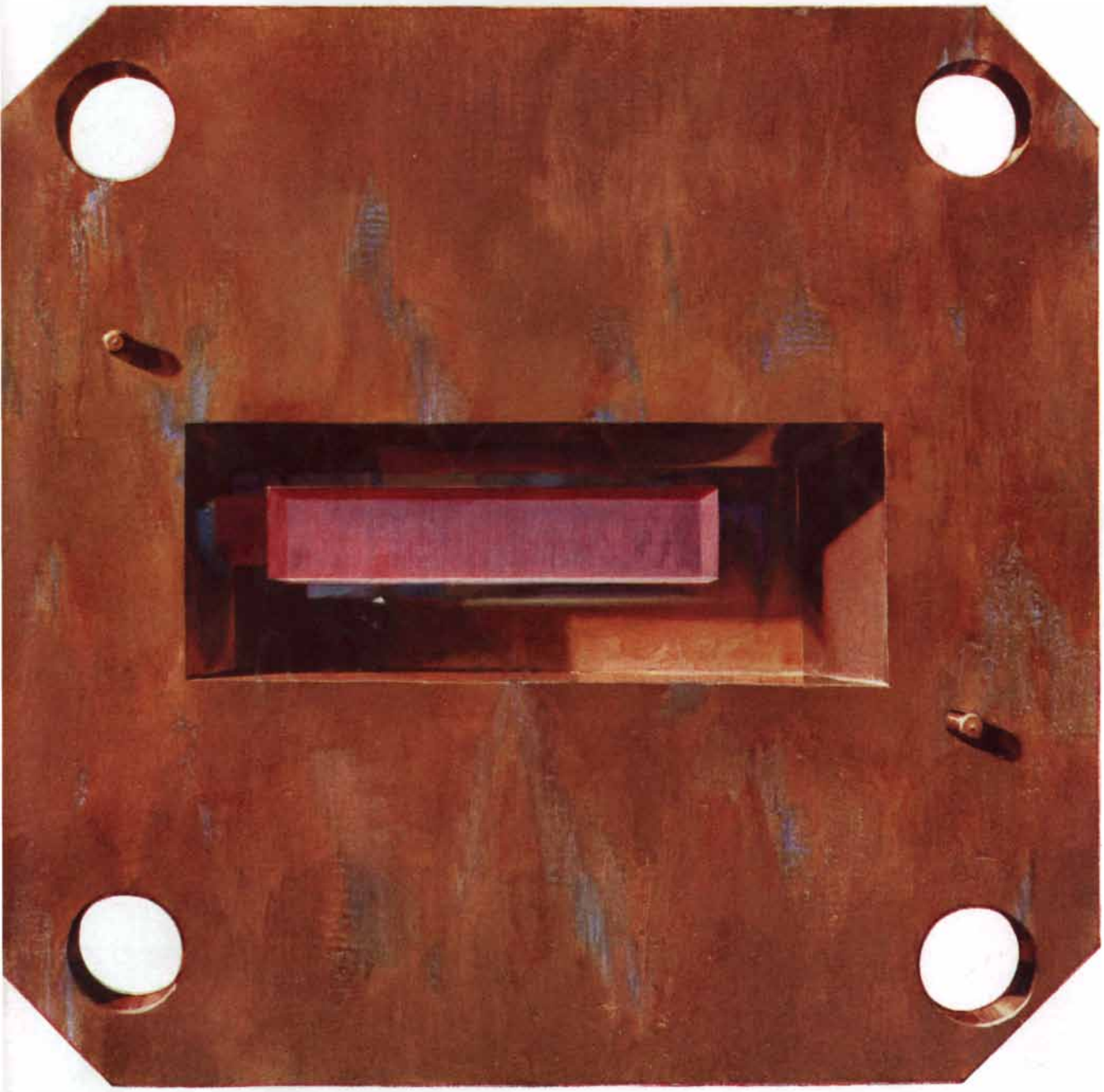
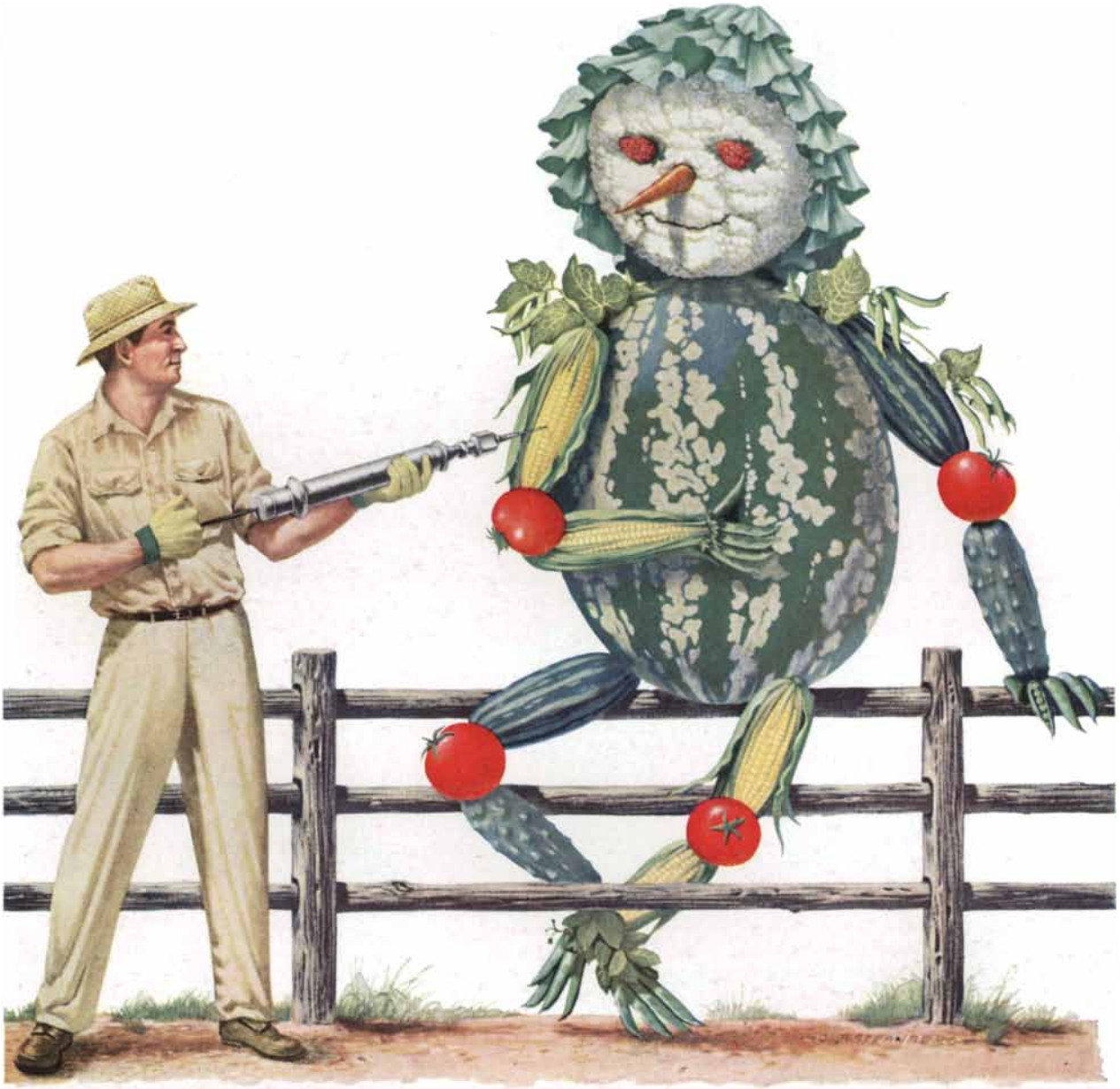
SCIENTIFIC AMERICAN



SOLID-STATE MASER

FIFTY CENTS

December 1958



Booster shots for bumper crops

All living things need help to grow, the fruits of the earth no less than the children of man. In the West, crop yields are kept high with nitrogen-rich ammonia fertilizer by Shell Chemical.

Nitrojection Service® is the Shell-developed method of injecting ammonia gas directly into the soil with modified cultivator shanks. Nitrogen—vital to plant growth—is placed at root depth . . . with startling results. Fertilizer investment is usually repaid *fourfold* by increased crop yield.

Pioneering with nitrogen fertilizers and better ways to use them is an important Shell Chemical contribution to the nation's agricultural productivity.

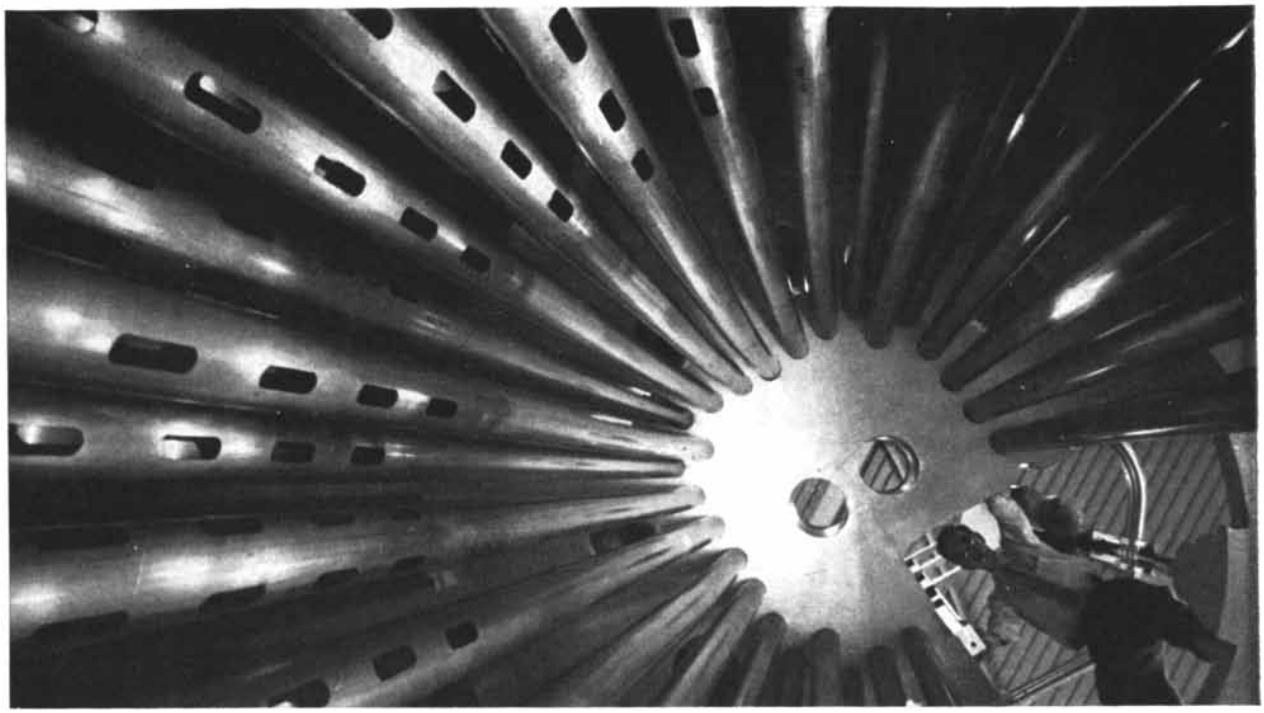
SHELL

Shell Chemical Corporation

Chemical Partner of Industry and Agriculture

SAN FRANCISCO

Anhydrous Ammonia • Ammonium Sulphate • Urea • Ammonium Phosphate Sulphate • Di-Ammonium Phosphate • Triple Superphosphate



A view of the heart of a full-scale model of the great Shippingport nuclear power reactor at Pittsburgh. The Westinghouse Electric Corp. designed and developed its nuclear portion. Bendix built the control rod drive mechanisms which are located inside the tubes shown above. Reactor control rods are used to control the atom splitting, heat producing process.

BENDIX REPORTS ON SOME OF ITS ATOMIC PROJECTS

Some of Bendix' contributions to commercial and military nuclear projects are listed here to give you an idea of our growing activity in the "atom business":

We supplied control rod drive mechanisms for the great Shippingport reactor, the first full-scale atom power plant in the U. S. designed for civilian needs. These mechanisms enable precise control for the position of the hafnium control rods which regulate the amount of power produced. We are also associated in the development of the reactor being built to supply power to the Detroit Edison system.

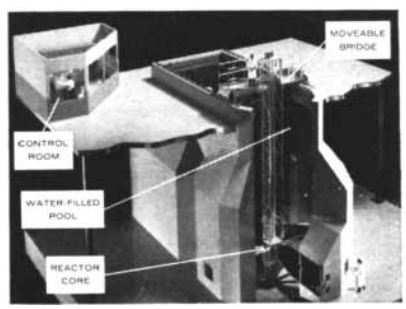
We are manufacturing control rod drive mechanisms for the prototype of the nuclear propulsion plant for the Navy's nuclear-powered surface ship being built at the U. S. Atomic Energy Commission's naval reactor facility in Idaho; also for the Navy's first nuclear-powered guided-missile-firing cruiser *USS Long Beach* and for several nuclear-powered submarines. These developments are directed by the Naval Reactors Branch of the AEC. In addition we are developing the control rod mechanisms for an AEC nuclear-powered rocket project.

We are also supplying the new nuclear-powered U. S. Navy destroyer with transistorized nuclear instrumentation.

We are building a nuclear research reactor, somewhat similar to the model pictured on the right, for the Atomic Energy Commission for use in connection with the nuclear aircraft propulsion project. We are also performing radiation damage tests for the Air Force.

We are supplying transistorized nuclear instrumentation to the Army Package Power Reactor at Fort Belvoir. This project deals with reactors to supply all power requirements in remote locations such as the Arctic where fuel is lacking.

We have developed a new type "cut-off switch" for the large research reactor being built for the new National Aeronautics and Space Agency. Transistorized for reliability, it will warn of any abnormal condition and automatically shut down the reactor, if safety requires it.



Cutaway of Bendix research reactor.

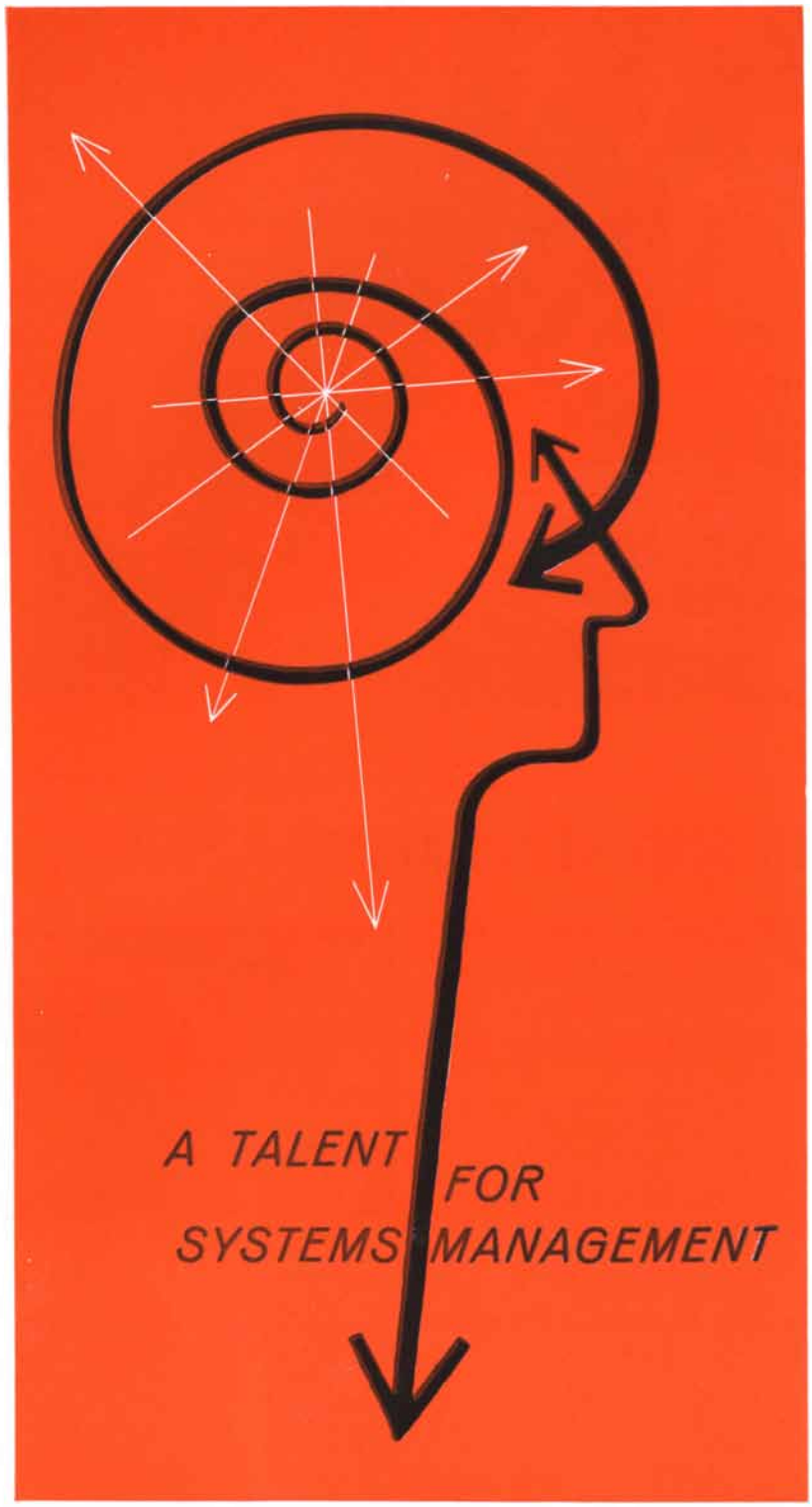
For more than nine years we have held a prime contract to operate the Kansas City Division, a very large AEC facility, devoted to the atomic weapons program.

We make many specialized nuclear instruments and have delivered thousands of pocket size radiation detectors.

We invite you to write if you have problems involving nuclear controls, instrumentation, fuel elements, research reactors, or other nuclear problems.

A thousand products **Bendix** *a million ideas*

AVIATION CORPORATION
Fisher Bldg., Detroit 2, Mich.



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A DIVISION OF GENERAL DYNAMICS CORPORATION
1470 NORTH GOODMAN STREET • ROCHESTER 3, N. Y.
ELECTRONICS AND COMMUNICATION FOR HOME, INDUSTRY AND DEFENSE

Firm central control . . .

over interlocking functions of Engineering and Finance . . .

under a member of top management whose authority is undiluted—

this, the Stromberg-Carlson concept of Systems Management, is a definite departure from conventional methods.

It's working extremely well.

Unified direction of all our own divisions, leading consultants and qualified subcontractors assures a tight control of costs and more efficient utilization of facilities.

Currently, this concept is helping develop an electronic countermeasures system vital to the defense of the free world.

Our talent is equally applicable to Communication, Navigation, Test Equipment and other complex electronic systems. Our brochure 709 would be of interest.

Established 1845 **SCIENTIFIC AMERICAN** December, 1958 Volume 199 Number 6

ARTICLES

DEPARTMENTS

PUBLISHED MONTHLY BY SCIENTIFIC AMERICAN, INC., 415 MADISON AVENUE, NEW YORK 17, N. Y. SECOND CLASS POSTAGE PAID AT NEW YORK, N. Y., AND AT ADDITIONAL MAILING OFFICES. SUBSCRIPTION RATE IN THE U. S. $5 PER YEAR.

THE COVER

The painting on the cover is a symbol of the three-level solid-state maser, a new device for the amplification of microwaves (*see page 42*). In the middle of the metal plate is a resonant cavity, and within the cavity is a synthetic ruby. The electrons in the ruby occupy three energy levels; when microwaves of the appropriate frequency are piped to the crystal in an actual maser, electrons in the lowest energy level are "pumped" into the higher level. Electrons in the higher level can then fall back into the middle level, emitting microwaves of a lower frequency. Thus when microwaves of the latter frequency are piped into the cavity, they are amplified. The advantage of the device is that it operates without "noise"; it can amplify a very weak signal without distortion. For this reason the maser is particularly promising for the amplification of the faint signals which come to radio telescopes from outer space.

THE ILLUSTRATIONS

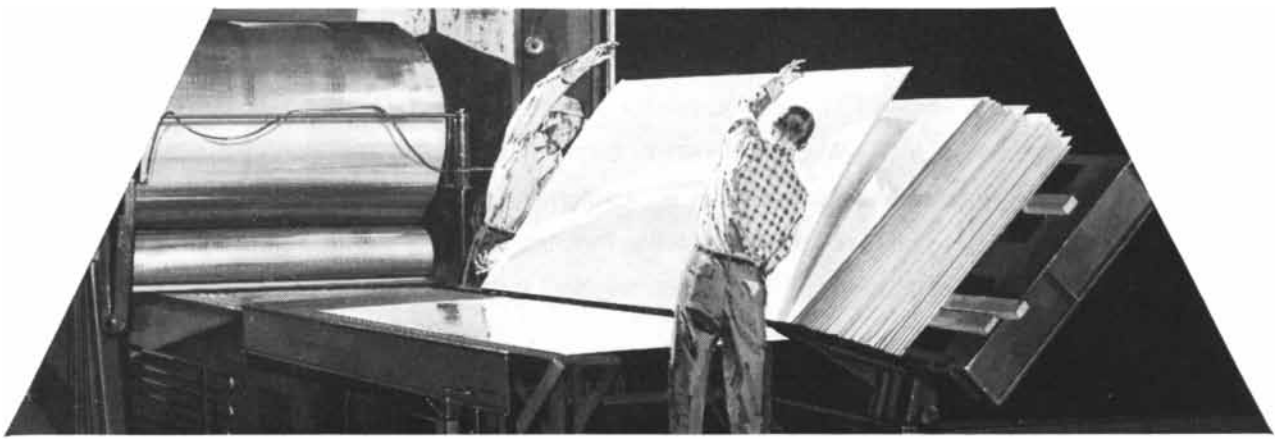
Cover painting
by Stanley Meltzoff

Page	Source
30-35	Alex Semenoick
36-41	Eric Mose
43	Naval Research Laboratory
44-47	Irving Geis
48-49	Irving Geis (*top*), William Vandivert (*bottom*)
50	William Vandivert
67-78	Rudolf Freund
83	Marine Studios, Marineland, Fla.
84-90	Bunji Tagawa
92-93	John Langley Howard
94	Harold E. Edgerton
96	John Langley Howard
105-107	James Egleson
115	David Linton
116-117	David Linton (*top*), James Egleson (*bottom*)
118-122	James Egleson
126-132	Bunji Tagawa
135-140	Roger Hayward

Udimet 500

a vacuum induction melted alloy

NOW AVAILABLE IN SHEET...



Udimet 500, a superior alloy proven by extensive high temperature applications, is now available in sheet in production quantities for early delivery. It is produced in widths to 48″ by 144″ in length and in thickness down to .010″. The alloy combines very high stress rupture life with excellent ductility and fatigue resistance in the 1200°F to 1800°F ranges.

Many other vacuum induction melted alloys are also now marketed in sheet form by the Utica Metals Division.

New alloys are being developed at Utica for critical sheet application. We are interested in discussing uses for our sheet material where high tensile strength, corrosion resistance, high stress rupture life and electrical or magnetic properties are critical requirements.

The technical strength and experience of our organization, together with highly precise melting and inspection practices, enable us to guarantee absolutely consistent quality from heat to heat. Utica Metals Division, Kelsey-Hayes Co., Utica 4, N. Y.

UTICA METALS DIVISION OF **KELSEY-HAYES**

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ANNOUNCING TWO

SPACE TECHNOLOGY LABORATORIES, INC.

Space Technology Laboratories, Inc., previously a division of The Ramo-Wooldridge Corporation, became a separate company on October 31, 1958. Space Technology Laboratories will be directed by Lieut. Gen. James H. Doolittle, Chairman of the Board (after January 1, 1959); Dr. Louis G. Dunn, President; and Dr. Ruben F. Mettler, Executive Vice President. The other members of the Board of Directors are Robert F. Bacher, Head of the Division of Physics, Mathematics and Astronomy at the California Institute of Technology; James T. Brown, Vice President of the Mellon National Bank, Pittsburgh, Pennsylvania; and Samuel E. Gates, Attorney with the New York firm of Debevoise, Plimpton and McLean.

Space Technology Laboratories has the largest professional scientific and engineering staff in the nation devoted exclusively to Ballistic Missile and Space programs. STL is responsible for the systems engineering and technical direction of the Air Force THOR, ATLAS, TITAN, and MINUTEMAN ballistic missile programs. While it does not engage in production, STL performs experimental and analytical research projects in advanced space technology, including the fabrication and assembly of special equipment and the conduct of test programs. A recent example is the lunar probe project assigned to STL by the Air Force and the National Aeronautics and Space Administration.

Space Technology Laboratories, Inc., plans to maintain a combination of technical competence and organizational strength appropriate to its special and continuing role in the important national program of space weapons development.

SPACE TECHNOLOGY LABORATORIES, INC.

5730 Arbor Vitae Street
Los Angeles 45, California

Thompson Ramo Wooldridge Inc.

On October 31, 1958, **Thompson Ramo Wooldridge Inc.** was formed by the merger of *Thompson Products, Inc.,* and *The Ramo-Wooldridge Corporation.*

Thompson Ramo Wooldridge will be directed by J. D. Wright, Chairman of the Board; Dean E. Wooldridge, President; Simon Ramo, Executive Vice President; and F. C. Crawford, Chairman of the Executive Committee. The other members of the Board of Directors are B. W. Chidlaw, A. T. Colwell, J. H. Coolidge, H. L. George, R. P. Johnson, and H. A. Shepard. Each is a Vice President of the merged company.

Thompson Products, Inc., has been for many years a large manufacturer of components and accessories for the automotive and aircraft industries. In recent years, it has also been active in the fields of Missiles, Electronics, and Nuclear Energy. Thompson has concentrated on products which require a high level of competence in engineering and precision manufacturing.

The Ramo-Wooldridge Corporation was organized five years ago to conduct research, development, and manufacturing operations in the field of electronic and missile systems having a high content of scientific and engineering newness. In addition to the work performed by Space Technology Laboratories, Inc., Ramo-Wooldridge has been engaged in major systems work in such areas as digital computers and control systems, communications and navigation systems, infrared systems, and electronic countermeasures.

The merger of the two companies into Thompson Ramo Wooldridge Inc. is intended to provide an integrated team having strong capabilities for scientific research, engineering development, and precision manufacturing.

Thompson Ramo Wooldridge Inc.

Main Offices • Cleveland 17, Ohio
Los Angeles 45, California

LETTERS

Sirs:

May I suggest that also the humble coincidences of "The Creative Process" about which J. Bronowski writes in your September issue be duly recognized? When Gilbert Murray in his famous address "Religio Grammatici" (1918) set out to distinguish between creation and invention he used these examples:

"The invention of the . . . telephone is a fine achievement of man. . . . If we take on the other hand the . . . creation of Romeo and Juliet. . . ."

Dr. Bronowski, setting out to make the same distinction, wrote:

"I have used . . . invention and creation. . . . Alexander Graham Bell invented the telephone. . . . By contrast we feel that Othello is genuinely a creation."

HANS ZEISEL

Professor of Law and Sociology
The Law School
University of Chicago
Chicago, Ill.

Sirs:

I enjoyed your September issue very much and found the articles, particularly those by J. C. Eccles, Frank Barron and J. Bronowski very stimulating.

However, I would like to take excep-

Scientific American, December, 1958; Vol. 199, No. 6. Published monthly by Scientific American, Inc., 415 Madison Avenue, New York 17, N. Y.; Gerard Piel, president; Dennis Flanagan, vice president; Donald H. Miller, Jr., vice president and treasurer.

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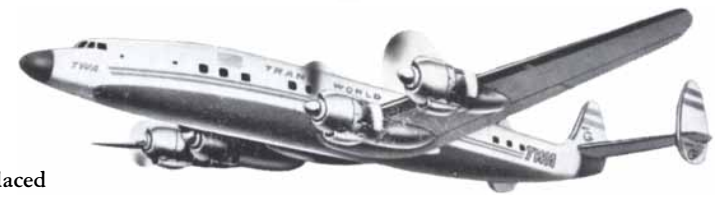
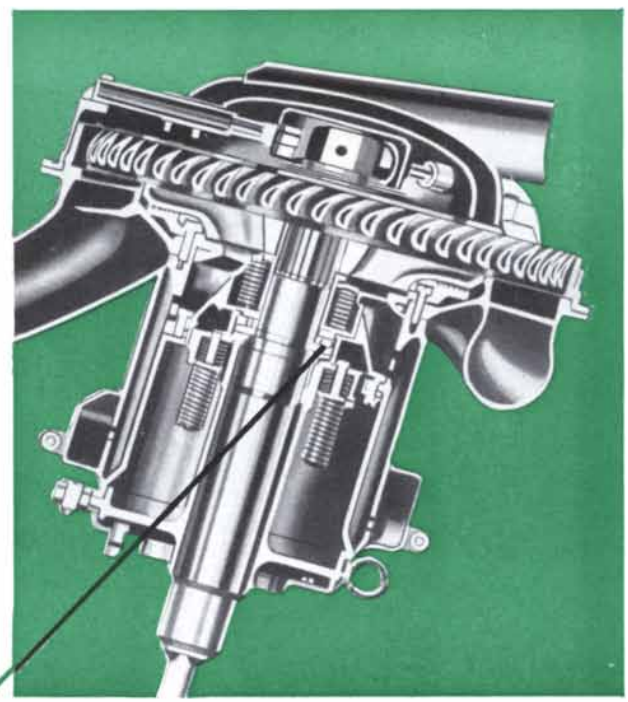
GRAPHITAR® OIL SEALS PLAY

IMPORTANT PART IN DEPENDABLE PERFORMANCE OF NEW POWERFUL CURTISS-WRIGHT TURBO COMPOUND ENGINES

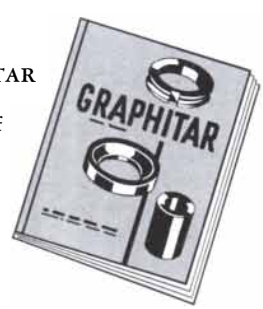


Increased demand for faster non-stop service has placed great demands on the engines that power modern airliners. Helping to meet this need is the powerful EA Series Turbo Compound engines built by the Wright Aeronautical Division of the Curtiss-Wright Corporation, Wood-Ridge, New Jersey. In each of these 18-cylinder giant engines, 3 GRAPHITAR oil seals play an important part in maintaining the dependability, efficiency and power. Three power-recovery units are employed on the Turbo Compound to utilize normally wasted exhaust gases and provide still additional thrust. The GRAPHITAR seals are used on the turbine shaft in each of these units and must withstand continuous high speeds and high temperatures. These seals prevent hot gases from reaching the shaft bearings and carbonizing the lubricant. Low coefficient of friction, and the excellent wear and sealing properties of GRAPHITAR make it ideally suited for this demanding installation.

Compacted under extreme pressure, and fused at heats to 4500° F., GRAPHITAR can be formed into relatively complex shapes, ground to tolerances as close as .0005″. Since it is entirely self-lubricating, GRAPHITAR can be used where only steam or water are present. GRAPHITAR is lightweight, durable, chemically inert and virtually unaffected by extremes of vibration, pressure, or temperature.



Get the fact-filled GRAPHITAR engineering Bulletin No. 20. Write today for your copy. If you have design questions on problems, our engineering staff will be happy to assist you in any way possible.



R-248-1

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tion to a portion of the Bronowski article. On page 62 he refers to "the principle of choice . . . Occam's Razor: we choose, among the theories which fit the facts we know now, that one which is simplest."

This is not an accurate statement of Occam's (or Ockham's, if you prefer) rule. The chosen theory is not the simplest but the one which makes the fewest assumptions. ("Entia non sunt multiplicanda praeter necessitatem.")

The fewer assumptions made, the less testing has to be applied to the theory before it may be tentatively accepted as the proper description of the universe-subject to future amendment, or rejected.

Bronowski then uses the Copernican theory as an example of a non-simple theory (to others) which appealed to Copernicus because of its "esthetic sense of unity." This may have been its appeal to Copernicus (I find no information on this point to confirm or deny Bronowski's statement) but the appeal to others who came to accept it appears to have been somewhat different.

By postulating a non-geocentric system and a rotating earth, Copernicus eliminated the tremendously complicated system of epicycles which had been introduced to make the Ptolemaic theory function.

And I submit, if any theory had esthetic appeal to the human mind, it was the comforting one which placed the earth at the center of creation.

ARTHUR W. SEAR, JR.

