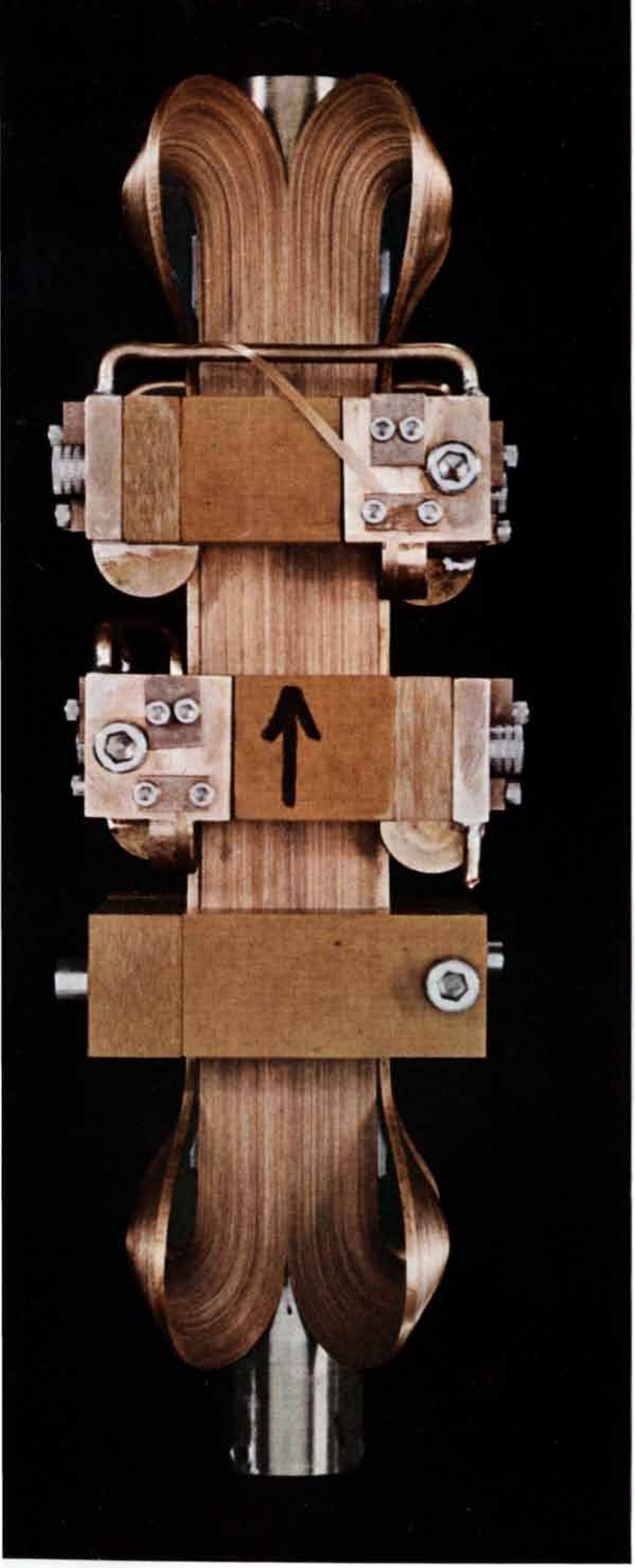
Otto's idea of the stratified charge may not be technically respectable, but it guided him to the most important single step in the evolution of the automobile engine, and it continues to have a powerful fascination for engine designers in many countries.

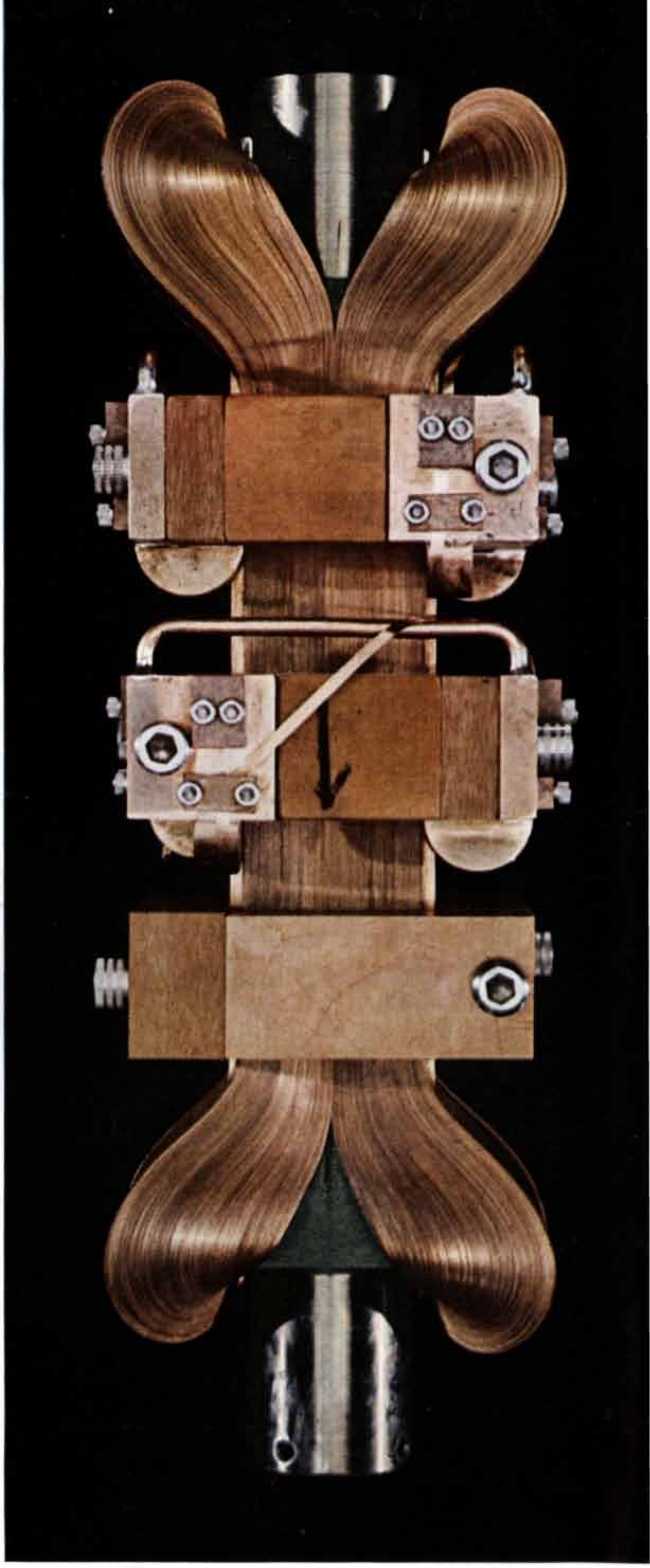
MONUMENT to Otto and Langen stands in the main square of Deutz, a suburb of Cologne, near the former site of Gasmotorenfabrik Deutz. On top of the monument is a model of their atmospheric engine of 1866.

How to get your husband to fasten his Rover 2000  safety harness:

Tell him it's a Sam Browne belt
and he looks like a World War I aviator

The Rover Motor Co. of N. America Ltd.: Chrysler Bldg., New York, N.Y. 10017; 231 Johnson Ave., Newark, N.J. 07108; 1040 Bayview Drive, Ft. Lauderdale, Fla. 33304; 373 Shaw Rd., South San Francisco, Calif. 94080; 10889 Wilshire Blvd., Los Angeles, Calif. 90024. Offices also in Vancouver and Toronto.





SUPERCONDUCTING MAGNET was designed by one of the authors (Sampson) as a prototype of a class of magnets that will be used to focus the beam of protons from the 33-billion-electron-volt accelerator at the Brookhaven National Laboratory. The device, called a rectangular quadrupole magnet, consists of four mutually perpendicular current sheets made of superconducting niobium-tin ribbon encased in copper. The direction of the current (*painted black arrows*) is opposite on adjacent sheets, two of which are visible in these two side views. The magnet is shown approximately actual size. When it is in use, it is immersed in liquid helium.

Advances in Superconducting Magnets

In the past five years superconducting magnets have developed from a laboratory curiosity into the most practical means of generating intense magnetic fields for a growing number of research projects

by William B. Sampson, Paul P. Craig and Myron Strongin

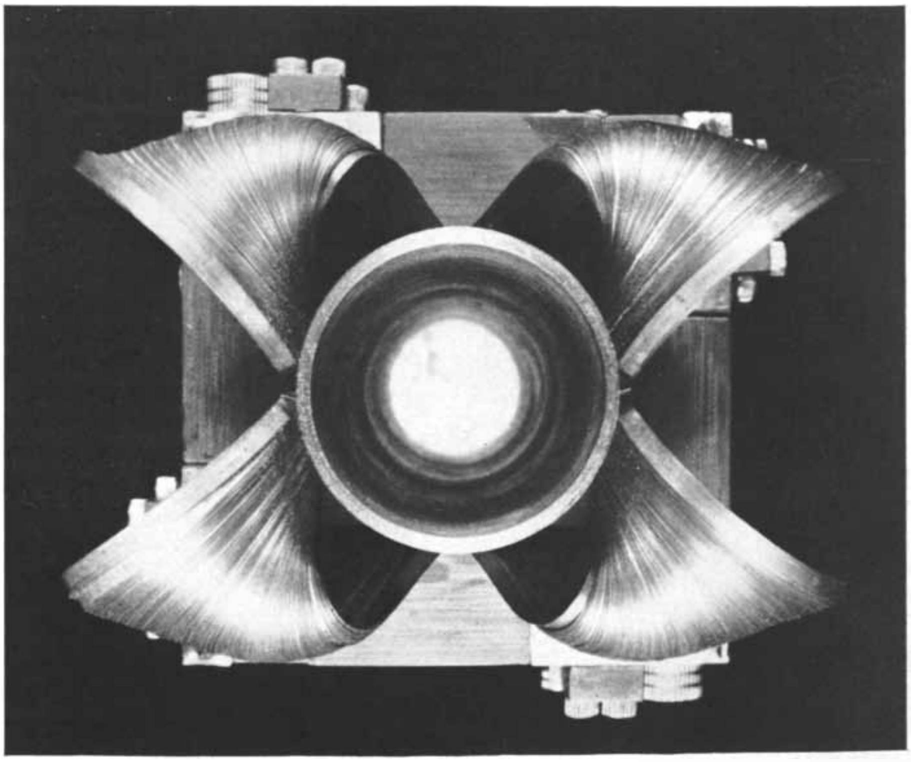
Five years ago superconducting magnets were a laboratory curiosity. An adequate supply of superconducting wire was available, and experimental magnets capable of generating fields as high as 70,000 gauss had been built and operated successfully [see "Superconducting Magnets," by J. E. Kunzler and Morris Tanenbaum; SCIENTIFIC AMERICAN, June, 1962]. Nevertheless, numerous technical difficulties remained, and in spite of their widely recognized potential such magnets were held to be economically impractical for most purposes in competition with conventional electromagnets.

Today this situation has changed drastically. Considerable progress has been achieved in the past few years in the design and fabrication of superconducting magnets. For a substantial number of applications superconducting magnets now perform better and more economically than comparable conventional magnets. Moreover, it seems probable that in the not too distant future the growing need for stronger and cheaper magnetic fields in many areas of science and technology will be filled by superconducting magnets.

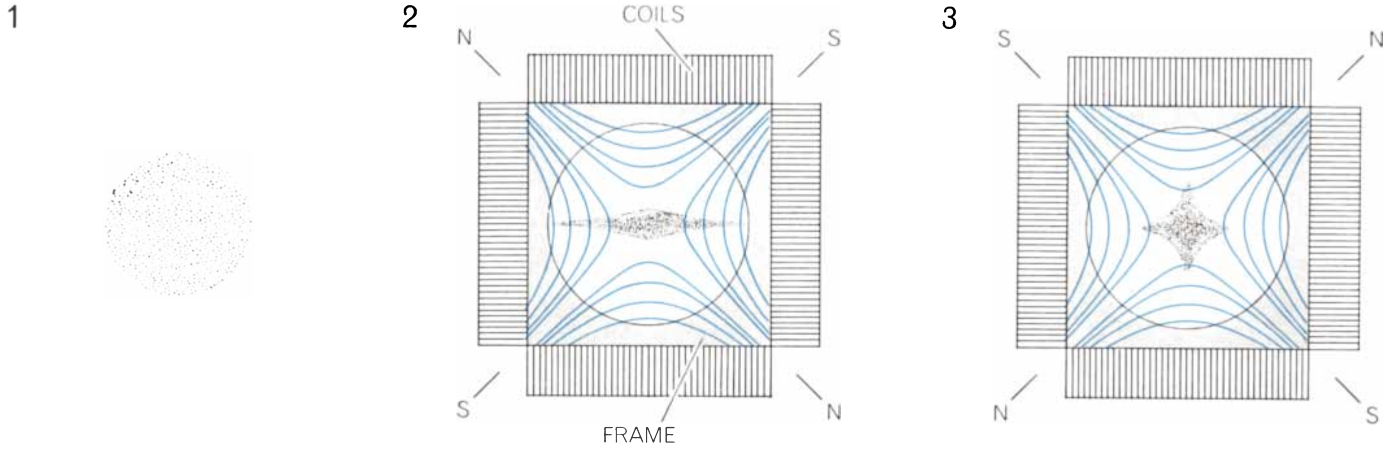
At the Brookhaven National Laboratory we are engaged in building and testing superconducting magnets for use primarily in the fields of high-energy physics and solid-state physics. We have also begun to use such magnets for specific experiments in these fields. Other investigators have recently speculated on some potential uses of superconducting magnets in space research. Although the space applications seem much further in the future, they do not require any unreasonable extension of existing knowledge.

The most important property of superconducting materials from the point of view of a magnet designer is their complete lack of resistance to an electric current at temperatures near absolute zero. This property, discovered by the Dutch physicist Heike Kamerlingh Onnes in 1911, makes it possible in principle to build an extremely strong magnet that requires no input of power. (Permanent iron magnets also produce magnetic fields with no power input, but the strongest fields they can attain are only about 10,000 gauss.) The vast amount of power consumed by a conventional high-field electromagnet appears in the form of heat as a result of electrical resistance in the current-carrying coils. This power input produces no useful work and must be carried away by some cooling agent, usually large quantities of water. At the National Magnet Laboratory in Cambridge, Mass., continuous fields as strong as 250,000 gauss have been achieved with a conventional electromagnet, but the electric power consumed by the magnet is about 16 million watts—approximately the power requirement for a town of 15,000 inhabitants [see "Intense Magnetic Fields," by Henry H. Kolm and Arthur J. Freeman; SCIENTIFIC AMERICAN, April, 1965].

Since there is no electrical resistance in the current-carrying coils of a superconducting magnet, no power is dissipated as heat, and strong fields can be



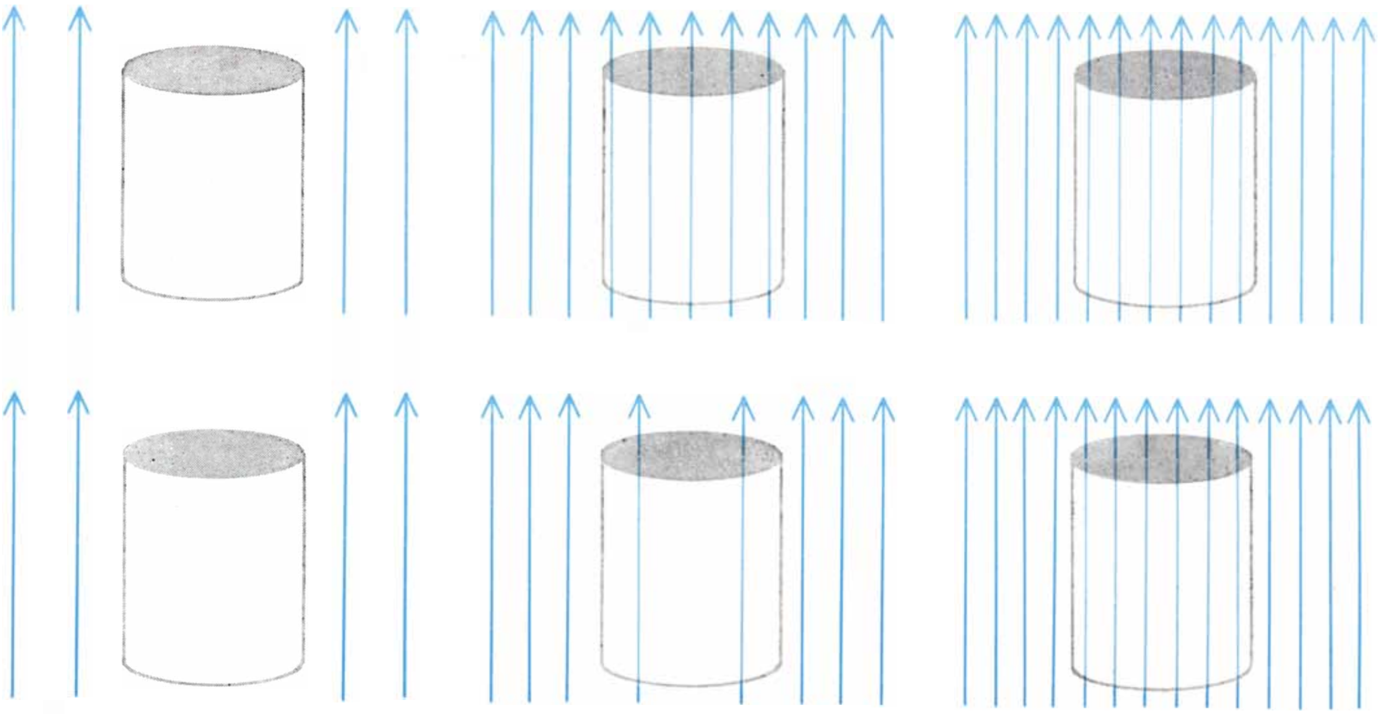
END VIEW of the superconducting quadrupole magnet on the opposite page shows the rectangular array of current sheets around the bore, which is slightly more than an inch across.



BEAM OF PROTONS can be focused by a pair of superconducting quadrupole magnets in two stages. As the beam leaves the accelerator (*1*) it has a diverging circular cross section. The beam then enters the bore of the first magnet (*2*), where the magnetic field forces the protons to converge along a vertical plane and diverge along a horizontal plane. The second magnet (*3*) is rotated 90 degrees with respect to the first and completes the focusing. Because of its higher current density, such a superconducting magnet has a field gradient (change in field intensity with distance) more than five times greater than a comparable conventional magnet.

maintained with practically no expenditure of power. External power is required only to establish the field initially and to refrigerate the superconducting coils. As a result the operating cost of a superconducting-magnet installation is only a fraction of the cost of a comparable conventional system; in addition the superconducting system is usually easier to operate. Because of its more compact structure a superconducting magnet is capable of producing a much steeper field gradient than a conventional magnet; in other words, the distance from a region of high field to a region of low field can be made extremely small. This characteristic is particularly useful when auxiliary apparatus is sensitive to a magnetic field or when rapidly decaying elementary particles are being studied.

A second basic property of the superconducting state that affects magnet design was discovered in 1933 by the German physicists W. Meissner and R. Ochsenfeld. They found that certain superconducting materials completely exclude an external magnetic field. A few years later Fritz and Heinz London developed a macroscopic theory of the phenomenon of superconductivity in which they predicted that the magnetic field decreases very rapidly inside a superconductor, falling to a third of its surface value at a distance of approximately a hundred-thousandth of a centimeter below the surface. The exact dis-

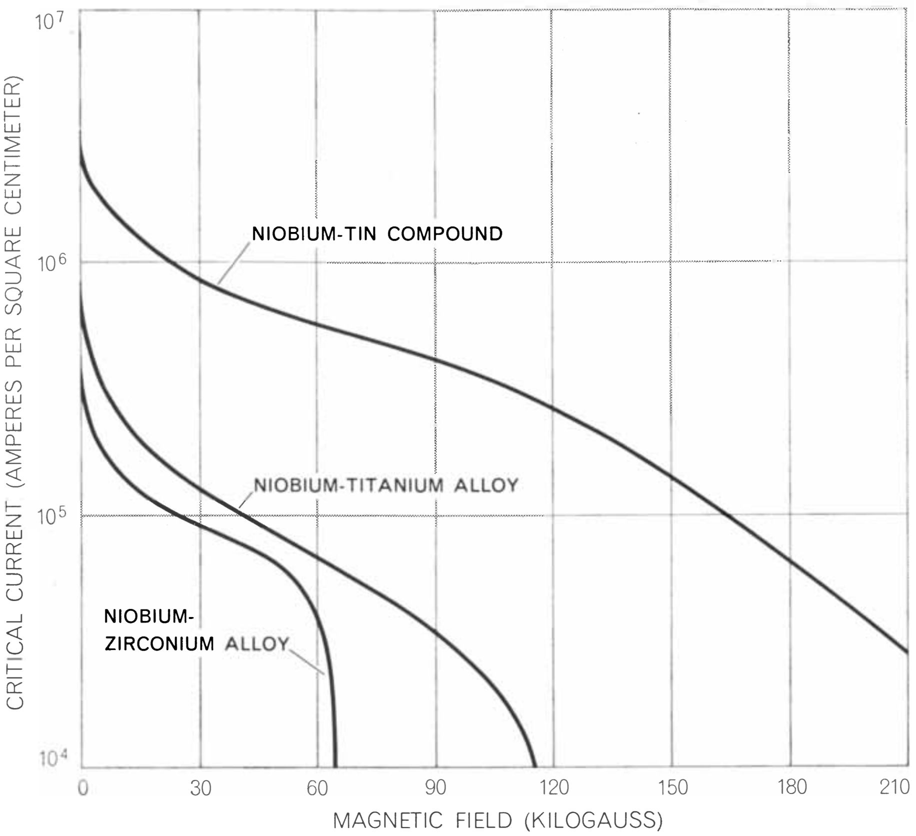


TWO TYPES OF SUPERCONDUCTOR can be distinguished by the way they behave in an external magnetic field (*arrows*). The Type I superconductor (*top*) totally excludes the magnetic field up to a certain point, called the critical field, whereupon the sample suddenly loses all trace of superconductivity and the field penetrates fully into the interior of the material (*top center*). The Type II superconductor (*bottom*), predicted on theoretical grounds in 1957, excludes the magnetic field only until some *lower* critical field is reached, at which point partial field penetration takes place (*bottom center*). Beyond a second, *upper* critical field penetration is complete and the sample loses superconductivity (*bottom right*). The drawings represent portions of a theoretically infinite cylinder.

tance varies slightly from one superconductor to the next and is known as the characteristic penetration depth of the material. A comprehensive microscopic theory of the superconducting state, in which the observable properties are explained in terms of the coherent movement of pairs of electrons over macroscopic distances, was put forward in 1957 by John Bardeen, L. N. Cooper and J. R. Schrieffer of the University of Illinois.

The exclusion of a magnetic field from a superconducting material (the Meissner effect) constituted the first serious obstacle to the operation of high-field superconducting magnets: beyond a certain point a magnetic field tends to penetrate the superconducting material and destroy its superconductivity. As early as 1930, however, the Dutch investigators W. J. de Haas and J. Voogd discovered that some alloys of lead and bismuth retain a trace of superconductivity in magnetic fields higher than 20,000 gauss. This finding led to several unsuccessful attempts to fabricate superconducting magnets in the early 1930's. It was not until 1955, however, that G. B. Yntema, then at the University of Illinois, succeeded in operating an 8,000-gauss superconducting magnet made of niobium wire wrapped around an iron core. Shortly thereafter workers at the Westinghouse Research Laboratories built the first successful air-core superconducting magnet. In 1960 a small air-core superconducting magnet designed for use in a solid-state maser was built by Stanley A. Autler, then at the Lincoln Laboratory of the Massachusetts Institute of Technology.

It was Autler's magnet that apparently stimulated the widespread interest in the practical applications of superconducting magnets. An intensive effort was begun to discover new superconducting alloys that would be capable of sustaining much higher magnetic fields than were possible with pure niobium. Several such alloys were discovered during the early 1960's by workers at the Bell Telephone Laboratories. The stage was set for the decisive technical achievements of the past few years.



CURRENT V. FIELD CURVES indicate the maximum current density that a short sample of a superconducting material will carry as a function of an applied magnetic field. The curves shown here represent the three most commonly used superconducting materials.

All the known bulk superconductors can now be divided into two categories, called Type I superconductors and Type II superconductors. The two types are distinguished from each other by the way they behave in an external magnetic field [*see bottom illustration on opposite page*]. In the case of a Type I superconductor the magnetic field is totally excluded from the interior of the superconductor up to a certain point, known as the critical field, whereupon the sample suddenly loses all trace of superconductivity and the magnetic field penetrates fully into the interior of the sample. This transition is reversible: when the external field is reduced below the critical field, the field is again expelled from the sample and the sample reenters the superconducting state. For Type I superconductors the highest known critical fields are only on the order of 1,000 gauss, making these materials unsuitable for use in high-field superconducting magnets.

In a Type II superconductor, on the other hand, something quite different happens. The external field is excluded until some *lower* critical field is reached, at which point partial field penetration occurs. The penetration increases until a second, *upper* critical field is reached, at which point penetration is complete and the sample loses all trace of superconductivity.

The existence of Type II superconductors was predicted in 1957 by the Russian physicist A. A. Abrikosov, who had extended earlier theoretical work by V. L. Ginzburg and L. D. Landau. Evidence derived from extensions of Abrikosov's work suggests that certain Type II superconductors may have upper critical fields as high as 300,000 gauss. As new Type II alloys are developed there is every reason to suppose that superconducting magnets capable of producing fields approaching this value will be built in the next few years.

The essential difference between the two types of superconducting material can be stated in terms of the relative values of two factors: field-penetration depth and coherence distance. The penetration depth, as we have mentioned, is the distance into a superconductor to which a small external field penetrates, typically about a hundred-thousandth of a centimeter. The specific distance depends on the number of superconducting electrons available in the material. The coherence distance can be regarded as the smallest distance over which the number of superconducting electrons can change. This distance is typically about a ten-thousandth of a centimeter in a very pure Type I superconductor; it decreases rapidly as the materials are made less pure. When the ratio of the penetration depth to the coherence distance is small, it is energetically unfavorable for an external magnetic field to penetrate the superconductor. When the ratio exceeds a certain value ($1/\sqrt{2}$), the energy balance changes; for fields stronger than the lower critical field of a Type II superconductor this leads to partial field penetration accompanied by the division of the superconductor into high-field regions and low-field regions.

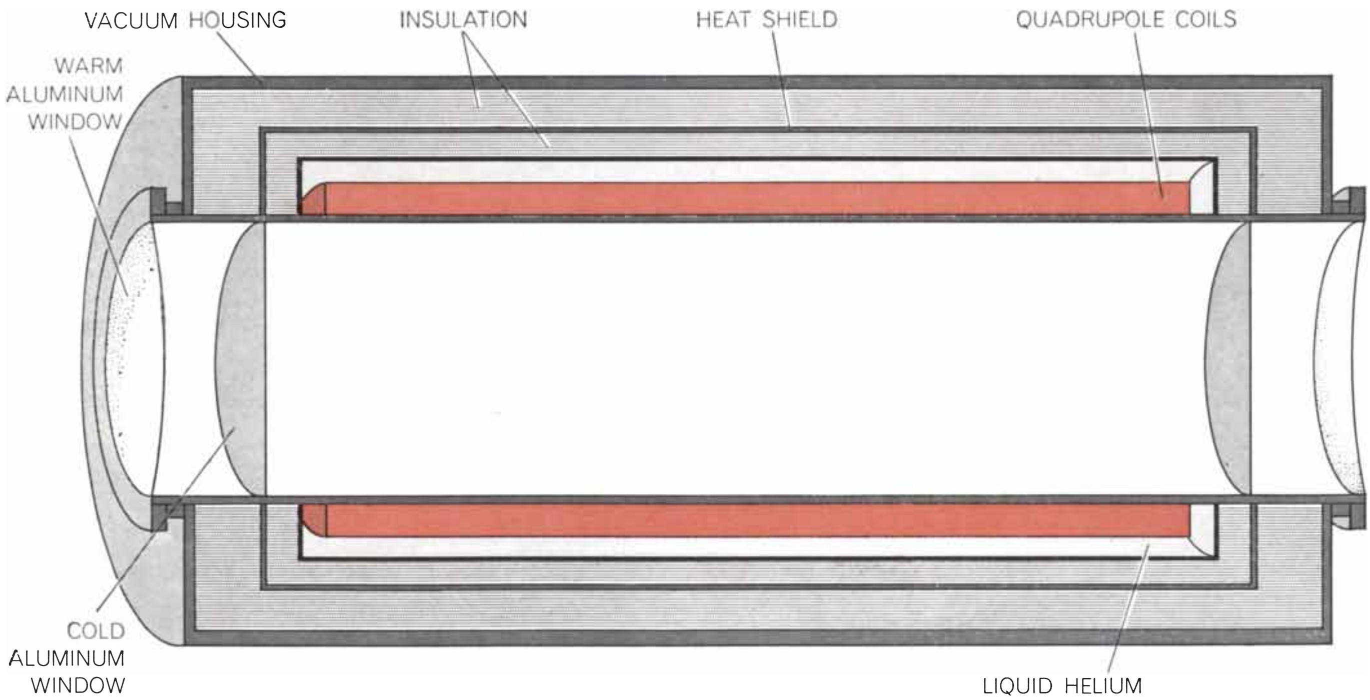
Abrikosov's solution of the problem of field penetration showed that penetration could be expected to occur in discrete units of magnetic flux called flux quanta. He estimated the strength of each of these units to be two ten-millionths of a gauss per square centimeter. Experiments designed to search for such flux quantization have since verified that the flux quantum is indeed two ten-millionths of a gauss per square centimeter. Inside a Type II superconductor the flux quanta form an array of high-field regions embedded in a nonmagnetic, superconducting matrix. The presence of such a lattice of flux lines was confirmed in 1964 by experiments performed at the Center for Nuclear Studies at Saclay in France. Workers there used the flux lattice as a diffraction grating for scattering a beam of slow neutrons. The spatial arrangement of the flux lines could be inferred from the angular distribution of the scattered neutrons.

A further consequence of Abrikosov's calculations is the prediction that the upper critical field of a Type II superconductor will be proportional to the ratio of the field-penetration depth to the coherence distance. Since this ratio is increased by using impure materials, it is apparent that the superconducting alloys best suited for a magnet will be those whose electrons have a short mean free path, which indicates that they will be alloys with a large number of scattering centers and hence a rather high electrical resistance in the normal, nonsuperconducting state.

This picture of Type II superconductors unfortunately has certain limitations, the most important of which is that the idealized Type II superconductor described by Abrikosov's theory has no surface and therefore is not able to carry an electric current without resistance. This conclusion arises from the fact that the force exerted on the unconfined flux lines by a current can cause the lines to move, thereby generating a voltage and hence a resistance. Several suggestions have been made to circumvent this difficulty and to modify Abrikosov's theory so as to describe real Type II superconductors. The most promising approach has been developed by workers at the Bell Laboratories and the General Electric Research Laboratory; it is based on the idea that in a Type II superconductor capable of carrying a large current the quantized flux lines cluster together to form microscopic "flux bundles." These bundles are "pinned" to definite sites in the superconductor by impurities and defects and can therefore withstand the forces exerted by a current flowing through the material. As the current is increased the forces on the flux bundles grow, until eventually the bundles begin to "jump" over the pinning barriers. This process, known as "flux-jumping," produces localized heating, which lowers the pinning barriers and may lead to a runaway process capable of destroying the sample's superconductivity. In designing superconducting magnets a number of techniques have been developed to minimize the effect of flux-jumping. In general it has been found that materials that have been mechanically worked, and hence have more defects in their crystal lattices to serve as pinning sites, can sustain higher critical currents than unworked materials can.

Having outlined some of the characteristics required of any superconductor for service in a high-field superconducting magnet, we shall now discuss a few of the materials that have been found to possess these characteristics. To date only three such materials are commercially available: an intermetallic compound of niobium and tin (Nb_3Sn) and two metallic alloys, niobium-zirconium (Nb-Zr) and niobium-titanium (Nb-Ti).

The usefulness of a particular superconducting material depends on a number of factors. The temperature at which a material becomes superconducting (known as the transition temperature) must be appreciably higher than the temperature of liquid helium (4.2 degrees Kelvin, or degrees centigrade above absolute zero), so that maintain-

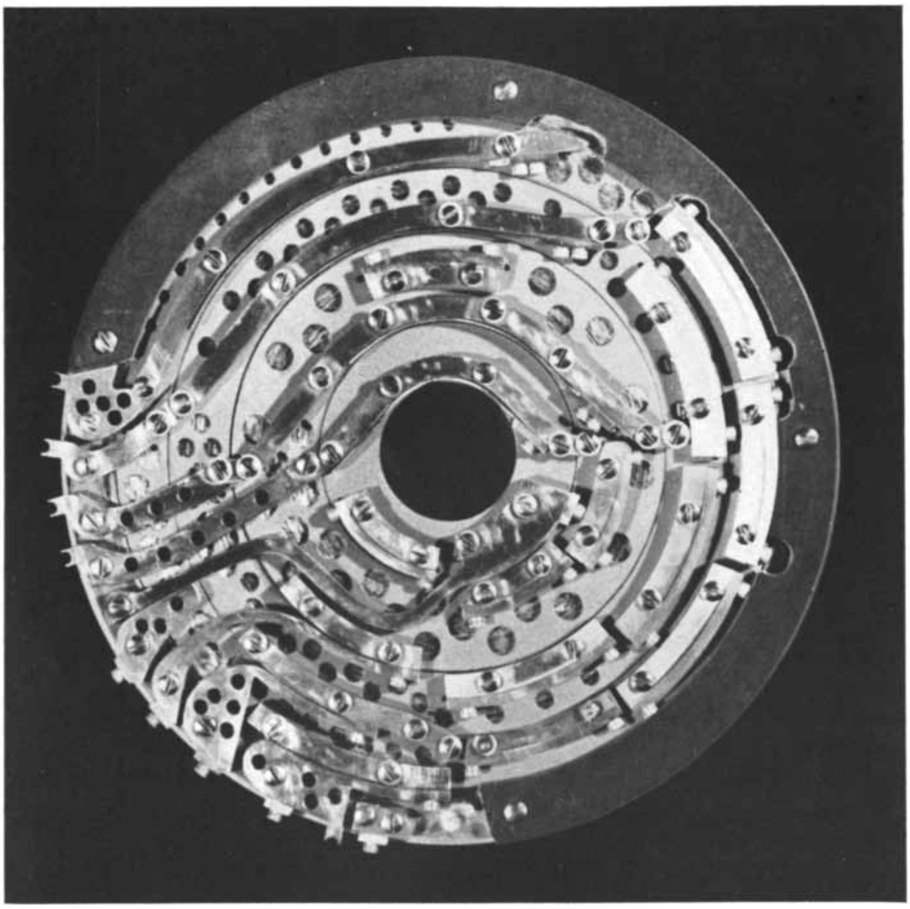


PROTON-FOCUSING MAGNET IS COOLED by installing it in a Dewar, an insulating vessel that contains liquid helium at 4.2 degrees Kelvin (degrees centigrade above absolute zero). The foil windows reduce the flow of radiant energy into the cold bore.

ing the sample in the superconducting state is not too difficult. The material must also be capable of carrying large currents in the presence of a high magnetic field, and it must be at least reasonably easy to fabricate into magnet coils.

The relation of current to magnetic field in a particular superconductor is usually represented by a curve that shows the maximum current density a short sample of the material will carry as a function of an externally applied magnetic field. Typical curves for the three most common superconducting materials—niobium-tin, niobium-zirconium and niobium-titanium—are given in the illustration on page 117.

The highest field at which any trace of superconductivity remains is an intrinsic property of the material and does not depend on the method of fabrication to any great extent. The critical current, however, depends markedly on the metallurgical procedures used to make the material, particularly on the method of heat treatment. For this reason there is a large spread in the current v. field curves for any given superconductor. The niobium-zirconium alloys provide rather large current densities up to fields of about 60,000 gauss. The niobium-titanium alloys are useful to about 90,000 gauss, whereas with niobium-tin it should be possible to achieve fields approaching 200,000 gauss.



FOUR CONCENTRIC COILS are employed to generate the field inside the bore of this superconducting magnet, used at Brookhaven to measure the gyromagnetic ratio of the negative xi particle (Ξ^-). The four sections can be powered separately to produce a maximum field of 125,000 gauss. Short-circuiting switches that allow the magnet to operate without power once the field is established are housed in the insulating ring around the magnet.