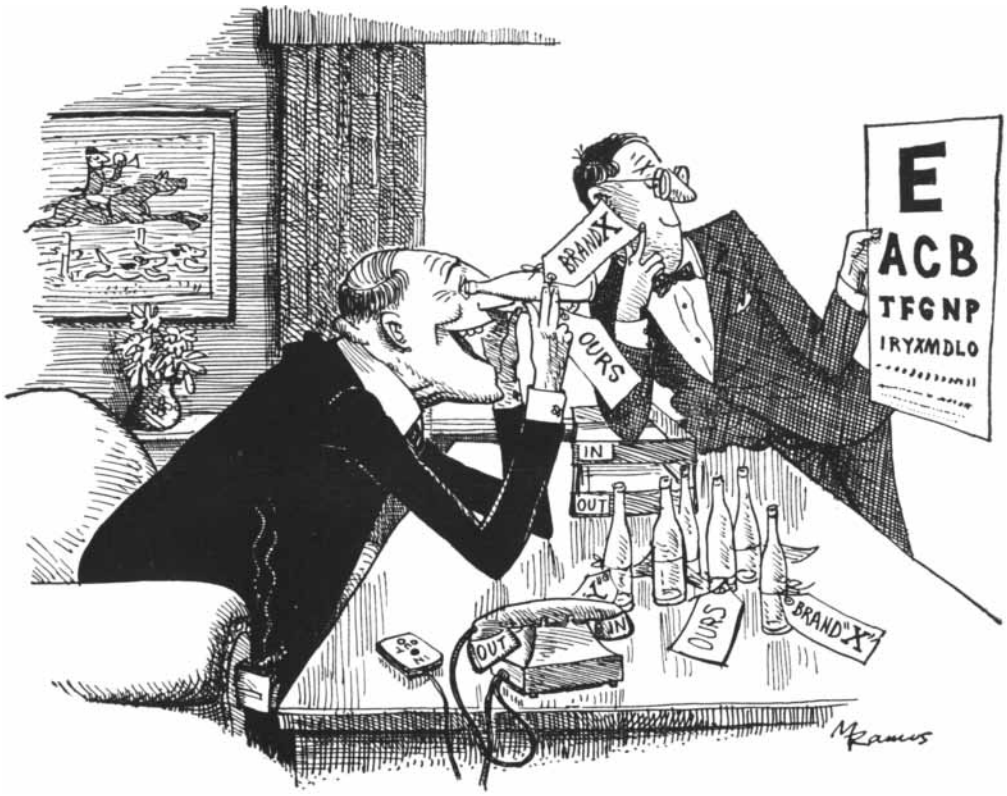
Arcadia, Calif.

Sirs:

Martin Kamen's clear "A Universal Molecule of Living Matter" in *Scientific American* for August might have added a neat fillip by reference to the commercially important and very closely related blue and green phthalocyanine synthetic organic pigments, discovered and developed by R. P. Linstead and his co-workers in 1932. The essential differences are that in the natural porphyrins, the pyrrole units do not carry benzene nuclei and are connected to one another by methine groups rather than nitrogen atoms.

GEORGE W. INGLE

Research Department
Plastics Division
Monsanto Chemical Company
Springfield, Mass.



The Perfect Solution:

(it really sparkles)

"Try this simple eye test Bradshaw," requested Smathers, the stately soft drink scion. "It'll prove to you that our bottles aren't as clean as theirs."

"Now let's see," replied Bradshaw, the blue-blooded bottling baron, "I hold their bottle up to my right eye and our bottle to my left and . . . you're right Smathers I can see through theirs much better."

"Sure, our research department tells us it's the Pfizer GLUCONATES in their washing solution that makes the difference—eliminates haze and rust spots. It also helps reduce maintenance costs by preventing rust and scale on washer equipment."

"You know, Smathers, Pfizer GLUCONATES sure can clean up the bottle-washing picture."

★ ★ ★ ★ ★ ★ ★ ★ ★ ★ ★ ★

For really sparkling bottles combined with highly efficient washing operations you should be sure you have Pfizer GLUCONATES in your washing solution. If you are confronted with a bottle washing problem or any other problem which might be solved by a high-quality organic chemical, think of Pfizer first. Chas. Pfizer & Co., Inc., Chemical Sales Division, 630 Flushing Avenue, Brooklyn 6, N. Y.

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. . . sells more than 100 organic chemicals for food, medicinal and industrial uses.

Some bulk products of this Division are:

CITRIC, TARTARIC, OXALIC ACIDS AND SALTS • ASCORBIC ACID AND OTHER VITAMINS • CAFFEINE • ANTIBIOTICS • PLASTICIZERS

The electron and

the raindrop

How many electrons would you guess there are in a raindrop?

There are more electrons in a *single raindrop* than there are raindrops in all the rain that falls on the United States in an *entire year.**

These incredibly small electrically-charged particles exist in everything—in the air you breathe, the water you drink, the ground you walk on...in *you.* Radio, television, all of today's electronic miracles are based on the simple fact that the behavior of electrons can be controlled.

Electronics—the science of controlling electrons—is our business at HUGHES. Over 5,500 HUGHES scientists and engineers develop and manufacture better devices utilizing the behavior of electrons.

We make semiconductor devices, which are used in miniaturized electronic circuits because of their tiny size and unlimited life. We make specialized electron tubes which display and store information in the form of letters, pictures or graphs. We make control systems which automate industrial machines and processes. In addition, we make specialized relays and switches, crystal filters, and oscilloscopes.

If you manufacture or use electronic equipment, chances are that you are using Hughes systems or components. These highly reliable products are backed by a huge force of engineering brain power which is available to you.

This Hughes engineer, shown growing a silicon ingot, is part of the team of engineers and scientists who are continually probing the frontiers of advanced electronics.

*There are about 1.4 sextillion (1,400,000,000,000,000,000,000). If you're interested in the computation of this statistic, just write: HUGHES PRODUCTS, International Airport Station, Advertising Dept., Los Angeles 45, California.

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HUGHES PRODUCTS

50 AND 100 YEARS AGO

SCIENTIFIC AMERICAN

DECEMBER, 1908: "The latest awards made by Nobel's representatives seem to be fair. Metchnikoff and Ehrlich receive conjointly the prize for valuable contributions to medicine. Of the two, the former is better known. A disciple of Pasteur, he has devoted much time to bacteriological research. His studies of the possibility of postponing old age have recently attracted attention to his work. Rutherford, who won the chemistry prize, is well known to our readers as an ardent and painstaking student of the phenomena presented by radium."

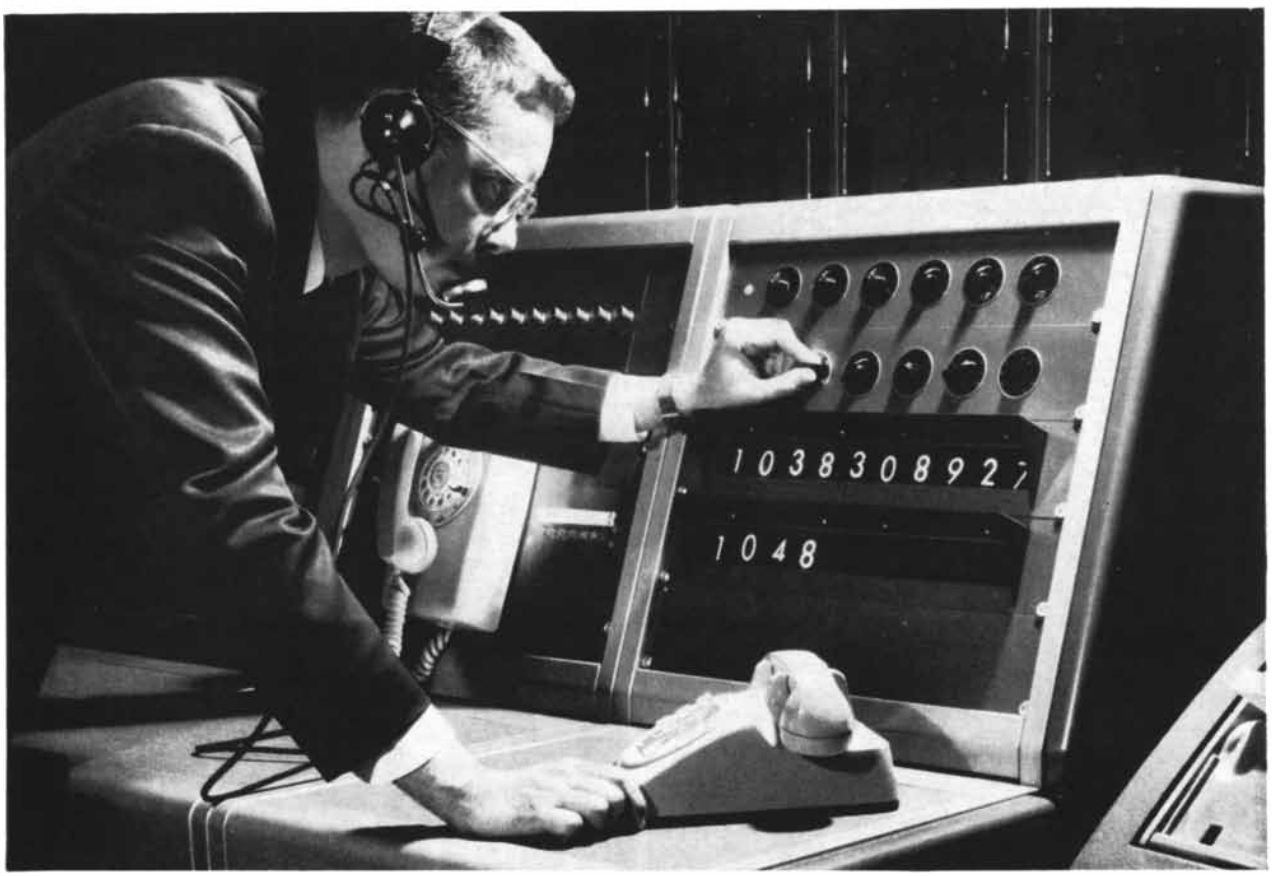
"Mme. Curie, who with her husband, the late Prof. Curie, discovered radium, has been appointed Chief Professor of Physics in the Faculty of Sciences, University of Paris. Mme. Curie succeeds her husband in the professorship held by him at the time of his death."

"The War Department has considered the advisability of immunizing soldiers against typhoid fever by vaccination. It has decided that inoculation as a preventive against typhoid has been so thoroughly demonstrated in foreign countries and its efficacy so well established that the vaccination method is to be adopted in the United States Army."

"Dr. Alexander Graham Bell's Aerial Experiment Association is busily engaged conducting a test of Dr. Bell's tetrahedral-cell aeroplane, which he has constructed at his summer home near Baddeck, on Cape Breton Island, Nova Scotia. A year ago the late Lieut. Selfridge made a successful ascent in the former aeroplane of this type, which had 3,392 tetrahedral cells. The present aeroplane has 5,000 cells and a spread of 42.65 feet. The machine will be tested by towing as a kite above Bras d'Or Lake by means of two powerful racing motorboats."

"The plans of the Pennsylvania Railroad Company for establishing a large terminal station for their system in the center of Manhattan Island and connect-

MECHANIZED ORACLE EXPLORES BELL SYSTEM COMMUNICATIONS



At monitoring console, designer H. D. Irvin watches performance of "Sibyl" during test of user-reaction to experimental telephones. A computer-like machine, Sibyl simulates the functions of future communications devices and records interplay between phones and users. Sibyl is named after the women oracles of ancient Greece.

A mechanized "oracle" is helping Bell Telephone Laboratories predict the future in communications devices and systems.

The oracle is "Sibyl," a computer-like machine developed by Bell Laboratories engineers and psychologists. It can simulate the action of many kinds of communications devices. Through Sibyl, new kinds of telephone service can be evaluated without the considerable expense of building actual equipment. Observing and recording users' reactions to the simulated equipment, Sibyl provides indications of how users would react to proposed new systems features and equipment.

Sibyl, for example, is used to test the reaction of Bell Laboratories people to experimental push-button telephones. Each test subject has a push-button telephone in his office and he uses it in the ordinary course of his business. But the set is not connected directly to the local PBX: it is connected *through* Sibyl, which performs the special signaling functions required by such a push-button telephone. In this way, push-button telephone service is given to a group of people without modifying the PBX, or providing completely instrumented push-button telephones.

At the same time, Sibyl gathers information on how the call was placed—date, time, originator, speed of operation, errors, whether the line was busy or the call completed. Sibyl does all this without violating the privacy of telephone conversations.

Bell engineers expect that Sibyl will provide a better understanding of the relationship between telephone equipment and the people who use it. Sibyl's rapid and economical technique for evaluating new types of telephone sets is an important contribution to the art of telephony.

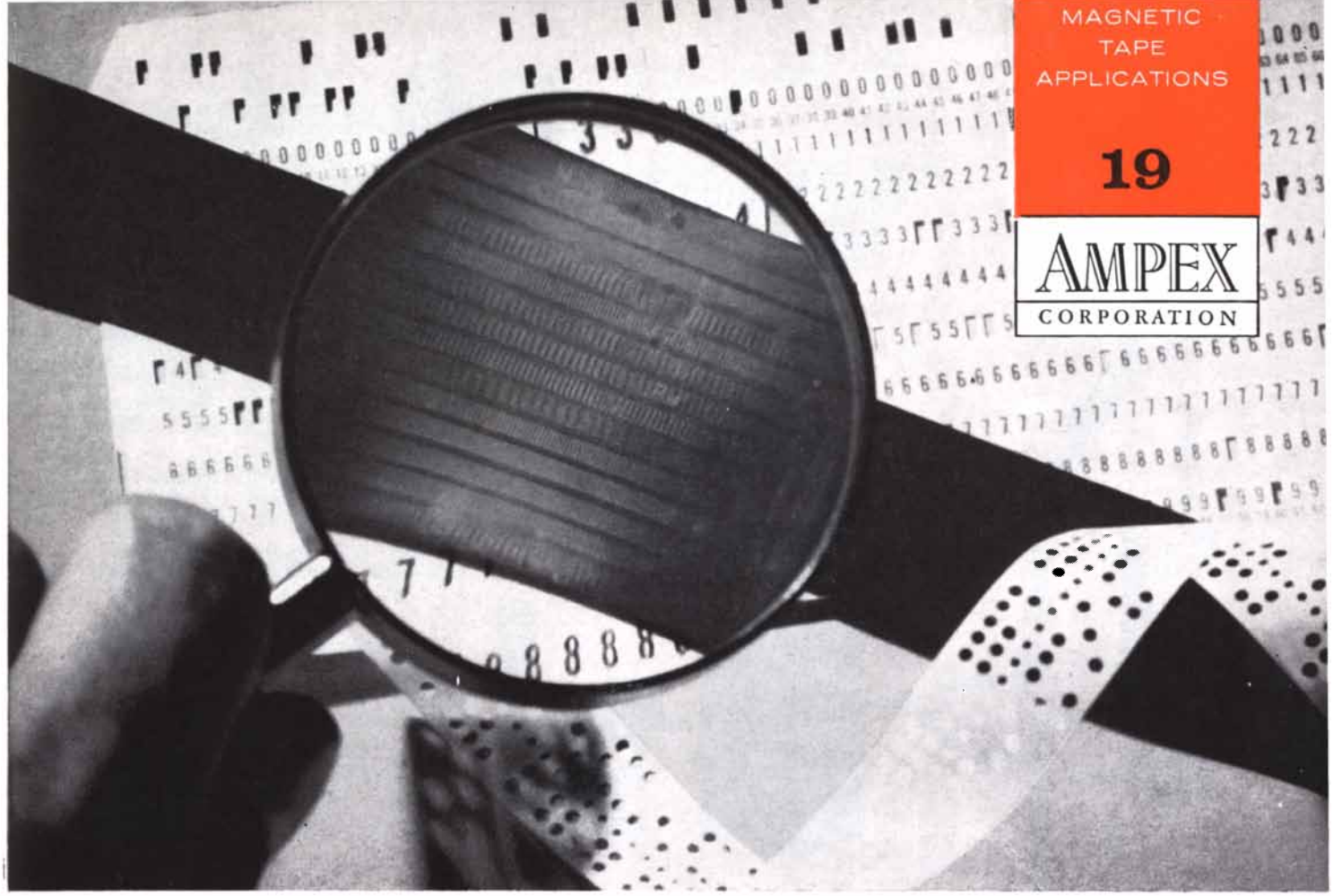
ing it with their trunk line to the West and with the extensive system of roads of the Long Island Railroad to the East, has involved the construction of 16½ miles of tunnels. The terminal area itself comprises 28 acres. The railroad was willing to forego the opportunity to erect a huge office building above the station site, and preferred to memorialize its entrance into New York City by the erection of a magnificent and purely classic structure, commensurate with the dignity of the great city in which it has at length found a fitting terminal. The architects of the building, McKim, Mead and White, took the baths of Caracalla in Rome as the inspiration of their plan."

"The recent trial of the British battleship *Invincible*, in which she attained, under reduced power, a speed of 25 knots, was followed by a full power trial in November, when she steamed at the unprecedented speed of 28 knots on a continuous run of eight hours' duration. This is certainly wonderful going for a ship protected with seven inches of armor and carrying a battery of eight 12-inch guns."

"In the Morris K. Jesup North Atlantic expedition it was found that in prehistoric times there was a distinct relation between the North American Indians and the tribes of Siberia. Dr. Waldemar Jochelson recently started from New York to supplement the information obtained at that time. There are at present only about 2,000 Aleuts in the Aleutian Islands, which belong to the United States, and in Komandorski, which is Russian territory. The race is rapidly dying out, and for that reason the investigations about to be made are considered of exceptional value."

"Prof. Otto Lehmann has discovered that many substances, on cooling after fusion, do not pass directly from the ordinary liquid to the crystalline solid condition but go through an intermediate stage in which they retain the external characters of liquids, which are revealed in the power to form drops and to assume the form of the containing vessel, and at the same time exhibit the internal optical characters of crystals. Lehmann has given the name of liquid crystals to these crystalline drops, and has collected a vast mass of experimental results in his study of this remarkable phenomenon."

"There has recently been brought to this country an optical mirror for the Mt. Wilson Observatory, said to be the larg-



When to use magnetic tape in automatic control

Iron dust and a magnifying glass provide a revealing visual comparison

You are seeing iron dust clinging to signals recorded on magnetic tape. There can be 3200 extremely reliable binary bits on one square inch—or analog control information similarly compact. In the compacting of automatic control data, magnetic tape is supreme—second only to nature's remarkable chromosome. Nature makes people, dogs, cats and monkeys. Magnetic tape recorders make, for example, machined parts—their shapes the most complex and precise that have ever been produced in quantity. It is done by numerical control. The principles involved are very widely applicable to all kinds of control applications. Three main criteria determine where magnetic tape is your best choice.

Criterion 1: QUANTITY OF CONTROL DATA

Any automatic control operation that can benefit from very large numbers of time-synchronized commands is a natural candidate for magnetic tape. For example, continuous-path control of a milling cutter may require X, Y and Z coordinates at several hundred points per inch of tool movement. The more points, the greater the accuracy. A reel of magnetic tape can define millions of points at extremely low unit cost.

Continuous real-time control of variables is applicable to process programming, simulation devices, automatic inspection and electronic-system checkout—provided there is need for great accuracy in a complex situation. The program tapes may incorporate the work of giant computers and intricate interpolating devices. A great advantage of magnetic tape is that the computer and interpolator are used only during tape preparation, hence may be shared with many other needs.

Criterion 2: HIGH TRANSFER RATE

The Ampex FR-300 digital tape handler can spew out alpha-numeric characters at rates as high as 30,000 to 90,000 per second. A short burst of digital information equivalent to a standard punched card can be extracted from magnetic tape under 4 milliseconds—including start and stop.

On analog position-control data, magnetic tape can provide many hundreds of complete commands per second—200 per second in one example and up to eight times this many if needed.

On control-system monitoring, a recording of as much as two hours duration can be played back in one minute for review by high-speed computers. Ampex tape recorders with overall speed ratios as high as 120-to-1 are available.

Criterion 3: ERASURE AND RE-RECORDING

Magnetic tape can be erased to accept new data an endless number of times. Hence tape-loop recorders can operate on a repetitive cycle of recording, reproduction, erasure and re-recording to serve as time-delay devices or endless monitors. Such a loop can be the analog equivalent of a production line, conveyor belt or process flow. The loop keeps in step, accepts sensing information at one place and then triggers commands at some fixed time downstream. Or as a calamity monitoring device, the tape loop stores information briefly and erases it to make way for new data if nothing has occurred.

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"Mr. Fox Talbot, the inventor of the well known 'paper process' of photography, and who, with a liberality seldom found, relinquished his patent (being a wealthy man), and threw his improvements open to the world, has just been inventing a new process of engraving by light on plates of copper, steel or zinc."

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"Considerable sensation was produced among iron manufacturers in 1856 by an invention called the 'Bessemer process,' which consisted in blowing air through the molten pig iron as it was run from the cupola furnace, by which action, it was stated, a portion of the carbon in the iron united with the oxygen of the air and was thus disengaged in the form of carbonic acid, whereby the metal was purified at one continuous operation and converted into good malleable iron and steel. Since that period reports have prevailed that the merits of the invention had been grossly exaggerated, in short, that it was a failure. Such reports seem to have recently met with a confutation from G. F. Goransson, a large manufacturer at Edsken, in Sweden. He uses a converting vessel situated near the taphole of the blast furnace, and into this he runs the fluid pig iron—one ton at a time—then lets in the blast to it for about seven minutes, by which action the iron is converted into steel. The whole time occupied, from the moment the fluid pig iron leaves the furnace until it is cast into the mold, does not exceed twelve minutes."

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g/cc	6.24
lbs/cu. in.	0.225
Electrical resistivity (microhm-cm)	
19.6°C (67.3°F)	200,000
Electrochemical equivalent	
Te++++++ (mg/coulomb)	0.22040
Index of refraction	
(vapor) 5893 Angstroms	1.002495
(solid) 3500 to 4000 Angstroms	
Parallel to plane of incidence	1.9 to 2.4
Perpend. to plane of incidence	1.7 to 2.7
Latent heat of fusion (cal/g at m.p.)	7.3
Latent heat of vaporization (cal/g at b.p.)	159
Linear coefficient of thermal expansion/°C	16.8×10^{-6}
Magnetic susceptibility	
cgs at 18°C (64°F)	Minus 0.31×10^{-6}
Mechanical properties	
Hardness (Mohs)	2.3
Modulus of elasticity, psi	6,000,000
Melting point	449.5°C ± 0.3°
Molecular weight, 2100°C (3812°F)	160
1880°C (3416°F)	265
Nuclear Data	
Stable Isotopes (120, 122, 123, 124, 125 126, 128, 130)	8
Thermal neutron cross section (2200 m/s)	
Absorption (barns)	4.5 ± 0.2
Scattering (barns)	5 ± 1
Specific heat (cal/g/°C) (solid)	0.047
Specific volume (cc/g) 20°C (68°F)	0.1603
Thermal conductivity (cal/sq. cm/cm/°C/sec)	
20°C	0.014
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THE AUTHORS

GERALD W. JOHNSON and HAROLD BROWN ("Non-Military Uses of Nuclear Explosives") are physicists at the University of California's Radiation Laboratory in Livermore, Calif. Johnson comes from Spangle, Wash., and studied physics at Washington State College. During World War II he worked for the U. S. Navy on armor and armor-piercing projectiles. After receiving a Ph.D. from the University of California, he taught for two years at Washington State, then joined the staff of the Brookhaven National Laboratory to work on neutron physics. Since 1951 Johnson has been studying the effects of nuclear explosions, first for the Department of Defense in Washington, D.C., and more recently at Livermore, where he is Test Division Leader. Brown, who was an adviser at the Geneva discussions on nuclear-test detection this year, is associate director of the Livermore laboratory. A graduate of New York's Bronx High School of Science and a Columbia University Ph.D., he joined the laboratory at its founding in 1952.

S. MERYL ROSE ("Feedback in the Differentiation of Cells") says "I became an experimental biologist because I happened along at Amherst College when three very able biologists—Otto C. Glaser, Harold H. Plough and Oscar E. Schotté—were making the practice of their science seem to several young men more desirable than any other way of life." Now a professor of zoology at the University of Illinois, Rose has taught at Amherst, Columbia University (where he received his Ph.D. in 1939) and Smith College. He is a trustee of the Marine Biological Laboratory in Woods Hole, Mass., and has spent some 16 summers there.

JAMES P. GORDON ("The Maser") was associated with C. H. Townes in the making of the first maser [see "Atomic Clocks," by Harold Lyons; SCIENTIFIC AMERICAN, February, 1957]. Gordon, then a graduate student under Townes at Columbia University, was especially concerned with investigating the properties of the ammonia molecule, which was the basic amplifying element of the early masers. Gordon comes from Scarsdale, N.Y., and is a graduate of the Massachusetts Institute of Technology. Upon receiving his Ph.D. from Columbia in 1955, he joined the staff of the Bell Telephone Laboratories, where he has worked on ammonia masers and on questions of physics underlying the operation of solid-state masers.

KONRAD Z. LORENZ ("The Evolution of Behavior") is perhaps best known in the U. S. as the author of two entertaining works on animal psychology: *King Solomon's Ring* and *Man Meets Dog*. Born in Vienna, he is a son of Adolf Lorenz, a well-known orthopedic surgeon. Lorenz followed in his father's footsteps by acquiring an M.D. degree from the University of Vienna. In 1928 he became an assistant in the University's anatomical institute and four years later acquired a second doctorate, this time in zoology. After several years as lecturer in comparative anatomy and animal behavior, Lorenz left Vienna in 1950 to head the department of psychology at the University of Königsberg. He now serves on the scientific council of the Max Planck Society for the Advancement of Science and is vice-director of the Max Planck Institute of Comparative Ethology.

RICHARD D. KEYNES ("The Nerve Impulse and the Squid") is a physiologist at the University of Cambridge, where his undergraduate career was interrupted by five years of wartime radar research for the British Admiralty. Returning to Cambridge to take his A.B. and Ph.D. degrees, he became a fellow of Trinity College and entered on a long collaboration with his fellow physiologist (and radar expert) A. L. Hodgkin. Keynes is now a university lecturer and fellow of Peterhouse College. He is married to a daughter of Lord Adrian, the noted Cambridge physiologist. Keynes himself comes from one of England's most distinguished scientific families. His father is Sir Geoffrey Keynes, surgeon and bibliographer of John Donne, Jane Austen and William Harvey. The economist John Maynard Keynes was his uncle, and (on his mother's side) he is a great-grandson of Charles Darwin.

BRIAN HOCKING ("Insect Flight") is professor of entomology at the University of Alberta. Born in England, he was trained at Christ's Hospital (the "Blue Coat School") and the University of London, where he studied natural sciences—especially entomology—and won the Murchison Medal for geology. Upon graduating in 1937, he married, took a two-week training course at the British Cast Iron Research Association and be-

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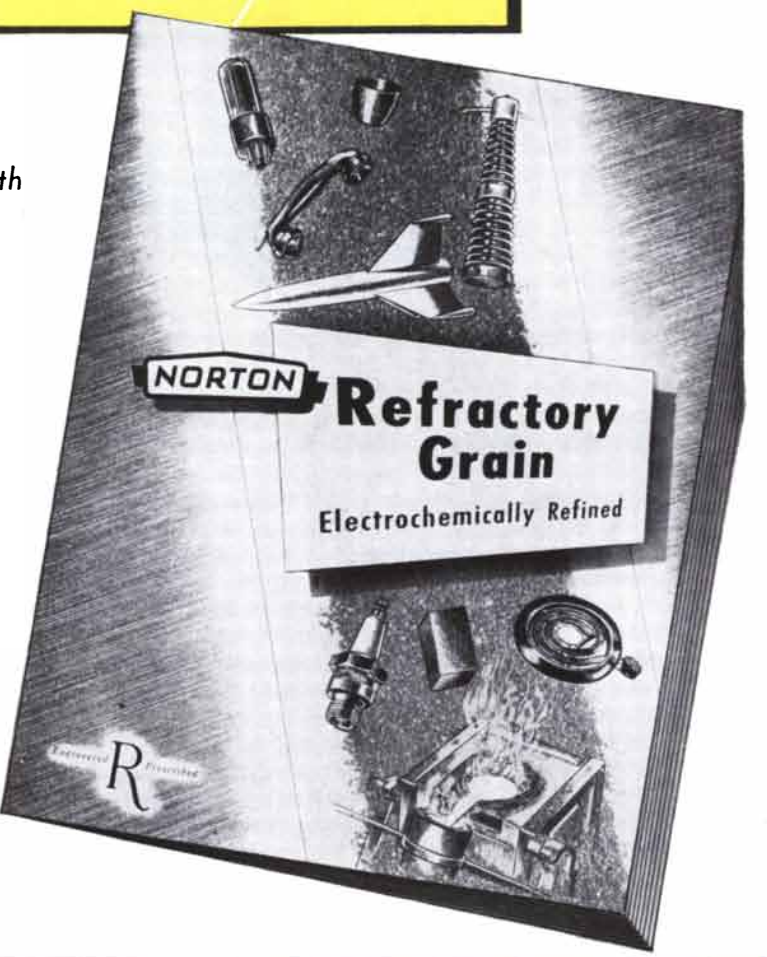

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came a ferrous metallurgist in India. Hocking spent some of the war years there as a science teacher. Later, as a major in the Indian Army, he tried to organize systematic insect control to protect Allied stores throughout the Southeast Asia Command. At the end of the war he fixed upon western Canada as the best possible place to bring up his three children. He joined the entomology department at Alberta and, excepting time out for a University of London Ph.D., he has been there ever since.

DAVID HAWKINS ("Mathematical Sieves") says that the "unifying thread, if there is one," of his diversified career is "an interest in applied mathematics and scientific methodology." Hawkins graduated from Stanford University and received his Ph.D. from the University of California in 1940. "In college I was a chemist who drifted through mathematics to philosophy," he says. "My real concern with mathematics started when I was a graduate student in philosophy and was working on the theory of probability and its foundations. After getting my degree I taught briefly at Stanford and Berkeley and then in 1943 went to Los Alamos. There I was a minor administrative figure until early 1945 when I was given the job of project historian."

SANFORD ROSENTHAL ("Wound Shock") has for 30 years headed the laboratory of pharmacology in the National Institute of Arthritis and Metabolic Diseases. A native of Georgia, he acquired an M.D. in 1920 from Vanderbilt University, then interned at Boston City Hospital and was a National Research Fellow at Johns Hopkins University. Rosenthal taught at McGill University from 1924 to 1928.

ROBERT R. WILSON, who reviews Robert Jungk's *Brighter than a Thousand Suns* in this issue, is currently working for the General Atomic Corporation in San Diego, Calif., on leave of absence from Cornell University, where he is professor of physics and director of the Laboratory for Nuclear Studies. In reviewing Jungk's book on the history of the atomic scientists, Wilson—like Aeneas—speaks of "deeds mine eyes have beheld, and whereof I was no small part": he headed the Experimental Nuclear Physics Division at Los Alamos and was chief administrator of the wartime community. A fuller account of his career may be found in the March issue of SCIENTIFIC AMERICAN, in connection with his article "Particle Accelerators."