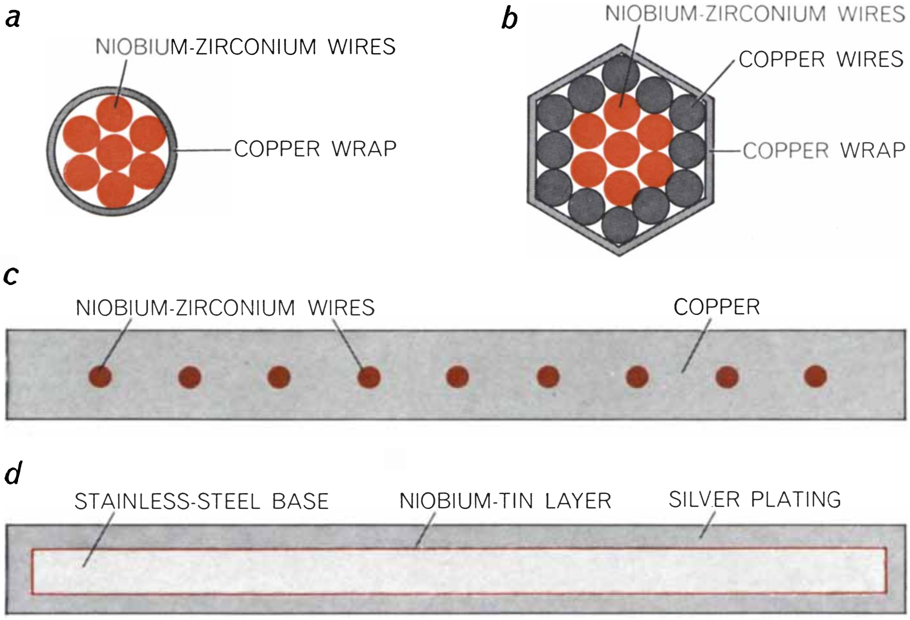
Because niobium-tin permits such high fields as well as larger current densities at low fields, it would appear that this material is the obvious choice for all magnet applications. The current v. field curves, however, fail to take into account problems of fabrication and the cost of materials. Niobium-zirconium and niobium-titanium are strong ductile alloys that can be easily fabricated. Niobium-tin, on the other hand, is an exceedingly brittle compound and requires highly specialized fabrication techniques. Recent advances in those techniques have made niobium-tin competitive throughout the range of magnetic fields, and it is expected that further reductions in cost arising from mass production will eventually lead to the use of niobium-tin for almost all applications.

A number of promising techniques have been developed for producing niobium-tin magnet coils. In some of these techniques the intermetallic compound is actually formed after the coil has been wound, when the entire magnet is heat-treated. This procedure, however, generally results in a magnet that cannot be unwound if some part should fail. Another technique allows the conductor to be flexed in its superconducting form by the stratagem of coating a thin metallic ribbon with an extremely thin layer of niobium-tin. The thinness of the niobium-tin allows it to be bent around a diameter of less than an inch without damage.

In either case a large fraction of the cross-sectional area in a niobium-tin magnet is devoted to inert material. As a result the overall packing of the magnet is comparatively poor: only about 15 percent of the total cross-sectional area of a typical niobium-tin magnet is superconducting. Nevertheless, because of the large current-carrying ability of niobium-tin, the average current density in a niobium-tin coil can be considerably higher than the maximum current density attainable with coils made of the two alloy superconductors, even at lower fields.

Given the appropriate current v. field curves and an adequate supply of superconducting wire, it would appear a trivial matter to proceed to wind a solenoid, or helical coil magnet, capable of producing any desired magnetic field up to the critical field of the wire. Unfortunately things are not so simple, and several new difficulties appear at this stage. The main problem can be summarized by the term "current degradation," which means that the current in a solenoid is considerably less than what is expected from measurements of short pieces of wire. At first current degradation was blamed on flaws in the wire, but it soon became apparent that the effect was more fundamental. Coils made from niobium-zirconium alloys, for example, often show an effect known as "training," in which the critical current of the coil increases each time the coil is "quenched" (that is, returned to the nonsuperconducting state). At a certain maximum current, which is still much less than the critical current of a short piece of wire, an additional quenching may cause the coil to revert to a lower critical current and begin the cycle again.

This difficulty is compounded by the fact that the magnetic field produced by a superconducting solenoid does not always stay in direct proportion to the



COMPOSITE SUPERCONDUCTORS commonly used in winding high-field magnets are shown in cross section. In each case the superconducting material is in color. The two cables (*a*, *b*) are composed of wires a hundredth of an inch thick. The two ribbons (*c*, *d*) are about half an inch wide and four-hundredths of an inch thick. They are not drawn to scale.

current flowing through the coil. As we have mentioned, the flux bundles sometimes jump abruptly. These local discontinuities in field strength are intimately related to current degradation. Flux jumps represent energy that is deposited in the coil, a process that can raise the temperature of a local region above the transition temperature of the superconductor. The renewed electrical resistance of this region causes additional heating, which in turn can trigger a quenching of the entire solenoid.

Another problem encountered in designing a superconducting magnet is how to dissipate the energy of the magnetic field when the coil is quenched. This energy must either be distributed evenly throughout the volume of the solenoid in order to prevent local "hot spots" or, if possible, be released outside the Dewar, or cooling vessel, by means of a protective circuit. It is interesting to note in this respect that the energy stored in a superconducting magnet can be very large indeed, and that this energy can be liberated quickly by breaking the superconducting circuit. A superconducting magnet is an efficient energy-storing device, comparable to a bank of electrical capacitors or a flywheel.

In brief, the magnet designer is faced with two basic problems: first, to fabricate a coil that approaches as nearly as possible the theoretical maximum field that can be obtained for the particular geometry and superconductor used, and second, to build a device that can be cycled repeatedly without being permanently damaged. One technique that enables current degradation to be partially overcome depends on a concept known as "field stabilization." It has been known for some time that if a superconducting solenoid is placed in an external applied field, the critical current can be raised to a value higher than the value obtained in the absence of the external field. As the applied field is increased, the current in the solenoid will also increase until it reaches the theoretical maximum value for the solenoid's field plus the applied field.

To take advantage of this situation a solenoid can be built in two or more concentric sections, and the outer sections can be used to apply a "stabilizing" field to the inner sections. This method of construction results in only the outer sections of the compound coil's operating at the degraded current. It has the additional advantage that for very-high-field coils, where the critical current in a short piece of wire may be lower than the degraded current, only the center, or high-field, sections have to be operated at this low current, allowing the outer sections to be used more efficiently. The disadvantages of such a system are the added complexity of the energizing procedure and the need for several power supplies.

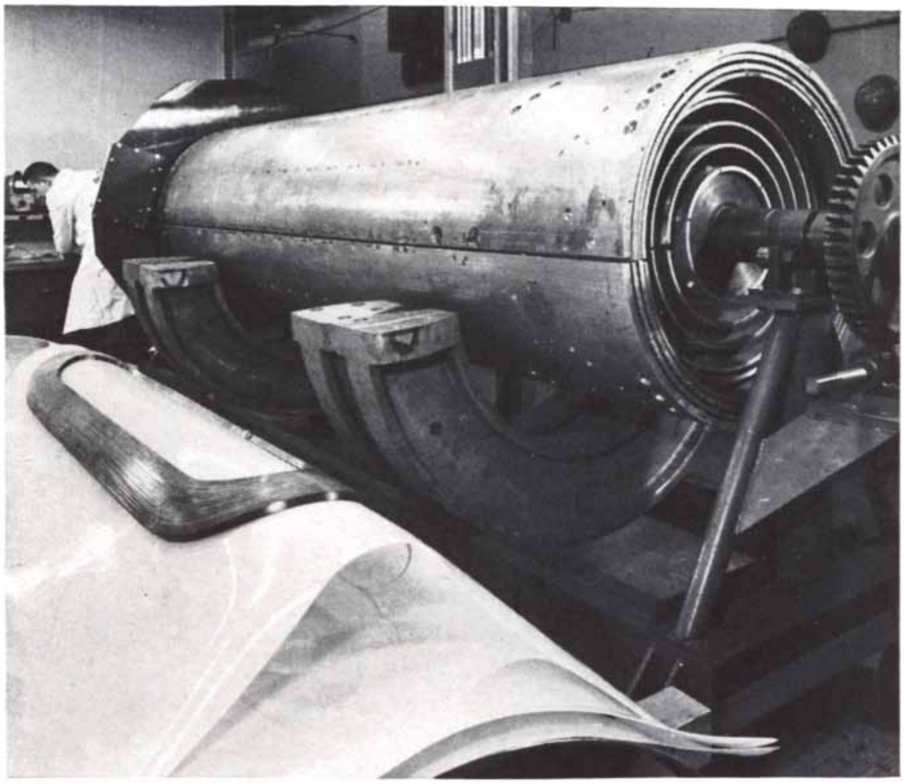
For very large coils, in which the problem of current degradation is most severe, an interesting solution has been devised by Charles Laverick of the Argonne National Laboratory. By placing a number of small niobium-zirconium wires together and coating the resulting cable with a good conductor such as indium, he has produced a very strong high-current conductor that has been used to wind a solenoid magnet capable of producing 45,000 gauss in a bore of 11 inches. The indium coating reduces the effect of flux jumps, thereby minimizing current degradation, and also provides shunting paths to prevent high voltages from developing when the magnet quenches. Z. J. J. Stekly and A. R. Kantrowitz of the Avco Everett Research Laboratory have carried this technique one step further. By providing enough normally conducting material around the superconductor the local temperature can be prevented from exceeding the transition temperature of the superconductor. Such a coil does not quench when the magnet current exceeds the critical current; instead a small voltage, created by the resistance of the shunting material around the superconductor in the highest field region, which quenches first, appears across the coil when the critical current is exceeded. In operation the current in the magnet is increased until a small voltage is observed across its terminals, and then the current is reduced until this voltage disappears. The disadvantage of this type of stabilization is the very poor ratio of superconductor to normal material, which makes the technique applicable only to magnets with large bores.

At Brookhaven we have recently discovered another type of stabilization that works well with niobium-tin ribbon. By pumping the liquid helium surrounding the magnet the temperature can be reduced below 2.18 degrees K., whereupon the helium goes into a "superfluid" phase. In the superfluid state the effective thermal conductivity of liquid helium can be 10,000 times as large as copper and its viscosity very small, enabling the helium to flow into confined spaces. These properties doubtless account for the fact that in superfluid helium the performance of solenoids is considerably improved. This is particularly true of solenoids in which superconductivity is degraded, but a substantial increase can be gained even for magnets that operate at the maximum current of a short piece of wire at 4.2 degrees K. In one case we have used this technique to increase the maximum field of a solenoid from 86,000 gauss at 4.2 degrees K. to 98,000 gauss at 1.3 degrees K. The effect of flux-jumping is also reduced when the magnet is operated in superfluid helium.

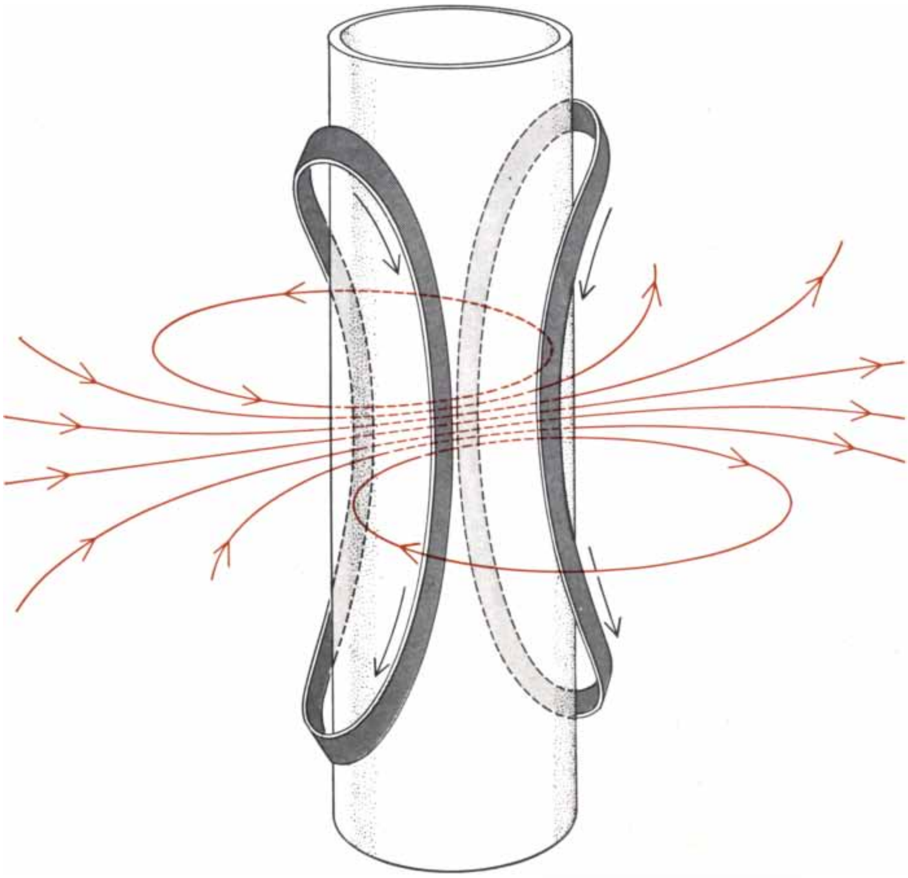
Since superconductors have no resistance and do not consume power, if the terminals of a superconducting solenoid are short-circuited by another superconductor, the current in the coil, once established, will flow indefinitely and the magnetic field will remain absolutely stable. In order to establish the initial current, however, the superconducting short circuit must be capable of being switched off. The switching action is usully accomplished by providing a section of superconducting wire between the solenoid terminals with a heater. To energize the solenoid the heater is turned on, raising the temperature of the section of short-circuiting wire above the transition temperature, so that the wire is no longer superconducting. The solenoid current is then raised to the desired value, the heater is switched off and the power-supply current is reduced to zero, leaving the current to circulate endlessly through the solenoid and switch.

The fields that can be achieved with superconducting magnets are rapidly increasing in strength. To date fields as high as 140,000 gauss have been produced, and there is every reason to expect fields of from 150,000 to 175,000 gauss within a few months. Because the stress exerted by the magnetic field on the wire in the magnet increases as the square of the field, it becomes important at the higher fields to consider the mechanical strength of the materials that go into the magnet. In a 50,000-gauss magnet used at Brookhaven for neutron-scattering experiments, in which the neutrons must enter and leave the magnet at right angles to the field, the magnet is split into two sections; these must be held apart by materials that do not unduly attenuate the neutron beam and yet are sufficiently strong to withstand the force of about five tons acting to pull the magnet sections together.

Much effort has been expended in recent years to produce special types of magnets. For example, by building long solenoids equipped with corrective windings it has proved possible to produce fields as high as 60,000 gauss that vary in strength only a few parts per million across a volume of more than a cubic inch. A field of such high homogeneity is valuable in studies of nuclear magnetic resonance, in which the strength of the resonant signal depends critically on the uniformity of the field. A disadvantage of superconducting magnets for such applications lies in the slight residual fields of a few percent of the maximum field that remain after the magnet has been



WORLD'S LARGEST SUPERCONDUCTING MAGNET is shown being assembled at the Avco Everett Research Laboratory. The eight-ton magnet generates a 40,000-gauss magnetic field in a space five feet long and a foot in diameter. It is capable of storing five million joules of energy, or the equivalent of nine sticks of dynamite. The magnet is a working model of a type designed to be used in a large-scale magnetohydrodynamic power generator. Its windings consist of 20 saddle-shaped coils similar to the one visible in the foreground.



SADDLE-SHAPED COILS employed in the magnet shown at the top of the page set up a field that is perpendicular to the axis of the bore. Only two simplified windings are shown.

turned off. This residual flux disappears, of course, when the magnet is heated above its superconducting transition temperature.

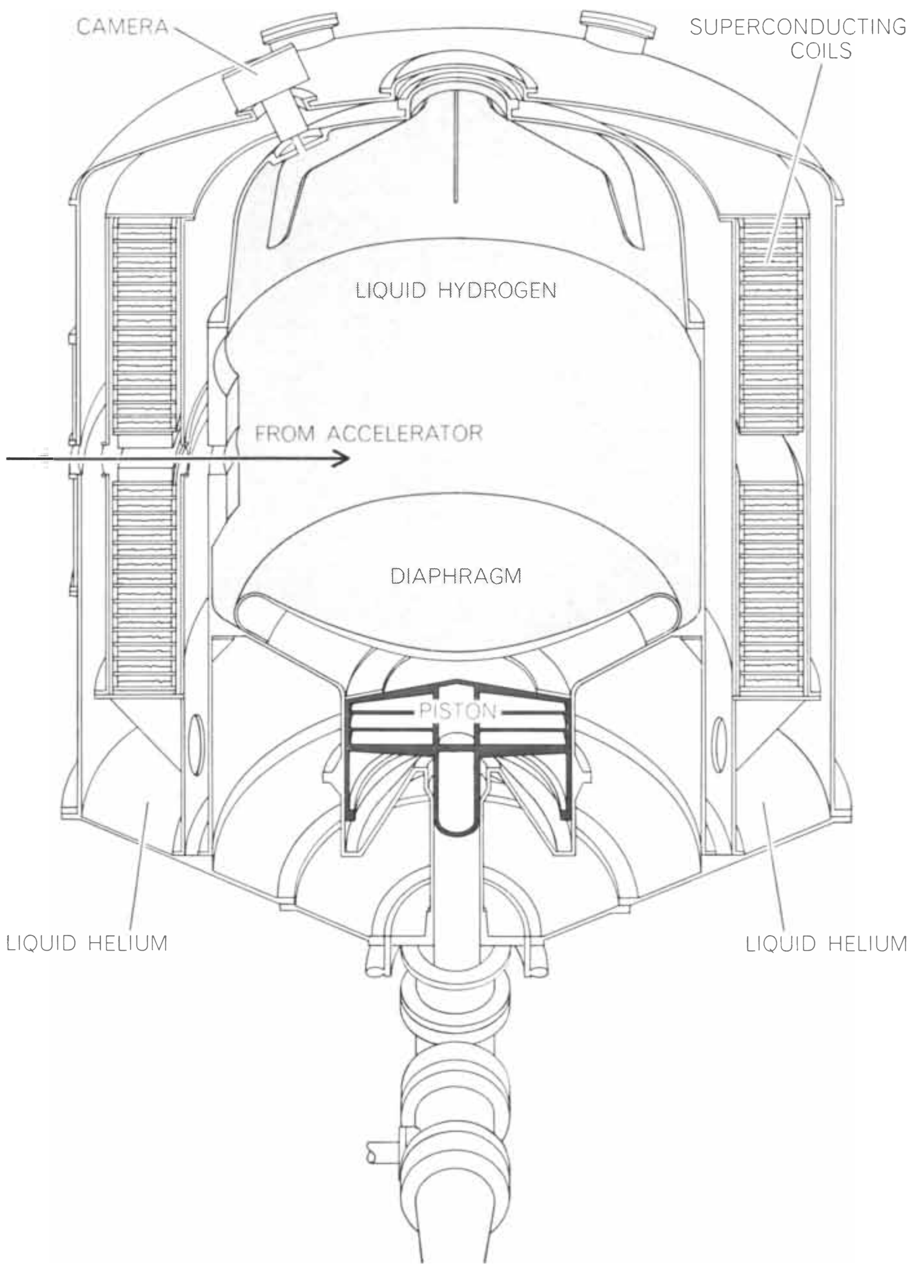
For certain applications uniformity of field is not significant, but it is important that the distance from the high-field region to the outside of the helium Dewar be minimized. This requirement is of special importance in studies utilizing the Mössbauer effect, now a standard approach to many problems in solid-state and nuclear physics. The ability of superconducting magnets to provide large fields in small devices reduces the size of the radioactive source required for such studies, thus making possible certain experiments that would otherwise not be feasible. In an apparatus being used in the laboratory of one of the authors (Craig) the distance from the experimental region containing a 60,000-gauss field to a radiation detector is less than two inches. This is about a fifth of the distance attainable with conventional magnets.