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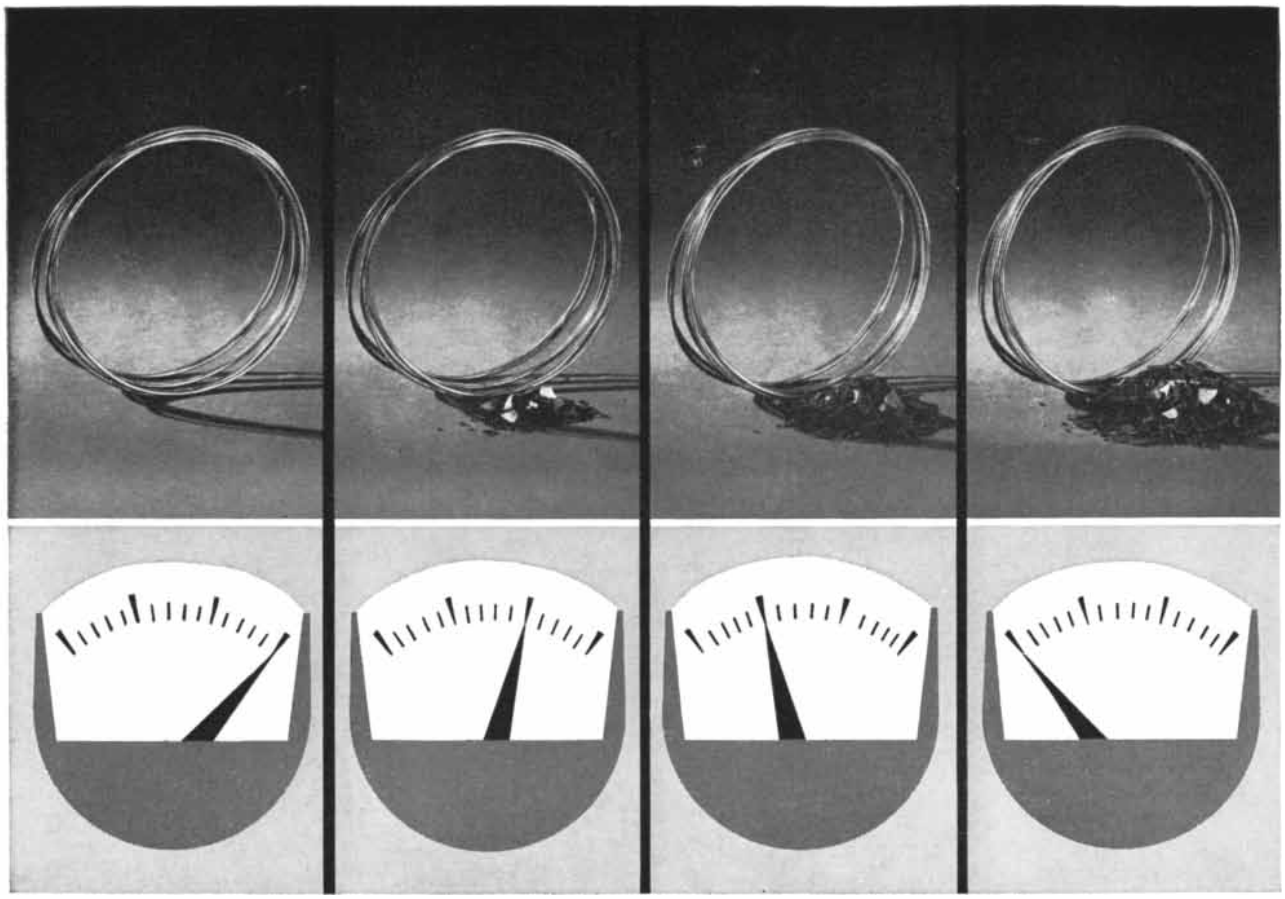

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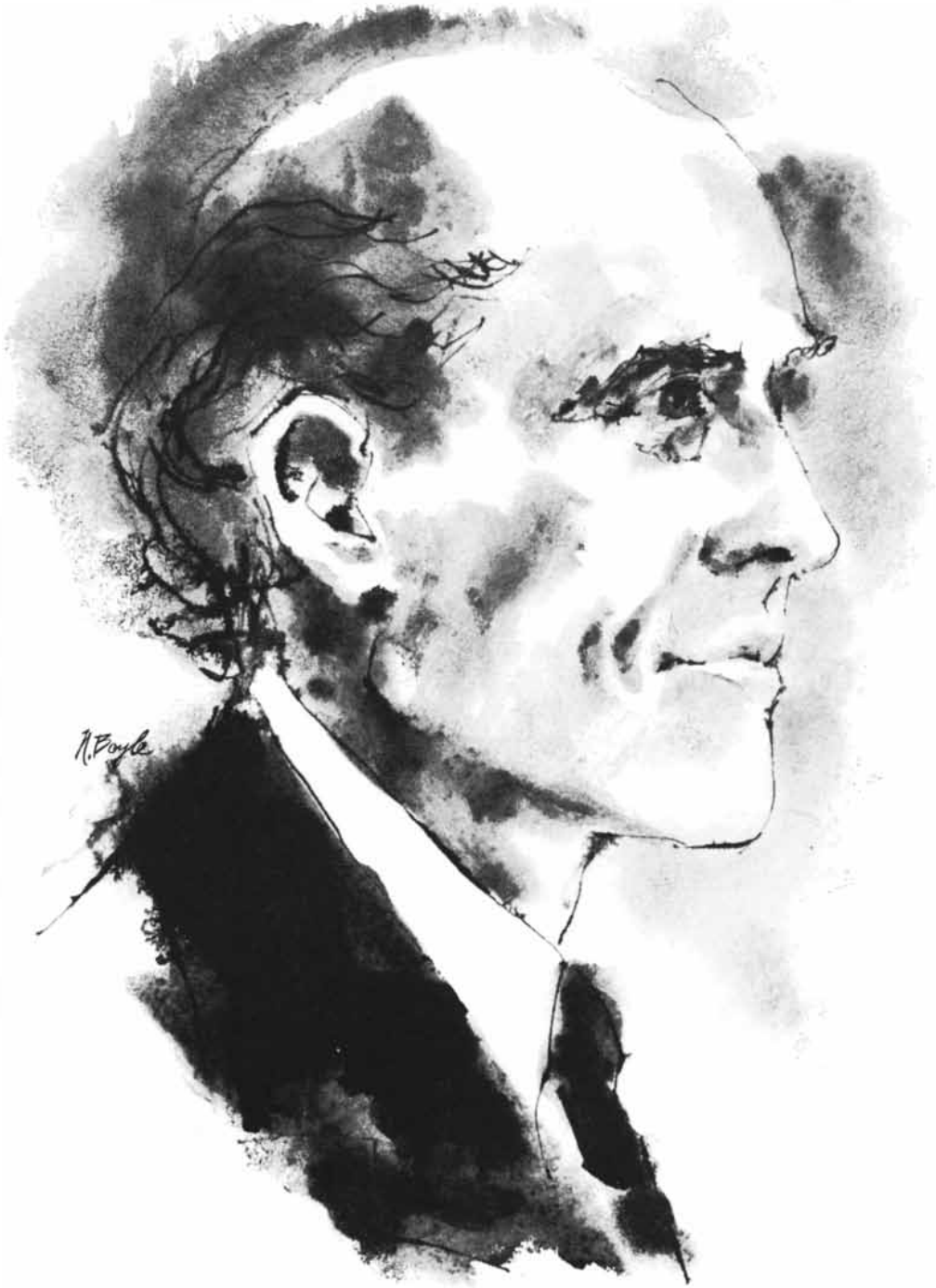

Karl Pearson...on mystery versus ignorance

"Does science leave no mystery? On the contrary, it proclaims mystery where others profess knowledge. There is mystery enough in the universe of sensation and in its capacity for containing those little corners of consciousness which project their own products, of order and law and reason, into an unknown and unknowable world. There is mystery enough here, only let us clearly distinguish it from ignorance within the field of possible knowledge. The one is impenetrable, the other we are daily subduing."

—*Grammar of Science, 1892*

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Established 1845 SCIENTIFIC AMERICAN December, 1958 Volume 199 Number 6

Non-Military Uses of Nuclear Explosives

Research under the Plowshare program seeks constructive use for nuclear detonations. Underground explosions may be used for power production and mining; surface explosions may excavate harbors

by Gerald W. Johnson and Harold Brown

The nuclear reactor has become a symbol of the constructive uses of atomic energy; the nuclear bomb, a symbol of destruction. What peaceful end could ever be served by a nuclear explosion? In answering this question, let us reflect a moment on the precedent of an earlier expansion in the violence of explosives available to man's use. The fixation of atmospheric nitrogen, at the turn of the century, made possible the unlimited manufacture of chemical explosives for two world wars. But the fixation of nitrogen also relieved mankind of the prospect of nitrogen starvation. Synthetic fertilizers were regarded as the "good" side of this advance in science and technology; explosives, as the "bad." Yet it is not hard to think of peaceful and constructive uses for chemical explosives. In fact, the tonnage of these explosives consumed in mining and heavy construction now aggregates more than has ever been used for military purposes. Is it really impossible to conceive of such constructive uses for nuclear explosives?

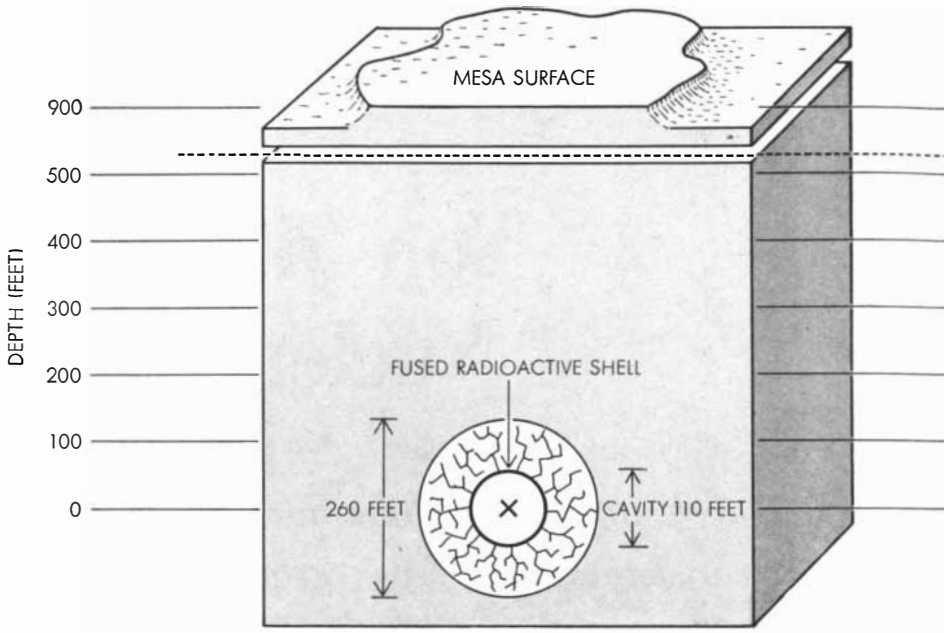
Engineers have been setting ever larger charges of dynamite in recent years to accomplish more daring objectives more quickly and cheaply. The biggest so far on record is the 1,300-ton charge detonated last year in the Ripple Rock explosion, which removed a large, dangerous rock from an inland waterway near Vancouver, B.C. It is reported that the Chinese have used up to 10,000 tons in a single explosion for mining purposes. The biggest chemical explosions begin to approach the minimal nuclear explosion. With thermonuclear explosives we can think of undertaking projects 100 to 1,000 times larger than engineers have contemplated in the past. Indeed, the Soviet press has reported that nuclear explosions have been employed to "move mountains" in that country; no technical accounts, however, have been published to substantiate these claims.

In the U. S. the constructive uses of nuclear explosions are being actively explored, under the Plowshare program of the Atomic Energy Commission, by our group at the Livermore branch of the University of California Radiation Laboratory. In September, 1957, the detonation of a nuclear charge equivalent to 1,700 tons of TNT under a mesa in Nevada (Operation Rainier) demonstrated that a nuclear explosion could be successfully contained underground. Since then drilling and tunneling of the site has given us solid evidence to support our expectations of the constructive possibilities of such an explosion. The most recent series of nuclear weapons tests in Nevada, ending on the eve of the Geneva negotiations that look to the cessation of tests, included five underground shots in the energy-release range from 100 to 20,000 tons. The evaluation of these explosions promises to broaden the foundation for proceeding next to underground nuclear explosions designed for specific engineering purposes. In addition, the Plowshare program has been exploring the feasibility of large-scale excavation by surface and shallowly buried explosions. On the remote northwest coast of Alaska, if all goes well, nuclear explosives will excavate a new harbor by way of demonstration and experiment sometime in 1960. It is not too much to say that we are on the verge of a new period of "geographical engineering."

In defining the U. S. position on the discussion at Geneva, President Eisenhower proposed that the Plowshare experiments be exempted from any agreement to suspend the testing of nuclear weapons. These experiments, it has been announced, will be open to observation by invited representatives of other nations and their results will be fully disclosed through the scientific press.

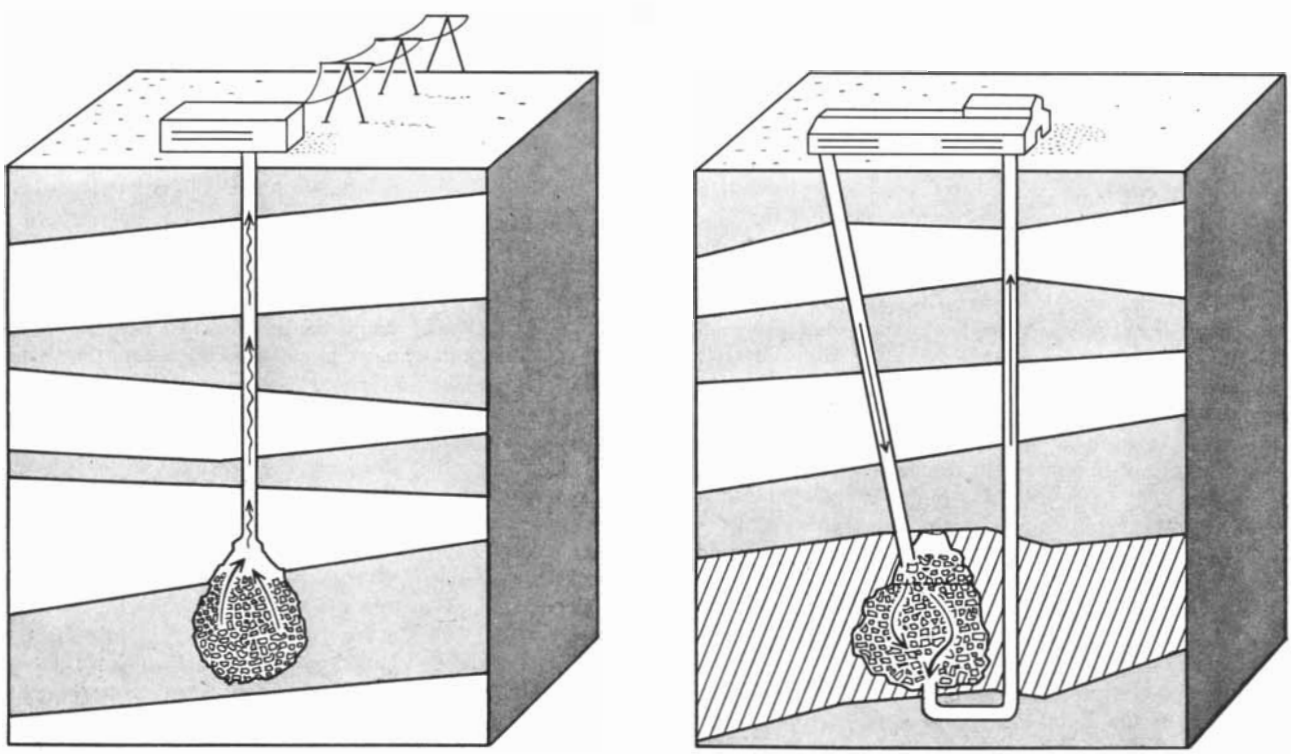
The reconstructed history of the Rainier explosion provides a vivid picture of what happens when the enormous energy of a nuclear explosive is contained within the earth. The charge was placed in a small chamber at the end of a 1,600-foot tunnel which spiraled in on its objective in a manner such that the upheaval of the explosion would seal it off. In its first instants the explosion melted and vaporized some 700 tons of

rock. The small chamber inflated to a hollow cavity 110 feet in diameter enclosed in a four-inch-thick shell of liquefied rock, which dripped from the ceiling in stalactites and condensed in glassy "raindrops" as it fell. The peak pressure of six million atmospheres developed in the cavity is indicated by the compression of this shell; samples of the fused rock expanded many times in volume when heated in the laboratory. As an assurance of the safety of future underground explosions, it was found that almost all of the radioactivity was concentrated in this hard, insoluble material. About one minute after the explosion the ceiling of the cavity collapsed under the burden of the tons of crushed and broken rock above it; successive caving produced a "chimney" which ran upward several hundred feet through the rock toward the top of the mesa. The shock of the detonation and the collapse of the shell together produced a large permeable region comprising at least 200,000 tons of material. Calculations based upon cores and tunnels drilled into the site show that about 50 per cent of the total energy of the explosion was transferred in heat to the surroundings. The large volume of water, trapped in the porous volcanic rock, quickly redistributed the heat to the masses of cold rubble surrounding the cavity, and the tremendous initial temperatures were reduced to the boiling point of water.

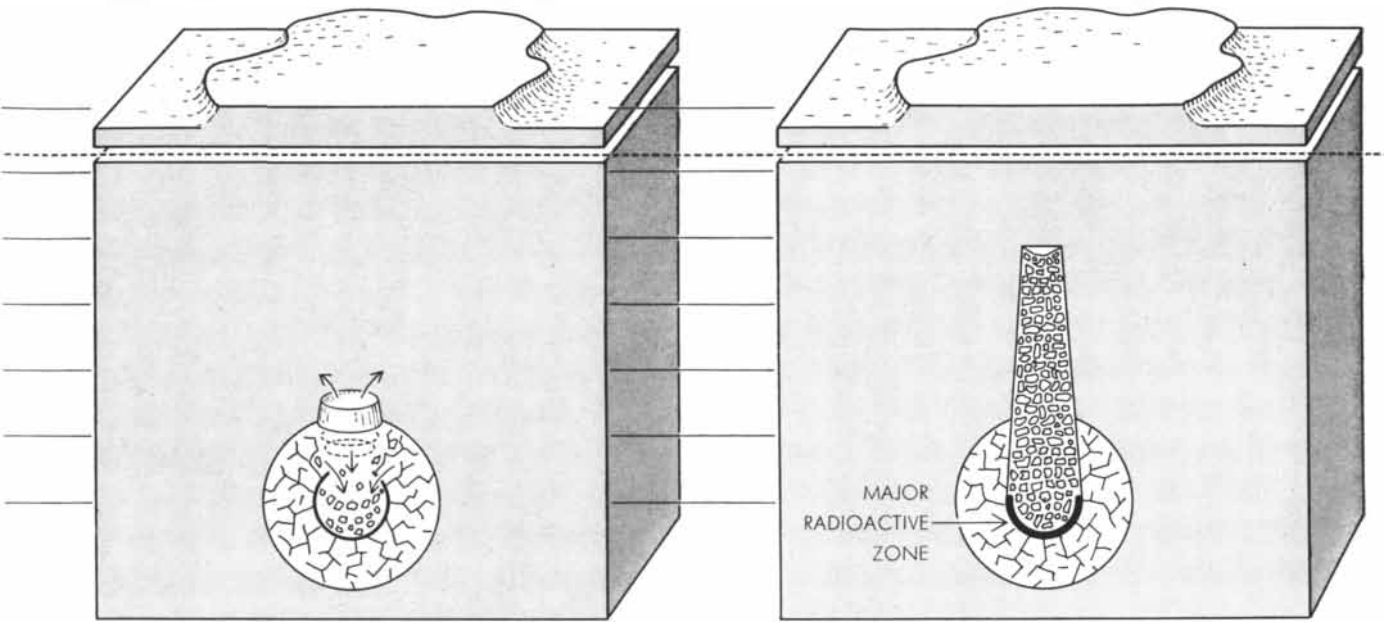


UNDERGROUND NUCLEAR EXPLOSION under a Nevada mesa (Operation Rainier) is shown in three stages. In its first instants (*left*) the explosion melted some 700 tons of

The first industrial possibility suggested by this experiment is that of electrical power production. On preliminary calculation, the economics of this route to nuclear power is so attractive that a number of large power companies are conducting studies along with our own. For maximum yield, the energy of the explosion must be trapped at the highest possible temperature. In the Rainier explosion at least half of the energy was

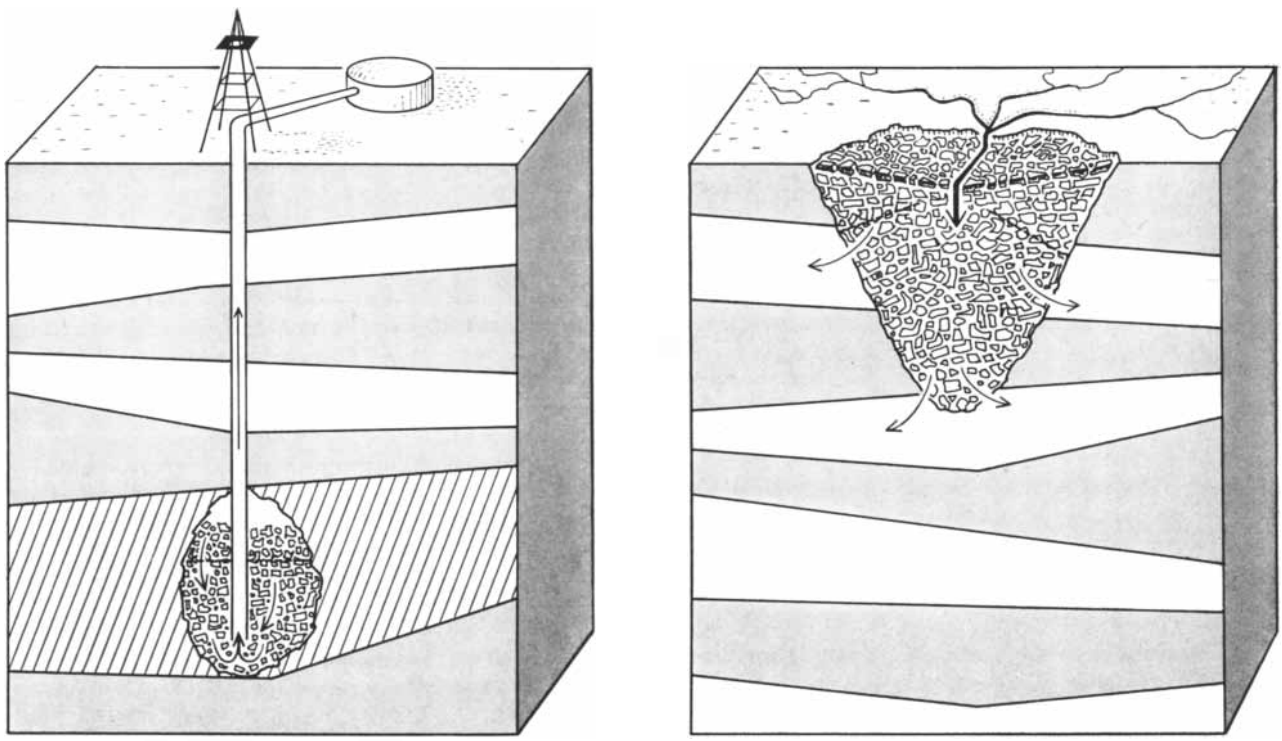


POSSIBLE INDUSTRIAL APPLICATIONS of nuclear explosions are illustrated. The heat of the explosion, trapped underground, may be converted to electricity by percolating a heat-transfer agent through the shattered rock (*left*). To extract minerals a leaching

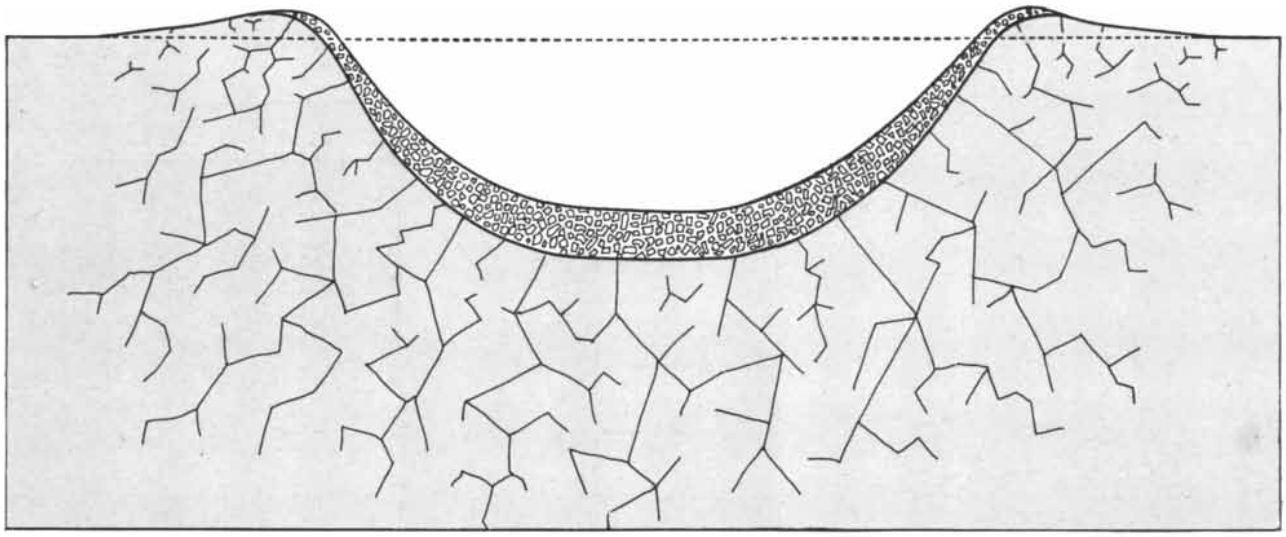


rock and compressed it in a four-inch shell enclosing a cavity 110 feet in diameter. After one minute (*center*), the roof of the cavity caved in under the burden of fractured rock. The cave-in then continued (*right*), running a "chimney" upward in the formation.

released as heat at an initially high temperature, but the energy was quickly dissipated to the rubble of the collapsing cavity by the large quantity of water in in the rock. Workers in the field have proposed numerous ways to avoid this rapid heat dissipation. One calls for the construction of a cavern (or the location of a suitable natural cavern) that would survive the explosion. The cavern would have to be large enough to permit attenuation of the shock wave of the explosion before it strikes the walls. High-pressure steam or other gas, contained in the cavern, would be heated directly by passage of the shock. The shock wave of a 100-kiloton explosion in a chamber with a radius of 1,000 feet would exert an initial pressure of 600 pounds per square inch at the wall; this would be multiplied at least twice upon reflection



agent may be percolated through a shattered ore bed (*second from left*). An explosion in an oil-shale bed may shatter the shale for retorting (*third from left*). An explosion nearer the surface (*fourth*) may create a huge underground water-storage reservoir.



NUCLEAR EXPLOSION ON DRY LAND produced a crater of this proportion. The one-kiloton bomb was buried at a depth of about 50 feet. It blasted a crater some 300 feet in diameter and some 90 feet deep. The crater was partly filled in with its own debris.

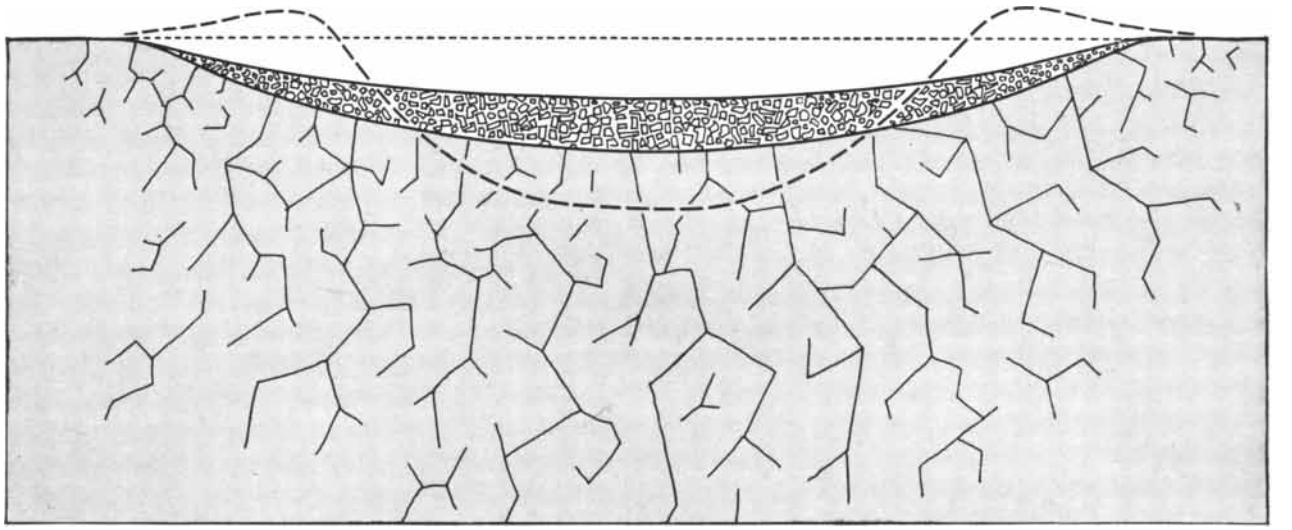
to something more than 1,200 pounds per square inch. To contain this pressure an above-ground chamber would have to be built with walls of high-strength steel, 12 inches or more thick, and would weigh several million tons. Whether such a container could be built to withstand a multitude of explosions in series is dubious. For economic reasons alone it would be better to attempt its construction deep underground.

A simpler alternative is to return to the Rainier model and try to trap the heat in a natural formation underground. What is needed is an essentially waterless formation, such as a salt dome. In fact, it is now planned to set off the first Plowshare explosion in a thick salt-bed near Carlsbad, N.M. Each kiloton of energy released will raise 3,000 tons of salt to a temperature of 1,500 degrees Fahrenheit, thus melting it. A megaton device will therefore yield three million tons of melted salt, a mass of material 600 feet in diameter. The heat from such a thermal reservoir can be recovered by pumping a heat-transfer fluid, such as water or carbon dioxide gas, through the salt and thence to a turbine or other energy converter [*see illustration on page 30*]. In a limestone or dolomite formation, a nuclear explosion would evolve huge quantities of carbon dioxide gas from the rock itself. This gas can serve directly as a heat-transfer agent, and additional energy can be recovered from the calcium oxide residue of the rock by treating it with water.

Existing power plants which exploit natural underground heat provide ample precedent for this approach to electrical power production. The world's largest natural steam-power plant at Larderello, Italy, has been generating electricity from a volcanic heat-source since 1904; it produces 5 per cent of the country's power, and its 150,000-kilowatt capacity is now being doubled. In New Zealand a natural heat source is being opened up in the volcanic Wairakei region to produce power and direct boiler heat for pulp and paper production. The operating and engineering experience at these sites will contribute heavily to the technology of power generation by nuclear explosions. For one thing, they establish the impressive cost figure of .47 cent per kilowatt hour. This compares to .88 for gas or coal plants and .27 for hydroelectric stations in New Zealand. Since geothermal costs are all for plant and operations and include no fuel charges, it is clear that in calculating the economics of power from a thermonuclear explosion an extra figure must be added for the cost of explosives. If such explosions can be produced at a depth of 3,000 feet, which would probably be sufficient for containment, at a cost of $1 million, then the thermonuclear fuel cost would be .1 cent per kilowatt hour, resulting in a total cost of .57 cent per kilowatt hour.

Thermonuclear explosions might also be used to release geothermal energy and thereby achieve even more favorable results. From Larderello and Wairakei we know that steam plants can be operated efficiently at 400 degrees F. Based upon the Rainier explosion, a one-megaton detonation set off in a formation at this temperature and at a depth of 3,000 feet to ensure containment would produce about 12 million tons of broken rock. By percolating a heat-transfer fluid through this now-permeable mass of rock and converting the extracted heat at the efficiency standard of Larderello, a total of 8,000 million kilowatt hours of electrical energy could be derived from one explosion. Since the explosion itself contributes a little more than 1,000 million kilowatt hours to this total, the extraction of natural geothermal heat multiplies the explosion yield by a factor of eight. At the normal geothermal gradient of 100 degrees F. per mile it would require a hole 10 miles deep, about four times the feasible drilling depth, to reach 1,000 degrees. At many sites, however, 1,000 degrees can be reached at three miles. This is fully deep enough to contain a 30-megaton explosion. The heat reservoir created by a single such explosion would yield 2,400 million million kilowatt hours of energy, enough to operate a 500,000-kilowatt generating station for 15 years.

The Rainier experience can be applied even more directly to the technology of mining, which calls for a completely contained underground explosion and does not involve the special requirements of power production. Nuclear explosion provides a new way to extract the wealth of ore beds too deep or too poor for conventional mining. In a bed of low-grade copper the 200,000 tons of broken rock produced by a one-kiloton blast can be multiplied 10 times by preliminary tunneling to direct the energy of the explosion. The percolation of acidified wa-



NUCLEAR EXPLOSION IN SHALLOW WATER would probably dig a wider and shallower crater. Among other things, the action of the water would later cause material around the crater to slump into it. Such a crater may be dug to make a harbor in Alaska in 1960.

ter through the ore bed would then bring the copper to the surface in solution.

Nuclear explosions may be similarly employed to get at the huge reserves of petroleum in the Canadian tar sands and Colorado shales which presently lie beyond the reach of economical extraction. At only 15 per cent recovery, each 100-foot depth of the tar sands along the Athabaska River would yield 100 million barrels of oil per square mile. The oil is released when the tar sand is heated to only 200 degrees F. By firing directly in the sand or beneath it a fluid oil-field might be produced. We understand that the Canadian Government is planning to investigate this possibility. The oil shales present a more difficult problem, because the release of the oil requires a temperature of 750 degrees. The oil might be brought to the surface by controlled burning of the shale in the region shattered by the explosion. A megaton explosion at a depth of 3,000 feet could be expected to release directly about a million barrels of petroleum products and to produce, in addition, some 50 million tons of broken shale. Retorting of this mass of broken shale in place might release an additional 25 million barrels of petroleum products. It may also be that the yield of gas and petroleum from certain formations can be improved by judicious use of nuclear explosives.

An entirely new possibility is the creation of underground reservoirs and aquifers for storage of water, for flood control and for recharging water-bearing strata. The explosion would be set off in a natural drainage-basin at such a depth that the progressive cave-in of the initial cavity would proceed completely to the surface. In a dry river bed in a desert area such a storage chamber would be filled during spring or storm runoff. With the water stored underground, evaporation losses would be reduced essentially to zero. Calculation shows that a 100-kiloton explosion would yield a storage capacity of 12,000 million gallons. Another use for nuclear explosions might be the conversion of fresh water from sea water in the heat reservoir of a deep underground explosion.

All these ideas, of course, depend upon the reduction of residual radioactivity to acceptable levels. In silicate rocks, as at the Rainier site, the radioactivity is almost entirely trapped in the rock melted in the first phase of the explosion. This material is highly refractory and insoluble and so should keep the residual activity from contaminating water, oil or leaching agents. At the same time the glassy radioactive rock may itself prove to be a valuable by-product. Enormous numbers of neutrons are produced in a thermonuclear explosion; by capturing these neutrons in suitable materials, buried with the explosive, specific isotopes could be produced in large quantities. The Rainier explosion is also pertinent here. Six months after the detonation a tunnel was driven to the edge of the radioactive sphere, and the radioactive glass was mined by hand. With rather primitive methods of shielding, using the tunnel material itself, all of the 700 tons of material might be mined.