Recently superconducting magnets have begun to play an increasingly important role in high-energy physics. One of the most obvious applications is in liquid-hydrogen bubble chambers, in which the liquid-helium system required for the superconducting coils can be partially incorporated in the existing cooling apparatus of the chamber. Chambers as large as 14 feet in diameter are in the design stage, and it is probable that they will employ superconducting magnets with an inside diameter as large as 16 feet and an energy-storage capacity as high as 10^9 joules.

The bending and focusing magnets used to direct the beam produced by a particle accelerator to an experiment require enormous amounts of power. At the Brookhaven alternating-gradient synchrotron considerably more power is consumed by the beam-handling apparatus than by the synchrotron itself! Studies are in progress aimed at producing superconducting versions of these magnets. The higher fields and field gradients that can be achieved with the superconducting magnets will make it possible to analyze and focus the beams in much shorter distances than had previously been feasible, a fact of considerable importance where short-lived particles are involved. The model superconducting quadrupole focusing magnet shown on page 114 produces a field gradient approximately five times as high as those obtained with a conventional magnet. Ultimately we expect that superconducting magnets will be used in the operation of the accelerator itself. By bending the paths of the charged particles in tighter circles, high-field superconducting magnets may help to reduce the size of future accelerators.

There are also specific experiments in high-energy physics in which superconducting magnets can be used to good advantage. We have built a superconducting solenoid that is being employed at Brookhaven in an experiment to measure the gyromagnetic ratio of the negative xi particle (Ξ^-). The purpose of the magnet is to produce the largest product of field times distance along the flight path of the particles. A superconducting magnet was used because it would have been impossible to produce the required direct-current field by any other means in the very small space available. The magnet is constructed in four concentric sections and produces a maximum field of 125,000 gauss.

Up to this point we have confined our discussion to applications of high-field superconductors that are either under development or are known to be feasible on the basis of present knowledge. Because of the rapid progress in this field it is worth mentioning a few of the more speculative possibilities. Perhaps the most exciting area for



PROPOSED BUBBLE CHAMBER designed for use at the Brookhaven synchrotron will incorporate large superconducting magnetic coils with an inside diameter of 16 feet. The liquid-helium cooling system required for the superconducting coils could be integrated with the system already required to prepare the liquid hydrogen for the chamber. The large diaphragm at the bottom of the chamber is designed to reduce the pressure suddenly in the chamber, so that the incoming particles can produce bubbles in the liquid hydrogen.

possible future applications of this new technology is space research. Studies in this area have been pioneered by a group at Avco. They have considered in detail the problem of energy storage and conclude that there exists a fundamental relation between the energy that can be stored in a magnetic field and the weight of the structure required to support the magnetic forces. This relation states that the minimum magnet weight equals the energy stored in the field times the density of the magnet material divided by the tensile strength of the material. Under favorable conditions a magnetic energy-storage device for use in outer space could be about 10 percent as efficient a storage device as TNT. In a magnet, however, the stored energy can be converted directly into electrical energy rapidly and with high efficiency.

Another space application with even more promise is magnetic radiation shielding. One of the most severe problems that will arise on long missions in outer space is that of protecting the crew from the intense flux of high-energy particles produced by solar flares. The conventional solution to this problem calls for massive armor plating. A much more promising approach is to deflect the charged particles away from the space vehicle by charging the vehicle to a high electrical potential. This can be accomplished by surrounding the vehicle with a cloud of electrons moving in a magnetic field strong enough to keep the electron orbits close to the space vehicle. Calculations by the group at Avco show that by using superconducting magnets such shielding can be achieved with a weight saving of a factor of 20 over conventional shielding.

A final area of space research in which superconductors might be used is in the reentry of a space vehicle into the earth's atmosphere. A large magnetic field could produce hydromagnetic drag in the cloud of ionized air the vehicle produces as it enters the atmosphere. With hydromagnetic braking the kinetic energy of the vehicle would be absorbed through the magnetic field rather than through heating of the vehicle itself, with the result that the total weight required to protect the vehicle from overheating and destruction could be markedly reduced.

In any case, it is already clear that superconducting magnets are competitive with even the most sophisticated alternative techniques for producing strong, stable magnetic fields, and that for many experimental purposes they offer unique advantages.

MATHEMATICAL GAMES

An array of problems that can be solved with elementary mathematical techniques

by Martin Gardner

Only an elementary knowledge of mathematics is needed for solving any of the following problems. We begin with a collection of a dozen "quickies" and close with a combinatorial problem that is the most difficult of the lot. The answers will be given next month.

1.

1. The square root of any number n is always smaller than n. True or false?

2. Why are 1963 pennies worth almost $20?

3. In the sequence of integers 1, 2, 3, 4... are there two prime numbers separated by exactly 10 composite (nonprime) numbers? (Supplied by Edwin M. McMillan.)

4. Alan W. Wolff of Sacramento, Calif., writes (I quote from a letter): "I am the only registered civil engineer in the state of California who has a twin brother who is also a registered civil engineer in California." Explain.

5. How many outs are there in one inning of baseball?

6. Volume I, two inches thick, stands on a shelf to the left of Volume II, which is an inch and a half thick. These dimensions include the covers, which are an eighth of an inch thick. A tiny worm starts on the first page of Volume I and eats his way horizontally until he reaches the last page of Volume II. How far does he go?

7. Without doing the multiplication, prove that $1234567890^2 - (1234567889 \times 123456791) = 1$. (Contributed by Stephen Barr.)

8. Does a tetrahedron have four or five faces? Answer yes or no.

9. Write the digits 9 to 1 in order, backward.

10. The integers 1, 3, 8 and 120 form a set with a remarkable property: the product of any two integers is one less than a perfect square. Find a fifth number that can be added to the set without destroying this property.

11. A telephone call interrupts a man after he has dealt about half of the cards in a bridge game. When he returns to the table, no one can remember where he had dealt the last card. Without learning the number of cards in any of the four partly dealt hands, or the number of cards yet to be dealt, how can he continue to deal accurately, everyone getting exactly the same cards he would have had if the deal had not been interrupted?

12. What four-letter word ends in "eny"?

2.

A college girl has the unusual palindromic name Nora Lil Aron. Her boyfriend, a mathematics major, was bored one morning by a dull lecture and amused himself by trying to compose a good number cryptogram. He wrote his girl's name in the form of a simple multiplication problem:

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NORA
   L
----
ARON
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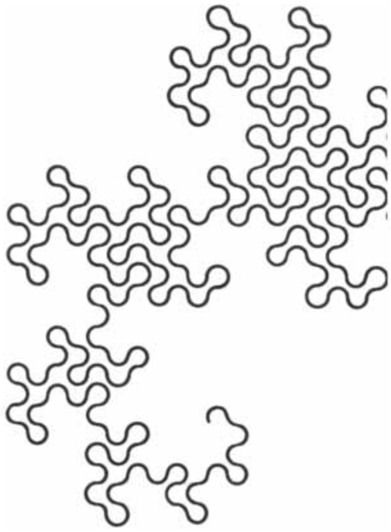
Was it possible to substitute one of the 10 digits for each letter and have a correct product? He was amazed to discover that it was, and also that there was a unique solution. The reader should have little trouble working it out. It is assumed that neither four-digit number begins with zero.

3.

A weird cover design decorated a booklet that William G. Harter, now a candidate for a doctorate in physics at the University of California at Irvine, prepared for a National Aeronautics and Space Administration seminar on group theory that he taught last summer at NASA's Lewis Research Center in Cleveland [*see illustration at right*]. The "dragon curve," as he calls it, was discovered by his NASA colleague, physicist John E. Heighway, and later analyzed by Harter, Heighway and Bruce A. Banks, another NASA physicist. The curve is not connected with group theory, but it was used by Harter to symbolize what he calls "the proliferation of cryptic structure that one finds in this discipline." It is drawn here as a fantastic path along the lattice lines of graph paper, with each right-angle turn rounded off to make it clear that the path never crosses itself. You will see that the curve vaguely resembles a sea dragon paddling to the left with clawed feet, his curved snout and coiled tail just above an imaginary waterline.

The reader is asked to find a simple



method of generating the dragon curve. Next month I shall explain three: one based on a sequence of binary digits, one on a way of folding paper and one on a geometric construction. It was the second procedure that led to the discovery of the curve. I shall also explain the significance of the 12 colored spots, which indicate that this is a dragon curve of order-12. They happen to lie on a logarithmic spiral, although this was not noticed until later and it plays no role in the construction of the curve.

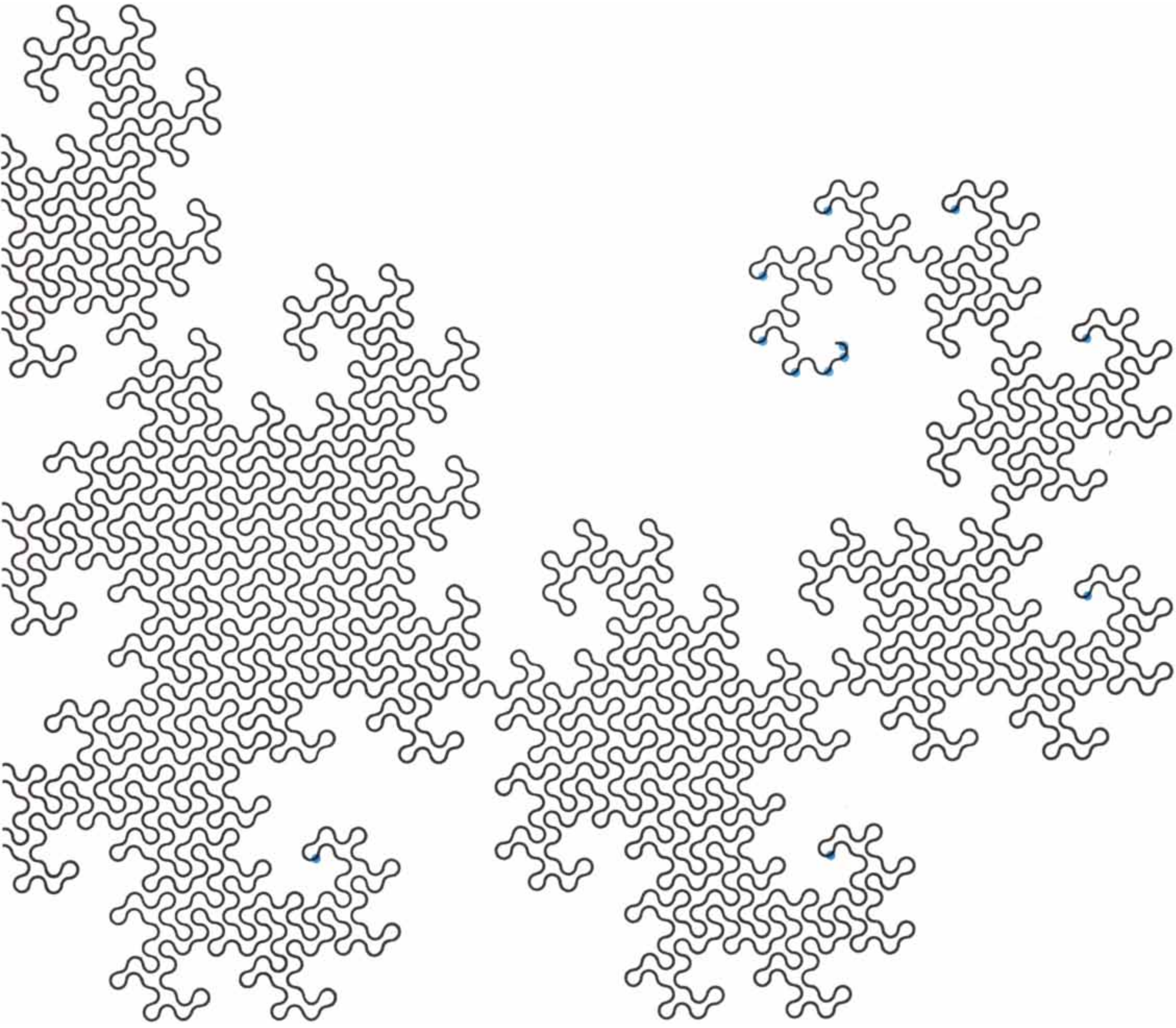
4.

Polyominoes are shapes formed by joining unit squares. A single square is a monomino, two squares are a domino, three can be combined to make two types of trominoes, four make five different tetrominoes, five make 12 pentominoes, and so on. I recently asked myself: What is the lowest order of polyomino four replicas of which can be placed so that every pair shares a common border segment? I believe, but cannot prove, that the octomino is the answer. Five solutions were found by John W. Harris of Santa Barbara, Calif. [*see illustration on next page*]. If each piece is regarded as a region on a map, each pattern clearly requires four colors to prevent two bordering regions from having the same color.

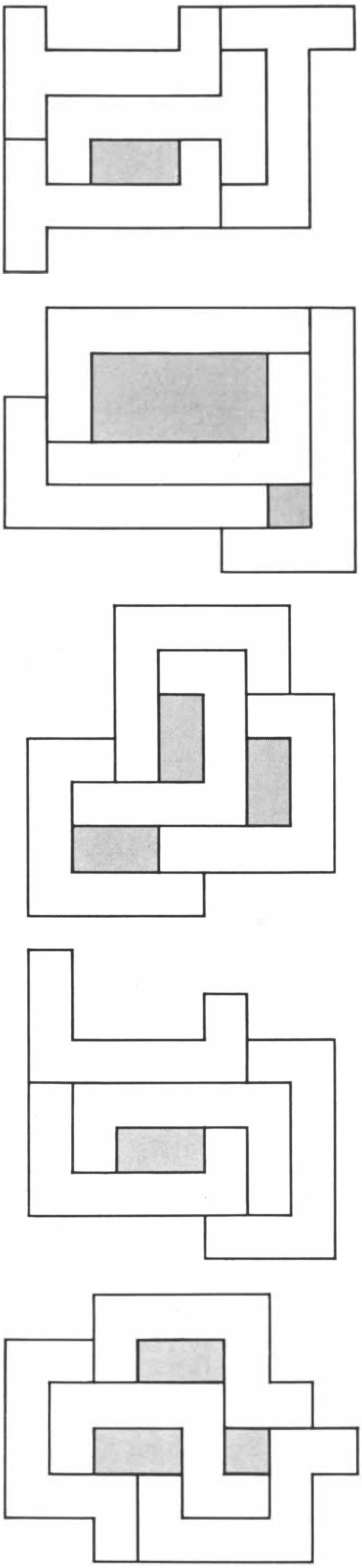
Let us now remove the restriction to four replicas and ask: What is the lowest order of polyomino any number of replicas of which will form a pattern that requires four colors? It is not necessary for any set of four to be mutually contiguous. It is only necessary that the replicas be placed so that, if each is given a color, four colors will be required to prevent two pieces of the same color from sharing a common border segment. Regions formed between the replicas are not considered part of the "map." They remain uncolored. The answer is a polyomino that is of much lower order than eight.

5.

An amusing double problem was given by D. Mollison of Trinity College, Cambridge, in a 1966 problems contest for



A "dragon curve" of the 12th order



John W. Harris' octomino arrangements

members of the Archimedeans, a Cambridge student mathematics society. The first question: What is the maximum number of points that can be placed on or within the figure shown on the opposite page, provided that no two points are separated by a distance that is less than the square root of 2? The second question: In how many different patterns can this maximum number of points be placed, not counting rotations and reflections of patterns as being different? The dotted lines were added to the figure to show that it is formed by a unit square surrounded by four half-squares.

6.

While your back is turned a friend places a penny, nickel and dime on the table. He arranges them in any pattern of heads and tails provided that the three coins are not all heads or all tails.

Your object is to give instructions, without seeing the coins, that will cause all three to be the same (all heads or all tails). For example, you may ask your friend to reverse the dime. He must then tell you whether you have succeeded in getting all the coins alike. If you have not, you again name a coin for him to turn. This procedure continues until he tells you that the three coins are the same.

Your probability of success on the first move is 1/3. If you adopt the best strategy, what is your probability of success in two moves or fewer? What is the smallest number of moves that guarantees success on or before the final move?

The reader should find those questions easy to answer, but now we complicate the game a bit. The situation is the same as before, only this time your intent is to make all the coins show heads. Any initial pattern except all heads is permitted. As before, you are told after each move whether or not you have succeeded. Assuming that you use the best strategy, what is the smallest number of moves that guarantees success? What is your probability of success in two moves or fewer, in three moves or fewer, and so on up to the final move at which the probability reaches 1 (certainty)?

7.

Ten soldiers, no two of them the same height, stand in a line. There are 10!, or 3,628,800, different ways the men can arrange themselves, but in every arrangement at least four soldiers will form a series of ascending or descending heights. If all but those four leave the line, the four will stand like a row of panpipes.