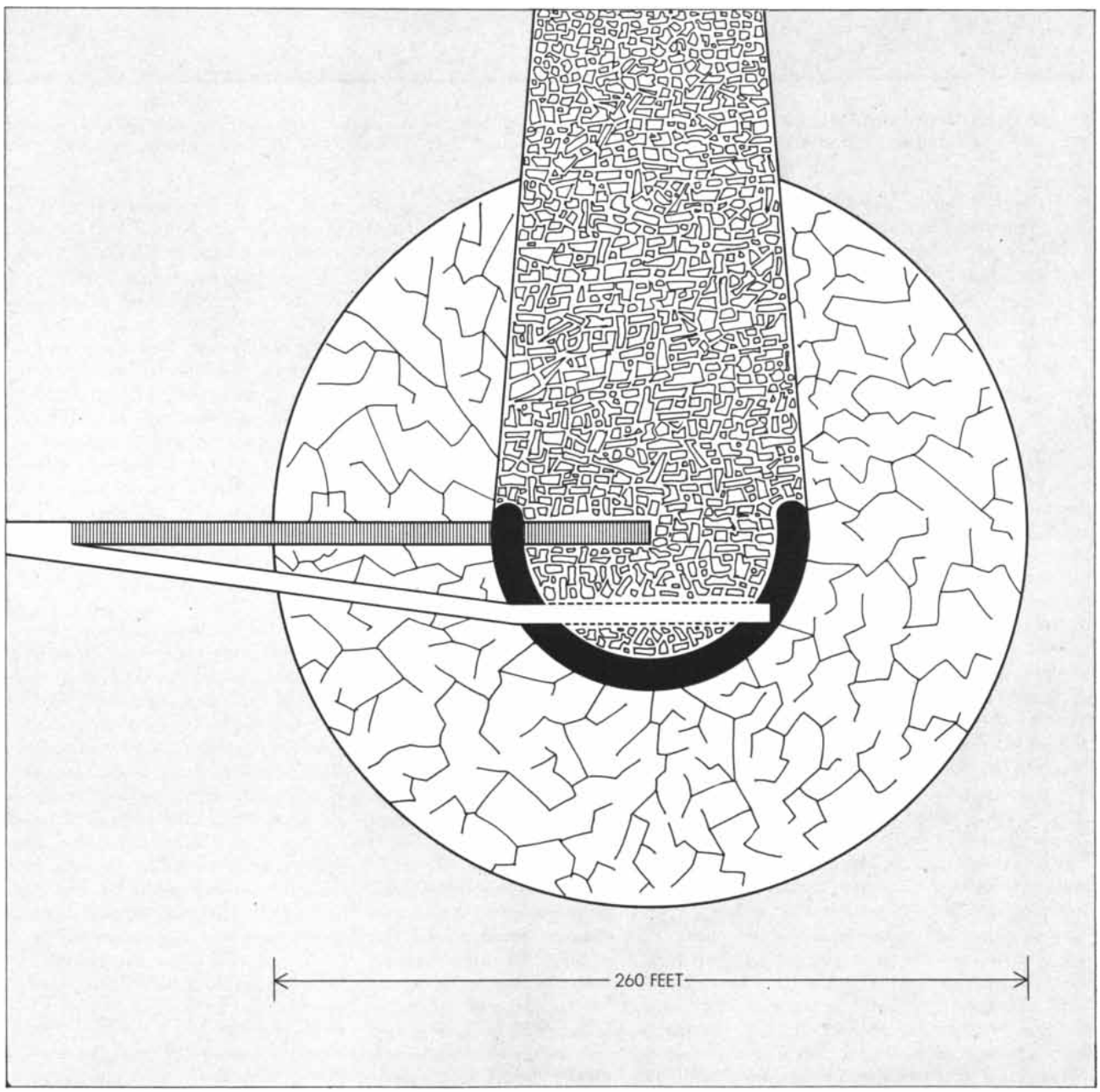
Perhaps the most obvious constructive application of thermonuclear explosions is in earth-moving, that is, the production of craters to be used as harbors, canals or reservoirs. Surface explosions for these desirable ends, however, would have as undesirable side effects all the destructive consequences that make nuclear bombs such formidable weapons. As everyone knows by now, these comprise the incendiary effects of the fireball; the so-called "prompt" radiation at the instant of explosion, composed primarily of neutrons and gamma rays; the residual radiation due to fallout of fission products and radioactive isotopes produced by neutron capture in the surrounding soil, and the air-blast and ground-shock effects. None of these effects, of course, is essential to the objective of producing a crater. We are confident, however, that appropriate precautions in a given project can reduce each of them to acceptable levels. Surface and shallowly buried detonations in the kiloton range have been observed in lightly cemented, dry sand and gravel at the Nevada weapons-testing site. Several megaton shots have been fired on the surface of coral atolls at Eniwetok. These observations, extended by our much longer experience with chemical explosives, should help to minimize the undesirable effect of surface explosions.

To gauge the excavating power of nuclear explosives we have the data on a one-kiloton shot fired at a depth of approximately 50 feet in Nevada. This explosion removed 100,000 cubic yards of material, leaving a crater about 300 feet in diameter and 90 feet in depth. In general, the dimensions of the crater increase as the cube root of the power of

the explosive. An explosion in a dry formation will produce a crater with a profile as shown in the illustration on page 32; in a wet formation the crater will have a shallower profile as shown in the illustration on page 33. At a burial depth of only 15 feet a one-kiloton explosive produced no incendiary effects beyond the rim of the crater. Significantly it left a crater with a diameter only 20 per cent less than that attained with a 50-foot burial depth. This result is helpful to the economics of nuclear excavation. Since the cost of burial is a large fraction of total cost, it is well that the effect of the fireball is suppressed by shallow burial.

Let us now apply these data to the construction of, say, a harbor for ocean-going vessels. Calculation shows that four 100-kiloton detonations fired at a depth of 50 feet would produce a channel 1,200 feet wide and 5,000 feet long. A one-megaton shot fired at a depth of 150 feet at the inland end of the chain would evacuate a turning basin 3,000 feet in diameter. Granting that costs of construction are difficult to estimate, this calculation provides an instructive comparison of nuclear and conventional earth-moving. Our harbor requires the excavation of 28 million cubic yards. At a low estimate of $2 per cubic yard, this gives a conventional earth-moving cost of $56 million. With thermonuclear explosives the cost might be as little as $5 million.

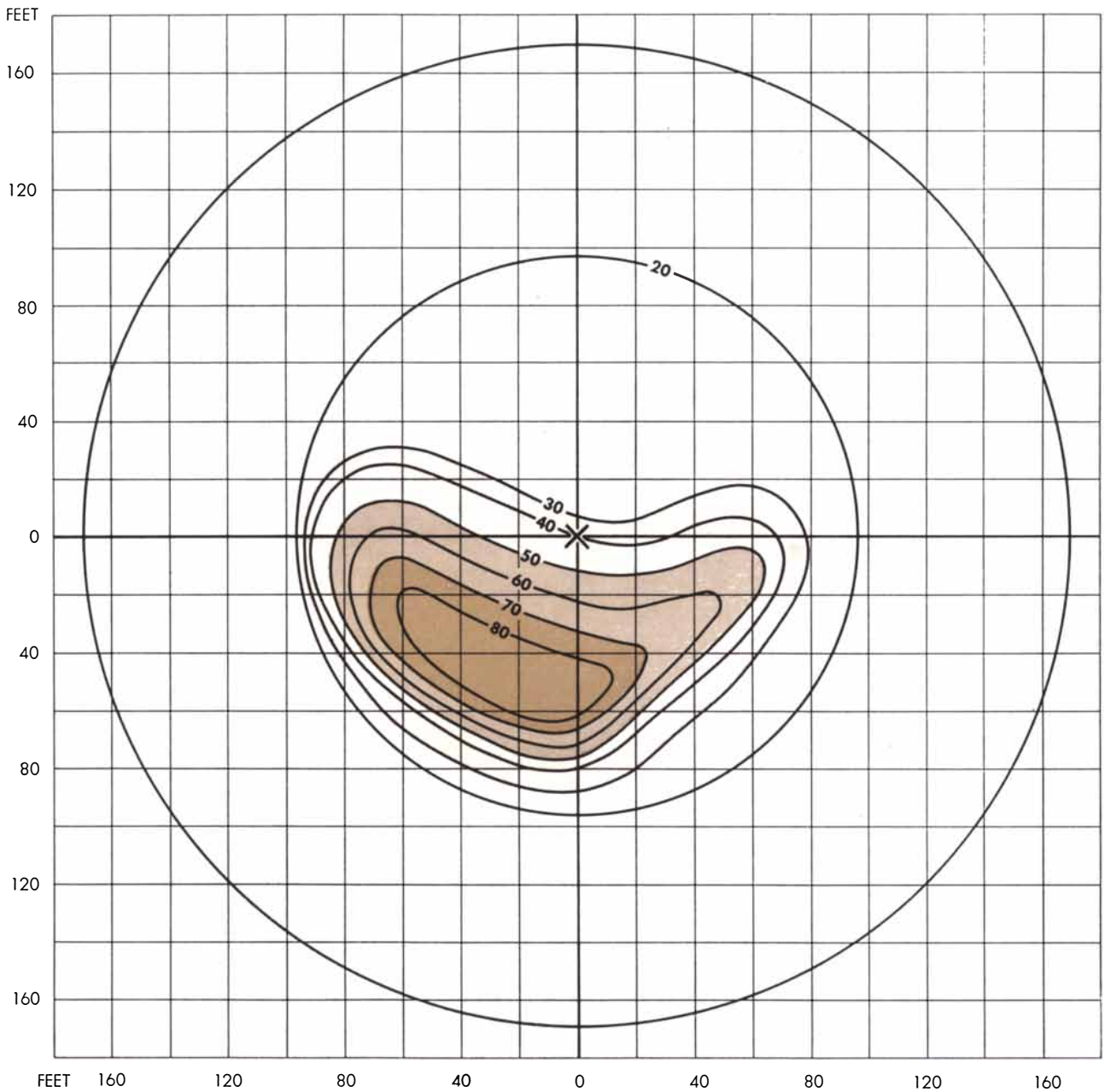
The burial depths that produce efficient cratering and minimize incendiary side-effects also remove "prompt" radiation hazards. These are reduced to acceptable levels by only a few feet of soil



SITE OF RAINIER EXPLOSION was prepared by way of a tunnel designed to collapse during the explosion along the shaded stretch shown in this diagram. An exploratory tunnel driven below it has reached the zone of radioactive fused rock (*black semicircle*).

or water and by the fact that the blast and fall-out effects require observers to stand back at a distance at which the atmosphere fully attenuates the neutron and gamma-ray output. The radius at which air blast and ground shock will cause damage and public annoyance can be estimated in advance. Beyond 30 miles the earth-shaking effects of a megaton explosion would be of interest only to seismologists with their sensitive instruments. Air-blast effects are more difficult to predict; the shock waves may be focused in the atmosphere by wind and temperature gradients. The principal long-range nuisance of air blast is the breakage of windows. For a megaton explosion, the radius of window breaking is not much less than 30 miles even under the best meteorological conditions. Prohibitively large depths of burial would be required to produce a significant reduction of this nuisance.

Radioactive fall-out and the secondary radioactivity induced in the surrounding terrain by neutron radiation present the major safety problems. These hazards can be reduced by the use of thermonuclear explosives. Because they depend on fusion rather than fission, they produce less fall-out in ratio to yield. Their heavy neutron output can be reduced by surrounding the explosive with a neutron-absorbing blanket. Even with these measures there will be some local radioactivity. In each situation a careful study must be made of the effects on agriculture, fish and game, and on water supplies, to be sure that no continuing hazard is created. Based on experience to date, it seems clear that these effects can be restricted to acceptable magnitudes.



DISTRIBUTION OF TEMPERATURE at the site of the Rainier explosion after four months is shown in cross section. The temperature rose above the 17 degrees C. ambient temperature about 160 feet from ground zero and reached 80 degrees in explosion site.

Feedback in the Differentiation of Cells

What makes the unspecialized cells of an embryo differentiate to specialized cells? One view is that the products of the chemical activity of the organism are fed back to control its development

by S. Meryl Rose

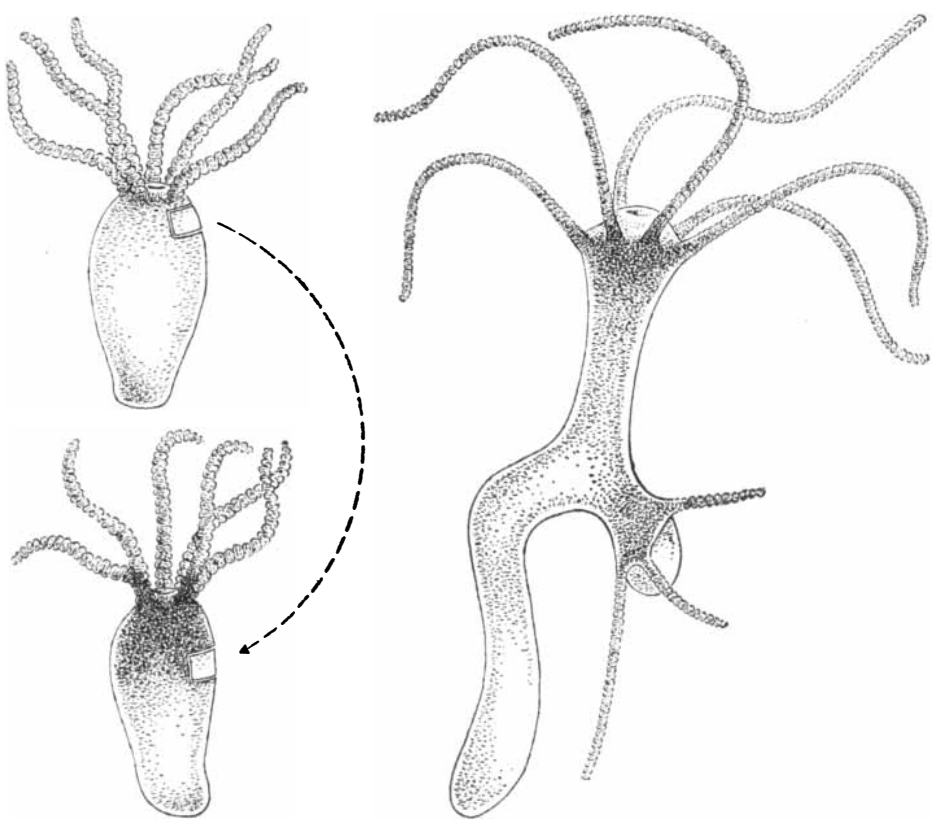
When the egg cell of an animal is fertilized, it divides into two cells, which in turn cleave into four cells, then eight cells, and so on. At this pre-embryonic stage the multiplying cells appear to be identical, but in the embryo they begin clearly to differentiate. In the fullness of the developmental process they multiply into the cells of the heart, the brain, the eye, the skin—into all the exquisitely specialized tissues and structures of the adult organism.

What makes the cells differentiate? This fundamental question is beginning to yield to the efforts of modern biologists. We are now fairly sure that all the information needed to make an organism is contained in the nucleic acids of the fertilized egg-cell. It would appear that the giant nucleic acid molecules are blueprints for the manufacture of protein molecules, which include the enzymes that catalyze the multifarious chemical reactions of living matter. When the fertilized egg-cell divides, it distributes a complete file of blueprints to each of its daughter cells, which in turn bequeath an identical file to each of their descendants. In the process of differentiation, however, cells in different parts of the pre-embryo begin to act on different blueprints.

The problem of differentiation can thus be stated: What makes cells in different parts of a developing organism use different blueprints? One can think of at least two answers. The first, which many biologists have favored, is that certain cells distribute various blueprints to other cells. The second is that the cells receive a different kind of information which causes them to use blueprints of their own. As the reader will presently learn, we are inclined toward the second possibility.

Even before the egg cell has been fertilized, there are subtle differences among its parts. The "north pole" of the egg, for example, may contain more of a given enzyme than the "south pole." In that case the south pole will contain more of another substance. The same substances are found throughout the egg, but their proportions vary.

The same is true of the dividing cells



DOUBLE HYDRA formed when tissue from the head of one hydra (*top left*) was transplanted to the trunk of another hydra (*bottom left*) by Ethel Browne Harvey. Graft tissue induced trunk cells to change into head tissue and finally give rise to a whole new hydra.

of the pre-embryo, as we have learned from the microsurgical experiments of the Swedish embryologist Sven Hörstadius. He was able to dissect the tiny pre-embryo of the sea urchin into three groups of cells: a north polar group, a south polar group and an equatorial group. Of the three groups only one—the equatorial group—subsequently matured into a complete sea urchin; the north and south polar groups lived for a few days but never really developed. One might easily jump to the conclusion that the equatorial group of cells contains all the substances needed to make a sea urchin, and that the polar groups do not. This would be wrong. If the dissected polar groups are placed in contact, they too give rise to a normal sea urchin. The experiment tells us that for a complete sea urchin to develop there must be a balance of the differences between the two poles of its pre-embryo. The equatorial cells alone, or the north and south polar cells together, are balanced; the north or south polar cells alone are not.

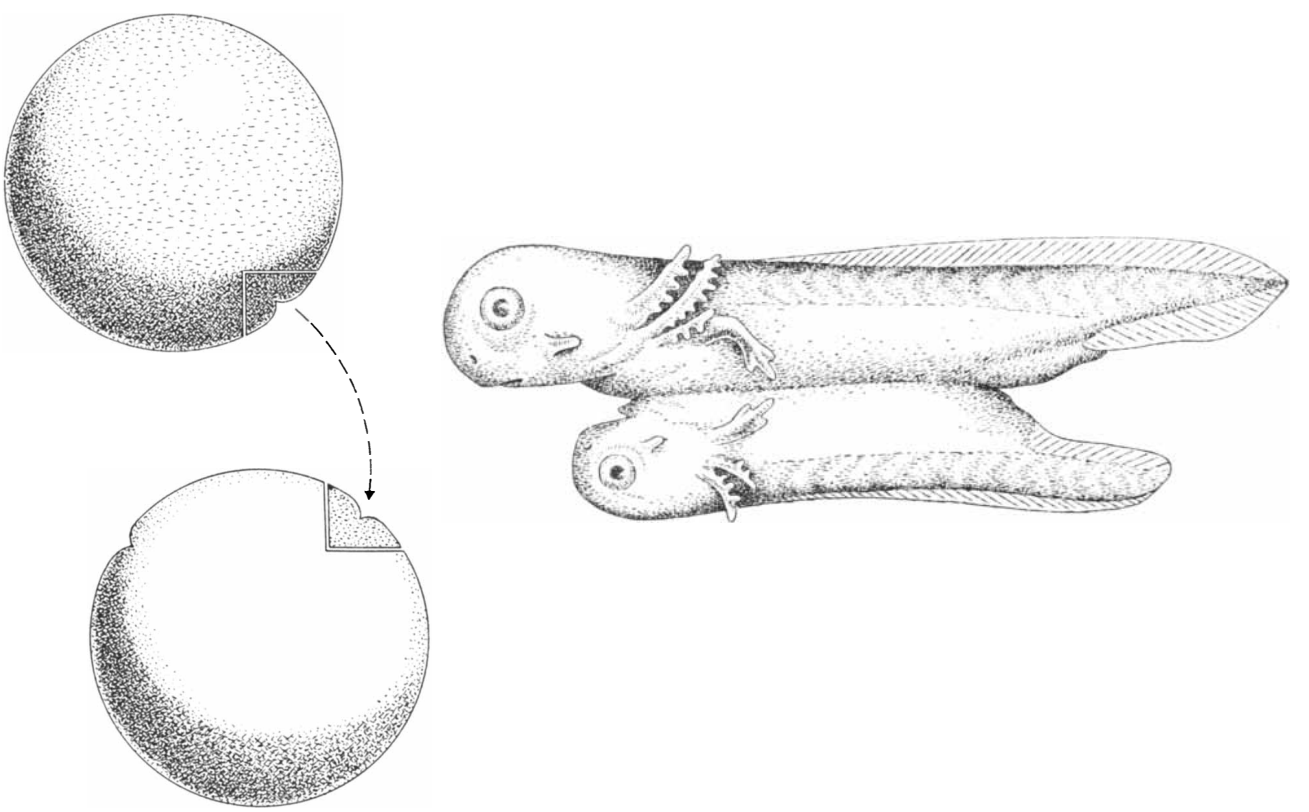
The importance of polar balance in animals more complex than the sea urchin has recently been demonstrated by Mabel Paterson, formerly of the University of Illinois and now at Vassar College. By dissecting the pre-embryo of the frog she showed that here too the equatorial cells can give rise to a complete animal. It has not been possible to combine the two polar groups so that they stay together, but the necessity of polar balance has been demonstrated in another way. When the equatorial group of cells is combined with the north polar group, development stops: the added polar cells have upset the balance.

The experiments of Hörstadius and Paterson substantiate the idea that each cell of the pre-embryo has been dealt a complete file of blueprints. Any part of the pre-embryo is expendable; whatever remains has all the blueprints and will use the appropriate ones if the polar balance has not been upset too much. This still does not tell us, however, how the differentiating cells know what blueprints to follow.

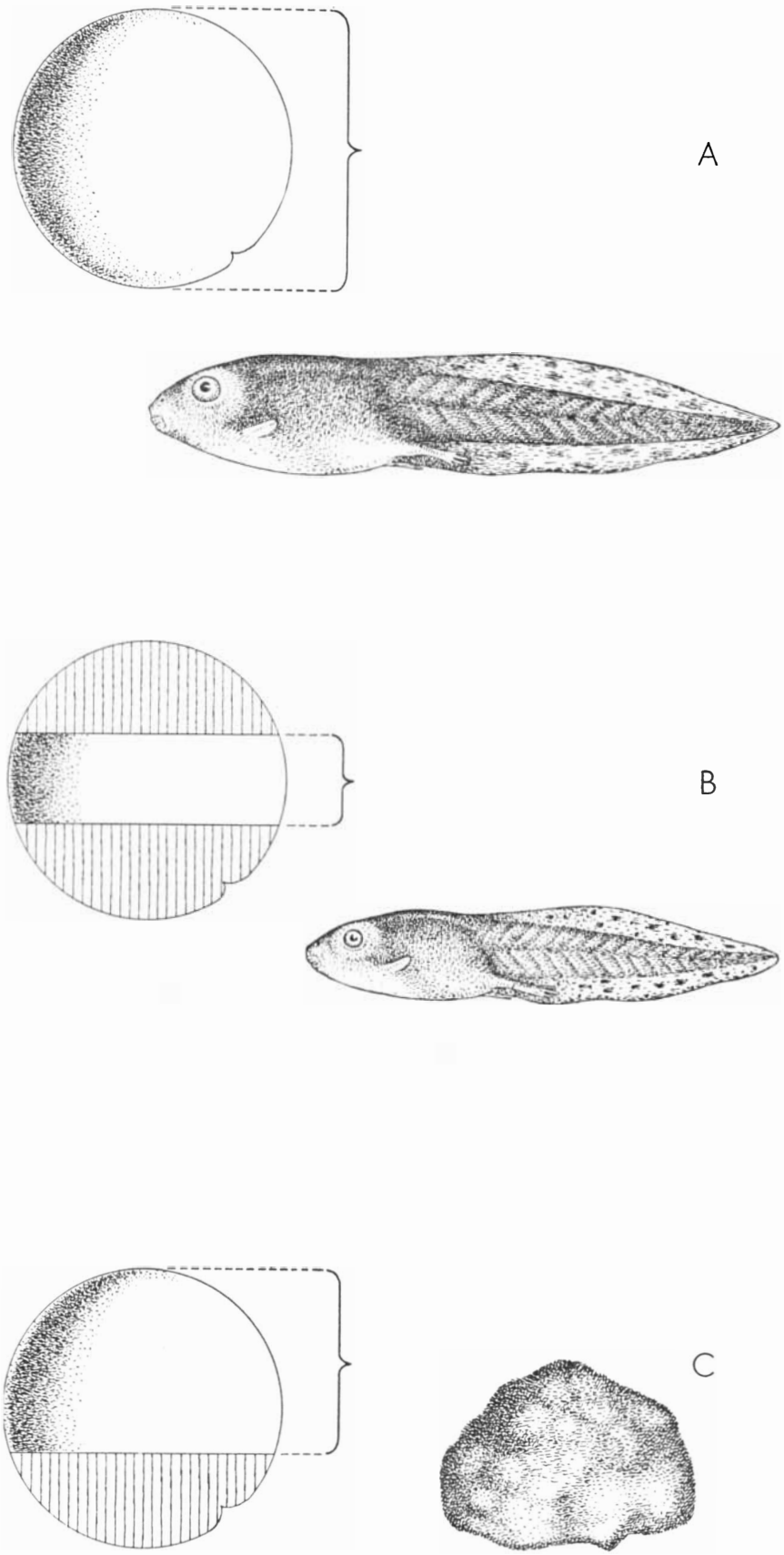
Ironically this problem was long obscured by two great biological experiments. The first was done by Ethel Browne Harvey, now at Princeton University but then of Bryn Mawr College. She worked with Hydra, the small freshwater animal which consists of a worm-like trunk and a tentacled head. When she transplanted a bit of Hydra head to the trunk of another Hydra, the head tissue induced the trunk to grow an extra head and trunk [*see illustration on opposite page*]. The second experiment was performed by Hans Spemann of Germany with the pre-embryo of the salamander. When he transplanted a particular bit of one pre-embryo to another, the second pre-embryo grew into two embryos, one of which developed around the graft. The bit of tissue which induced the surrounding cells to form a second embryo was named the "organizer."

Out of these experiments came a hypothesis which was to dominate embryological research for three decades. It was assumed that the organizer released chemical substances which were called inductors. It was further assumed that the inductors were incorporated into cells around the organizer, and that they directed the cells to form a particular tissue or structure. This was an appealing concept, but it no longer fits the experimental facts.

The first really incompatible fact was



DOUBLE SALAMANDER EMBRYO was produced by Hans Spemann of Germany, who transplanted tissue from the pore of a salamander pre-embryo (*top left*) to another part of a second pre-embryo (*bottom left*). The graft tissue formed part of the extra skeleton, and induced cells from the host to make up the rest of the embryo. Spemann concluded pore tissue acts as an "organizer."



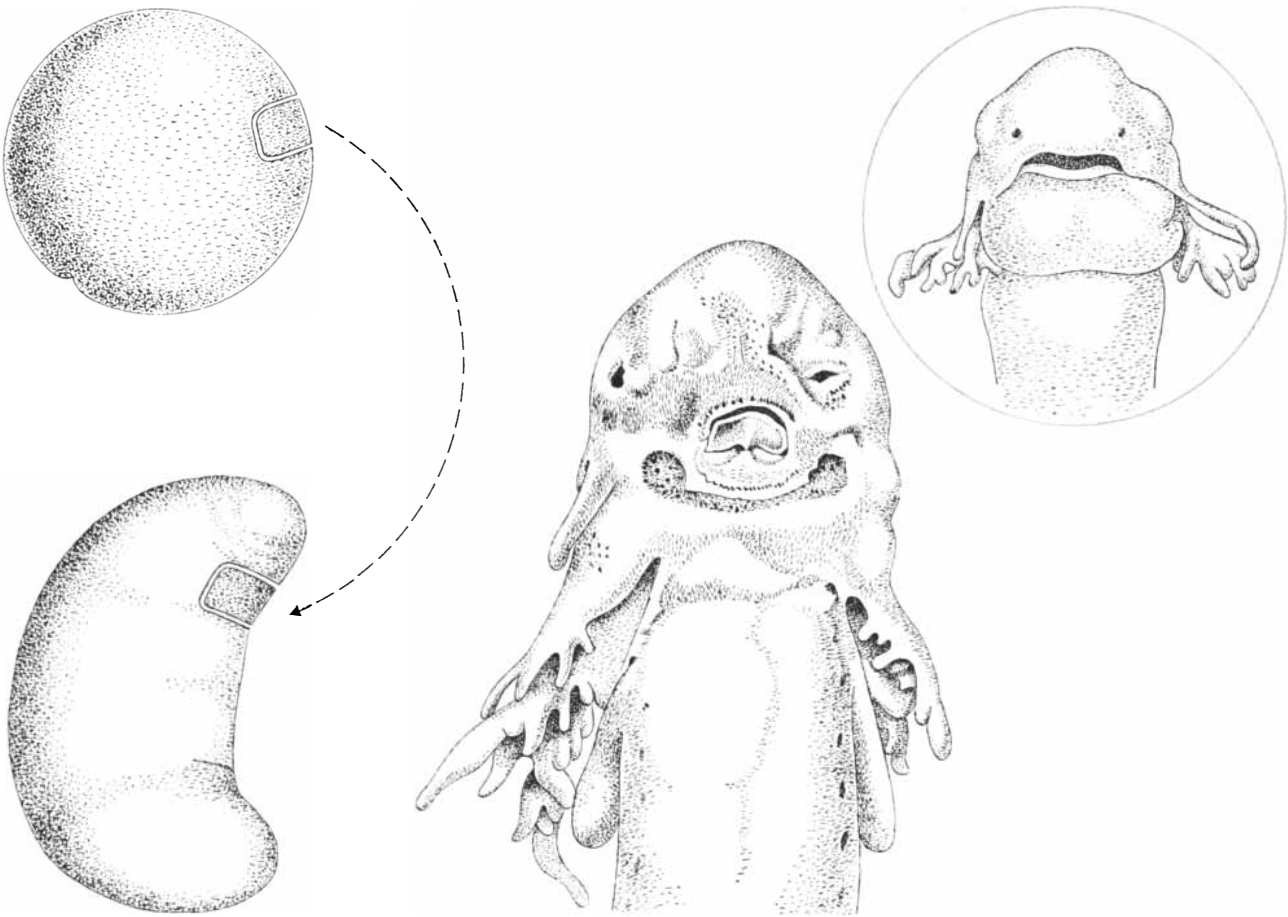
COMPLETE TADPOLES develop from the whole frog pre-embryo (*A*) or from the equatorial third of the pre-embryo (*B*). But a pre-embryo cut as at *C* produces only a structureless mass because the proportion of substances, present in complementary amounts at the poles, is unbalanced. This experiment was performed by Mabel Paterson of Vassar College.

adduced by Oscar Schotté, now at Amherst College but then working in Spemann's laboratory. From the pre-embryo of the frog Schotté took a bit of tissue which was destined to become belly skin. This he transplanted to the mouth region of a salamander embryo. The transplanted tissue became mouth tissue, but not salamander-mouth tissue. It was frog-mouth tissue! Now if the salamander organizer had distributed salamander-mouth blueprints to the frog cells, the frog cells would have become salamander-mouth tissue. The fact that the frog cells became frog-mouth tissue strongly suggests that they were acting on blueprints of their own, and not on blueprints from the organizer of the salamander.

The organizer-inductor hypothesis has another weakness. Many plants and animals are able to regenerate a substantial part of themselves which has been lost. When part of such an organism is amputated, a bud of undifferentiated cells forms at the surface of the wound. If inductors were involved in regeneration, one would expect that they would first reach the undifferentiated cells nearest the wound surface, and that the amputated part would be reconstructed from the wound outward. This, however, is surely not the rule. As the bud grows, new tissues differentiate first in the region farthest removed from the site of the wound.

A case in point is the regeneration of the marine worm Sabella, studied by N. J. Berrill of McGill University. Sabella consists of a head, a thorax and an abdomen [*see illustration on page 40*]. If the head, the thorax and the front part of the abdomen are removed, will the remaining piece of abdomen first regenerate the rest of the abdomen, then the thorax and finally the head? No. First a bud of tissue forms at the front end of the incomplete abdomen. The bud develops into a new head. Then the old abdominal tissue behind the head is transformed into thorax, and behind the thorax new abdominal tissue develops.

Let us now return to one of the original experiments which suggested the organizer-inductor hypothesis. The organizer itself—the bit of pre-embryonic tissue which apparently induces the other cells of the pre-embryo to differentiate—later develops into notochord: the backbone of the embryo. When Spemann and his collaborator Hilde Mangold transplanted this pre-notochord tissue into a pre-embryonic region which was destined to become belly tissue, the transplant continued its development



TRANSPLANTATION of tissue from frog pre-embryo (*upper left*) to mouth area of a young salamander embryo (*lower left*) produced an embryo with a horny frog's mouth (*center*) unlike normal soft mouth (*upper right*). Oscar E. Schotté did this experiment.

and became notochord. In addition—and this is the important observation—the cells around the transplant were transformed into the back tissues which normally flank the notochord. The host cells had already begun to use belly blueprints, but when a bit of developing back was put in their midst, they began to use precisely those blueprints needed for the completion of back.

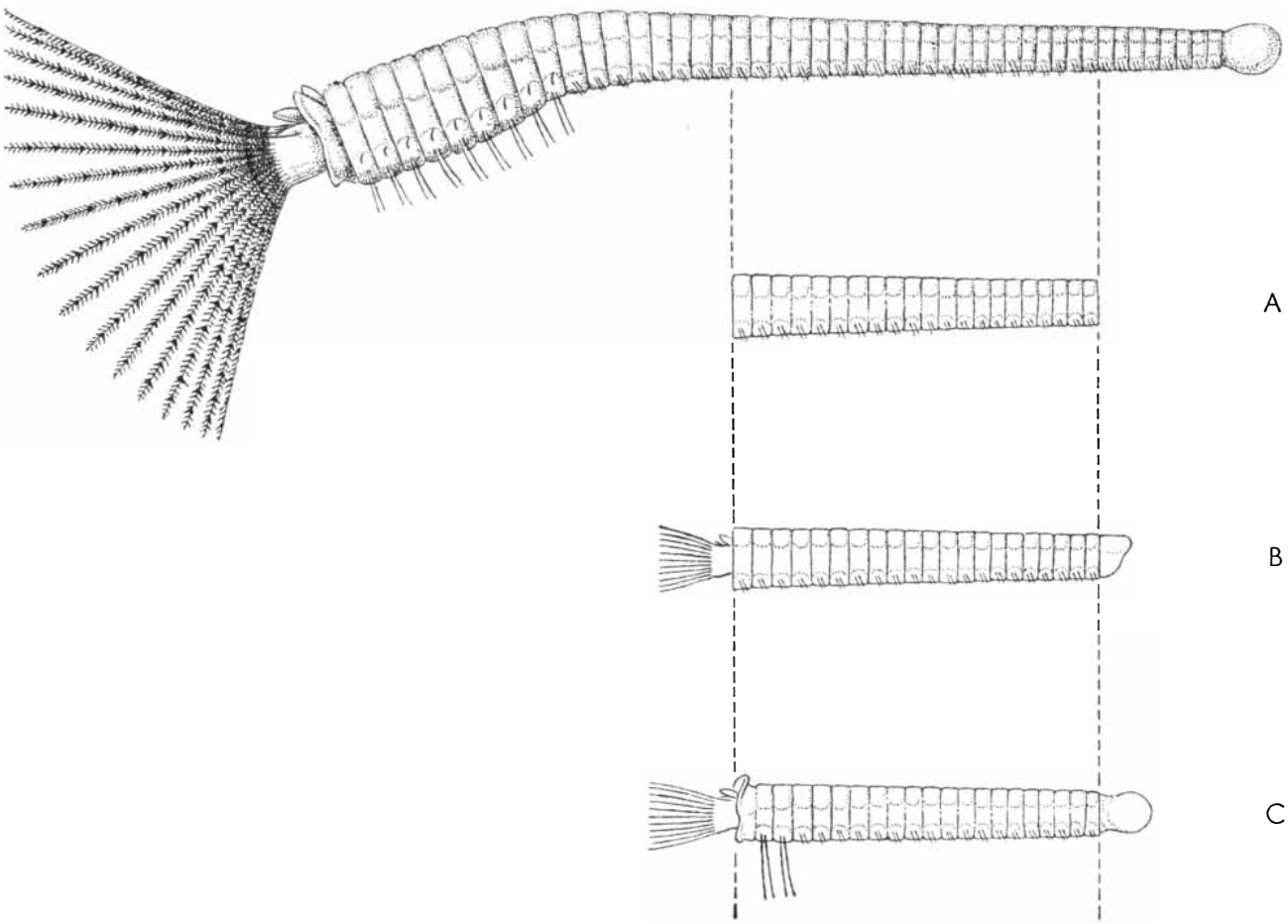
It is at this point that we can ask the question: Did the host tissues get their new blueprints from the transplanted piece of back, or did they get another kind of information from the transplant which made them use new blueprints of their own? We favor the latter explanation because of the Schotté experiment. From it we learned that frog cells contain various blueprints, and that even when these cells are transplanted to a salamander they can use blueprints appropriate to their location in the embryo. It would strain the imagination to suppose that the salamander possesses frog blueprints which it can distribute to the transplanted cells. Indeed, we may wonder whether cells ever influence one another by transmitting blueprints.

A few years ago an alternative hypothesis was suggested. First we assume that each cell in a developing embryo or regenerating bud has a complete file of blueprints. Then we suppose that a given cell begins to use a given set of blueprints—let us stretch our analogy and say that the cell follows the blueprints filed under A. To put it another way, the blueprints filed under A direct the cell to perform certain chemical reactions. Now let us suppose that the products of these chemical reactions enter adjacent cells and prevent them from using their blueprints filed under A. The cells have no choice but to follow another set of blueprints, let us say the blueprints filed under B. Thus they have differentiated from the cell using the blueprints filed under A. What is more, the cells using the blueprints filed under B will influence still other cells, causing them to differentiate by acting on the blueprints filed under C. So it would go until all the different parts of an organism were brought into being.

This might be called the feedback theory of differentiation. As most readers of *Scientific American* are aware, the term feedback was coined by electrical engineers to describe a system in which part of the output of the system is fed back into the system to control it. On the feedback theory of differentiation some of the products of the chemical activity of the organism are fed back to control its development.

The idea is not new; in fact, it is more than 50 years old. It is only recently, however, that biochemists have demonstrated the chemical mechanism of this feedback control. We now know that a variety of chemical reactions occurring in the living cell are inhibited by minute quantities of their products.

The feedback theory is illuminated by the experiments of the Swiss zoologist Martin Lüscher on termites [see "The Termite and the Cell," by Martin Lüscher; SCIENTIFIC AMERICAN, May, 1953]. Lüscher points out that the un-



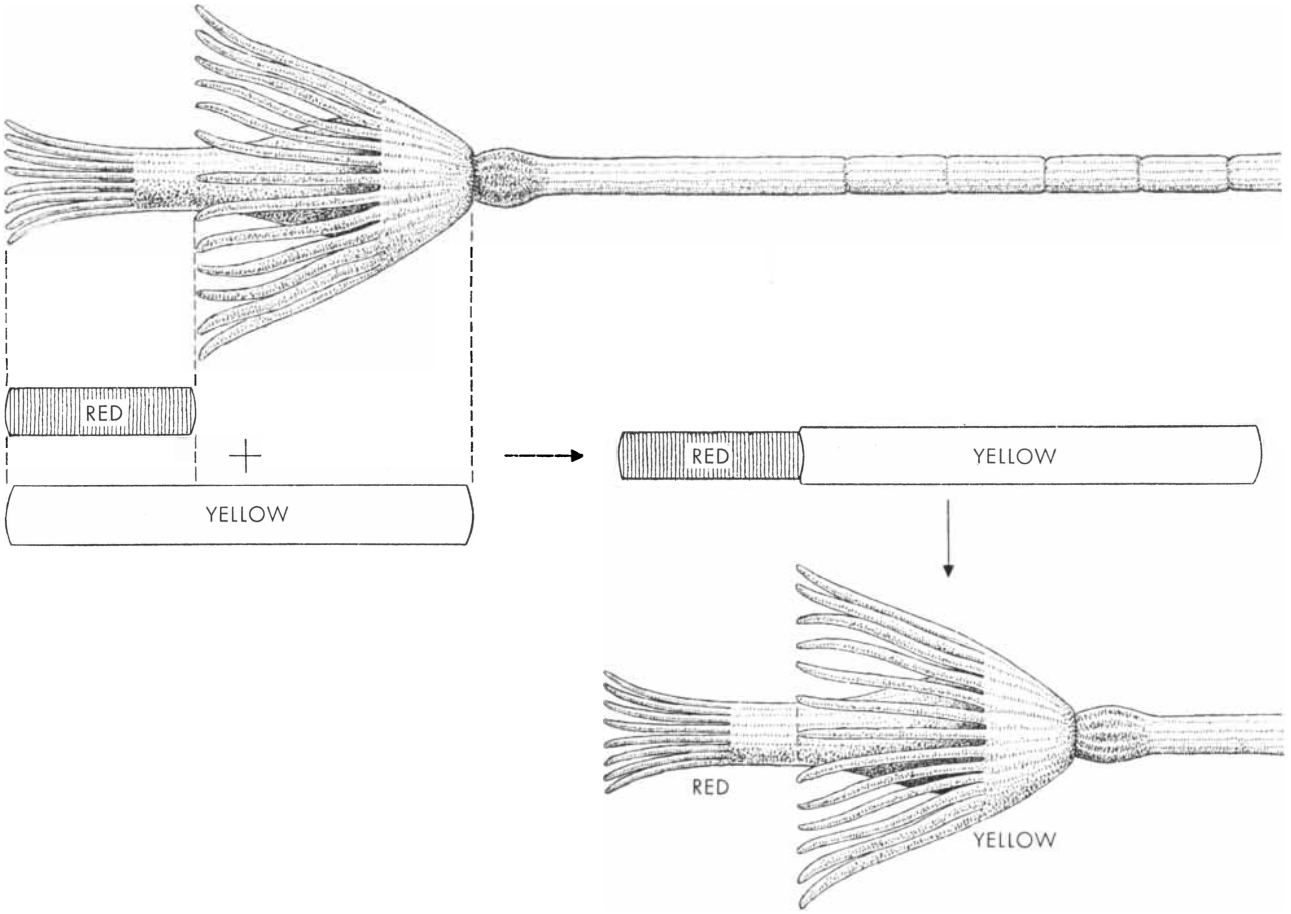
MARINE WORM SABELLA, studied by N. J. Berrill, was found to regenerate first the missing structures farthest "front." An isolated section from the rear part of the abdomen (*A*) first regenerates a new head (*B*); then abdomen behind the head transforms to thorax (*segments with longer hairs*) and new abdomen tissue forms at the rear end of the regenerating fragment (*C*).

specialized "nymphs" of the termite colony can develop into members of any of the colony's more specialized castes: reproductives ("king" and "queen"), "soldiers" and so on. When the specialized castes are filled, however, the development of the nymphs is inhibited. On the other hand, when one of the specialized castes is not filled, nymphs can develop into members of it. If, for example, the king and queen of a termite colony are removed, nymphs develop into "supplementary reproductives" and replace them. We visualize somewhat the same process in the developing embryo. In the beginning a termite or a cell has many pathways of differentiation open to it, but as others achieve caste status the open pathways become fewer and fewer.

An experiment rather like removing the king and queen from a termite colony can be performed with the pre-embryo. Some 20 years ago in Germany Gian Töndury and Johannes Holtfreter showed that, when the developing notochord—the organizer region—is removed from the pre-embryo of a salamander, a notochord will still form. The cells adjacent to the removed tissue, which ordinarily become the cells of back muscle, flow into the gap and become notochord. This suggests that, under normal conditions, the more rapidly developing cells of the back become notochord, and at the same time bar their less rapidly developing neighbors from such development. According to this view a cell adjacent to developing notochord becomes a muscle cell not because its notochord neighbors say, "Form muscle," but because they say, "Don't form notochord." With their primary differentiation reaction blocked, the cells adjacent to the developing notochord are automatically switched to the next most efficient reaction. If the developing notochord is removed, however, they can follow the primary reaction and form notochord.

We first tested the feedback theory in our laboratory at the University of Illinois by seeking specific organ inhibitors. We cultivated frog eggs with pieces of adult frog brain, or heart, or blood. The treatment was drastic, and many of the embryos failed to develop to the stage of organ formation. Of those which did develop, a few showed single defects. Some developed to the stage in which brain is expected, but no brain formed. In others the brain developed late or abnormally. These were the embryos which had been cultured with brain. In other embryos a heart failed to develop; these had been cultured with heart. A third group failed to produce blood on time; they had been grown for a day or two in diluted blood.

Since this demonstration of specific organ inhibition in the frog was made, workers in our laboratory and elsewhere have been learning that the phenomenon is a general one. It has been demonstrated in various worms, in the toad and in the chick. In addition it has long been known that in many plants the growing tip of the plant inhibits like development in branches down the stem. When the growing tip is removed, it is replaced by a growing tip on one or more branches. Almost as well known is the fact that, when the roots of a plant are removed, some of the differentiated cells



TUBULARIA has a flower-like head, or hydranth. In this experiment (a variation on those described in the text) a piece of regenerating stalk from the front of a red Tubularia is grafted to a larger piece from the front of a yellow Tubularia. When the pieces complete their regeneration, the red piece forms the tip of the hydranth and the yellow piece makes only those parts behind the tip.

of the stem will be transformed into the cells of root. Here too like normally inhibits potential like.

But to know that the products of like can suppress like is not enough. We still want to know why particular organs develop in particular places. One of the best organisms in which to study this question is Tubularia, a flower-like marine animal related to Hydra [*see illustration above*]. Embryologists have worked with Tubularia for more than half a century because it is relatively simple and regenerates rapidly. From an isolated piece of stalk the flower-like "front" part (called the hydranth) can regenerate in one or two days. Any isolated part of the stalk can give rise to a hydranth, provided the part is not too small; in that case it makes only the front of the hydranth.

If even tiny bits of stalk can form part of a hydranth, why do they not do so in the intact organism? Why is Tubularia not covered with hydranths? The answer has been given by experiments with combinations of regenerating parts.

Take two small pieces of regenerating stalk. Each is on its way to making the front part of a new hydranth. Graft the pieces together so that the rear end of one is joined to the front end of the other. What happens? The front piece continues to develop into a hydranth, and the rear piece reverts to stalk. The rule is that any section of stalk will make that part of the organism which is farthest front, except when the part has already been made. Then the section forms only the part behind the part in front of it.

The system is highly polarized. Any region of it receives information from only one direction; the region is affected by what is in front of it, but is unaware of what lies behind. If the front end of one piece of Tubularia stalk is joined to the front end of another, two hydranths form "face to face." Since the inhibitory information moves only from front to rear, neither of the two pieces is aware of the other. Their tissues are firmly joined, but each piece develops independently.

It is possible, however, to reverse the polarity of a part of Tubularia. Take a piece of stem which has visibly begun to make a whole hydranth. Graft to the rear of this piece a much smaller piece from the front part of another stem. Thus at the time of grafting there are two fronts and between them one rear. The polarity of part of the original single rear now changes. Some of its structures continue to face the original front, but a second set of rear structures forms facing the grafted front. Apparently organizational information is proceeding from both fronts. Each part forms those structures not already developing in front of it. The result is two hydranths back to back.

This phenomenon may explain how, when developing notochord or organizer tissue is transplanted into a pre-embryonic belly region, the belly cells become back cells. Perhaps the transplant has reversed the polarity of the belly region. Since back is no longer above belly, belly may be free to become back. In any case it is more than likely that polarized systems of inhibition operate to localize the structures in the embryos of organisms higher than Tubularia.

THE MASER

It is a quantum-mechanical device which amplifies very short radio waves with extraordinary fidelity. The basic element of the early masers was gaseous ammonia; the latest models make use of crystals

by James P. Gordon

The 50-foot radio telescope at the Naval Research Laboratory in Washington, D.C., recently acquired a strange accessory. Mounted just behind the antenna, at the center of the telescope's parabolic reflector, is an oblong box containing a synthetic ruby and some standard microwave equipment. A bath of liquid helium chills the ruby to the temperatures of the cold reaches of space which the telescope surveys. With the help of this refrigerated gem astronomers hope to extend their range of observation far beyond its present limits, perhaps far enough to clear up once and for all the mysteries of the size and geometry of the universe.

The ruby is part of a new microwave device called the "maser." The letters of this odd word stand for Microwave Amplification by Stimulated Emission of Radiation. The maser represents the ultimate in high-fidelity amplifiers. The best previous amplifiers, using vacuum tubes, put out a mixed signal which combined an amplified version of the input with a wide assortment of oscillations originating in the tubes themselves. If the input signal becomes weaker, the percentage of noise in the output increases, and the resemblance between input and output diminishes. Eventually a point is reached where the input, though still amplified, can no longer be recognized in the output. The great virtue of the maser is that it generates practically no noise. It can detect much weaker signals than other amplifiers can, and hence pick up radio waves from far more distant points in space. As we shall see, it is also finding a number of other important applications in science and technology.

What makes the maser so quiet? It is perhaps helpful to ask first: What makes vacuum tubes so noisy? Vacuum tubes utilize a stream of agitated electrons which are boiled out of a cathode and sent crashing into a collecting plate by an outside voltage. The signal to be amplified imposes its variations on the electron stream. But the particles have their own random variations, which are inevitably part of the output of the tube. It is a tribute to the ingenuity of electrical engineers that, in improvements such as the traveling-wave tube, they have been able to go so far toward muffling the effects of unruly electrons. The least noisy of these tubes, however, leaves a lot to be desired.

The maser dispenses with streams of electrons altogether. Instead it makes use of certain intrinsic oscillations in many types of material particles. These oscillations are basic phenomena of nature. The idea of harnessing them for useful work occurred independently a few years ago to several workers in the field of microwaves, including C. H. Townes of Columbia University, N. G. Basov and A. M. Prokhorov in the U.S.S.R. and J. Weber of the University of Maryland.

To appreciate what led to this notion we should briefly consider the interaction between high-frequency radiation and matter. Every student of elementary physics has witnessed the experiment in which light from a sodium lamp is shined into a container of cool sodium vapor and is completely absorbed. At the same time light of a different frequency—that is, color—from some other source passes through the container undimmed. The classical explanation is that every atom and molecule has certain natural vibrations which occur at sharply defined frequencies. When the oscillations of light or of other electromagnetic waves coincide with one of these frequencies, the radiation gives up energy to the atom or molecule, causing it to vibrate like a pendulum which has been set swinging by a series of properly timed pushes. Conversely, if atoms or molecules can be made to vibrate by some other means, say by thermal agitation, they will emit electromagnetic waves of the same characteristic frequency. In the experiment just mentioned, waves from hot, vibrating sodium molecules are absorbed by the cold molecules. Waves whose frequency does not correspond to the frequency of the sodium vibrations pass through unaffected.

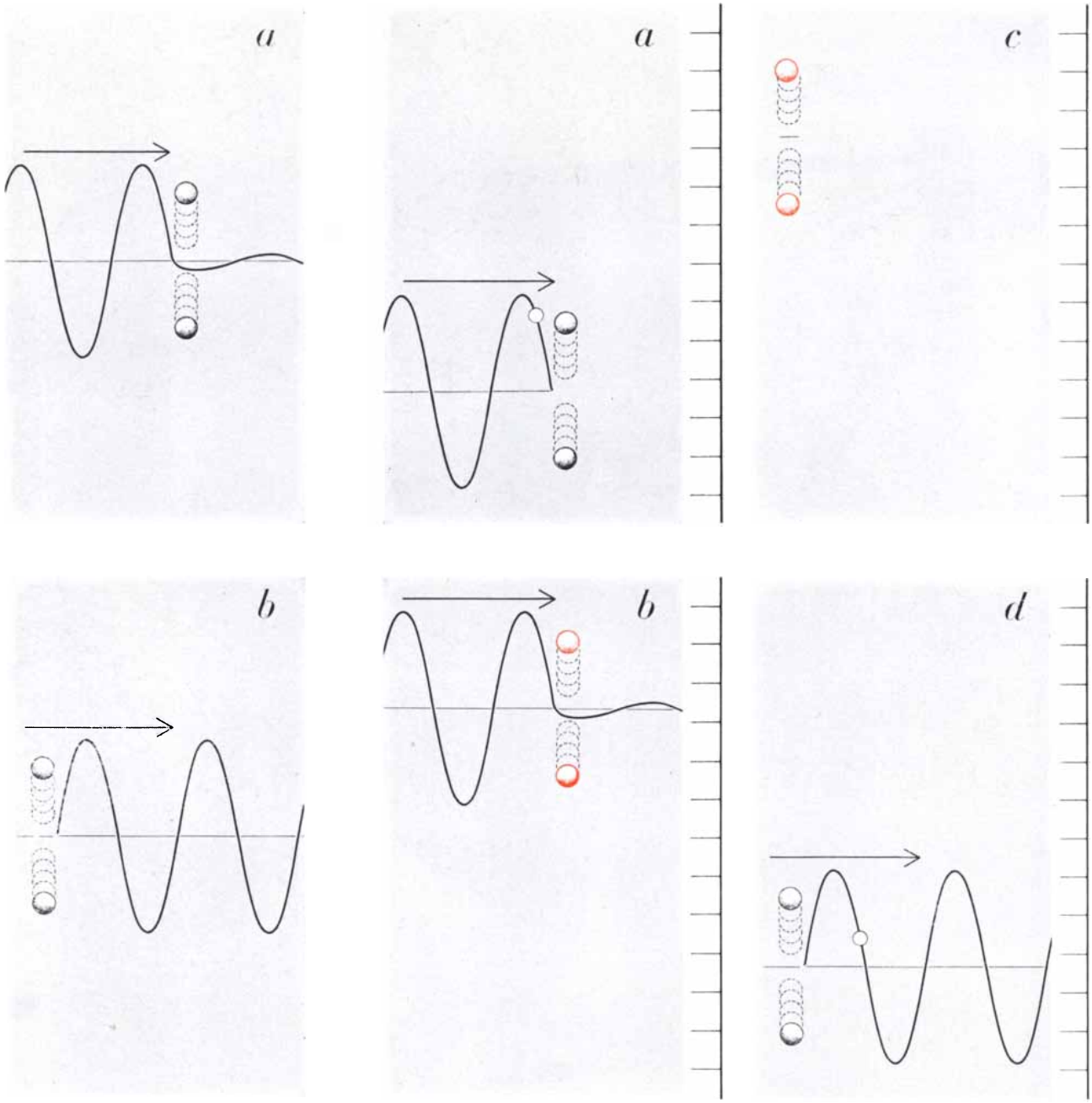
If the reader is wondering how such a mechanism can be made to amplify the energy in a wave, he may as well stop. If the "classical"—that is, pre-quantum mechanical—explanation were completely correct, there would be no maser. (As a matter of fact, there would be no atoms. On the classical theory electrons revolving around atomic nuclei would continuously radiate away their energy and spiral into the nucleus. All of ordinary matter would thus collapse.)

To discover the secret of the maser we must turn to the quantum picture of matter and radiation. In this view atoms and molecules exist most of the time in one of a number of stable, nonradiating states. Each state corresponds to a fixed quantity of energy. Radiation, on the other hand, consists of the particles called photons, carried by a sort of guiding wave. The frequency of the wave is a measure of the energy of the photons, according to Max Planck's famous equation $E = hf$. A particle of radiation is produced when an atom falls from a higher to a lower energy state, and the energy of the photon is exactly equal to the difference in energy between the states. When an atom jumps the other way, from a lower to a higher energy state, it absorbs a photon of the same frequency. Thus

SOLID-STATE MASER is mounted at the focus of the 50-foot radio telescope of the Naval Research Laboratory in Washington, D.C. By largely eliminating the "noise" inherent in conventional amplifiers, the maser enables the telescope to detect very faint signals.

when radiation passes through an assembly of atoms, one of three things can happen. If the energy of the photons does not equal the difference between a pair of energy levels in the atoms, there is no interaction. If the energies match, and a photon collides with an atom in the lower of the two states, the radiation will be absorbed and the atom will be "excited" to the higher state. If the photon collides with an atom in the higher state, it will cause the opposite jump, down to the lower state, and a new photon will be emitted. Thus there will now be two photons where before the collision there was only one.

In any assemblage of atoms there is always some traffic between low- and high-energy states. The atoms keep hopping up and down in their energy states, boosted by energy received in chance collisions and falling because of their natural tendency to seek the lowest energy level. Under ordinary conditions the lower states are always more densely populated than the higher ones. Thus when radiation of the appropriate fre-



CLASSICAL VIEW of the interaction of electromagnetic radiation and matter is depicted. At top an electromagnetic wave (*wavy line*) of the appropriate frequency sets a two-atom molecule (*balls*) to vibrating. The process absorbs energy from the wave. At bottom a molecule spontaneously emits energy (*wavy line*) of characteristic frequency.

QUANTUM-MECHANICAL VIEW of the interaction is similarly depicted. Here the electromagnetic radiation is regarded not as a wave but as a photon (*white dot*) guided by a wave. The frequency of the guiding wave is related to the energy of the photon. The molecule does not vibrate; the broken circles merely indicate that the atoms are regarded as simultaneously occupying a number of positions. At top left the molecule is at a lower energy level. At bottom left the molecule has been "excited" by a photon of the appropriate energy, and raised to a higher energy level. At top right the molecule is at the higher energy level. At bottom right it has fallen to the lower energy level and emitted a photon of characteristic energy. Scale at right of these four illustrations suggests energy levels.

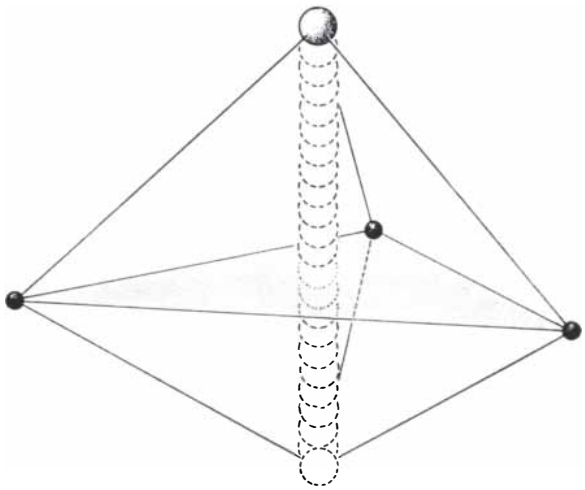
quency passes through the assemblage of atoms, more photons will be absorbed than new ones created, and the outgoing beam will be weaker than the incoming beam.

But suppose it were somehow possible to change the distribution of energy levels so that there were more atoms in the higher of two states than in the lower. Then a beam of photons of the appropriate frequency would produce more downward jumps than upward ones; the net effect would be that more photons would come out than went in. In other words, the output wave would have more energy than the input wave. This is the secret of how the maser amplifies.

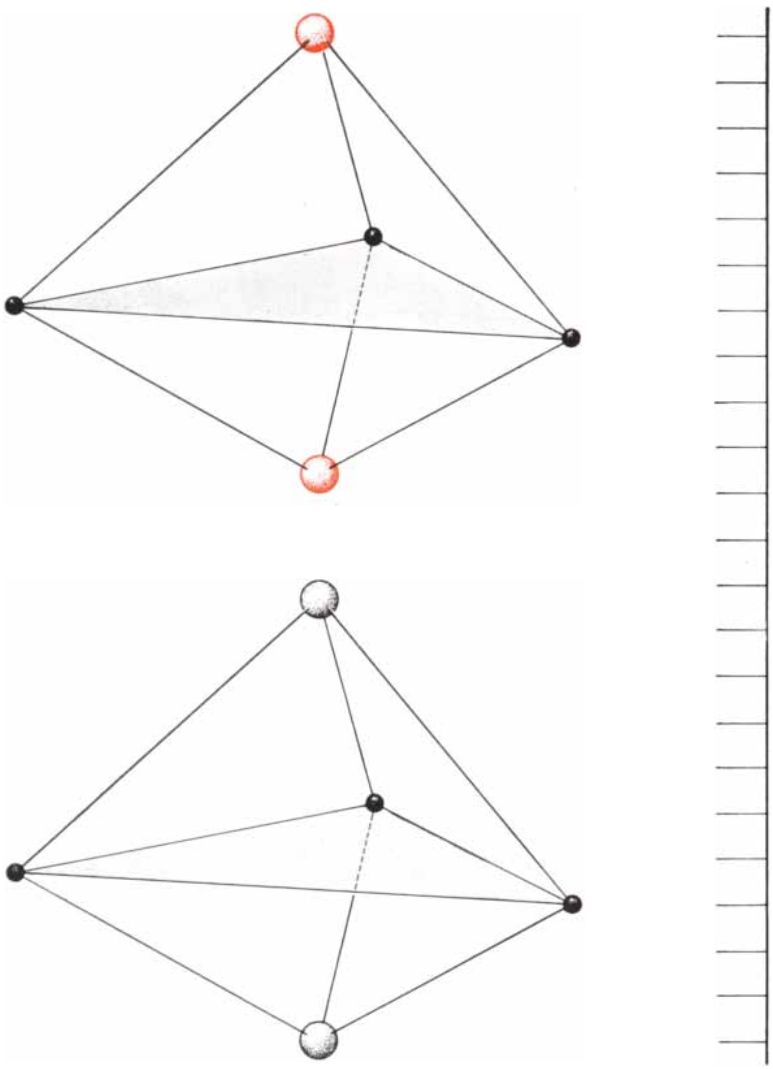
The first of the masers to be developed is based on the molecule of ammonia. For reasons we shall mention in a moment, the ammonia maser is more useful as an oscillator and a timekeeper than as an amplifier. It is in any case a remarkable device: a simple metal chamber, into which only a little ammonia gas is admitted, which yields a weak microwave signal of almost unbelievable purity. Its output wave falls short of a mathematically perfect sine curve by less than one part in 100 billion!

The molecule which produces this perfect monotone has the shape of a pyramid. At the apex of the pyramid is a nitrogen atom; at the base, three hydrogen atoms [*see illustrations at right*]. The nitrogen atom is able to move through the plane of the hydrogen atoms. thus turning the pyramid inside out. On the classical theory we picture the nitrogen atom flipping back and forth at a characteristic frequency of about 24,000 million vibrations per second, or 24,000 megacycles per second. At any given instant the nitrogen atom is on one side of the hydrogens or on the other. From the quantum point of view the nitrogen has at a given time a certain probability of being on either side—in a sense it is partly on both sides. Moreover, the molecule as a whole has two distinct energy states. The difference in energy between the states equals the energy of a photon with a frequency of 24,000 megacycles per second.

Now it happens that ammonia molecules in the higher state are repelled by strong electrostatic fields, whereas those in the lower state are attracted. Thus we have a method for segregating the high-energy molecules and getting maser action. The separator is a cylinder of charged rods [*see illustration at top of page 48*]. In the vicinity of the rods the field is strong; along the axis of the cylinder the field is weak. When a beam of



CLASSICAL VIEW OF THE AMMONIA MOLECULE is that its single nitrogen atom (*large ball*) vibrates back and forth across the plane of its three hydrogen atoms (*small balls*).



QUANTUM-MECHANICAL VIEW OF THE MOLECULE is that, in a sense, the nitrogen atom is simultaneously on both sides of the plane of the hydrogen atoms. The molecule may occupy either a higher energy level (*top illustration*) or a lower energy level (*bottom*).

ammonia molecules is sent through the separator, those in the upper state are attracted to the axis, while those in the lower state are pulled toward the electrodes and dispersed. Out of the far end comes a stream of molecules, virtually all of which are in the upper energy-state. If these molecules are irradiated with 24,000-megacycle microwaves, only downward transitions will be induced. Energy will be given up by the molecules to the microwave field, and the incoming wave will be amplified.

In the actual instrument ammonia gas at low pressure escapes from a nozzle into an evacuated chamber containing the separator and a resonant cavity. After passing through the separator, molecules in the upper state enter the cavity, into which the microwave signal is fed through a waveguide.

The resonant cavity is simply a metal box with highly reflecting walls. Each incoming photon can bounce back and forth across the chamber thousands of times before it escapes again, greatly increasing its chance of interacting with a molecule in the beam.

Whenever there is a collision, a new photon is born. It too is trapped in the chamber for a time and may collide with another molecule, producing a second new photon, and so on. If there are enough molecules in the cavity, this chain reaction becomes self-sustaining; the amplifier turns into an oscillator, generating its own wave without any input signal.

The ammonia maser is an extraordinarily stable oscillator. Its virtually unvarying sine waves can be used as a "pendulum" to regulate an almost perfect clock [see "Atomic Clocks," by Harold Lyons; SCIENTIFIC AMERICAN, February, 1957]. Although such timepieces have not yet been fully tested, it has been demonstrated that two ammonia masers will maintain their frequencies with respect to each other for at least a year with an accuracy of one part in 10 billion. A maser-regulated clock should gain or lose no more than one second in a few hundred years.

As an amplifier the ammonia maser has a remarkably narrow band-width: it will not amplify waves which depart from its central frequency by more than 3,000 to 5,000 cycles. The ammonia maser is not readily tunable; the central frequency cannot easily be changed. This means that it is not really a practical amplifier. If it were used in a communications channel, it could transmit only one voice at a time; it could not come close to receiving a television station. The ammonia maser was, however, the instrument which first demonstrated the great potentialities of maser amplifiers. Moreover, studies of its resonance curve have contributed important information about the magnetic fields within the ammonia molecule.

It was not until the invention of masers that utilize solids rather than gases that practical low-noise microwave amplifiers became a reality. Solid-state masers have a noise level even lower than that of the ammonia maser. Furthermore they are tunable, they have much broader band-widths and they put out much more power. The fact that their frequencies can be varied makes them unsuitable as standards of frequency or of time, but it adds considerably to their general usefulness as amplifiers.

The action of the solid-state maser also depends on quantum jumps, but they are jumps of electrons within individual atoms rather than energy transitions of whole molecules. It is by now a familiar fact that every electron is in effect a small spinning magnet. In most atoms, which are nonmagnetic, the electrons are paired off with their poles opposed to each other so that their magnetism is canceled out. There are a few substances, however, in whose atoms the cancellation is incomplete; some electrons are unpaired and the material as a whole is magnetic, or, in technical terms, paramagnetic.