You can convince yourself of this by experimenting with 10 playing cards bearing values from ace to 10. The values represent the height order of the soldiers. No matter how you arrange the 10 cards in a row, it will always be possible to pick out at least four cards (there may, of course, be more) in ascending or descending order. Suppose, for instance, you arrange the cards in the following order: 5, 7, 9, 2, 1, 4, 10, 3, 8, 6. The set 5, 7, 9, 10 is in ascending order. Can you eliminate such a set by moving, say, the 10 to between the 7 and the 9? No, because you then create the set 10, 9, 8, 6, which is in *descending* order.

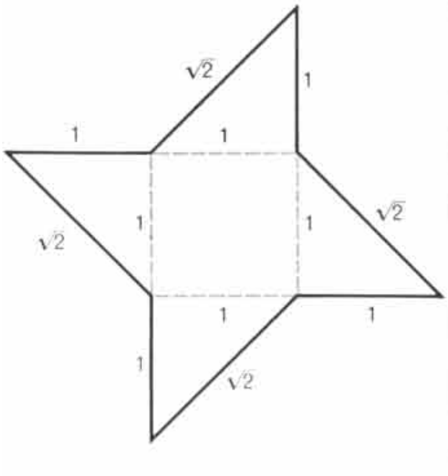
Let p (for panpipe) be the number of the largest set of soldiers that will always be found in order in a row of n soldiers of n different heights, no matter how they arrange themselves. The problem—and it is not easy—is to prove that if n equals 10, p equals 4. In doing so you are likely to discover the general rule by which the p number is easily computed for every n.

8.

Every square of a five-by-five chessboard is occupied by a knight. Is it possible for all 25 knights to move simultaneously in such a way that at the finish all cells are occupied as before? Each move must be a standard knight's move: two squares in one direction and one square at right angles.

Readers were asked last month to search for the winning move of the first player in a game of kayles, starting with the *Marienbad* pattern of four rows of one, three, five and seven objects. The only winning move is to take the center object from the row of five.

The string game, about which two problems were posed, is isomorphic with kayles! Allowing strings to have irrational lengths seems to complicate the game, but actually it does not, because any fraction over an integral length proves to be irrelevant and can be ignored. Consider a piece of string with a length of 6½ inches. Snipping one inch at a time from one end corresponds to removing one object at a time from the end of a row of six objects in kayles. The leftover fraction—in this case 1/2 inch—plays no role whatever in the game. Snipping an inch from inside the string, starting, say, 3/4 inch (or any fraction between 1/2 and 1) from the end, corresponds to removing two objects from the end of a row

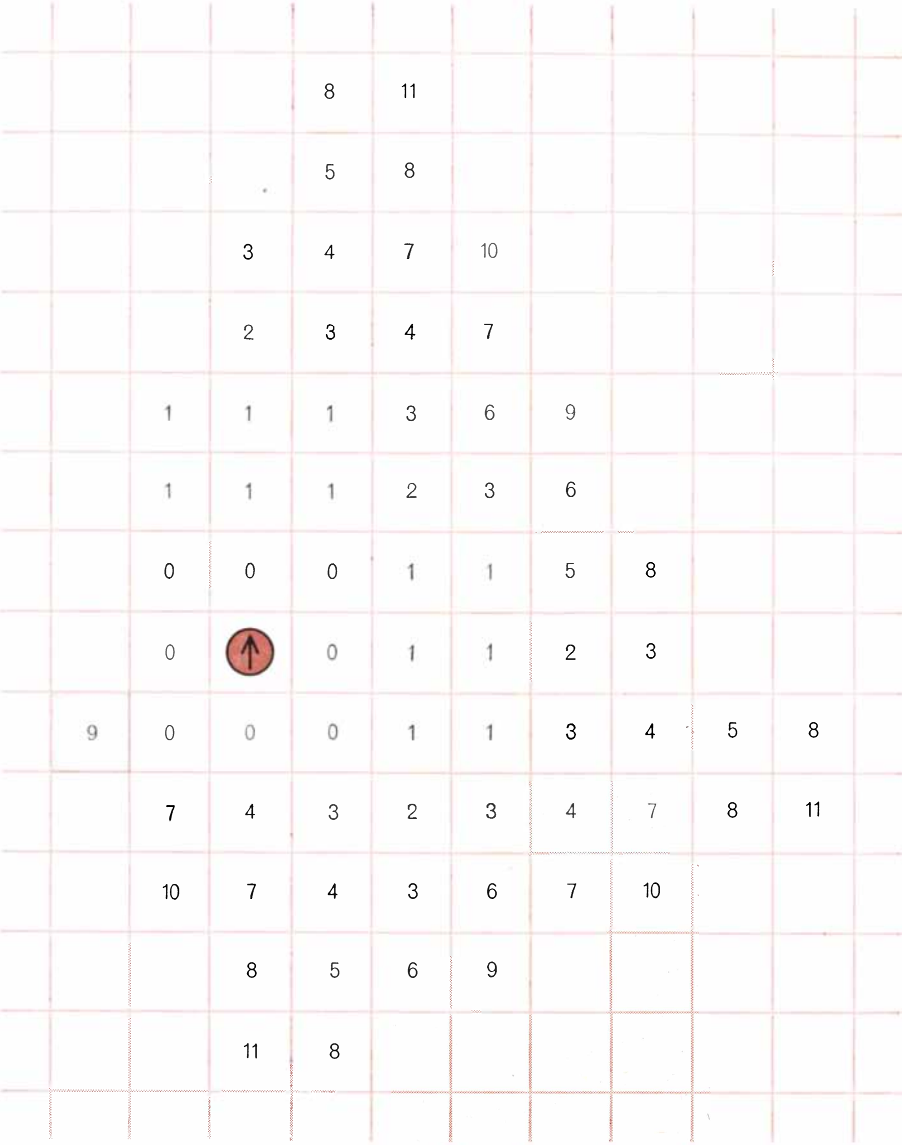


D. Mollison's problem

of six in kayles; the 3/4-inch piece obviously plays no further role in the game, and you are left with a piece of 4¾ inches, which is equivalent to a row of four in kayles. Snipping an inch from the interior of the 6½-inch piece, an integral number of inches from one end, corresponds to removing one object from the interior of a row of six objects in kayles. Snipping an interior inch that is an integral number of inches, plus a fraction between 1/2 and 1, from the end of the 6½-inch piece corresponds to removing two adjacent objects from inside a row of six in kayles. A little reflection and testing will soon convince you that every move in kayles has its counterpart in the string game and vice versa. Each piece of string corresponds to a row in kayles with a number of objects equal to the number of whole inches in the string.

Once the equivalence of the two games is recognized, last month's first question about the string game is immediately answered. If strings have lengths of 1, pi (3.14+), the square root of 30 (5.47+) and the square root of 50 (7.07+), the strings are equivalent to the *Marienbad* pattern of rows with one, three, five and seven objects. The first player can win, therefore, as explained: he snips an inch that is two inches from one end of the 5.47+ string, then continues with moves that correspond to the kayles strategy as outlined last month.

If the string game is played with any number of closed loops, each longer than two inches, the second player has an easy win. Whenever his opponent opens a loop by removing an inch from it, the second player simply removes an inch from the exact middle of the same string. This leaves two equal pieces. As in kayles, this is a safe pattern, for whatever his opponent does to one piece, the second player does to the other piece.



Solution to the "hamstrung squad car" game

Thus the pattern quickly becomes a set of pairs of duplicate strings, and therefore the second player is sure to get the last inch.

If the starting pattern includes one closed loop at least an inch long but no more than two inches long, the first player wins by taking an inch from it and then playing the strategy just described with the remaining pieces. It is easy to see that the first player wins if there are an odd number of such small loops and loses if there are an even number of loops.

The illustration above shows the area of fatal starting positions for the criminals' car in the "hamstrung squad car" game. The squad car starts at the position shown by the colored counter with the vector arrow. The criminals' car can be captured if it starts on any numbered square. The number on each square is the number of squad-car moves required for the capture if both sides play rationally. The illustration also answers last month's final question: Of the 10 starred starting positions that were shown for the criminals, the only fatal square is the one [*gray*] that is a knight's move left and down from the squad car. Nine squad-car moves effect the capture if both sides make their best moves.

For a simple procedure by which the positions and numbers of moves can be obtained the reader is referred to Rufus Isaacs' *Differential Games*, pages 56–62, in which the game is analyzed and from which the illustration of the answer is taken. I leave it to the reader to work out the strategies by which the squad car captures the criminals' car with the minimum number of moves and by which the criminals either delay their capture as long as possible or escape permanently if they start from an unnumbered square or if the police blunder.

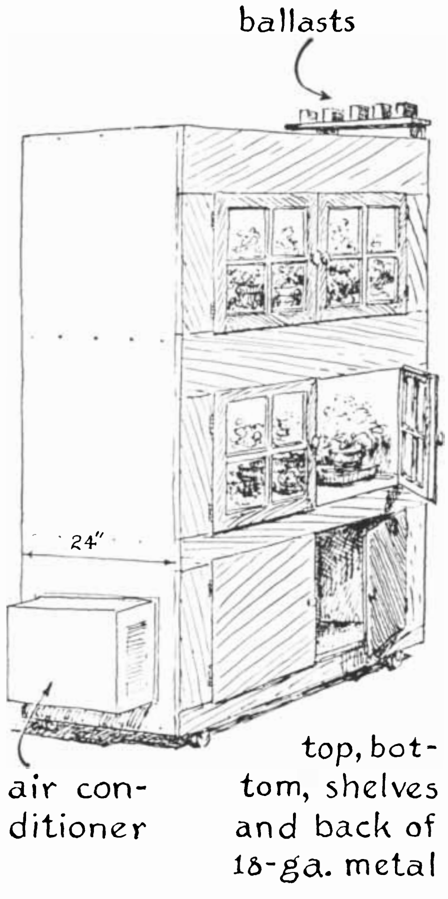
THE AMATEUR SCIENTIST

Two kinds of apparatus for growing plants in a controlled environment

Conducted by C. L. Stong

A miniature greenhouse with artificial sunshine and a controlled atmosphere can be built by the horticulturist for experiments with plants. The experimenter can regulate the color, intensity and duration of the light and the composition, temperature and humidity of the air. Hence he can rear plants under conditions that match those of almost any region of the earth in any season.

The miniature artificial greenhouse is simple and effective and so has found its way not only into the horticultural laboratory but also into the home of the city dweller who likes to raise unusual plants. One such person is Francis C. Hall, a lighting engineer who lives in an apartment at 222 Henry Street, Brooklyn, N.Y. 11201. Hall started 10 years ago after he had unexpected success with a single philodendron; now apartment gardening is an active avocation. During the 10 years he has built several miniature greenhouses, making as he did so some interesting innovations. He writes:



Francis C. Hall's indoor greenhouse

"After many attempts to grow flowering plants in our living room, I finally gave up. They all turned yellow, lost their leaves and died. So, like many of our neighbors, I settled for a wall pot of philodendron. This vine will live for a time almost anywhere, and it is easy to replace when it dies. Ours was replaced about every two months for a year or so until one of them unaccountably thrived, growing so vigorously that the tip of the vine reached the floor. I thought we had somehow acquired an exceptionally hardy specimen.

"At about that time we had a visit from a friend who teaches botany at a nearby high school. I called her attention to the thriving plant and asked for an explanation. After examining the pot and its surroundings she asked: 'How long has this table lamp been close to the vine?' I told her we had bought the lamp at about the time we planted the vigorous philodendron. The lamp is turned on every evening at dusk and stays on all night. 'There's your explanation,' she said. 'In effect you have converted this corner of your living room into a miniature greenhouse—not a very good one, but a greenhouse nonetheless.' She went on to explain the lighting requirements of plants and how I could improve my setup. I have been dabbling in amateur botany ever since.

"The key to a successful indoor greenhouse is the lighting, which should consist of a combination of cool white fluorescent lamps of the quick-start type and incandescent lamps that are operated at about 95 percent of their rated voltage. No single kind of lamp will suffice because none radiates the copious amount of energy plants require in the red and blue portions of the spectrum.

"Fluorescent lamps emit energy mainly in the violet, blue and green portions of the spectrum, and incandescent lamps emit mainly in the red and progressively less toward the violet. Experiments have shown that most plants require only the blue, red and far-red rays—the wavelengths extending from about 4,000 to 5,000 angstrom units in the blue and 6,300 to 7,500 angstroms in the red and far red. The mixture of greens, yellows and oranges that the eye perceives as a single shade of green are largely reflected by the plant pigments. Ultraviolet rays are damaging to plants, but most of the ultraviolet radiation in sunlight is absorbed by the atmosphere. The colors in sunlight that are essential to plant growth can therefore be provided by a properly balanced and filtered combination of fluorescent and incandescent lamps.

"In what proportions should the lamps be combined? The question has not been fully resolved. When I built my first battery of lamps, the optimum proportion was thought to be 10 watts of fluorescent light to each watt of incandescent light. Since then the recommended ratio has gradually changed. Some experiment stations, including the U.S. Department of Agriculture's Agricultural Research Service in Beltsville, Md., have used ratios in which the wattages of fluorescent and incandescent light are equal. The results of my own experiments appear to favor the closer proportions.

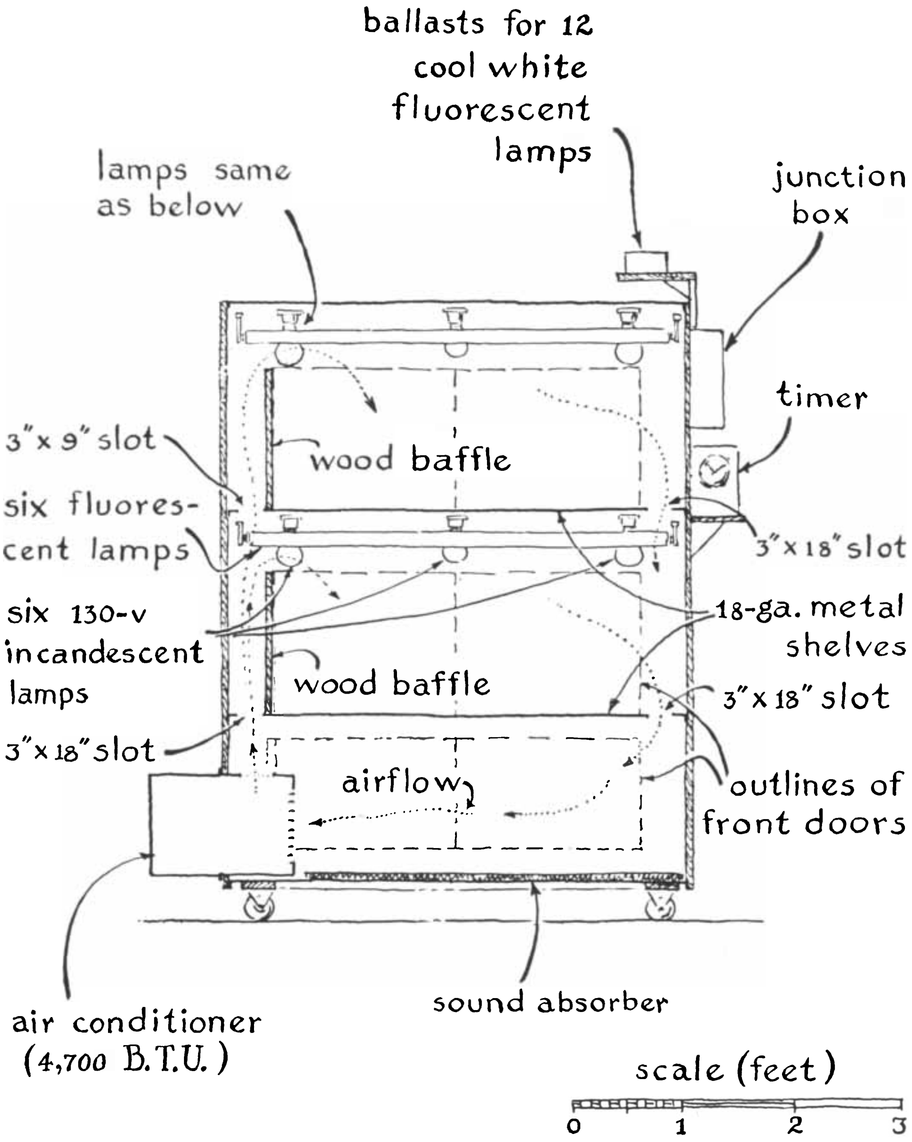
"Power consumption is doubtless a poor index of spectral intensity because it neglects the performance characteristics of the lamps. A lamp of one type may radiate far more energy in certain portions of the spectrum than a lamp of another, depending on the design of the lamp and the voltage at which it operates. The variation occurs particularly in incandescent lamps. For fluorescent lamps I now use 30-watt cool white tubes of the rapid-start type equipped with ballasts, or transformers, designed to operate 40-watt tubes. Driving the lamps above their normal rating increases the emission of the desired blue light by 30 percent but does not appreciably shorten the life of the tubes. The trick will work only with 30-watt tubes.

"Ordinary incandescent lamps can be used for radiating the essential red light. When they are operated at their rated voltage, however, they do not emit strongly in the far red. For this reason I have switched to lamps that are rated at 130 volts. These lamps are used chiefly by industry in inaccessible places where lighting requirements are not severe and where the cost of replacing bulbs must be minimized. Although the lamps are rated at 130 volts, they are operated on 120 volts. Hence they last several times longer than conventional lamps. The yellowish-red emission is ideal for plants.

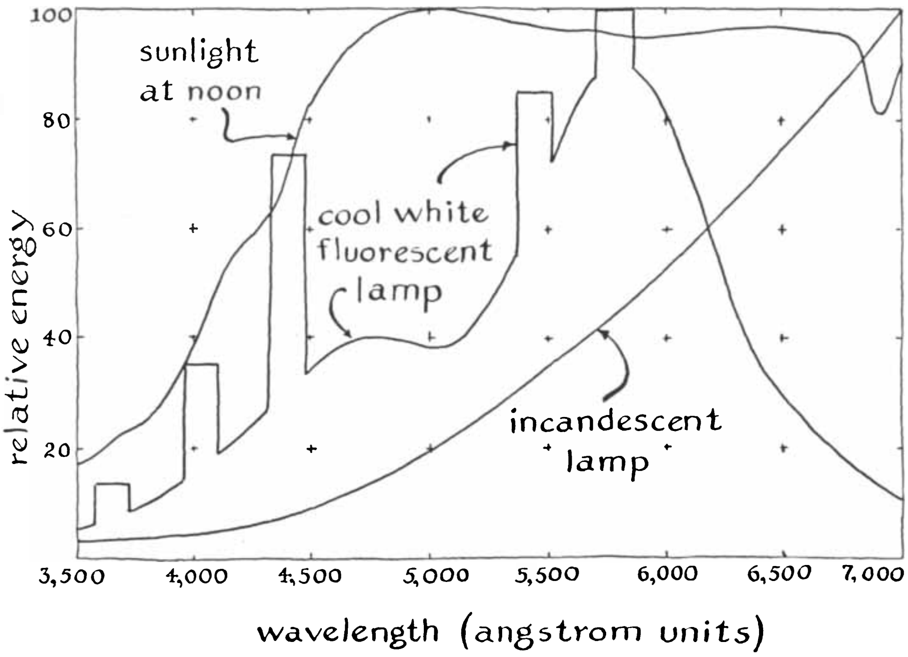
"These extended-service lamps are available from dealers in electrical supplies in the same wattages and at the same prices as standard lamps. They should not be confused with the long-life bulbs that are currently advertised. I now use six 30-watt fluorescent tubes in combination with six 15-watt incandescent lamps, a power ratio of 180 watts of fluorescent lighting to 90 watts of incandescent lighting.