It is the behavior of unpaired electrons placed in an external magnetic field that makes the solid-state maser possible. As usual, there are two ways to describe this behavior: the classical way, which has the advantage of being easy to visualize but the drawback of being incomplete; and the quantum way, which is implausible but correct. Classically we imagine that the spin axis of the electron wobbles, or precesses like a top around the direction of the field [*see diagram at left in illustration at top of opposite page*]. In quantum terms we say that the spinning electron can have just two positions: one in which its axis points in the same direction as that of the field; the other in which it points in the opposite direction. The two positions constitute different quantum states, the higher of which is represented by the electron whose axis points in the direction of the field. As in the case of molecules, the difference between the levels corresponds to the energy of a photon whose frequency equals that of the classical vibration. Also as in the case of molecules, there are normally more electrons at lower levels than at higher.

To make a maser we simply need to find a way of reversing the normal distribution and putting the majority of electrons in the upper state. Then if they are irradiated with photons of the correct frequency, they will jump down, amplifying the incoming beam.

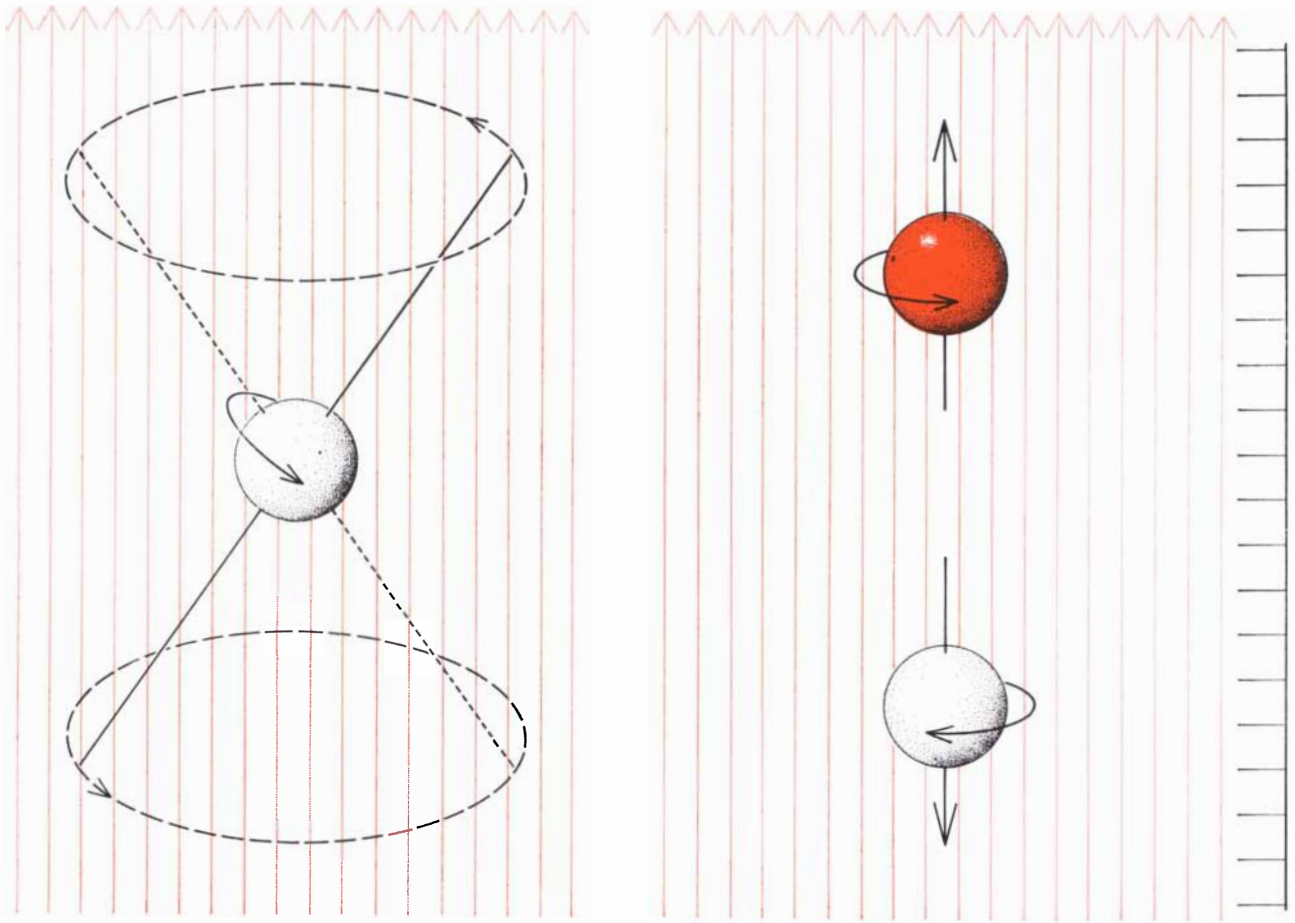
The first type of solid-state maser that was developed is known as the two-level paramagnetic maser. In some versions the paramagnetic material is a silicon crystal containing some impurity atoms, such as those of phosphorus, which have one more electron than they need to satisfy their role in the crystal lattice. In other versions it is a quartz crystal which has been subjected to neutron bombardment to release unpaired electrons. The crystal is placed between the poles of a strong magnet and cooled to a temperature a few degrees above absolute zero in a bath of liquid helium, so that most of its unpaired electrons fall into the lower of their two possible energy states. Then it is subjected to a fairly high-powered microwave pulse, which briefly raises the majority of the electrons to the higher state. While this "inverted population" of electrons lasts, it can act as an amplifier for a weak microwave signal. In silicon the amplifying period lasts about a minute after each "pumping" pulse; in quartz, only a few thousandths of a second.

The difference between the energy of the upper and lower levels depends upon the strength of the magnetic field. Hence by adjusting the strength of the magnet, the maser can be tuned over a wide range of frequencies. With very strong fields it may be possible to reach the never-never land of waves a fraction of a millimeter long.

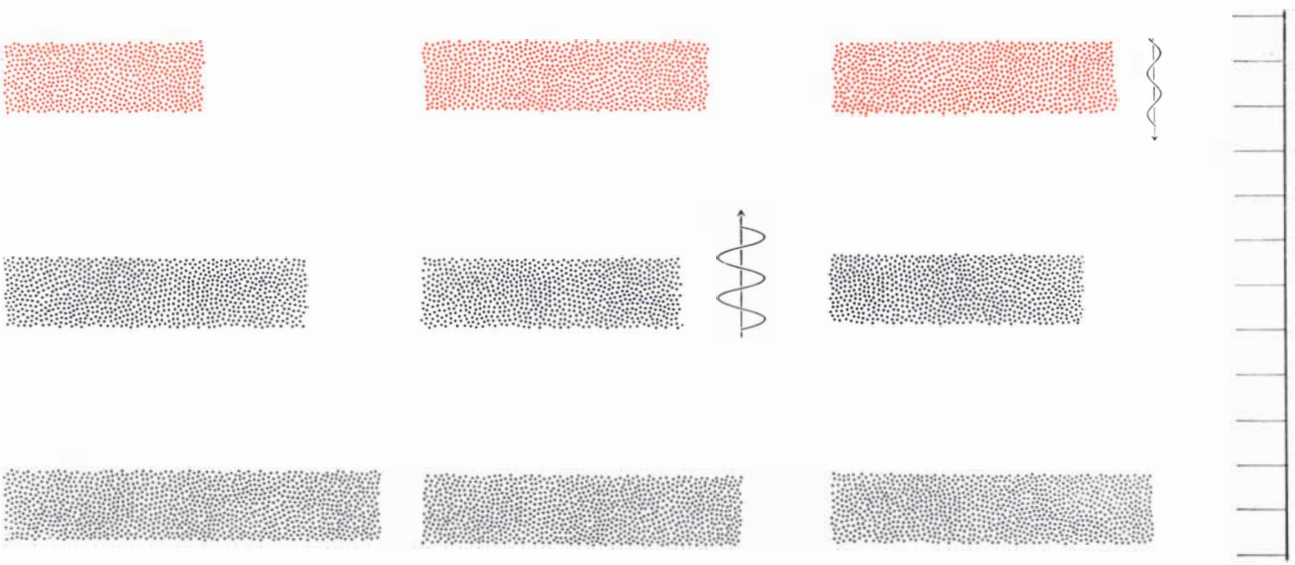
In a solid crystal the outside field is not the only one to act on unpaired electrons. The electrons are also influenced by the magnetism of neighboring atoms. The internal magnetic effect varies from point to point in the crystal, so that not all the electrons are subjected to exactly the same field. Thus they respond to slightly different frequencies, and this is the reason for the wider band-width of the solid-state devices.

The chief disadvantage of the two-level maser is that it can be operated only in bursts; its amplifying action stops each time its electrons drop down again to the lower level. This problem has been overcome with the development of the newest member of the maser family: the three-level paramagnetic maser.

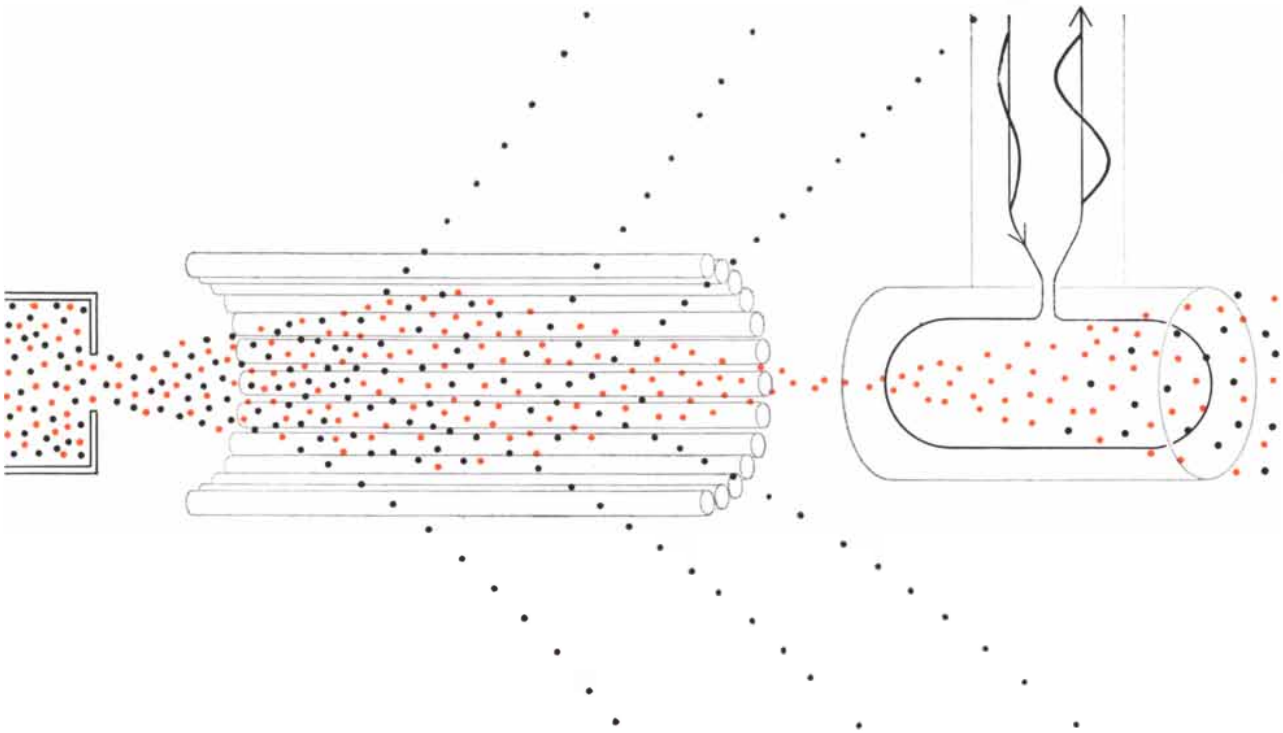
Conceived by Nicolaas Bloembergen of Harvard University, the three-level paramagnetic maser has a basic element



ELECTRON IN A MAGNETIC FIELD (*colored arrows*) is depicted from the classical standpoint (*left*) and from the quantum-mechanical (*right*). In the classical view the axis of the electron's spin precesses, or wobbles, around the direction of the magnetic field at a frequency related to the strength of the field. In the quantum-mechanical view the electron has a higher energy state (*top right*) in which its "south" magnetic pole is pointed in the direction of the field, and a lower energy state (*bottom right*) in which the pole is pointed in the opposite direction. The difference in the energy levels is related to the strength of the field.



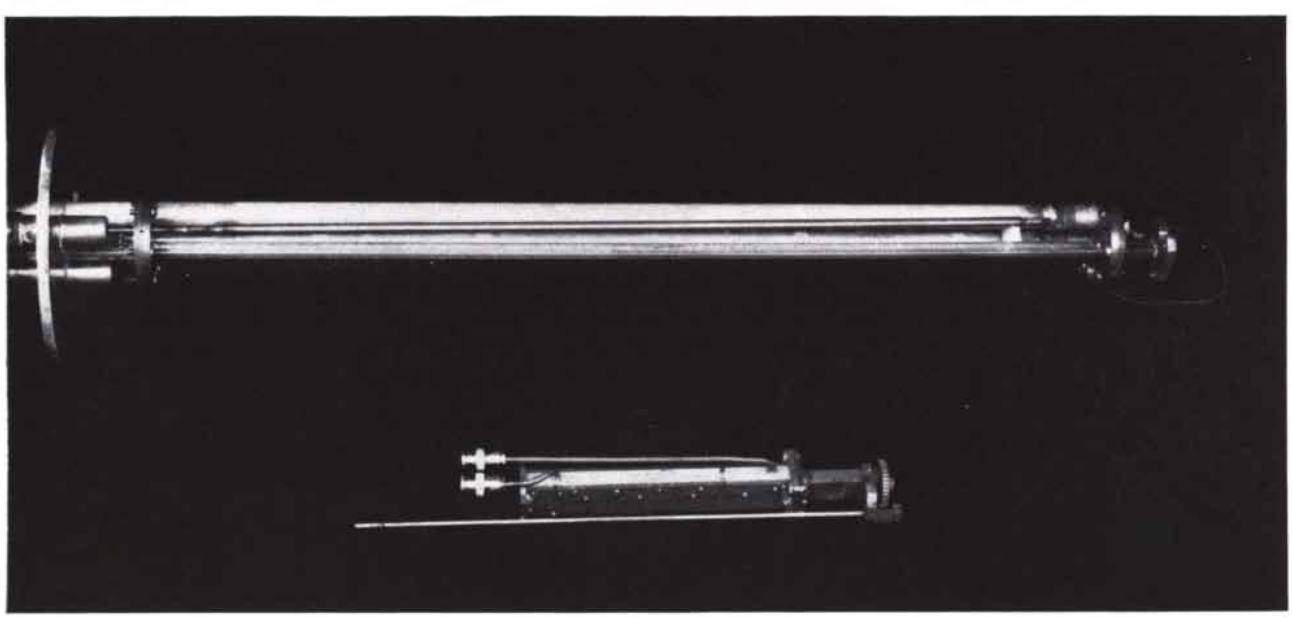
THREE-LEVEL SOLID-STATE MASER is considered. At left are electrons in three energy states; the largest number of electrons is in the lowest state, the smallest number is in the highest state. In the middle electrons are "pumped" from the lowest state to the highest by microwave energy of the appropriate frequency. At right electrons drop from the highest state to the middle state, emitting microwave energy of a lower frequency. Thus energy put into the maser at the latter frequency can be amplified.



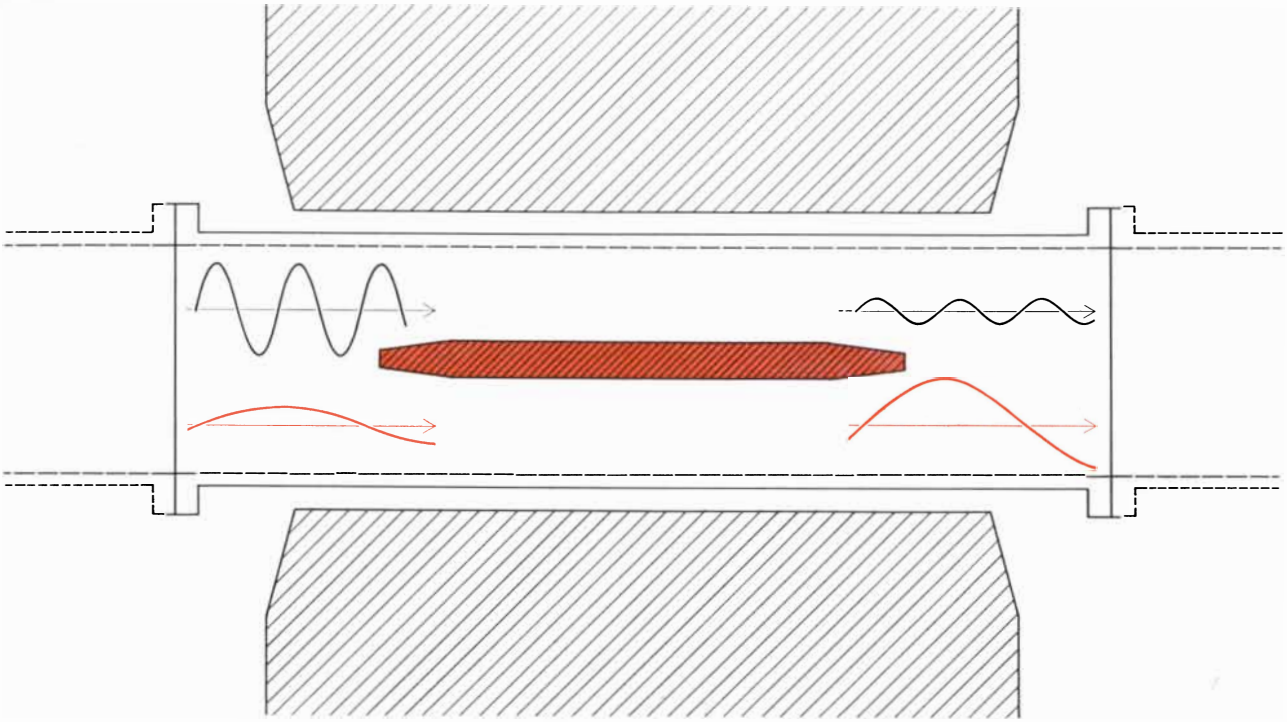
AMMONIA MASER sends ammonia molecules in two energy states through a cylinder of electrically charged rods. The molecules in the lower state (*black dots*) are pulled toward the rods; the molecules in the higher state (*colored*) are attracted to the axis of the cylinder. The molecules in the higher state then enter a resonant cavity (*right*), where they may be used to amplify a microwave signal.

consisting of atoms with more than one unpaired electron apiece. Atoms of this kind are found in the naturally paramagnetic elements such as iron and chromium, in which one of the interior shells of electrons is not filled. Quantum mechanics tells us that in many such atoms there is one more energy level than the number of unpaired electrons. For example, chromium atoms, which make up part of the ruby crystal, possess three unpaired electrons and thus have four energy levels.

Any three of the available levels can be used. When the crystal is cooled to very low temperatures, the atoms distribute themselves among the energy states in the usual way, each higher level containing fewer atoms than the one below it [*see illustration at bottom of preceding page*]. Now we irradiate the solid with microwaves of the proper frequency, causing a jump from the lowest of our three levels to the highest. By this pumping action the top level is kept fuller than the middle one. Therefore a weak signal whose frequency corre-



COMPONENTS OF A THREE-LEVEL MASER appear in the photographs on these two pages. The object at top in the photograph at left is essentially a waveguide through which microwaves are conducted to the maser cell. The object at bottom in the same

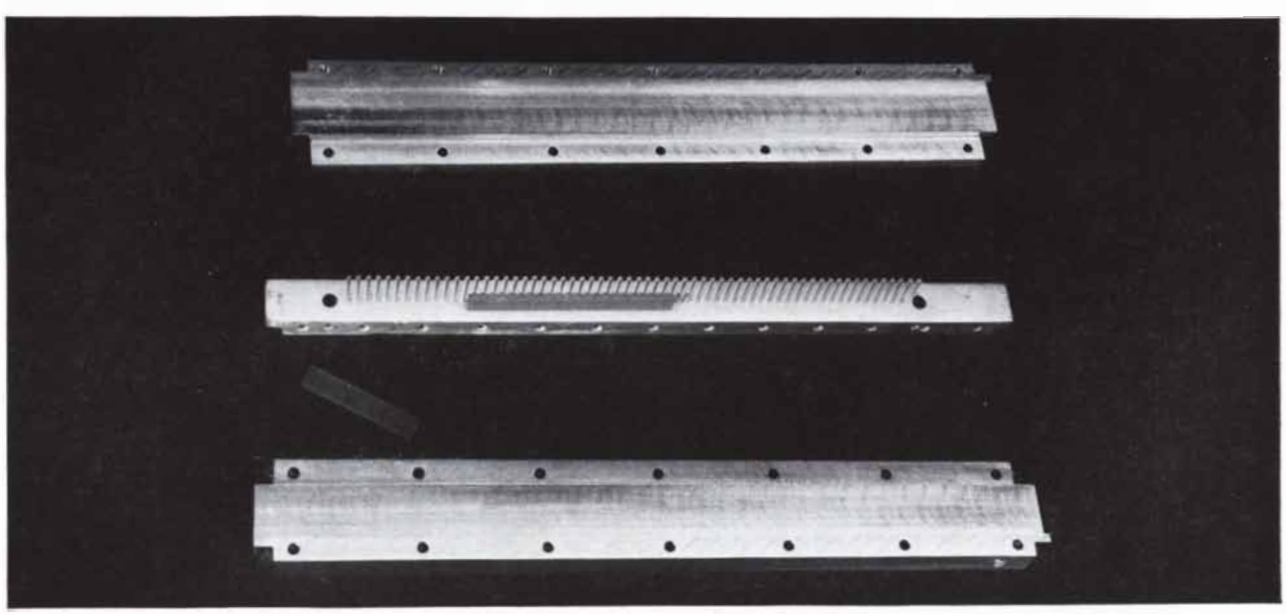


SOLID-STATE MASER consists essentially of a crystal (*center*) between the poles of a magnet (*top and bottom*). Microwave energy of an appropriate frequency (*black curve at left*) pumps electrons in the crystal to a higher state. An input signal (*colored curve at left*) of lower frequency is amplified (*colored curve at right*) at the expense of the pumping energy (*black curve at right*).

sponds to the energy gap between the top and middle levels will cause more downward than upward transitions, and the signal will be amplified. Pumping and amplification can go on at the same time, and so the maser operates continuously.

The first three-level maser was built at Bell Telephone Laboratories. Since then numerous masers of this kind, incorporating a variety of different crystals, have gone into operation at many other laboratories. One of them, as we have indicated, is already attached to a radio telescope. Soon they will be appearing in other applications.

There are jobs to be done by all the members of the maser family. In addition to simply telling time, ammonia and other gas-maser clocks will help explore some of the basic questions of physics. One plan is to recheck the celebrated Michelson-Morley experiment, which demonstrated that the speed of light is constant. Turning the maser's beam of molecules in two directions—along the path of the earth's travel and against it—



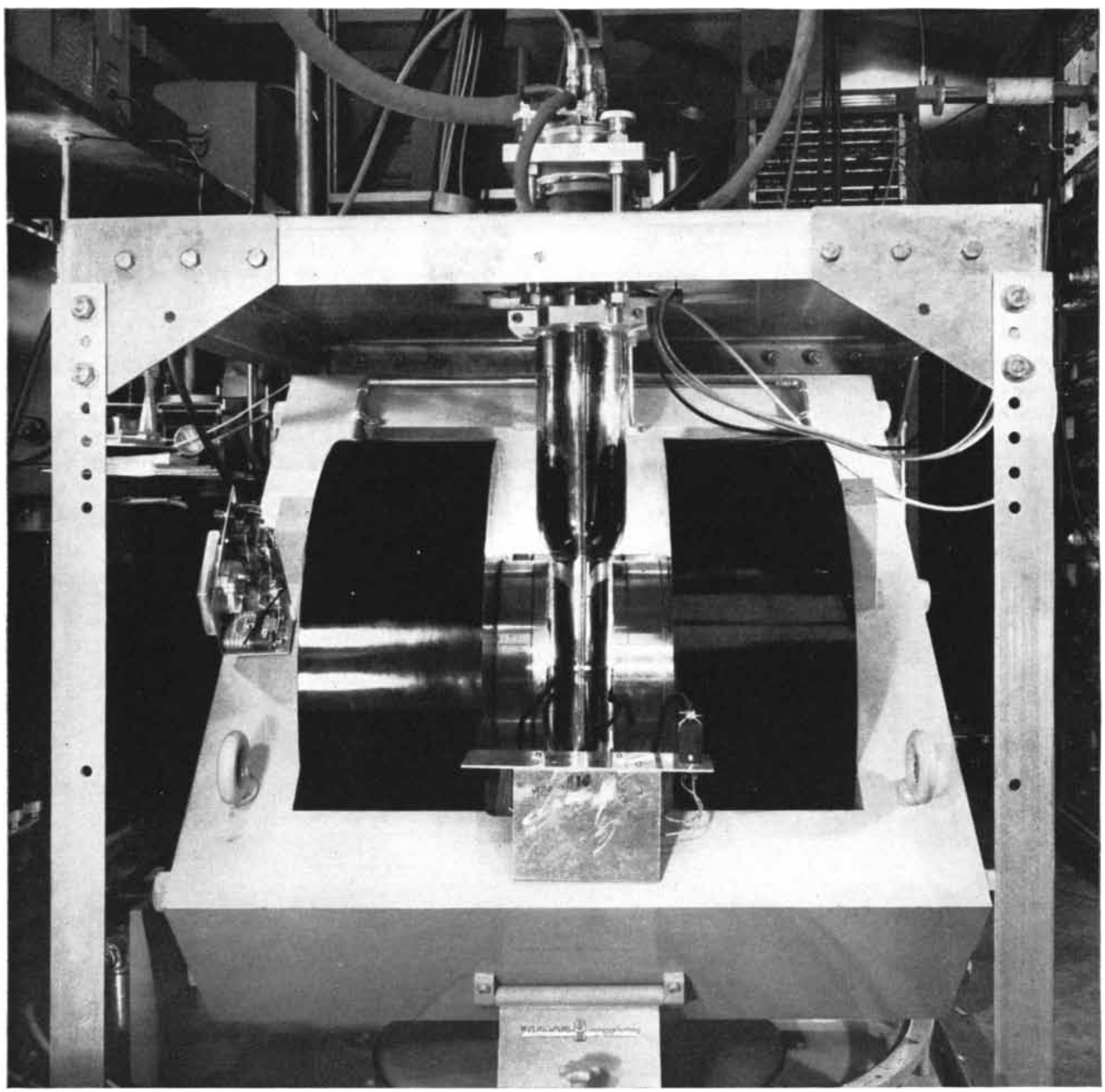
photograph is the maser cell, which is mounted at the right end of the waveguide. In the photograph at right the maser cell is dissected. One section of the large synthetic ruby of the maser stands against the row of pins in the middle; another one is to the left.

should result in no change of the output frequency, if light travels at a constant rate regardless of the motion of the observer. If there is a difference, it is too small to show up on Michelson's light interferometer. But the maser may be able to detect it. [As this issue of SCIENTIFIC AMERICAN went to press, it was announced that the experiment had been performed by Townes, working with J. P. Cedarholm, G. F. Bland and B. L. Havens of the International Business Machines Watson Laboratory at Columbia University. No difference was detected.]

Another project is a check on the general theory of relativity, which predicts that clocks are slowed up by gravitational fields. Artificial satellites will soon be circling the earth at distances where its gravity is noticeably weaker than at the surface. An atomic clock mounted in one of these vehicles could demonstrate the effect, if it exists.

Maser amplifiers may greatly simplify long-distance radio and television communication. As an example of what may be in the cards, suppose a ring of balloon satellites were made to circle endlessly around the earth. They would be permanent reflectors, from which signals could be bounced from any point on the earth's surface to any other. The received signals would be very weak. But the cold and lonely satellites would not contaminate them with much noise. Thus the sensitive, almost noiseless maser amplifiers could pick them up and boost them to useful levels without degrading them beyond recognition.

French workers have applied the maser principle to build a super-sensitive magnetometer for measuring the earth's field. In other laboratories people are thinking of using masers to produce beams of infrared radiation with an extremely narrow band of frequencies. The list is not exhaustive, and there are probably important applications that no one has thought of as yet. Quantum mechanics is adding a new dimension to "classical" electronics.



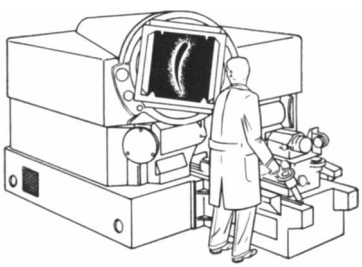
COMPLETE THREE-LEVEL MASER is photographed at Bell Telephone Laboratories. In center, between the poles of a large electromagnet, is a silvered flask which is filled with liquid helium. The maser cell is inside the flask between the two magnet poles.

Kodak reports on:

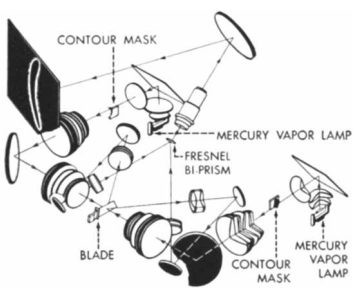
a large optical device . . . how sometimes they don't listen the first time . . . beating our heads against the spectrophotometers

For blades (also vanes and buckets)

This is a blade from a jet engine. Many mathematical minds, mighty mathematical machines, and much aerodynamical experimentation have created its shape. Violation of the plan to the extent of a few thousandths of an inch in a single cross-section of a single blade sucks at efficiency like a little leech. And there are so many blades in a single compressor or turbine that the total number of them made in the brief span of air-breathing non-reciprocating history must compare with all the wooden spokes in all the wagon wheels of all the supply trains in all armies since Alexander the Great. Tolerances on wooden spokes have always been broad.



Therefore we have been busy lately building this large optical device. It works as follows:



Not long before this periodical reached its subscribers, the two mercury lamps were turned on and the first cross-section of the first blade was seen in magnification against its tolerance envelope scribed on the screen. Inspection from now on should go well.

The device has been named Kodak Section-Profile Projector. *It is enough to restore faith in the future of geometrical optics. Inquiries go to Eastman Kodak Company, Military and Special Products Sales, Rochester 4, N. Y.*

Freezing here

In manufacturing *Kodak Frozen Section Stripping Film* we are attempting to perform a public service for and through pathologists. They are paying scant attention. Unless an upturn sets in soon, we shall give up.

This product is the ultimate in slow films, being endowed with no light sensitivity whatsoever. Its sole known function is to support a CO_2-frozen tissue section being microtomed. A description of the technique, stated to be quick and easy, may be found in *American Journal of Pathology, 28,* 863-873 (1952). This paper depicts a 10μ section of adenocarcinoma of the rectum showing invasion of the wall, bronchogenic squamous cell carcinoma cut at 5μ, lung tissue cut at 5μ showing edema secondary to cardiac failure, and other examples of tissues said to be otherwise difficult to handle.

The product consists of a 10μ gelatine layer atop a 30μ cellulose ester layer atop a heavier carrier base from which it is separated before use. If the gelatine layer is pre-stained, the stain transfers in seconds to the specimen. The film is supplied in unperforated 35mm rolls 25 feet long for $15 (list) by arrangement through Eastman Kodak Company, Special Sensitized Products Division, Rochester 4, N. Y. This is not the way great industrial empires are built.

Self criticism

We try our best, and over the years the level of quality rises.

• • •

At a certain point in a column where we distill a lot of mesityl oxide for intramural reasons, a peculiar substance was found to accumulate. Infrared spectroscopy showed it to be 4-methyl-4-penten-2-one, an unconjugated isomer of properly conjugated mesityl oxide. A busybody among us who is quick on the draw with his gas chromatography outfit then opened a bottle of our Eastman Grade *Mesityl Oxide*, numbered Eastman 582. Sure enough, a separable fraction was present, and sure enough, it was this very same isomer. Should we take the position that it is the nature of mesityl oxide to isomerize spontaneously? We decided we should not. Up went the "P" to make it Eastman P582, and down came the price to $2.30 a kilo. Even as a Practical Grade solvent, we plan to keep its isomer content below 0.5% when packed.

• • •

We are co-operating in a splendid project to measure and catalog the infrared absorption spectrum of every organic compound that can be rounded up. One observation from this experience has impressed itself: how often the infrared spectrum shows a carbonyl linkage in compounds that are not supposed to have any. "You are seeing carbonyls in your sleep," the boss chid our normally genial chief control chemist when he came in all worried and upset about finding a carbonyl dip in the spectrum of bis-(3-chloro-n-propyl) ether. But gas chromatography went on to demonstrate two fractions present to the extent of 2% and 4% respectively, and these were found by I-R to be carbonyl compounds. That is why we have shorn this ether of its capitals, italics, and Eastman number.

• • •

Our ultraviolet spectrophotometers are another thorn in our side. U-V is very good at showing isoquinoline bands, and it showed them in *1,2,3,4-Tetrahydroisoquinoline* (Eastman 7065), where there shouldn't be any. We have rehydrogenated our complete stock thereof, redistilled it, and resolved not to let it happen again. At least it was our spectrophotometer that discovered the impurity, not somebody else's.