"The structural details of mounting the lights and associated fixtures are determined largely by the application. For example, if the experimenter merely wishes to floodlight a shelf of plants, the hardware can be screwed to a simple wood frame suspended from the ceiling. In this case the fluorescent tubes can be mounted in standard twin-tube fixtures attached to the wood frame. The incandescent lamps can be spaced uniformly between the fluorescent fixtures. Normally the lamps will face downward. Heated air will rise from the lamps, so that porcelain sockets should be used. If the initial cost is a secondary consideration, the experimenter may wish to install a battery of the special fixtures that have been developed recently for service in miniature greenhouses. The fixtures provide space for both fluorescent and incandescent lamps in a single unit.

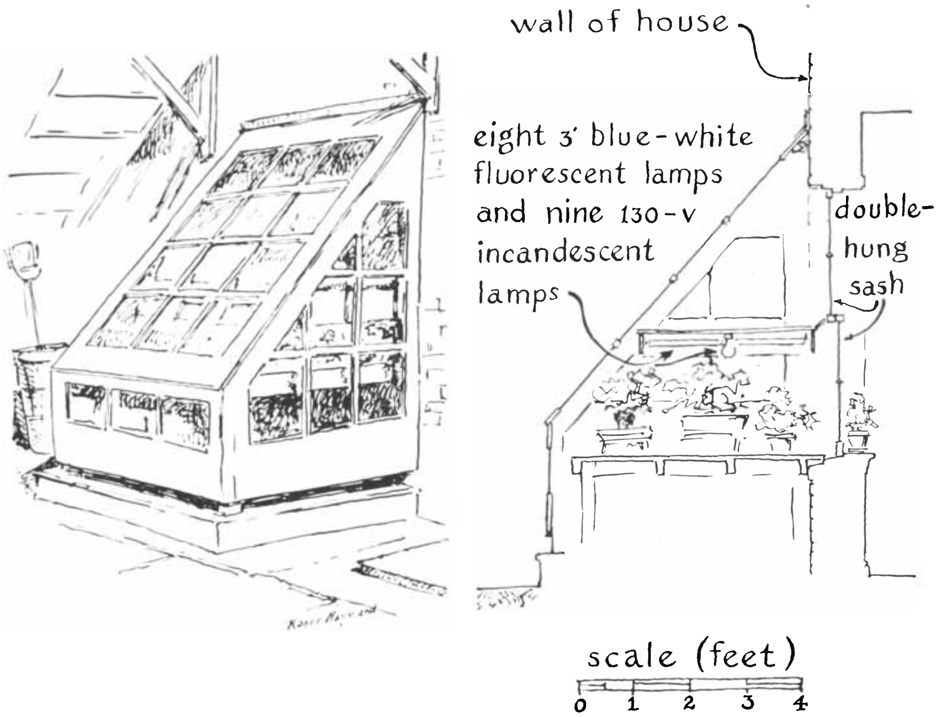
"The optimum quantity of light to be used varies with the requirements of the plant. In nature plants grow under a wide range of light intensities, from as little as 10 footcandles to about 10,000. Philodendron will thrive at intensities as low as 50 to 100 footcandles; African vi-



Details of the indoor greenhouse



Characteristics of three kinds of light



Lean-to greenhouse erected outdoors

olets do nicely at 600 footcandles, and orchids need 1,000. My experiments indicate that most popular varieties of flowering houseplants grow best at intensities ranging from 1,000 to 2,000 footcandles. Some growth chambers found in horticultural laboratories are equipped for lighting levels as high as 8,500 footcandles.

"Inexpensive light meters calibrated in footcandles are now available for measuring the intensity. Alternatively, simple tables for converting the indication of photographic exposure meters to footcandles can be compiled easily. Intensity can also be estimated. A pair of cool white 30-watt rapid-start fluorescent tubes that operate with a 40-watt ballast in a twin fixture will deliver about 1,100 footcandles at a distance of six inches from the tubes, 650 footcandles at 12 inches and 500 footcandles at 18 inches. Within a 30-degree cone below the tubes the intensity falls off uniformly to about 80 percent at the edge.

"At present I have two small greenhouses. One, a lean-to, is installed outside a rear window of our ground-floor apartment [*see illustration above*]. During part of the day the unit receives direct sunlight. The natural light is supplemented as desired by a battery of electric lights controlled automatically by a clock timer.

"The second chamber was constructed in the form of an ornamental cabinet, the basic details of which are shown in the accompanying illustration [*page 130*]. It consists of two compartments for growing stacked above a third compartment that houses an air conditioner, electrical controls and miscellaneous supplies. The lamps are suspended from the inner surface of the top of the cabinet and the bottom of the top compartment. They are controlled by the preset clock timer; the control for the air conditioner is a Honeywell Airswitch (type T-631-C) that operates when the temperature changes three degrees from the value at which the switch is set.

"Lamps develop a substantial quantity of heat that must be removed to prevent the temperature of the chamber from rising above 75 degrees Fahrenheit, the maximum to which common houseplants should be exposed. Fluorescent tubes operate at relatively low temperature and present no problem. The associated ballasts radiate a fair amount of heat, however, and must be located outside the growth chamber. I installed mine on the top of the cabinet.

"Incandescent bulbs of the recommended industrial type are much cooler than conventional bulbs; they are warm rather than hot to the touch. Even so, the temperature inside a glass and wood enclosure of 40 cubic feet equipped with 500 watts of mixed lamps will rise as much as 40 degrees F. above the temperature of the room. In order to remove this heat my cabinet was equipped with a small air conditioner of the type designed for window mounting (RCA Whirlpool, 4,700 British thermal units).

"The installation of automatic temperature controls adds considerably to the versatility of a growth chamber because it has recently been learned that plants require a daily rhythm of temperature change. This thermoperiod is analogous to the daily alternation of light and darkness. Although the thermoperiod is still under investigation, experiments indicate that for most houseplants the night temperature should be allowed to fall about eight to 14 degrees F. below the daytime temperature. With geraniums I maintain a temperature of 67 degrees during the day and a temperature of 55 degrees at night.

"The control of relative humidity is difficult, and I have not yet succeeded in improvising an automatic system. My cabinets contain trays of moist gravel, and I water the potted soil periodically. Nonetheless, the relative humidity of the air tends to fall substantially on dry days. For this reason I measure the humidity with a psychrometer and spray the plants with water as necessary by means of a hand atomizer. On days when the relative humidity of the room air is high I depend on the air conditioner to remove the excess from the cabinet. Houseplants appear to do well at a relative humidity of between 50 and 80 percent.

"The length of the simulated day is the easiest variable to control. All it requires is setting a clock timer. The importance of the daily rhythm of light and darkness to the growth of plants was first reported in 1920 by Department of Agriculture botanists who were investigating the flowering of tobacco plants. Subsequently it has been learned that the photoperiod acts as a kind of trigger that determines when a plant will blossom, when seeds will germinate, when bulbs will form and so on. The photoperiod also influences the color and size of leaves and the elongation and branching of stems. Commercial growers of flowers such as chrysanthemums now routinely delay the flowering of plants grown in the field by switching on batteries of incandescent lamps for intervals as short as 10 minutes during the night, thus synchronizing the production of flowers with the demands of the market. I follow the same procedure when growing entries for our local flower show.

"What is the optimum photoperiod? The answer depends on the plant. In general plants can be grouped according to their preference for short, intermediate or long days. The perennial chrysanthemum and the poinsettia do best when the days are short—10 hours

of light or less. Such a period is characteristic of plants that flower in the fall. Plants that do well at the opposite extreme—20 hours or more of daylight—include the China aster, the African violet, the tuberous begonia and the philodendron. The third category, which includes the rose and the carnation, consists of plants showing little sensitivity to the photoperiod.

"Most of the popular houseplants with which I have experimented seem to do well on a daily exposure of 16 hours to light from which the ultraviolet rays have been filtered. As indicated by the accompanying graph [*bottom illustration on page 131*] this emission in fluorescent tubes occurs between 3,500 and 4,000 angstroms. It can be suppressed by inserting a sheet of Mylar W-2 plastic between the lamps and the plants or, if this arrangement is inconvenient, by wrapping each tube in a single sheet of the material. (Mylar W-2 is a product of E. I. du Pont de Nemours & Co.)

"Experiments indicate that the triggering effects of the photoperiod are confined to the red rays in the vicinity of 6,600 angstroms. A few minutes of exposure to red light initiates biochemical reactions that continue for some time in the dark. Ordinary incandescent lamps emit enough red light to trigger the reaction in the case of houseplants. For example, houseplants that grow reasonably well on a window shelf will usually show dramatic improvement, particularly in winter, if they are grouped under a table lamp every day from dusk until bedtime.

"Like animals, plants must have food and water, each plant according to its needs. Conventional techniques of feeding and watering can be used for plants grown under electric lights. It is also possible to use the greenhouse for controlled experiments on nutrients. For instance, I once read that growth had been accelerated as much as threefold by fertilizing plants with carbon dioxide. The author went on to explain that, according to one hypothesis, the lush growth of plants during the Carboniferous period 300 million years ago resulted from the relatively large amount of carbon dioxide then present in the atmosphere and that the period ended when the carbon became locked up in deposits now represented by the fossil fuels. Why not flood my miniature greenhouse with carbon dioxide and grow giant plants?

"I quickly learned that the cost of the gas is too high for my pocketbook. It occurred to me, however, that something of the same effect might be observed if I sprayed the plants with carbonated water. I tried doing so but had poor results with bottled soda water. Apparently chemicals added to this water for retarding the escape of gas harm the plants.

"Carbonated water can be made at home, however, by means of a special bottle that accepts gas from small metal tubes. The homemade product worked. After trying various methods of applying the water in varying amounts I learned that a light mist applied to the leaves every other day doubles the growth rate and reduces the time required for the plant to reach maturity.

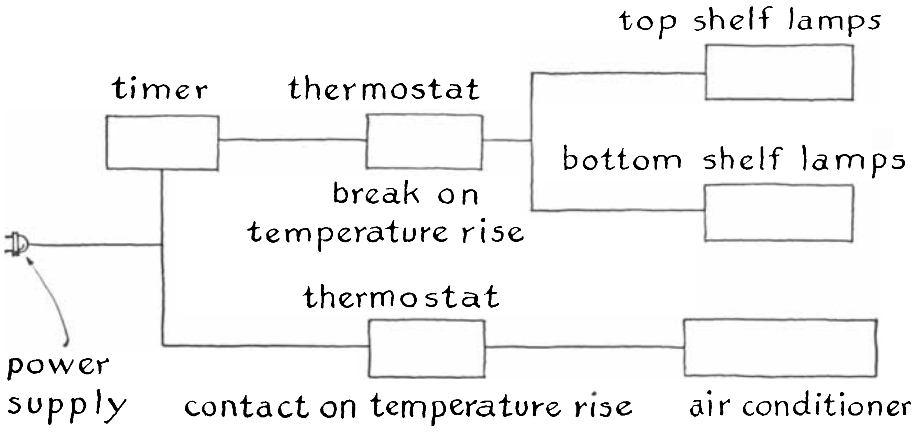
"The relatively small amount of gas liberated from the water does not substantially alter the ratio of carbon dioxide present in the air of the chamber. Why, then, do the plants respond so dramatically? I can only guess that the leaves absorb the gas through their stomata, or pores. The application must be made with an atomizer that develops a fine mist, and the leaves should be moistened only lightly. Moreover, the relative humidity of the chamber should be measured after the treatment and lowered if it rises excessively. Some experimenters who tried the procedure without initial success made the mistake of ignoring the relative humidity.

"Otherwise my plants receive conventional fertilizers applied according to the established requirements of each species. Much annoyance and expense can be avoided by using hygienic methods. Pans of water kept on the shelves for maintaining humidity encourage the growth of algae and fungi. The pans should be removed and cleaned periodically when the plants are washed. Much unwanted growth can be discouraged by adding an algicide to the water in the humidifying pans. I use a solution that consists of one ounce of cupric sulfate in one quart of tap water. One fluid ounce of this stock solution is added to each gallon of water used in the pans. Water so treated must not be allowed to come in direct contact with the potted soil. To prevent such accidental contamination surround the pots with plastic liners.

"Seedlings can be developed easily in the greenhouse. They do best in blue and red light; far-red light retards them. To make seedlings sprout I remove all industrial incandescent lamps and substitute a single standard 15-watt lamp. The result is a 12 : 1 ratio of fluorescent to incandescent light; the emission of the far red is minimized.

"Seedlings require a somewhat higher temperature for maximum rate of growth than mature plants do. The temperature should be between 75 and 80 degrees F. The soil can often be warmed to this temperature if the plants are raised to within four or five inches of the lamps. Alternatively, the added heat can be developed electrically by installing heating cables in or under the trays. Cables specially designed for this purpose can be bought from dealers in gardening supplies. It is good practice to plant seeds in sterilized soil in order to discourage the growth of fungi and molds.

"The cost of my greenhouse, including the air conditioner, was about $300. To this amount must be added about 15 cents a day for electric power. I can easily imagine a more elaborate and more costly installation. On the other hand, it is possible to conduct many fascinating experiments with little more than a potted plant and a single incandescent lamp. In my opinion few hobbies return more in terms of satisfaction per dollar and none appears to be attracting enthusiasts more rapidly. Gardening under lights came of age scarcely 20 years ago, yet it already has an extensive and swiftly growing literature."



Circuitry of the indoor greenhouse

Uniroyal invented the timing belt to solve the slippage problem inherent with V-belts and the noise and wear problem inherent with gears and chains.

Every mechanical device from an automobile engine to an electric typewriter has systems for transmitting the power from one moving part to another.

By far, the most popular "power transmission" systems are V-belts, gears and chain drives.

V-belts are low-cost devices that have the ability to absorb starting shocks and minor changes in alignment. However, they have the inherent problem of slippage which reduces efficiency.

Gears and chain drives are highly efficient but relatively expensive. Also, unless carefully built and installed, they are apt to be noisy and wear rapidly.

Uniroyal invented the timing belt some 17 years ago to combine the advantages of both. Sold under the registered "PowerGrip" tradename, the timing belt is essentially a belt with rubber teeth that act like gears.

Like many other inventions the timing belt was ahead of its time. It was only recently when Uniroyal found a way to mold fiber glass cord into rubber that the timing belt became a power transmission device of broad utility.

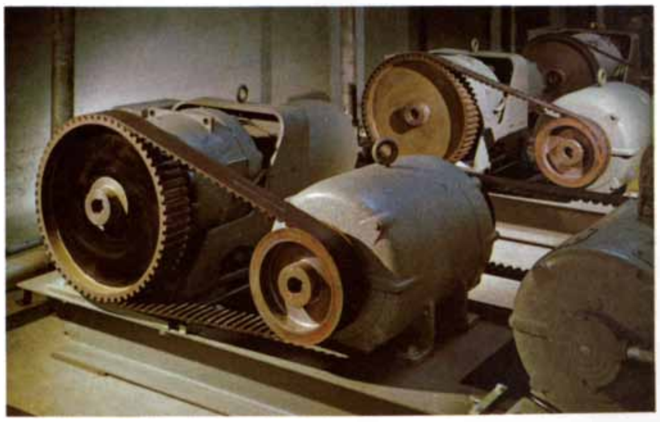
The timing belt was a key factor in the development of the first overhead camshaft automobile engine mass-produced in the United States. This camshaft drive is quieter and more economical than a gear or chain drive. It requires less maintenance.

Another engine with overhead camshafts driven by Uniroyal timing belts is shown at the left. This 2-litre V-8 racing engine has two camshafts driven through a two-stage timing belt drive. It was designed to produce 210 horsepower which it did the first time the engine was run on the test bed.

The overhead camshaft engine is a typical example of how rubber timing belt drives are creating new products. There is no question that an overhead camshaft is a more efficient way of opening and closing valves than the pushrod and rocker-arm arrangement used on most engines. The problem has always been the drive. Gears are expensive to machine and require much adjustment on the assembly line to produce a satisfactory engine. Manufacturing tolerances are critical.

The timing belt solves the problem neatly. Rubber teeth provide a positive drive that is efficient and quiet.

First overhead camshaft engine mass-produced in the U.S. has a rubber timing belt drive (shown in red) which is quieter, more economical than a gear or chain drive.