• • •

Recently a man wanted to buy one of our chemicals in mass-spectrographically-pure grade. We told him he couldn't afford the price and turned him down flat. Nor do we know how much money he has.

All this is for the benefit of Eastman Organic Chemicals. Our current List No. 41 catalogs some 3700 of them—a large number of battlegrounds for the war against impurity. Chemists who have the List find it a handy way to make sure they don't waste time making something they can buy. For a copy, write Distillation Products Industries, Eastman Organic Chemicals Department, Rochester 3, N. Y. (Division of Eastman Kodak Company).

Prices stated are subject to change without notice.

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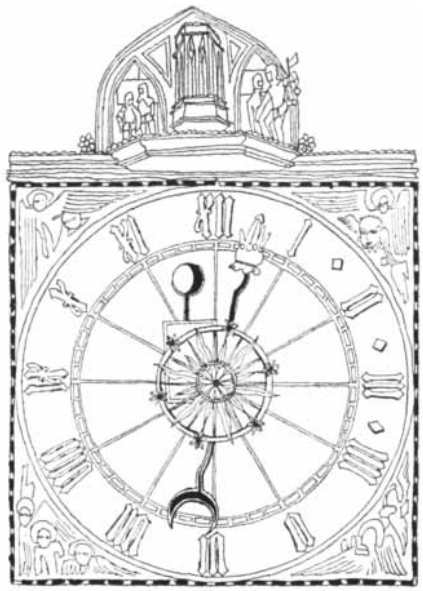
This is another advertisement where Eastman Kodak Company probes at random for mutual interests and occasionally a little revenue from those whose work has something to do with science

SCIENCE AND



The Nobel Prizes

Seven men—three from the U. S., three from the U.S.S.R. and one from Great Britain—share the three Nobel science prizes for 1958.

The physics prize was awarded to the Soviet physicists Igor Y. Tamm, Pavel A. Cerenkov and Ilya M. Frank for their work on Cerenkov radiation: the strange glow emitted when subatomic particles move through a transparent substance faster than the speed of light in that substance. Cerenkov discovered the radiation in 1934; Tamm and Frank later worked out the theoretical explanation of it. Because the angle at which Cerenkov radiation is emitted by a particle is related to the speed of the particle, the radiation has been widely used in experiments where it is necessary to detect particles of a given speed.

The chemistry prize was won by Frederick Sanger of the University of Cambridge. In 1944 Sanger had set out to determine the arrangement of the amino acid units in the molecule of the protein insulin. By 1954 he had discovered that the molecule consists of two cross-linked chains of amino acid units, one chain made up of 21 units and the other of 30 units. He had also determined the sequence of the specific units in the chains.

Half of the prize for physiology and medicine went to Joshua Lederberg of the University of Wisconsin. By his discovery of sex in bacteria Lederberg had opened up a flourishing field of investigation in which bacteria are used to study the fundamental mechanism of heredity. The other half of the prize was awarded to George W. Beadle of the California Institute of Technology and Edward L. Tatum of the Rockefeller Institute. Working with the red bread mold *Neurospora crassa*, Beadle and Tatum had demonstrated that single chemical reactions in the living cell are related to single genes.

Pugwash III at Kitzbühel

Eighty scientists, including 20 from the U. S. and 10 from the U.S.S.R., met in Austria from September 14 to 21 in the third of the informal conferences which began last year at Pugwash, Nova Scotia. Pugwash III, held at Kitzbühel and Vienna, had more than three times as many participants as Pugwash I or II. The conferees were guests of the President of Austria, who recently urged scientists throughout the world to get together to avert the menace of nuclear warfare. Despite its size and semi-official sponsorship, the meeting went almost unreported in the U. S. press, though both Soviet and Western European newspapers gave it considerable coverage.

Like its predecessors, the conference had as its main purpose the informal exchange of views between scientists of East and West. As one U. S. participant put it: "It helped us to understand the attitude of the Soviet scientists." Despite the fears of some participants that the meeting might become a forum for nationalistic views, the conference confined itself to technical discussions on nuclear war and disarmament, plans for international cooperation, and the drafting of a concluding statement on some of the problems discussed.

Previous Pugwash meetings had laid great stress on the dangers of nuclear testing. The Kitzbühel conference found strong confirmation for these misgivings in the recent report of the United Nations Scientific Committee on the Effects of Atomic Radiation. But they noted that biological damage from a war would be incomparably larger than from tests, especially since military considerations would make likely the use of "dirty" bombs now stockpiled by major states. "Mankind," the scientists declared, "must . . . set itself the task of eliminating all wars, including local wars. . . . Any step that mitigates the arms race

THE CITIZEN

and leads to even small reductions in armaments and armed forces . . . is therefore desirable." The conferees agreed that disarmament "requires measures of control to protect every party from possible evasion."

Observing that "the increasing material support which science now enjoys in many countries is due mainly to its importance . . . to the military strength of the nation and to its success in the arms race," they called on scientists to promote public understanding of the dangers and potentialities of science. "Studies and programs for the effective industrialization of [underdeveloped] countries," they declared, "would not only improve the level of living of the majority of the population of the world but would also help reduce the sources of conflict between highly industrialized powers."

Among the participants were Brock Chisholm and Sir Robert Watson-Watt (Canada); Lord Boyd-Orr and Bertrand Russell (Great Britain); Max Born (Germany); H. J. Bhabha (India); Hideki Yukawa (Japan); David Cavers, H. J. Muller, Linus Pauling, Alvin Weinberg, Victor Weisskopf and Eugene Wigner (U. S.); N. N. Bogolubov and A. V. Topchiev (U.S.S.R.).

The Pollution of Space

A plea for immediate worldwide action to prevent the biological contamination of the moon and nearby planets by rockets has been issued by the International Council of Scientific Unions. The eighth general assembly of I.C.S.U. met in Washington in October and made public the recommendations of CETEX (Committee on Contamination by Extraterrestrial Exploration), a group established by I.C.S.U. early this year. CETEX urges investigators to prepare papers on the problem of lunar and planetary contamination so that an advisory committee can draw up a detailed program of precautions before the end of 1958.

The I.C.S.U. also released a summary of the first CETEX meeting, held at The Hague in May. At that time the participants stressed the danger of depositing any sort of organic matter on the moon. The basic question concerning the origin

of life, they pointed out, is: How did complex molecules come to be made and duplicated? While they dismissed the possibility of finding any form of living matter on the moon, they said it is conceivable that pristine "moon dust" might provide clues to the beginnings of life. Some "pre-life" chemical processes may be occurring on the moon even now. If so, contamination by biological molecules from the earth might disturb the lunar processes. Under lunar conditions these molecules might act as templates and start a new kind of growth.

"Pioneer," the rocket which U. S. rocketeers hoped would circumnavigate the moon, was sterilized with a potent germicide. But as the CETEX summary explains, "a dead bacterium from an aseptic rocket would be as harmful as a live one." And possibly the germicide itself would act as a template for the formation of organic matter on the moon.

Gold from Uranium

What could turn out to be the richest patent in history is nearing settlement. In 1940 four investigators filed a patent claim on the separation of uranium 235 from uranium 238 by the process of gaseous diffusion. This process today makes possible the production of the most economical reactor fuel, uranium enriched with its unstable 235 isotope. The scientists had done their development work independent of the U. S. Government support then just beginning to trickle into the research enterprise that became the Manhattan Project. Their patent application remains classified but its claims have since been allowed by the U. S. Patent Office. Now the Atomic Energy Commission, under the terms of the Atomic Energy Act, is considering the investigators' claims for royalties. The decision will come "in a matter of a few months," states A.E.C. Commissioner Willard F. Libby.

Most of the money would go to the Basic Science Foundation, which has been set up by the four scientists: John R. Dunning and Eugene T. Booth, Jr., of Columbia University, Aristid V. Grosse of the Research Institute of Temple University and Alfred O. C. Nier of the University of Minnesota. The Foundation will support basic research at 20 to 30 universities, the major grant going to Columbia, where the four workers made their discovery.

The royalties might amount to 3 or 4 per cent of the development cost of the atomic bomb, suggests Robert L.

progress report on Aeronutronic

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Johnson, president of Temple University and head of the Foundation. If so, the award would amount from $60 million to $80 million, and would dwarf all previous royalty payments made by the A.E.C. In 1953 a group of workers, among them Enrico Fermi, got $300,000 for the method of making radioactive isotopes by bombardment with slow neutrons. Two years later another group including Glenn T. Seaborg received $400,000 for pioneer work on the artificial element plutonium.

Mohole

The drilling of a hole four miles into the ocean floor is being studied by a special committee of the National Academy of Sciences. The hole would be as deep as any oil well ever sunk on dry land and more than 10 times the depth of today's offshore oil wells. Near the bottom it might penetrate the Mohorovicic discontinuity at the boundary between the earth's crust and its underlying mantle.

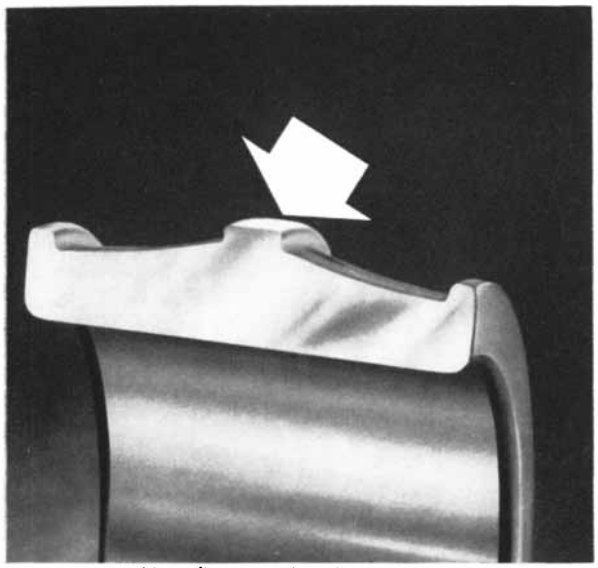
Up to now all information about the "Moho" has been deduced from the behavior of earthquake waves, which bend sharply as they cross the boundary. The deep hole may enable earth scientists to make a direct study of the boundary region and the mantle below.

The drilling is to be done at sea because the basaltic foundation of the earth's crust is thinnest under the oceans —only three to four miles thick in some places. Under the land there is an additional top layer of granitic rocks several miles thick. Before they can reach the basaltic layer, the drillers must penetrate 3,000 or 4,000 feet of oceanic sediment. Cores taken from this sediment, the committee members hope, will reveal in cross section the history of the earth in the time since the oceans were formed.

The National Science Foundation has granted $30,000 for the study phase of the project to the committee, which is headed by Gordon Lill, chief of the Geophysics Branch of the Office of Naval Research.

Protein Synthesis outside the Cell

Biochemists have accomplished an unusually clear-cut synthesis of amino acids into complete protein molecules outside the living cell. This significant feat is described in *Proceedings of the National Academy of Sciences* by Richard Schweet and Esther Allen of the City of Hope Medical Center in Duarte,



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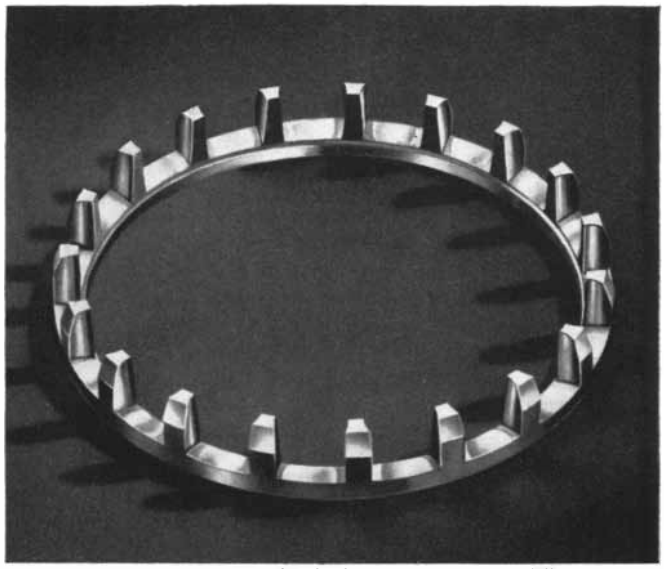
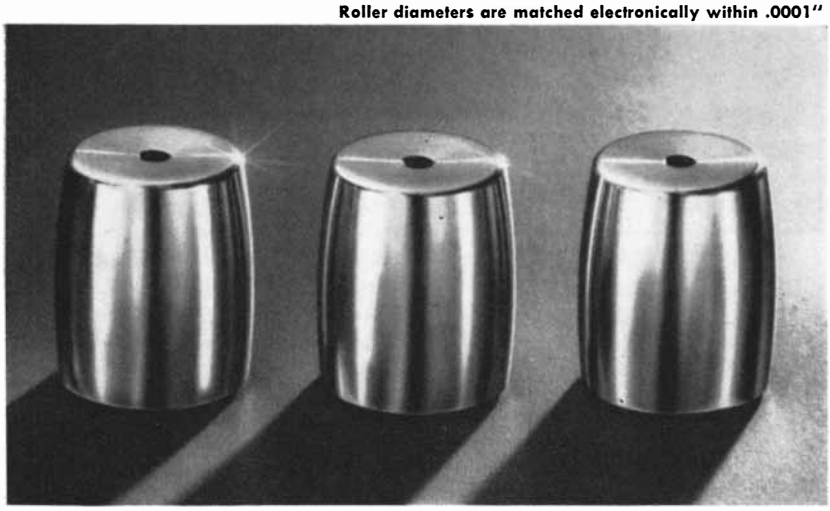


Land-riding bronze cages are fully machined.

Roller diameters are matched electronically within .0001"



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There's no effective substitute for any design feature of Torrington Spherical Roller Bearings. Consider the stabilizing effect of the integral center guide flange. Torrington's asymmetrical roller seeks this flange under load. Skewing and stress concentrations are eliminated. Every roller carries its share of the load because roller diameters are matched electronically within .0001" for even load distribution.

Rollers are *precisely* spaced by fully machined land-riding bronze cages that withstand even the high stresses of eccentric service. Two independent cages, one for each row, prevent roller drag and side stresses under thrust loads. Size-stabilized races prevent "growth" in service.

Torrington research has also adapted these bearings to unusual operating conditions. Races and rollers have been produced in stainless, monel, stellite, titanium carbide and other special steels—and cages in aluminum, ductile iron and plastic.

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RESEARCH FOR PROGRESS IN BEARING DESIGN AND PERFORMANCE

Calif., and by Hildegarde Lamfrom of the California Institute of Technology.

For some years it has been known that a major role in protein synthesis is played by small particles in the cell called microsomes [see "The Microsome," by Paul C. Zamecnik; SCIENTIFIC AMERICAN, March]. Indeed, microsomes isolated from cells and mixed with enzymes have been observed to incorporate amino acids into various proteins. Until the California group had done its work, however, microsomes had not so clearly been caught in the act of making a specific protein.

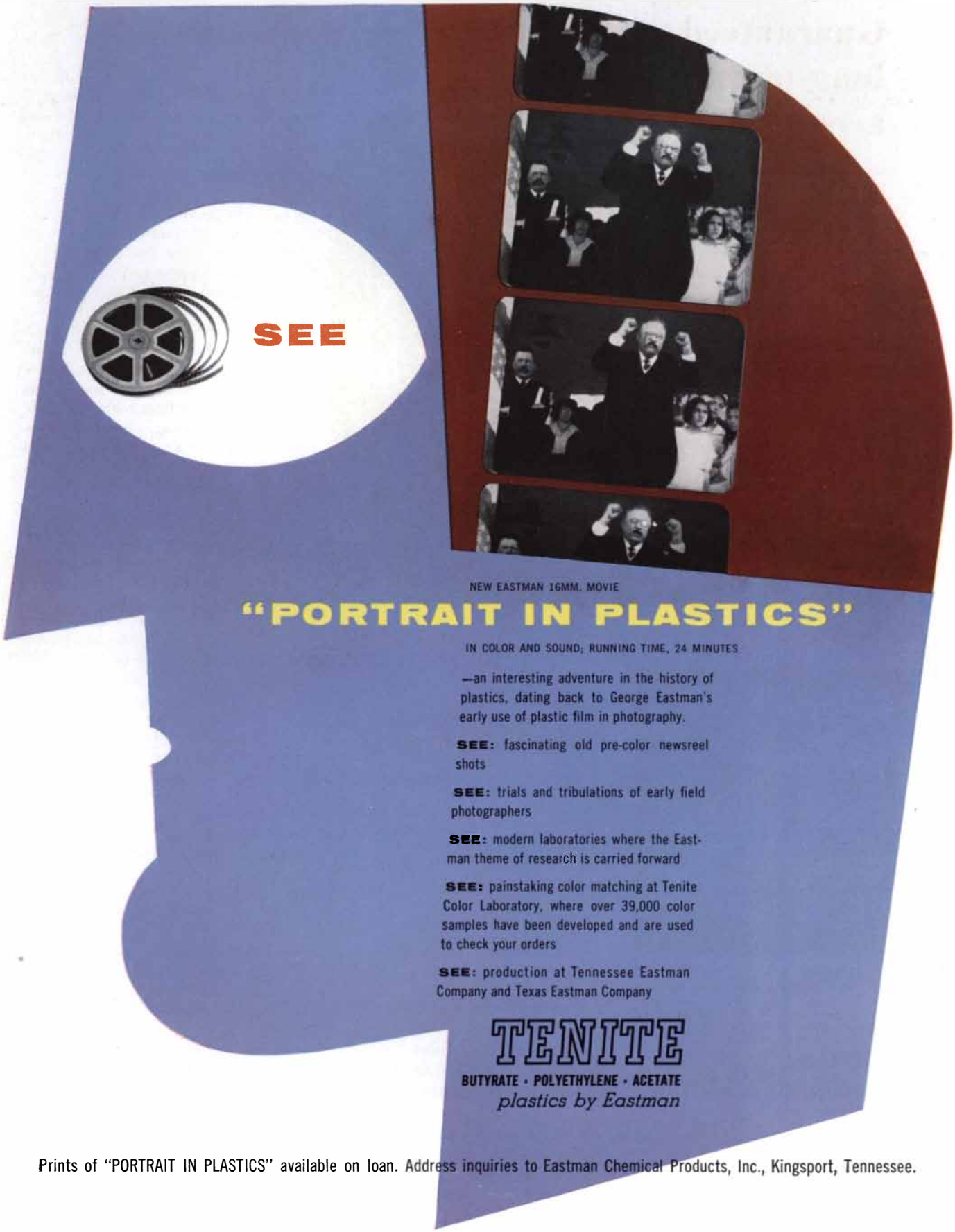
The protein is hemoglobin. The California workers obtained their microsomes from the red blood cells of the rabbit. Then they mixed with the microsomes (1) two enzymes from rabbit red cells, (2) energy-yielding phosphate compounds and (3) a complete assortment of amino acids. Three of the amino acids had been labeled with radioactive carbon atoms.

After the mixture had been incubated, the workers examined the protein in it. They found that the hemoglobin contained the labeled amino acids in the same ratio in which they occur in natural rabbit hemoglobin. This strongly suggested that the hemoglobin molecules had not merely incorporated the amino acids, but that the molecules had been built from the ground up.

The microsomes are essential to the experiment. When they were omitted, inactivated by boiling or replaced with other cell fragments, no labeled amino acids were taken up. The evidence of the California workers supports the idea that the microsome is a sort of jig or template for the manufacture of protein molecules. Rabbit red-cell microsomes themselves contain two of the amino acids which were labeled, but in a ratio unlike that of the acids in rabbit hemoglobin. The fact that the labeled acids were taken up in the latter ratio indicates that the microsomes were primarily making hemoglobin, not microsome.

Teaching by Machine

Can teaching be mechanized? B. F. Skinner, Edgar Pierce Professor of Psychology at Harvard University, believes that it must be if the rising worldwide demand for education is to be met. He has designed and built a number of "teaching machines" which not only present material to the student (as do conventional audio-visual teaching aids) but continually test the



Prints of "PORTRAIT IN PLASTICS" available on loan. Address inquiries to Eastman Chemical Products, Inc., Kingsport, Tennessee.

Information on "PORTRAIT IN PLASTICS" and bookings of this movie also may be obtained from local representatives listed under "Plastics—Tenite" in the classified telephone directories of the following cities: Atlanta, Chicago, Cleveland, Dayton, Detroit, Houston, Kansas City, Leominster (Mass.), Los Angeles, New York City, Portland (Ore.), Rochester (N.Y.), St. Louis, San Francisco, Seattle and Toronto. Elsewhere throughout the world, from Eastman Kodak Company affiliates and distributors.

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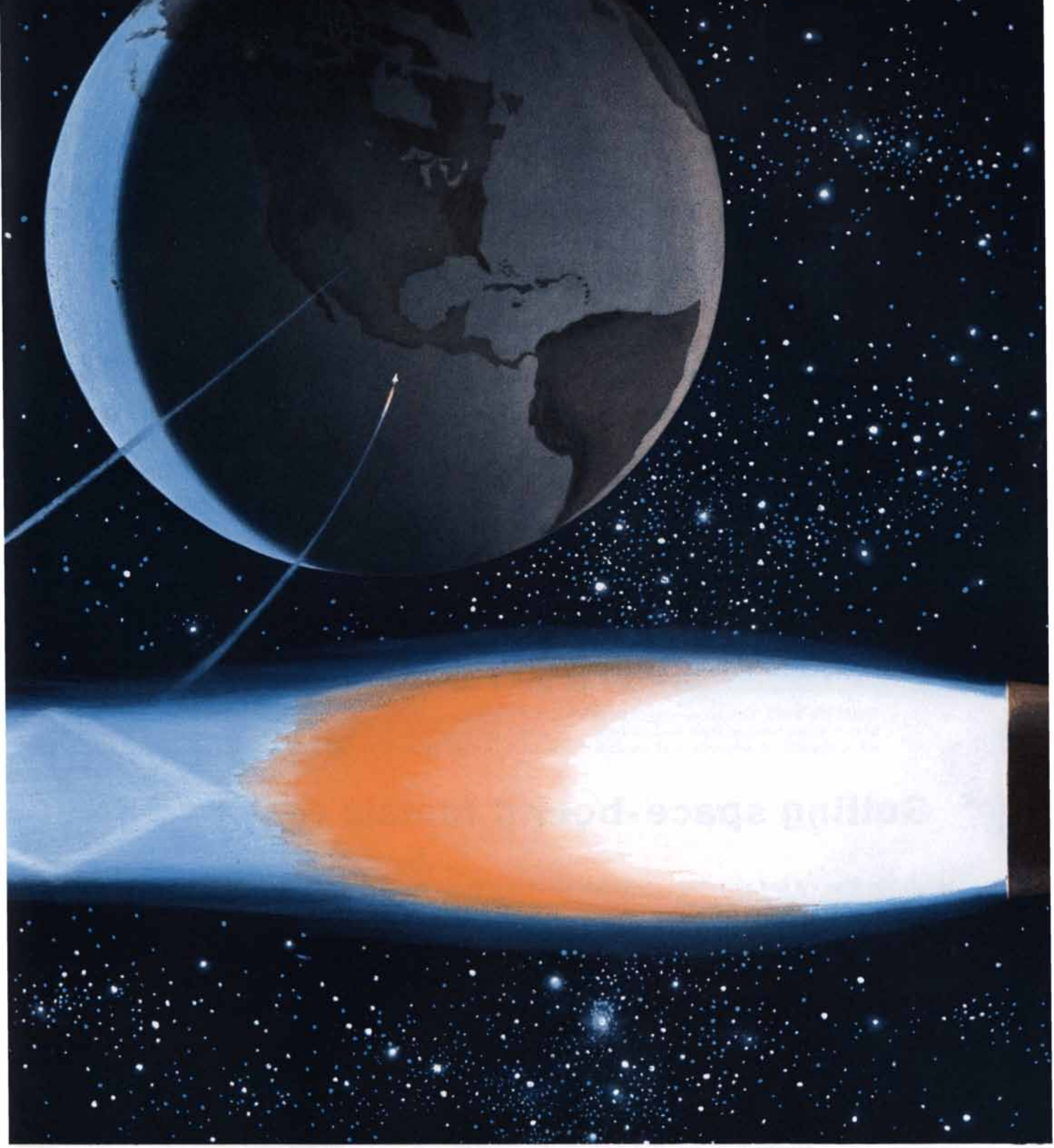
In addition, current application projects include supersonic ramjet power for Bomarc, Super Bomarc, X-7 (test vehicle), Q-5, and Kingfisher.



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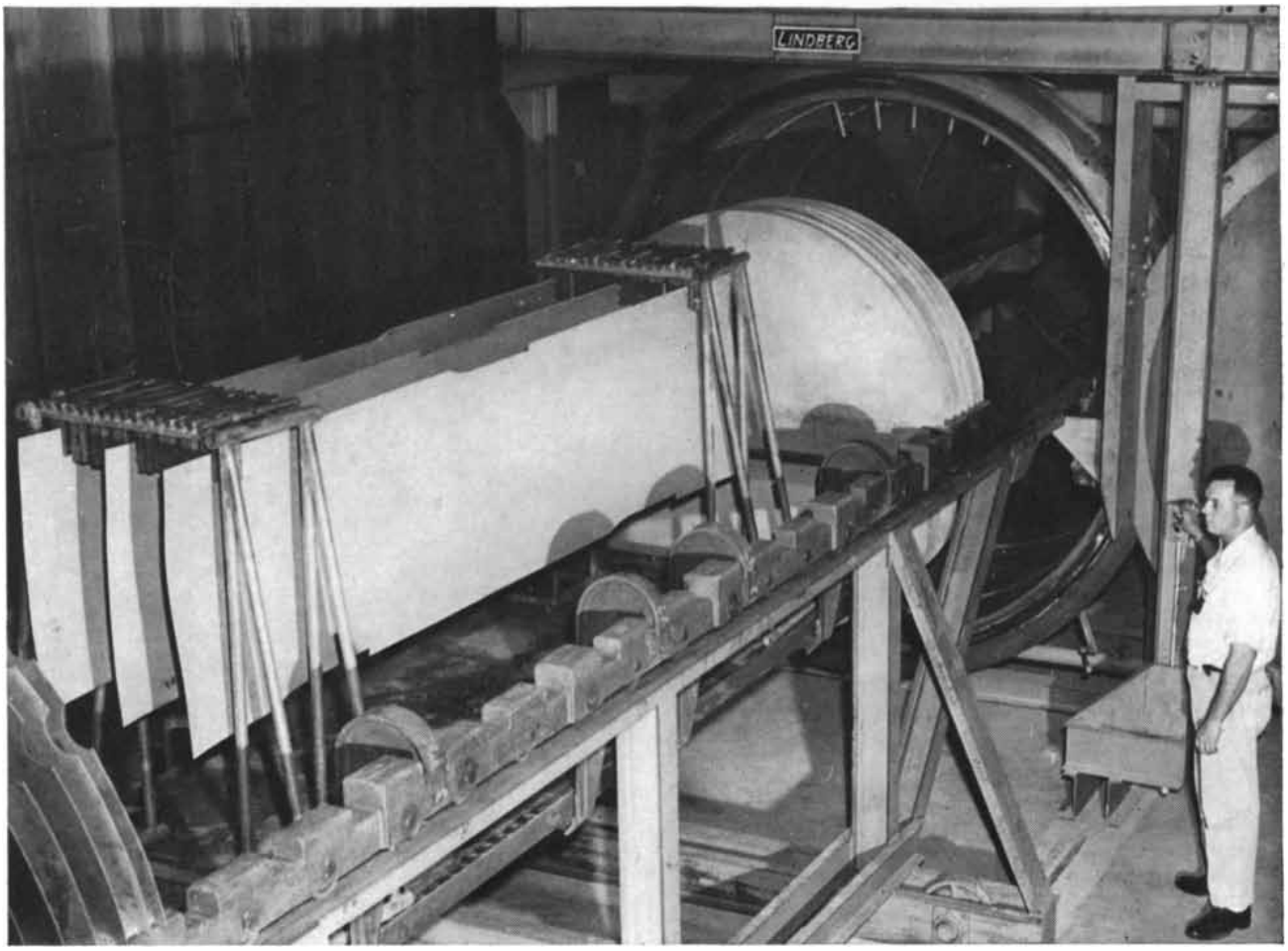

TAKES BIG ONES. This is the world's largest vacuum heat-treating furnace. Built by Lindberg Engineering Company, it degasses and anneals full-sized titanium alloy sheets in the flat, is also used for large forgings and extrusions. Work chamber of Inconel alloy is 14 feet long, 6 feet in diameter.

Getting space-bound metals ready to go

Metals like titanium and zirconium used in guided missiles are tricky to heat treat.

It's not so hard to imagine what usually happens as temperatures soar in the heat-treating furnace . . . these metals tend to "pick up" hydrogen, oxygen and nitrogen.

They become brittle. They crack under stress.

To put a damper on that, a degassing furnace like the one shown here is used. It runs so hot — at so high a vacuum — there's practically no gas left to worry about!

Under those conditions, you might wonder if its users wouldn't be worrying about how the furnace itself would react. No problem on that score, either. The huge retort — big enough to take full-size sheets in the flat — is made entirely of Inconel* nickel-chromium alloy. *Half-inch plate.*

With this protection, metals can be heated as high as 2100° F. in a vacuum of 0.3 microns without danger of collapsing the retort. Inconel alloy has all the strength, all the resistance to oxidation, that's required for such gruelling service.

Then, too, Inconel alloy gives long-term insurance against damage by thermal shock. And another big consideration: it is easy to fabricate in the large and heavy sections that are needed.

Do you have a metal problem in which high (or low) temperatures play a leading role? Or corrosion? Stress? Fatigue? Some other troublemaker? There is a good chance Inconel alloy will provide the combination of properties you need. To find out more about this versatile alloy, write for Technical Bulletin T-7, "Engineering Properties of Inconel."

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student on the information he is acquiring.

Skinner, one of the most influential investigators of learning processes, is well known for his extensive studies of learning in animals [see "How to Teach Animals," by B. F. Skinner; SCIENTIFIC AMERICAN, December, 1951]. His machines, which he describes in *Science* as the mechanical equivalent of a private tutor, utilize material which has been broken down into many small and carefully arranged steps. The machine presents only one "frame" of material at a time. In one type of apparatus the student writes his response to each frame on a paper strip in the machine. He then uncovers the correct answer by moving a lever. If the two responses correspond, he alters the machine so that the correctly answered frame does not reappear when he goes over the material again. Skinner believes that the machine, immediately reinforcing correct answers, teaches more effectively than examination papers which are corrected and returned several days later. Moreover, each student can progress at his own pace.

Skinner and his associates have used machines of this type in teaching part of a course in human behavior to nearly 200 Harvard and Radcliffe College undergraduates. The students covered material corresponding to about 200 textbook pages in an average "machine time" of 14½ hours. They reported that they learned much more in less time with less effort than they did by conventional methods.

The Negative Gene

Negative electric charges along the giant molecule of deoxyribonucleic acid (DNA) appear to be a significant feature of its function in the nucleus of the living cell. The experiments which suggest this conclusion are described in *Proceedings of the National Academy of Sciences* by V. G. Allfrey and A. E. Mirsky of the Rockefeller Institute.

Allfrey and Mirsky worked with nuclei which had been isolated from cells in the thymus gland of the calf. First they incubated the nuclei with an enzyme which removes up to 75 per cent of their DNA. Thus treated, the nuclei lost their capacity to synthesize the energy-yielding substance adenosine triphosphate (ATP), to incorporate amino acids into protein, and to incorporate adenosine into ribonucleic acid (RNA).

To the inactive nuclei Allfrey and Mirsky now added various large molecules bearing negative charges. Some of

the molecules were chemically unrelated to DNA; indeed, one of them was a synthetic molecule: polyethylene sulfonate. But when the molecules were taken up, the nuclei resumed their activity! When large molecules bearing positive charges were added, chemical activity stopped; in fact, when positively charged molecules were added to intact nuclei, the incorporation of amino acids into protein was greatly inhibited.

The End of the Rune Stone?

The Kensington Stone, one of the most celebrated historic relics in the U. S., has been firmly labeled a fraud. The stone, a large slab inscribed with rows of peculiar symbols, was found in 1898 by a Swedish immigrant, Olof Ohman, on his farm near Kensington, Minn. Language experts found the inscription to be Scandinavian runic writing and translated it: "Eight Swedes and 22 Norwegians on an exploration journey from Vinland westward. We had our camp by two rocky inlets one day's journey north of this stone. We were out fishing one day. When we came home, we found 10 men red with blood and dead. AVM save us from evil. We have 10 men by the sea to look after our ships, 14 days' journey from this island. Year 1362."