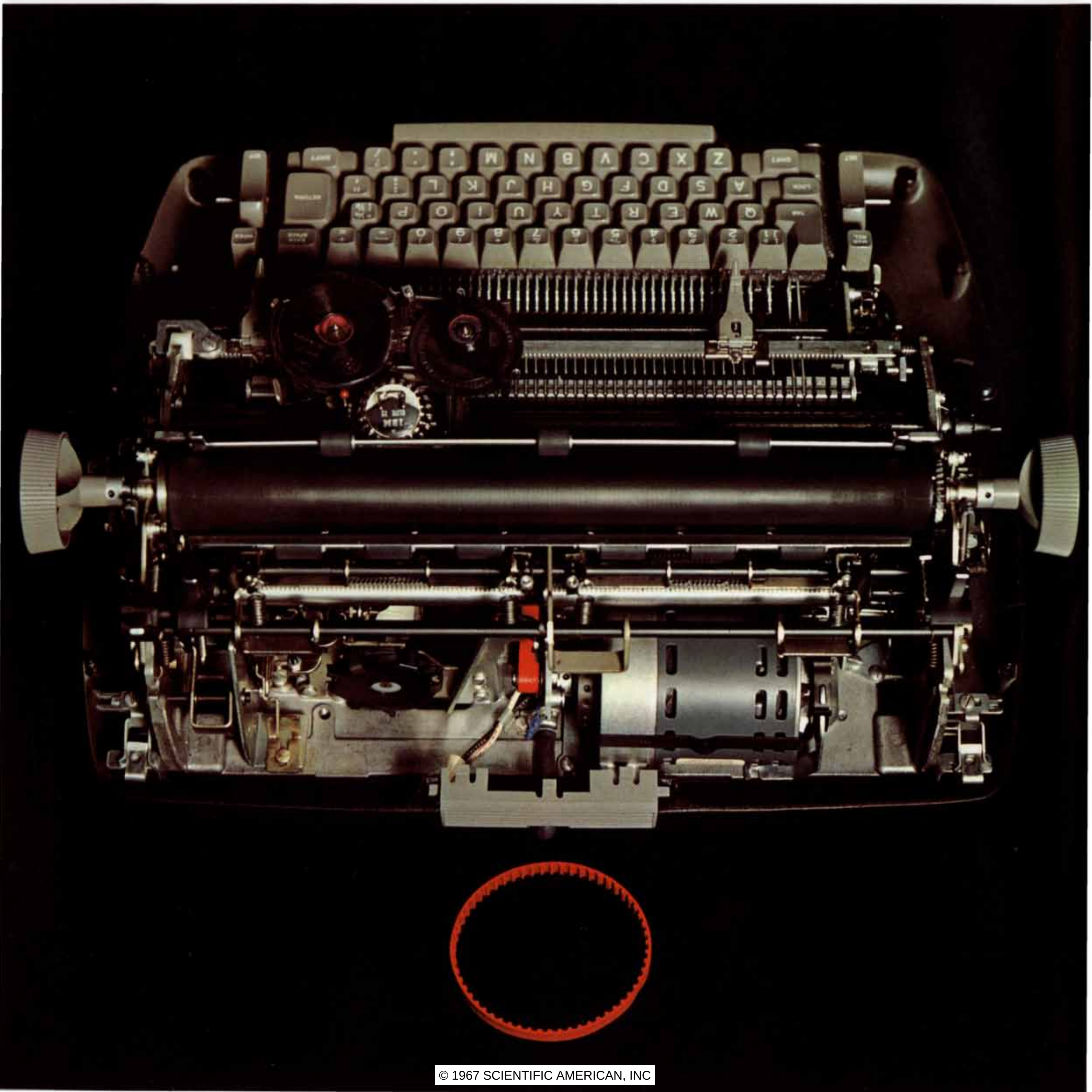


Textile machine is driven by rubber timing belt drives. Unlike gears or chains, timing belts require no lubrication or maintenance.

Continued...

Uses of timing belts range from business machines to snowmobiles.

Electric typewriter is driven by a single rubber timing belt (shown in red). Quietness is an important factor in this application.



UNIROYAL
U.S. RUBBER

Timing belts are versatile.

The one used in the electric typewriter at the left transmits a fraction of a horsepower. Others are capable of driving loads up to 600 horsepower.

The high efficiency and low cost of timing belts are the reasons for their use in a variety of new products from home appliances to milling machines and drill presses.

Uniroyal timing belts, sold under the registered "PowerGrip" tradename, are used in many other new and improved products including electric typewriters, sewing machines, gasoline pumps, office machines, television sets, appliances, outboard motors and power tools.

The quietness of timing belt drives accounts for their use in electric typewriters, motion picture projectors and sonar equipment for atomic submarines.

Their high reliability accounts for their use in recording instruments, computers, fuel transfer pumps for jet aircraft and of course, automotive camshaft drives.

Their smoothness accounts for their use in office copiers and tracking systems for missiles. A timing belt moves with "constant angular velocity." (A chain drive, which is articulated, does not offer the same smoothness of rotation.)

Their light weight accounts for their use in hand tools of all kinds.

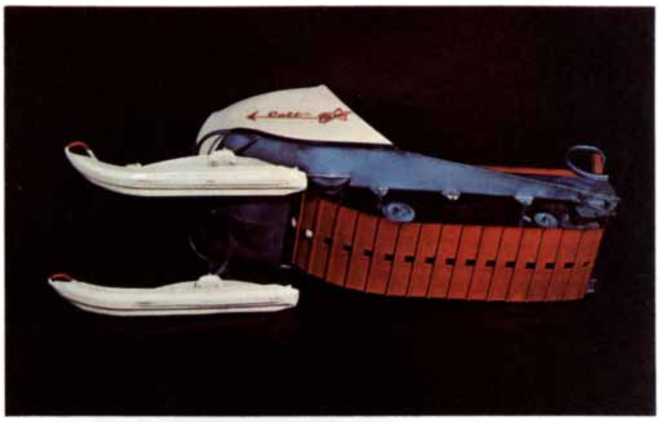
Because a timing belt doesn't stretch, it can be installed on fixed center drives which have no provision for adjustment. (Timing belts are reinforced with fiber glass cord, the same kind of cord used in Uniroyal "stretchless" V-belts.)

A timing belt requires absolutely no maintenance. Gears and chains must be lubricated. Ordinary V-belts must be retensioned. Timing belts, however, never need attention except for replacement.

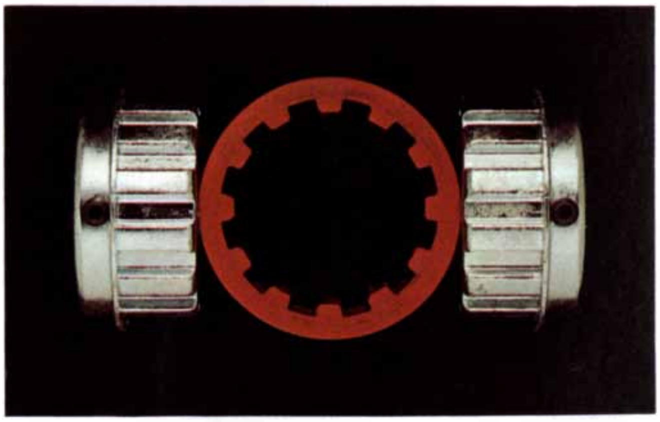
And replacement is seldom necessary. In many applications, well-engineered timing belts outlast gears and chains.

Timing belts are only one of our industrial products that might help you with a new product you're working on.

If you have a problem that one of our rubber, chemical or plastic products might solve, we'd like to hear from you.



Snowmobile is an unusual application of the "tooth" principal of timing belts. Here it is used as the track belt (shown in red) to propel the vehicle.



Flexible coupling made by Uniroyal uses "tooth" principle of timing belt (shown in red) as shock absorbing element. A low-cost "fail-safe" device, coupling is easy to install.

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

We'd like to help you. After all, we have almost 1,500 patents and we'd like to put a few more of them to work.

Uniroyal holds more patents than any other rubber company.

BOOKS

How molecular biology started

by John C. Kendrew

Phage and the Origins of Molecular Biology, edited by John Cairns, Gunther S. Stent and James D. Watson. Cold Spring Harbor Laboratory of Quantitative Biology ($12.50).

"From the moment I read Schrödinger's *What Is Life*," writes one of the contributors to this volume, "I became polarized towards finding out the secret of the gene." Erwin Schrödinger's small book, published at the end of World War II, had an enormous influence, particularly on physical scientists, in altering fundamental outlooks on biology, and in encouraging the new way of approaching the study of living organisms that has come to be known as molecular biology. Schrödinger himself had been greatly influenced by Max Delbrück; indeed, one chapter of *What Is Life*, describing a macromolecular model of the gene, is headed "Delbrück's Model." On the other side of the coin, the group Delbrück attracted to him to study bacteriophages (bacterial viruses) was recruited largely from those who, often not biologists by training, had had their interest in biology quickened, and a fruitful new approach presented to them, by *What Is Life*. The "phage group" consisted of the disciples of Delbrück, and in celebrating Delbrück's 60th birthday by writing essays for *Phage and the Origins of Molecular Biology* these disciples are celebrating also the history of an intellectual movement that, although it is only about 20 years old, has worked a major revolution in every branch of biology.

What was the nature of this intellectual movement? What *is* molecular biology? The phrase still arouses strong emotions. Classical biologists often think that molecular biologists, most of whom have had no formal training in biology, are guilty of hopeless oversimplifications, that (as George Beadle remarks in this book) any simple concept in biology must be wrong just because it is simple. Biochemists point out that their own field is molecular biology, in a strict sense of the words, and sometimes deride the assumption of the phrase as a title by a group whose members were ignorant of biochemistry and indeed often hostile to it. (Delbrück's own negative attitude toward biochemistry is mentioned several times in the book.) One distinguished biochemist has referred to molecular biology as the practice of biochemistry without a license.

Molecular biologists themselves are by no means unanimous about the nature of their subject. To anyone brought up in the British school of molecular biology, as the present reviewer was, it is a little odd to find in nearly every contribution to this book the explicit or implicit assumption that molecular biology had its only real beginnings in the phage group, and that the central theme of the subject is biological information. In the British school, which stemmed from the early X-ray studies of biological materials by W. T. Astbury, J. D. Bernal and their pupils, the emphasis has been on structure rather than on information, on knowledge of structure as the only road to an understanding of biological functions, among which information is an important example but by no means the only one. It is interesting to find that the contributors to this book, in describing their own work and the influence that determined its direction, hardly ever mention the word "structure."

It is true that the Watson-Crick double-helix structure of DNA has had an enormous influence on these workers; indeed, it has proved to be the central concept around which their thinking has developed. But the features of that structure that have been important to them have not been geometrical so much as topological: the one-dimensional nature of the information store and the role of specific pairs of nitrogenous bases in replication. Other kinds of biological structure, in particular the structures of proteins, are hardly mentioned. In the British school the notion of structure was central, and in the early days the emphasis was on proteins much more than on nucleic acids. Thus Astbury, writing in 1961 about the history of the term "molecular biology," quotes his Harvey Lecture of 1950 as follows: "It [molecular biology] is concerned particularly with the *forms* of biological molecules, and with the evolution, exploitation and ramification of those forms in the ascent to higher and higher levels of organization. Molecular biology is predominantly three-dimensional and structural—which does not mean, however, that it is merely a refinement of morphology. It must at the same time inquire into genesis and function."

The fact is that in the early days the two schools were almost entirely isolated from each other. On the one hand was the phage group of Delbrück and Salvador Luria, concerned primarily with the problem of interpreting the genetics of microorganisms at the molecular level in terms of a one-dimensional molecular information carrier that only by degrees emerged as the molecule of DNA. On the other hand the pupils of Astbury and Bernal were developing methods of elucidating the three-dimensional structure of all kinds of biological macromolecule but with a strong emphasis on proteins. For them the aim of interpreting function was a goal dimly discerned for the future, and they had little knowledge of, or interest in, the problems of genetics.

The schism was not entirely geographical in origin. I have not mentioned one of the most distinguished of the structural molecular biologists: Linus Pauling, whose biggest contribution was to define the alpha helix as a basic structural principle for protein molecules. Pauling, being situated like Delbrück at the California Institute of Technology, certainly brought the two schools in close geographical proximity, but it is questionable whether there was much intellectual relation between them. In this connection it is interesting to read in James Watson's contribution to the pres-

ent book that in the summer of 1949 he had the impression that the phage group thought that Pauling's world and theirs did not have a great deal in common. These articles were written 15 years later, and it is surprising to find how little evidence they contain of a concern with structural problems even now.

The first real link between the two schools was closed by the migration of Watson himself from the heart of the phage group by way of Copenhagen to Cambridge. The history is somewhat tangled, but I have it on Watson's own authority that it was basically his idea to move to the Cavendish Laboratory at Cambridge. It is curious that Watson, one of the few members of the phage school who was "a real biologist," was (in the words of another contributor to the book) "almost obsessed with the idea of a structural model," and that it was he who should have chosen this migration to a physics department. The result was the double-helix model of DNA, which in turn led to the extraordinarily rapid development of the field described in the book.

Even now the two schools, although they listen politely enough to each other's seminars, have less to say to each other in terms of real intellectual communication than one might expect. But times are changing; the latest fashion (which gets only a brief mention in the book) is allosteric effects: the influence of events in one part of a large molecule on the function of another part. The regulation of the genes and of metabolic activity, the operation of the ribosomes and of transfer RNA positively demand a concern for the precise details of the three-dimensional structures of both proteins and nucleic acids. Conversely, the genetic variations in the sequence of amino acids in proteins require that workers on protein structure should interest themselves in the mechanisms of heredity.

Let us now turn to some other striking aspects of the history of molecular biology that are revealed in the book. To this reviewer one of the most interesting is the revelation that, in spite of Schrödinger's insistence that the events taking place in living organisms could without doubt be accounted for by the laws of physics and chemistry, some of the earliest recruits were motivated by the faith that the study of heredity might lead to the discovery of "other"—and presumably new—"laws of physics." Gunther Stent, in his introduction to the book, says that "this search for the physical paradox, this quixotic hope that genetics would prove incomprehensible within the framework of conventional physical knowledge, remained an important element of the psychological infrastructure of the creators of molecular biology." Here we have a textbook example of the importance of fantasy in dealing with reality. The subsequent history of the field has shown no requirement for new physical laws; up to the present time conventional, normal laws of physics and chemistry have been sufficient, and at least in the opinion of this reviewer the forward horizon is clear of awkward facts that will require new or paranormal laws for their explanation. In any case, the actual development of the subject has been exciting enough, even if these particular fantasies have proved to be illusions.

We may also note the extraordinary slowness with which the notion of DNA as the substance of heredity emerged, and the caution with which this revolutionary idea was accepted by those such as Rollin Hotchkiss who performed the crucial experiments. In the early 1950's "we knew that the phage genome was replicated by a logarithmic process before we knew what it was made of." Then Thomas Anderson describes discussions in 1950 and 1951 of the "wildly comical possibility that only the viral DNA [as opposed to the rest of the phage] finds its way into the host cell." Yet two years later not only was the genetic role of DNA accepted but also the mode of its replication had been correctly proposed. As Anderson writes, "when we finally recognized this dichotomy [between the role of DNA and of other biological molecules] during the Cold Spring Harbor Symposium of 1953, it was like finally hearing the hilariously improbable punch line at the end of a long preposterous tale." After a slow start and prolonged battling with difficult problems, some of which are even now not properly understood, the development was fantastically rapid. In reading this book it is sometimes hard to believe that this chronicle of a movement that has revolutionized our understanding of heredity extends over a mere 20 years.

To disentangle the reasons for so rapid a development of fundamental ideas would take us into realms of speculation and inquiry beyond the scope of this review. However, the informality of many of the articles not only engages our interest to the point that the book holds our attention as closely as does any detective story but also reveals some special features of the intellectual atmosphere within which the ideas were born. We read of studies that were "carried out in blissful and protective ignorance of the past history of the problems involved." "Let us play with the wildest ideas we can imagine," says one of the contributors. The ideas often emerged during a blackboard discussion, with no single person responsible. And finally, in this atmosphere so far removed from that of classical biology, even the simplest ideas would sometimes turn out to be true.

This was a way of going to work that was as unorthodox as it was productive, and in reading this *Festschrift* volume we naturally wonder about the special role of Delbrück in guiding the whole development. At first he emerges not so much a guide as a critic. We read how he scared his colleagues, how long seminars under his direction were an ordeal, how he told dozens of people confidentially after they had delivered a seminar that it was the worst he had ever heard. We read of his suspicions of chemistry, of his deprecation of biochemistry, of his disdainful indictment of phage work that did not come up to his standards ("They had never taken the phage course"). He is said to have been careless in treating history, and he was critical of the most exciting new results. I myself remember visiting the California Institute of Technology shortly after Watson and Francis Crick had proposed the double helix, full of the excitement of seeing the model and of understanding the replication hypothesis, and finding Delbrück breathing skepticism whether all this cleverness had anything to do with biology. When Matthew Meselson and Franklin Stahl later performed the crucial experiment demonstrating that the replication of DNA was "semiconservative" as the model required, Jean Weigle recounts, Delbrück was still not convinced and invented other explanations.

But of course Delbrück's influence, although sometimes superficially destructive, was in fact of the most positive kind. Theodore Puck remarks that Delbrück's "passionate rejection of vagueness in the building and testing of conceptual models has helped to change radically the entire philosophy of biological research." His role was that of Socrates, and like Socrates he was constructive, and led others to be constructive, by way of criticism. George Streisinger concludes his chapter, and the book, by mentioning Delbrück's reaction to the discovery of the circular DNA in the T4 phage: "I don't believe a word of it." They all took a beating from Max, but they profited by it and they liked it—and him. The result was the most dramatic and rapid development in the whole of biology since

Darwin and Mendel. In this book it is described in a way that not only illuminates the subject itself but also has a much wider significance as an object lesson for the conditions under which scientific advances are made and an intellectual movement gathers momentum.

Short Reviews

CLEVER HANS (THE HORSE OF MR. VON OSTEN), by Oskar Pfungst. Edited by Robert Rosenthal. Holt, Rinehart and Winston, Inc. ($4.95). Hans was a large trotter, owned and lovingly educated by a white-haired old schoolmaster who exhibited the success of his pupil, without any payment, to all who would come around noon to the courtyard of the large apartment house in Berlin where for four years Hans had lived and been tutored. The gentle, if proud and irascible, teacher stood by Hans's right side to question him, a task interrupted by frequent carrots but never marred by the sight of a stick or a whip. Hans was of course mute; he responded by nods and shakes of the head, but particularly by tapping his right forefoot. He read and spelled rather well in German, coding his responses by number pairs that picked out letters from a blackboard array prepared by Herr von Osten. He knew the coins of the realm, the calendar for the year, how to tell time, and he recognized a good bit of music. (His taste in chords and melodies was somewhat old-fashioned.) He could walk toward people he was asked to single out, and could fetch from a row of colored cloths the piece of the color sought. He could recognize people from their photographs. In arithmetic he was outstanding. He could do all the schoolboy arithmetic for numbers up to about 100; tapping too long tired him, but conceptually he was not so limited. He could compute how many times 100,000 was contained as a whole in 659,321. Even fractions were acceptable; he first tapped the numerator, then the denominator, to give such sums as $2/3 + 3/4$. He made a few errors, which he could often correct at once when asked, "By how many units did you go wrong?" He always had a hard time with the answer "One."

The year 1904 was Hans's year. Droves of people came to see him, and he appeared in songs and light verse, as a toy and on liquor labels. Zoo directors and circus trainers, explorers, psychologists and philosophers declared him a horse genius. Educators were classifying him at the fifth-grade level. Some skeptics suspected trickery, but the weight of evidence about the sincerity of his teacher was too great to entertain the thought. As a last resort a learned commission assembled, only to find that Hans in fact would perform just as well for certain other questioners (finally as many as 40 different people succeeded) without even the presence of Herr von Osten. There was no deliberate trickery.

The mystery became the concern of Professor Stumpf, head of the Psychological Institute of the University of Berlin. His young colleague Oskar Pfungst solved the puzzle in a few months, and this reprint of the 1911 English translation of Pfungst's report relates the story. It is so clearly told, the sense of intellectual drama so tense, the personal engagement of Pfungst so evident, the experimental methods so simple, apt and elegant, the entire work so sensitive, penetrating and thorough that the book rightly became a classic of science and its methods.

One experiment, neat and conclusive, was this: When either of two acceptable questioners whispered an arithmetical sum into Hans's ear, the horse could solve the problem. But when one man whispered one number, and the other, not knowing the first number, whispered a second to be added, Hans muffed. If the two men had earlier agreed on the two numbers, Hans could find the sum. Wearing large blinders Hans failed; in the growing dusk Hans failed. Questioned in French, Hans succeeded. Indeed, without any audible question, he did quite well.

It was finally plain that Hans was no schoolboy but a clever and subtle watcher of his questioners. All the three or four people—they included Pfungst—who became very successful questioners gave unintended cues at the correct final tap, by tiny changes in the attitude of the head, relaxing the tension with which they watched the tapping forefoot. Even when Pfungst knew what cue he was giving, he could not easily suppress it.

Then Pfungst turned from analysis to synthesis: he became a human stand-in for Clever Hans. Clever Oskar asked subjects to think of a number between 1 and 100 but not to tell him what it was. He undertook to tap out the right answer, not with a hoof but more humanly with a forefinger. With 23 of 25 subjects tried, he succeeded brilliantly. He even recorded the cuing motions, using the smoked-drum and lever techniques of the era in a fully three-dimensional way, producing a kind of early polygraph.

The implications remain fascinating. The mind-reading act, the rapport of the wonderful pet, the rod diviner, the table-tipper, insofar as they perform as claimed, are subject to the lesson learned from Clever Hans. The polo pony that seems to know the rules of the game and the cavalry horse that knows the commands are probably tactile followers of Hans's. They are behaviorists. They cleverly learn their master's actions but nothing of the logic he follows. (Many schoolchildren are thought to act more like this than is good for humans.) The sensory interactions between organisms as complex as these animals, not to say from man to man, are too rich to prevent an occasional single bit of information from flowing quite involuntarily from one to another.

Dr. Rosenthal brings the tale up to date. Even the albino rat can learn from the way he has been handled whether the "experimenter" expects him to run the maze or not. Second-order experiments have shown such results, experiments in which the "experimenter" is himself the subject of a second experiment and is preloaded with information he then cannot fully conceal from horse, rat or human interviewee.

Finally one is led to quote Pfungst: "In spite of the huge mass of 'experimental evidence,' which has been collected chiefly in England and in America, it appears to me that telepathy is nothing but an unproven hypothesis based upon experimental errors." If 50 years ago Clever Hans had not been studied, a large class of those errors would be unknown. Whether other errors remain in the work of the parapsychologists will always require the insight and the hard work of a Pfungst to decide for sure. Lacking such studies, the claims of extrasensory transfer remain as suspect as the French of Clever Hans.

IF THE SUN DIES, by Oriana Fallaci. Atheneum Publishers ($7.50). The knowing publishers have placed on the dust jacket of this book a full-page photograph of its young Florentine author, curled barefoot in a chair with her long blonde hair loosened. This is the lady who visits NASA, in Houston and Los Angeles and Cape Kennedy and Huntsville and White Sands, who confronts astronauts and Ray Bradbury, public-relations men and motel keepers with her memories of vineyard and basilica, her literary values and her human charm. She asks these people "Why?" and "Who are you?" She tells the story with hot candor and a sharp eye, out of a remarkable experience of life.

The book, in rushing and poetic prose,

turned into flowing colloquial English by Pamela Swinglehurst, takes the form of long reflective letters to a distant father—off there in a villa in Chianti, a Tuscan country gentleman who was something of a hero in the Resistance. The war and the Nazi terror are strong in the book. Wernher von Braun (*Doctor* von Braun, the public-relations man insists weakly throughout the colloquy) is portrayed: likable, forceful, versatile, extraordinary, dominant. But over the whole of this expansive interview the scent of lemon hangs like the memories of Proust's childhood. Then she recalls. The German soldiers with the tommy guns who broke the door down to find and deport the two partisans she had just hidden in the well carried the same scent: German soap. " 'The future is always interesting,' said von Braun. 'More than the past,' said I."

She met a dozen or two of the astronauts. They come off not badly. To be sure, she finds most of them venerable, dull, bored, bald, mechanical. A few—she was fortunate—are different. She found a poet and a philosopher, and a few others who knew what wit and doubt and fancy mean. One day while driving with the astronauts' physician she invented a Project Cheese, which proposed to subvert Apollo to mine the moon, to sell the cheese here at great profit, working all the while on the other side of the moon to evade discovery. The rumor spread to all the astronauts, and a few of them understood.

And so this woman, a partisan at 14, an incredulous European witness of the vulgarity of Highway 66, of our motels and our extortionate economy, comes in the end not to bury Apollo but somehow to praise it. "And if the Earth dies, and if the Sun dies, we shall live up there, Father. Cost what it may: a tree, a billion trees, all the trees that life has given us."

No capsule review can exhaust the manysidedness and perceptivity and eccentricities of this book. It is one of very few pioneer works in a new genre: the criticism of science and technology as ways of life, as sets of values. It is not exposition of events or good reporting or philosophical analysis. It is quick and imperfect, but it is breathing with life.

THE EARTH-MOON SYSTEM, edited by B. G. Marsden and A. G. W. Cameron. Plenum Press ($12.50). The problems of origin are difficult when a unique system is under discussion. How the twin planets earth and moon were formed is the center of this technical symposium held in 1964 and reported quite fully in this volume. The participants include most of the people who have recently made contributions in the field; there is no better place to start to study the problem than with these papers.

The most stable period of the well-known motions is certainly the year. The great distance between the sun and the earth nearly guarantees that they move uniformly. Not so the moon and the earth. The spin of the moon is gone, locked to the earth, and the spin of the earth has changed too. This story is contained in the coral growth rings of Professor J. W. Wells of Cornell University, told here in an early but striking version. The day and the month have got longer. Putting this evidence beside the uncertain chemical nature of the moon, its irregular shape and its circular orbit, no clear conclusion is yet at hand. The spin of the earth can be checked with marvelous accuracy year by year today, and with some misgivings into the past by using eclipses known in history. They agree with the coral evidence. But what is the source of the spin-slowing? Is it losses due to the tides? Losses at the deep interfaces of crust and mantle? Loss to magnetic plasma in space? Mere mass readjustment deep in the earth? The arguments are complicated and uncertain, and without a mathematical theory we cannot extrapolate to the pre-coral past.

Is the moon a result of fission from the earth? Was it captured whole long ago? Was it built by amalgamation of many small moons, already captured in circular orbit? Or are our difficulties a sign of a fundamental problem in physics, like a gradual change in the laws of gravity?

Here are the experts, rather in doubt. A telling point made by D. U. Wise of Franklin and Marshall College is that Lord Kelvin about 80 years ago "proved" that the sun was less than half a billion years old, although Charles Darwin and the geologists, ignorant of the defect in his theories, knew he was wrong. Good calculation from erroneous assumptions does not lead to knowledge. More data are needed, or better ideas. Both will almost certainly be forthcoming.

As usual, useful papers are entered by Walter H. Munk, S. K. Runcorn, Gordon J. F. MacDonald, Thomas Gold and R. H. Dicke. The entire symposium is a worthwhile, well-indexed collection for either the serious student or the browser.

ENGINEERS OF THE RENAISSANCE, by Bertrand Gille. The M.I.T. Press ($12). This work, by a distinguished French scholar, is remarkable for its beauty. The page format is square, and in the wide margins strong line drawings are found by the score. One sees cannons and catapults, hand mills and cranes, drawn by the men of whom the book treats. They include Leonardo da Vinci, but there are many others. One of the author's two main contentions is demonstrated plainly in word and line: Leonardo, although justly held to be the prince of these artist-engineers, was only first among equals. A hundred years before Leonardo, Konrad Kyeser, born in a small Bavarian town, began the line by designing chariots, siege engines, military fireworks and fireworks for festivities, in a tone much like that of Leonardo's famous job application to Ludovico Sforza. After Kyeser there was a string of even more able and versatile workers. What becomes clear is that we know less of real technology than of great craftsmanship, less of engineering than of dreams; the men who wrote and drew books, not the men who bored the cannon and drained the marshes and built the mills, are the ones we know best. Only sometimes were they the same.

Francesco di Giorgio of Siena is perhaps the most interesting of the still-little-known men whom Professor Gille searches out. His drawing shows a kind of "automobile," a heavy frame moving on four wheels. The wheels received their power from hand-turned capstans on the deck, transmitted through a maze of rods and worms and pinions. The machine is bewitching, even if it has some aspects of a display of mechanical devices. The moving parts appear to be made of wood, not metal. Di Giorgio designed a hand mill in which flying balls on chains moved out at high speed and fell in at low, thereby supplying the principle of Watt's governor (except that the feedback loop was closed not mechanically but through the actions of the man turning the crank). He took a young engineer with him to Parma to consult about the cathedral then being built there; this was Leonardo.

The book is illustrated with many halftones of manuscripts or of castles and mills as they now stand. They are often beautiful photographs, but they are all presented with an arbitrary wash of solid color, now blue, now green, now buff. This contrivance is of doubtful taste in a work part of whose function is that of archive and transmission.

MODERN MICROSCOPY: OR SEEING THE VERY SMALL, by V. E. Cosslett. Cornell University Press ($5). The Christmas lectures of the Royal Institution, in the spirit of (and dedicated to) Sir Lawrence Bragg. They begin easily enough with analogies of size and a fine plot of magnification and focal depth for all kinds of instrument. But they are thereafter somewhat denser with fact, concept and equation than the easygoing style would suggest. Light is thoroughly handled, with phase contrast and interference microscopes both described. Then point-emission microscopes are presented for use in X rays and with electrons and ions. The standard electron microscope comes in for anatomizing—and praise—by an expert. The last and most unusual chapter describes the new flying-spot devices in some depth, those using light and electron images as well as the powerful instruments that perform an X-ray analysis element by element of the surfaces they scan, at a scale of a few microns. The book closes with 32 splendid halftones that show microscopy and microscopes from Hooke and Leeuwenhoek up through the output from all the kinds of instrument discussed in the text. The iron in the surface enamel of a rat's tooth section stands out clearly; it takes six or eight relay racks to get the picture. Crystal-lattice planes in gold are visible in another at a separation of two angstrom units—3.5 million times magnified. Beads of puffed Styrofoam in an X-ray projection image at 60 times magnification make an intricate array of overlapping circular patterns, which needs only another 20 times magnification onto canvas to sell at a high price on 57th Street.

SOLAR RADIATION, edited by Nathan Robinson. American Elsevier Publishing Company, Inc. ($24.50). Life is the gift of the sun. Nowadays people begin to think of using solar energy direct, and not merely through the subtle processes evolution has developed in the aeons since the sun first shone on our earth. Their first need, those designers of the solar furnaces and factories of the future, is a careful quantitative account of what is in the sunbeams. This book, which came out as the result of the effort of its expert contributors after the untimely death of its planner and editor, is a comprehensive and up-to-date census of sunlight.

The chapters summarize in graph, table and equation the entire journey of the solar energy, from the vacuum of space through the air to the ground. Solar X rays are described, but not solar radio—no energy. The volume tells the round of days and of seasons, taking due account of the toll lost to air and its dusts, to water vapor, and remember-

ing to add the blue-sky contribution back in. It closes with a careful chapter on the instruments and methods that do this painstaking job, and a final sketchier chapter on trapping sunlight behind glass layers, in hot fluids or with silicon photovoltaic cells.

A few facts from this comprehensive monograph: Less than half of the solar energy is in a form visible to the eye; the majority is infrared. What the air absorbs of the ultraviolet, which can be lethal to cells, is less than 1 percent of the whole. The fir forest sends back only 10 percent of sunlight, but the snowy plain can reflect more than 90 percent. The gloomier skies near cities are not much discussed; the data come from places such as Davos and are suited to those climates where the skies are not cloudy all day. Solar energy is not for Manhattan.

Portions of the monograph that wander afar (for example on the nuclear sources of solar energy) are not always reliable, but for the important matters really at hand this work is pretty sure to become the standard reference.

NOTES ON THERMODYNAMICS AND STATISTICS, by Enrico Fermi. The University of Chicago Press ($1.50). In Fermi's own clear and open handwriting these pages present his notes for a course he taught in 1951 in this most subtle of physical subjects. Here are some 75 topics, from the foundations of thermodynamics up to the elements of statistical turbulence, each tersely described in a page or two of equations, data and diagrams. The lucidity and the fresh, deep view that were always Fermi's stand out from these uncrowded pages. Not a text, it will be invaluable to students and teachers who have been through the subject once. Now and again there is an interspersed comment written in as a correction or an amendment after the lecture; the whole work evokes the man. A few worthwhile problems are set. His alternate proof of the Maxwell distribution from the steady state of an isothermal vertical column is one neat half-page.

BLACK WAR: THE EXTERMINATION OF THE TASMANIAN ABORIGINES, by Clive Turnbull. Ginn and Company ($5.80). "Not, perhaps, before has a race of men been destroyed utterly within seventy-five years." So begins the preface to this history of the killing of a culture and a people, numbering a few thousand, by the armed and enterprising free settlers of beautiful Tasmania, beginning about 1804. In fear, stupidity, lust and not a little sadism they decimated the aboriginals as though they had been beasts. Governmental self-deception led to a final punitive expedition and an exile of the remnant—a couple of hundred souls—in the 1830's. Fifty thousand English had taken their hunting lands. The last Tasmanian died in 1876, "a grizzled old woman, a bright kerchief bound about her head." She feared the body snatchers, and died with the request that she be buried "safely behind the mountains." She had reason to fear: her husband had had his hands and feet cut off and his skull broken in death, either by or against the resurrectionists. These gentle hunters of opossum, gatherers of fern and mussel could not save even their dignity. The record of their final agony in exile is falsified and incomplete; we shall never know their culture or their tongue. Turnbull writes with a petition in his heart: Let all Australia not repeat on the grand scale the crime of Hobart. The cycle is far advanced, but there was still hope in 1948, when the book was written. Who will speak for today?

ATHLETIC RECORDS: THE WHYS AND WHEREFORES, by George P. Meade. Vantage Press, Inc. ($3.75). Dr. Meade, a distinguished chemical engineer, watched the first 100-yard dash ever timed under 9.8 seconds. That was run by Arthur Duffey in 1902. The dash has become 5 percent faster between 1912 and 1965, while the javelin flies 50 percent farther. This knowing and affectionate book sets forth a rationale of records in track, field and swimming, analyzing them both by empirical and by physiologically based schemes. The author knows the work of the Nobel laureate A. V. Hill as well as he does that of the best modern coaches, and he combines his literature review and record-ordering with a sensible commentary on training, technique, nationality and the foibles of authority. The book ought to stimulate a good deal of amateur operations research, extending the same expertise to other sports and going deeper in this one. It is worthy of better typography and presentation, but it is irresistible reading as it stands.

WHO DESIGNS AMERICA? THE AMERICAN CIVILIZATION CONFERENCE AT PRINCETON, edited by Laurence B. Holland. Doubleday & Company, Inc. ($1.45). A lively collection of nine papers and discussion, pitting reason and industrial designers against automobiles and architects. Charles Eames, Edward J. Logue, Boris Pushkarev, Suzanne K.

Langer and others contribute excellent comment. One can learn that a highway designer counts it worth just $23,000 to stop one fatality. Russell Baker, the sage of *The New York Times*, is quoted: "The director of this tiny powerful group is known only as the Great Paver.... His philosophy is summed up...: 'The world must move cars.'" This was a 1964 meeting, but the answer to the title's question is still being sought.

THE EXPLORATION OF THE PACIFIC, by J. C. Beaglehole. Stanford University Press ($7.50). A new edition of the authoritative work by this noted New Zealand scholar. It follows the European explorers of the Pacific from Magellan to Cook's death. Many maps, and even more marvels. It reminds us that this year is the 200th anniversary of the first publication of the *Nautical Almanac*, used mainly for the lunar tables Cook relied on for the *Endeavor*—no chronometer aboard.

THE CALIFORNIA CONDOR, by Carl B. Koford; THE IVORY-BILLED WOODPECKER, by James T. Tanner; THE ROSEATE SPOONBILL, by Robert Porter Allen. Dover Publications, Inc. ($2 each). Handsome reprint editions—with cover photograph in color—of three Audubon Society Research Reports, detailed monographs on three fascinating species.

ON GROWTH AND FORM, by D'Arcy Wentworth Thompson. An abridged edition by John Tyler Bonner. Cambridge University Press ($2.45). The first paperback edition of a good abridgment of that treasure of a book. Superb line drawings.

TEMPO AND MODE IN EVOLUTION, by George Gaylord Simpson. Hafner Publishing Company, Inc. ($6). A reprint of the wartime classic, still as provocative a guide to the landscape of evolution as it ever was.

ROTIFERS, by Joseph Donner. Frederick Warne & Co., Inc. ($3.95). A slender key, a life history and a collection of cultivation tips on these lovely wheel-bearers, microscopic beasts of large variety and exquisite motion. Many stroboscopic flash photographs of the living animals.

ELEMENTARY PARTICLES, by William R. Frazer. Prentice-Hall, Inc. ($6.95). An admirable introduction to the theory of particles for people who know quantum mechanics well but not field theory.

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BIBLIOGRAPHY

Readers interested in further reading on the subjects covered by articles in this issue may find the lists below helpful.

TOXIC SUBSTANCES AND ECOLOGICAL CYCLES

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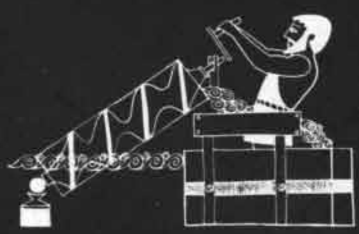

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