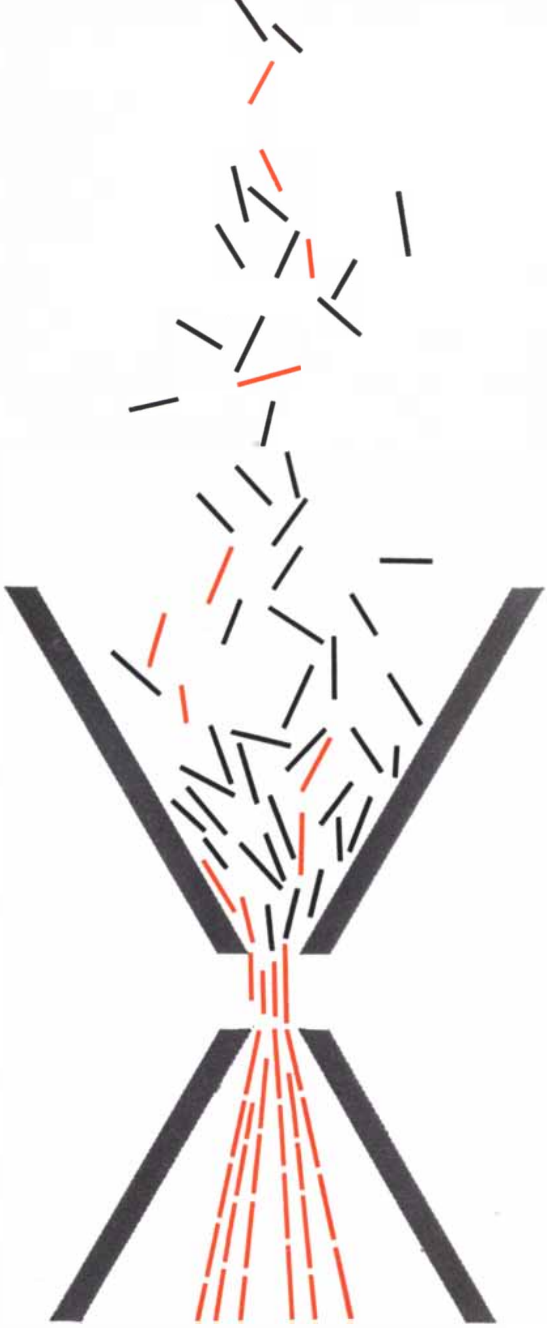
An authority on Scandinavian languages, Erik Wahlgren of the University of California at Los Angeles, now explains why the inscription on the stone cannot be authentic. In his new book *The Kensington Stone, a Mystery Solved* he sets forth many compelling reasons.

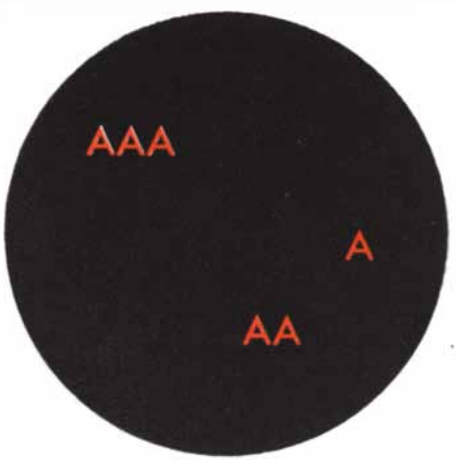
It is difficult to believe that Vikings could have left their ships only 14 days' journey from Minnesota. They could not have sailed their ships past Niagara Falls, and the next nearest shore is on Hudson Bay, 2,200 miles distant.

The inscription is unreasonably long. Most genuine rune stones are cryptic; stone carving is hard, slow work. Would Norse explorers beset by Indians have been long-winded?

The runic writing is not true to form. The date 1362, for example, is written in the runes for "one," "three," "six" and "two." On rune stones found in Europe the year numbers are written out in full or in Roman numerals.

Who perpetrated the hoax? Here Wahlgren does not come to a firm conclusion. He points out, however, that Ohman owned a Swedish encyclopedia which was well thumbed at a section on the history of the Swedish language.





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STEPS IN THE RACE TO OUTER SPACE

Mars Snooper

This nuclear-fueled reconnaissance craft is preparing to land on Mars' outermost satellite, Deimos—12,500 miles away from the "red planet" (center) and 35 million miles away from the Earth. Deimos' gravitational pull is so slight that a featherlight landing could be made, and a take-off could be accomplished with little more than a shove of the pilot's foot! (At Deimos' orbital speed, such a push would start the ship back to Earth at 3000 miles per hour.)

Our spaceship is designed to fly in two directions—nose first as a space rocket and tail-first as a ramjet airplane. Propulsion for both is provided by a single atomic heat source, reacting with hydrogen for rocket thrust, and with atmosphere to power the ramjets.

Travel to Mars, braking for landing, take-off and re-entry are accomplished by rocket-thrust. As the ship approaches the Earth's atmosphere, it assumes a tail-first attitude. The "petal doors" enclose the rocket nozzle, and the ship is transformed into a high speed, ramjet airplane with M-shaped wings. Control fins are located in the nose of the craft, near the crew's quarters.

* * *

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THE EVOLUTION OF BEHAVIOR

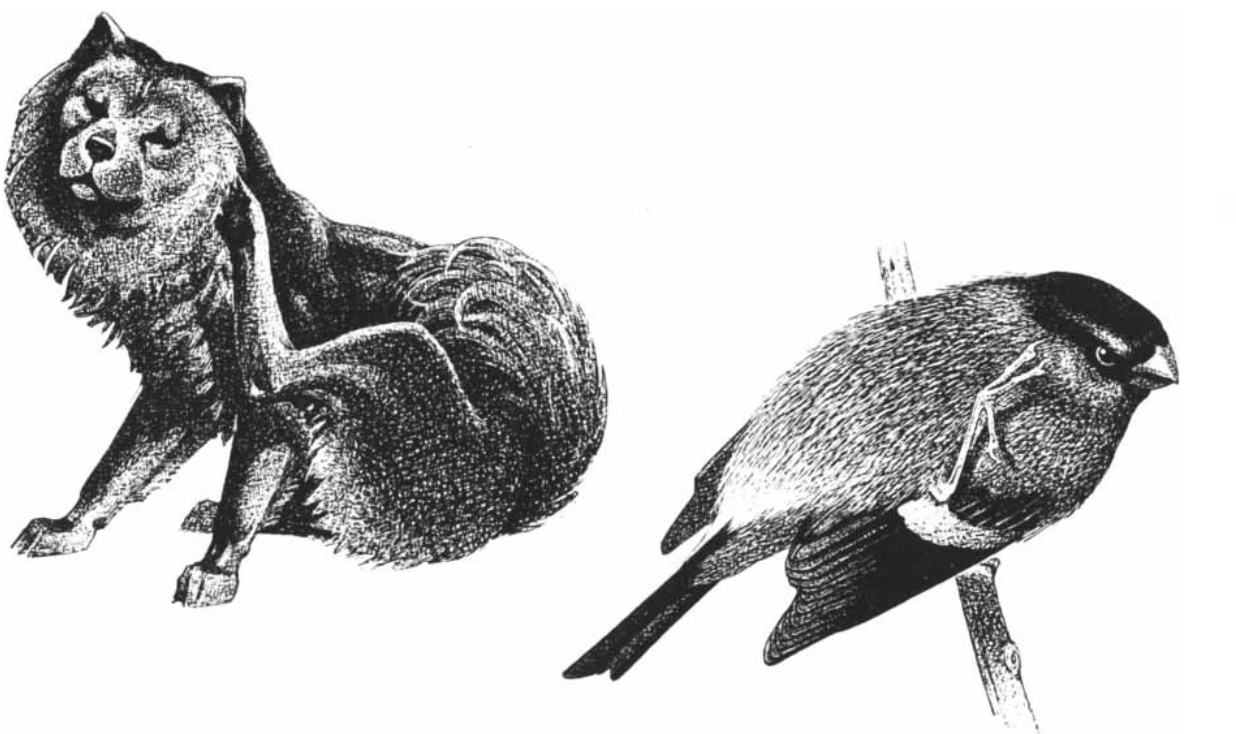
Beneath the varying behavior which animals learn lie unvarying motor patterns which they inherit. These behavior traits are as much a characteristic of a species as bodily structure and form

by Konrad Z. Lorenz

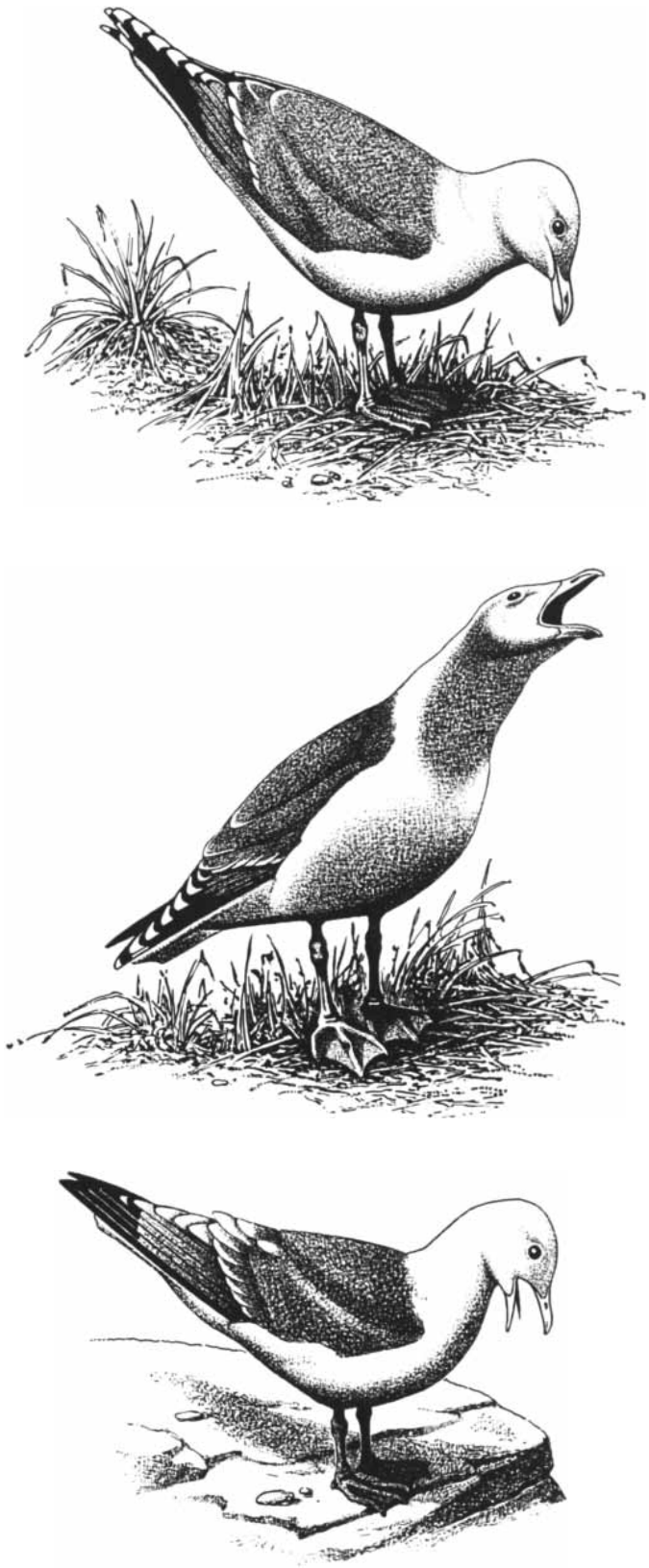
A whale's flipper, a bat's wing and a man's arm are as different from one another in outward appearance as they are in the functions they serve. But the bones of these structures reveal an essential similarity of design. The zoologist concludes that whale, bat and man evolved from a common ancestor. Even if there were no other evidence, the comparison of the skeletons of these creatures would suffice to establish that conclusion. The similarity of skeletons shows that a basic structure may persist over geologic periods in spite of a wide divergence of function.

Following the example of zoologists, who have long exploited the comparative method, students of animal behavior have now begun to ask a penetrating question. We all know how greatly the behavior of animals can vary, especially under the influence of the learning process. Psychologists have mostly observed and experimented with the behavior of individual animals; few have considered the behavior of species. But is it not possible that beneath all the variations of individual behavior there lies an inner structure of inherited behavior which characterizes all the members of a given species, genus or larger taxonomic group —just as the skeleton of a primordial ancestor characterizes the form and structure of all mammals today?

Yes, it is possible! Let me give an example which, while seemingly trivial, has a bearing on this question. Anyone who has watched a dog scratch its jaw or a bird preen its head feathers can attest to the fact that they do so in the same way. The dog props itself on the tripod formed by its haunches and two forelegs and reaches a hindleg forward in front of its shoulder. Now the odd fact is that most birds (as well as virtu-



SCRATCHING BEHAVIOR of a dog and a European bullfinch is part of their genetic heritage and is not changed by training. The widespread habit of scratching with a hindlimb crossed over a forelimb is common to most Amniota (birds, reptiles and mammals).



DISPLAY BEHAVIOR of seagulls shows how behavior traits inherent in all gulls have adapted to the needs of an aberrant species. At top is a typical gull, the herring gull, which breeds on the shore. It is shown in the "choking" posture which advertises its nest site. In middle the herring gull is shown in the "oblique" and "long call" postures, used to defend its territory. At bottom is the aberrant kittiwake, which unlike other gulls breeds on narrow ledges and has no territory other than its nest site. The kittiwake does not use the "oblique" or "long call" postures, but employs the "choking" stance for both advertisement and defense.

ally all mammals and reptiles) scratch with precisely the same motion! A bird also scratches with a hindlimb (that is, its claw), and in doing so it lowers its wing and reaches its claw forward in front of its shoulder. One might think that it would be simpler for the bird to move its claw directly to its head without moving its wing, which lies folded out of the way on its back. I do not see how to explain this clumsy action unless we admit that it is inborn. Before the bird can scratch, it must reconstruct the old spatial relationship of the limbs of the four-legged common ancestor which it shares with mammals.

In retrospect it seems peculiar that psychologists have been so slow to pursue such clues to hereditary behavior. It is nearly 100 years since T. H. Huxley, upon making his first acquaintance with Charles Darwin's concept of natural selection, exclaimed: "How stupid of me, not to have thought of that!" Darwinian evolution quickly fired the imagination of biologists. Indeed, it swept through the scientific world with the speed characteristic of all long-overdue ideas. But somehow the new approach stopped short at the borders of psychology. The psychologists did not draw on Darwin's comparative method, or on his sense of the species as the protagonist of the evolutionary process.

Perhaps, with their heritage from philosophy, they were too engrossed in purely doctrinal dissension. For exactly opposite reasons the "behaviorists" and the "purposivists" were convinced that behavior was much too variable to permit its reduction to a set of traits characteristic of a species. The purposivist school of psychology argued for the existence of instincts; the behaviorists argued against them. The purposivists believed that instincts set the goals of animal behavior, but left to the individual animal a boundless variety of means to reach these goals. The behaviorists held that the capacity to learn endowed the individual with unlimited plasticity of behavior. The debate over instinct versus learning kept both schools from perceiving consistent, inherited patterns in behavior, and led each to preoccupation with external influences on behavior.

If any psychologist stood apart from the sterile contention of the two schools, it was Jakob von Uexküll. He sought tirelessly for the causes of animal behavior, and was not blind to structure. But he too was caught in a philosophical trap. Uexküll was a vitalist, and he denounced Darwinism as gross materialism. He believed that the regularities he observed

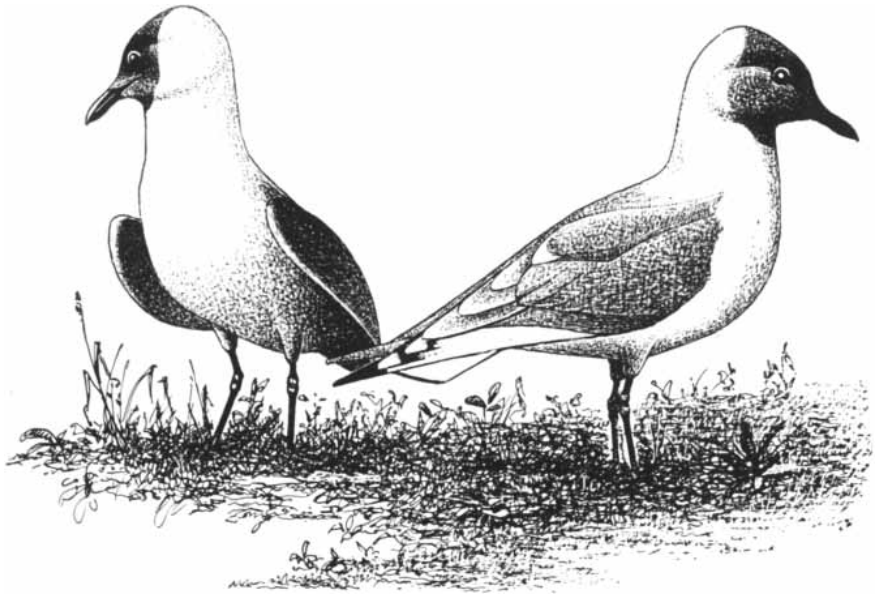
in the behavior of species were manifestations of nature's unchanging and unchangeable "ground plan," a notion akin to the mystical "idea" of Plato.

The Phylogeny of Behavior

But even as the psychologists debated, evolutionary thought was entering the realm of behavior studies by two back doors. At Woods Hole, Mass., Charles Otis Whitman, a founder of the Marine Biological Laboratory, was working out the family tree of pigeons, which he had bred as a hobby since early childhood. Simultaneously, but unknown to Whitman, Oskar Heinroth of the Berlin Aquarium was studying the phylogeny of waterfowl. Heinroth, too, was an amateur aviculturist who had spent a lifetime observing his own pet ducks. What a queer misnomer is the word "amateur"! How unjust that a term which means the "lover" of a subject should come to connote a superficial dabbler! As a result of their "dabbling," Whitman and Heinroth acquired an incomparably detailed knowledge of pigeon and duck behavior.

As phylogenists, Whitman and Heinroth both sought to develop in detail the relationship between families and species of birds. To define a given group they had to find its "homologous" traits: the resemblances between species which bespeak a common origin. The success or failure of their detective work hinged on the number of homologous traits they could find. As practical bird-fanciers, Whitman and Heinroth came to know bird behavior as well as bird morphology, and each independently reached an important discovery: Behavior, as well as body form and structure, displays homologous traits. As Whitman phrased it just 60 years ago: "Instincts and organs are to be studied from the common viewpoint of phyletic descent."

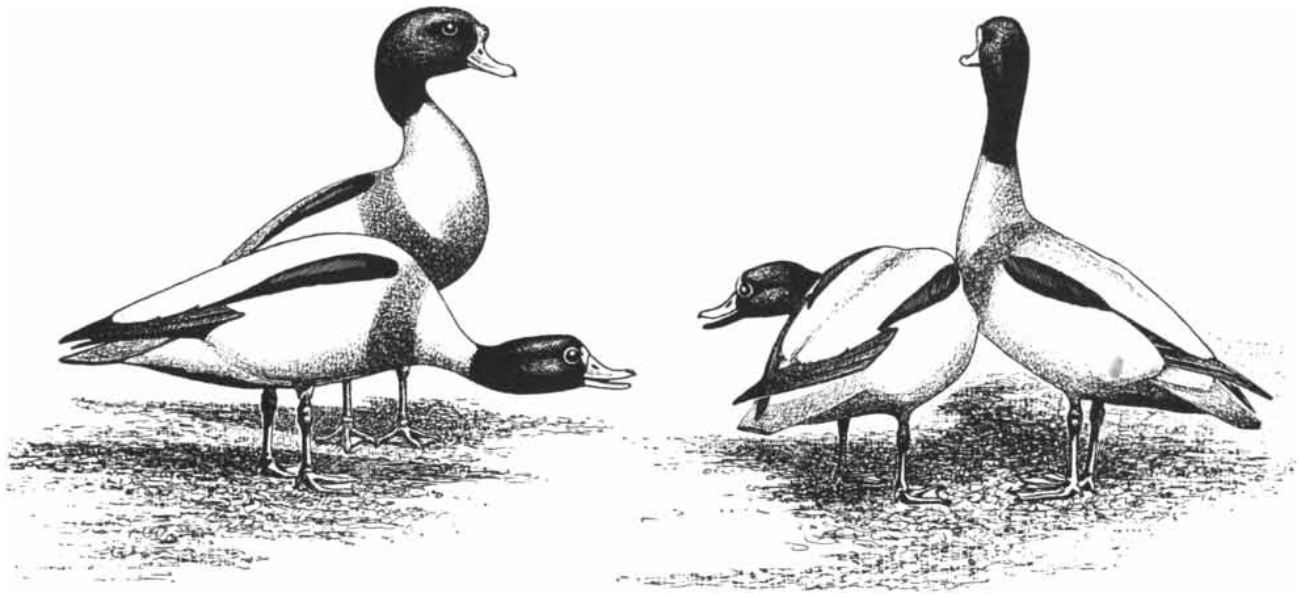
Sometimes these traits of behavior are common to groups larger than ducks or pigeons. The scratching habit, which I have already mentioned, is an example of a behavior pattern that is shared by a very large taxonomic group, in this case the Amniota: the reptiles, birds and mammals (all of whose embryos grow within the thin membrane of the amniotic sac). This widespread motor pattern was discovered by Heinroth, who described it in a brief essay in 1930. It is noteworthy that Heinroth observed the extreme resistance of such inborn habits to changes wrought by learning. He noticed that while most bird species maintain their incongruous over-the-shoulder scratching technique, some have lost this behavior trait. Among these are the larger parrots, which feed with their claws and use the same motion—under the wing—for scratching. Parakeets, however, scratch in the unreconstructed style, reaching around the lowered wing, and do not pick up food in their claws. There are a few exceptions to this rule. The Australian broadtailed parakeet has learned to eat with its claw. When eating, it raises its claw directly to its bill. But when scratching, it still reaches its claw around its lowered wing! This oddity is evidence in itself of the obstinacy of the old scratching habit. So far no one has been able to teach a parakeet to scratch without lowering its wing or to train a parrot to scratch around a lowered wing.



"HEAD-FLAGGING" is another form of display in which the kittiwake has adapted its behavioral birthright to meet unusual needs. Most gulls—like this pair of black-faced gulls—use this stance in courtship (by averting its menacing facial and bill coloration, the bird "appeases" the aggressive instinct of its mate). Kittiwakes alone evince this posture not only in mating adults but in ledge-bound nestlings, which use it to "appease" invaders.

Today a growing school of investigators is working in the field opened up by Whitman and Heinroth. They have set themselves the task of discovering inherited patterns of behavior and tracing them from species to species. Many of these patterns have proved to be reliable clues to the origin and relationship of large groups of animals. There is no longer any doubt that animals in general do inherit certain deep-seated behavioral traits. In the higher animals such traits tend to be masked by learned behavior, but in such creatures as fishes and birds they reveal themselves with great clarity. These patterns of behavior must somehow be rooted in the common physiological inheritance of the species that display them. Whatever their physiological cause, they undoubtedly form a natural unit of heredity. The majority of them change but slowly with evolution in the species and stubbornly resist learning in the individual; they have a peculiar spontaneity and a considerable independence of immediate sensory stimuli. Because of their stability, they rank with the more slowly evolving skeletal structure of animals as ideal subjects for the comparative studies which aim to unravel the history of species.

I am quite aware that biologists today (especially young ones) tend to think of the comparative method as stuffy and old-fashioned—at best a branch of research that has already yielded its treasures, and like a spent gold mine no longer pays the working. I believe that this is untrue, and so I shall pause to say a few words in behalf of comparative morphology as such. Every time a biologist seeks to know *why* an organism looks and acts as it does, he must resort to the comparative method. Why does the ear have its peculiar conformation? Why is it mounted behind the jaw? To know the answer the investigator must compare the mammalian frame with that of other vertebrates. Then he will discover that the ear was once a gill slit. When the first air-breathing, four-legged vertebrates came out of the sea, they lost all but one pair of gill slits, each of which happened to lie conveniently near the



"INCITING" is a threatening movement used by the female duck to signal her mate to attack invaders of their territory. At left a female of the European sheldrake (*with head lowered*) incites her mate against an enemy that she sees directly before her. The female at right (*with head turned*) has seen an enemy to one side. Each female watches her enemy regardless of her own body orientation.

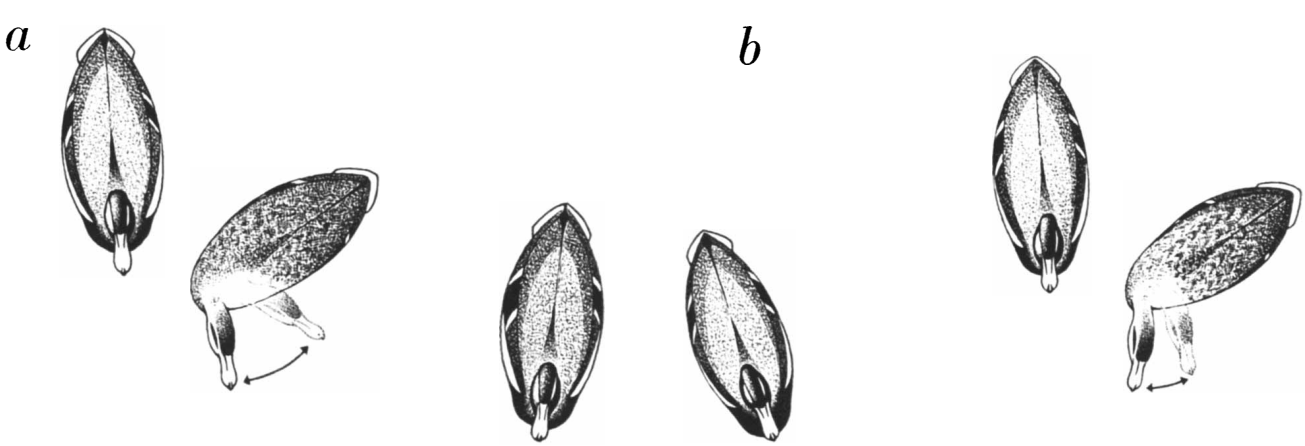
labyrinth of the inner ear. The water canal which opened into it became filled with air and adapted itself to conducting sound waves. Thus was born the ear.

This kind of thinking is 100 years old in zoology, but in the study of behavior it is only now coming into its own. The first studies leading to a true morphology of behavior have concentrated largely on those innate motor patterns that have the function of expression or communication within a species. It is easy to see why this should be so. Whether the mode of communication is aural, as in the case of bird songs, or visual, as in the "display" movements of courtship, many of these motor patterns have evolved under the pressure of natural selection to serve as sharply defined stimuli influencing the social behavior of fellow-members of a species. The patterns are usually striking and unambiguous. These qualities, so essential to the natural function of the behavior patterns, also catch the eye of the human observer.

Gulls, Terns and Kittiwakes

For some years N. Tinbergen of the University of Oxford has intensively studied the innate behavior of gulls and terns: the genus *Laridae*. He has organized an international group of his students and co-workers to conduct a worldwide study of the behavior traits of gulls and terns. They are careful to observe the behavior of their subjects in the larger context of their diverse life histories and in relationship to their different environments. It is gratifying that this ambitious project has begun to meet with the success which the enthusiasm of its participants so richly deserves.

Esther Cullen, one of Tinbergen's students, has been studying an eccentric



"RITUALIZED" INCITING is exhibited by mallards. In this species turning the head—as a female sheldrake does when inciting against an enemy to one side—has become an innate motor pattern. In situation *a* the female mallard turns her head toward the enemy. In *b*, with the enemy in front of her, she still turns her head even though this results in her turning it away from the enemy.

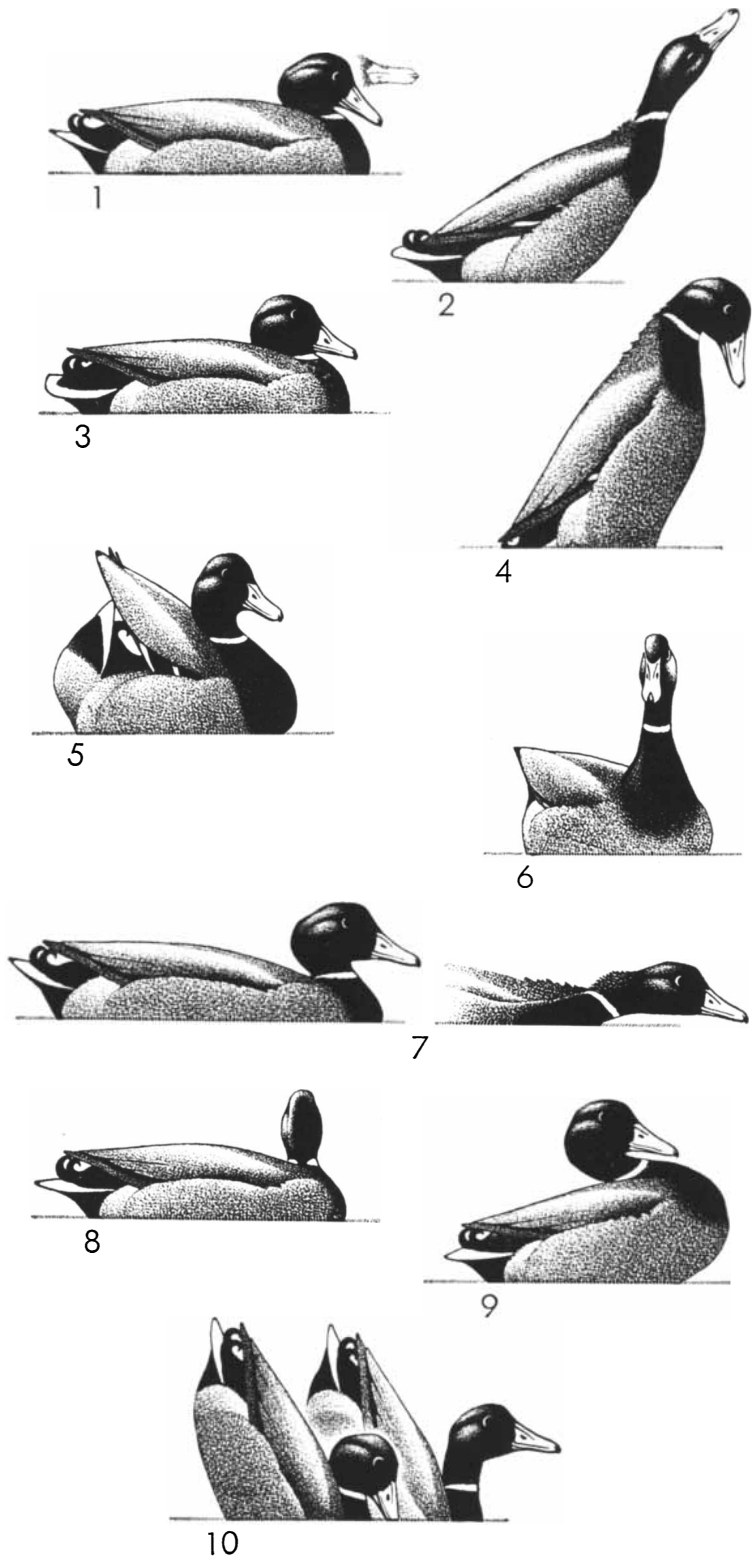
among the seagulls—the kittiwake. Most gulls are beachcombers and nest on the ground, and it is safe to assume that this was the original mode of life of the gull family. The kittiwake, however, is different. Except when it is breeding, it lives over the open sea. Its breeding ground is not a flat shore but the steepest of cliffs, where it nests on tiny ledges.

Mrs. Cullen has listed 33 points, both behavioral and anatomical, in which the kittiwake has come to differ from its sister species as a result of its atypical style of life. Just as the whale's flipper is a recognizable mammalian forelimb, so many of the kittiwake's habits are recognizably gull-like. But the kittiwake, like the whale, is a specialist; it has given its own twist to many of the behavior patterns that are the heritage of the *Laridae*.

For example, the male of most gull species stakes its claim to nesting territory by uttering the "long call" and striking the "oblique posture," its tail up and head down. To advertise its actual nesting site, it performs the "choking" movement. In the kittiwake the inherited patterns of behavior have been modified in accord with the habitat. On the kittiwake's tiny ledge, territory and nest sites are identical. So the kittiwake has lost the oblique posture and long call, and uses choking alone for display purposes.

Another example is the kittiwake gesture which Tinbergen calls "head-flagging." In other gull species a young gull which is not fully able to fly will run for cover when it is frightened by an adult bird. But its cliffside perch provides no cover for the young kittiwake. When it is frightened, the little kittiwake averts its head as a sign of appeasement. Such head-flagging does not occur in the young of other gulls, although it appears in the behavior of many adult gulls as the appeasement posture in a fight and in the rite of courtship. The kittiwake species has thus met an environmental demand by accelerating, in its young, the development of a standard motor habit of adult gulls.

Recently Wolfgang Wickler, one of my associates at the Max Planck Institute for Comparative Ethology, has found a similar case of adaptation by acceleration among the river-dwelling cichlid fishes. Most cichlids dig into the river bottom only at spawning time, when they excavate their nest pits. But there is an eccentric species (*Steatocranus*), a resident of the rapids of the Congo River, which lives from infancy in river-bottom burrows. In this cichlid the maturation of the digging urge of the mating fish is accelerated, appearing in



TEN COURTSHIP POSES which belong to the common genetic heritage of surface-feeding ducks are here shown as exemplified in the mallard: (1) initial bill-shake, (2) head-flick, (3) tail-shake, (4) grunt-whistle, (5) head-up—tail-up, (6) turn toward the female, (7) nod-swimming, (8) turning the back of the head, (9) bridling, (10) down-up. How the mallard and two other species form sequences of these poses is illustrated on pages 72 through 76.

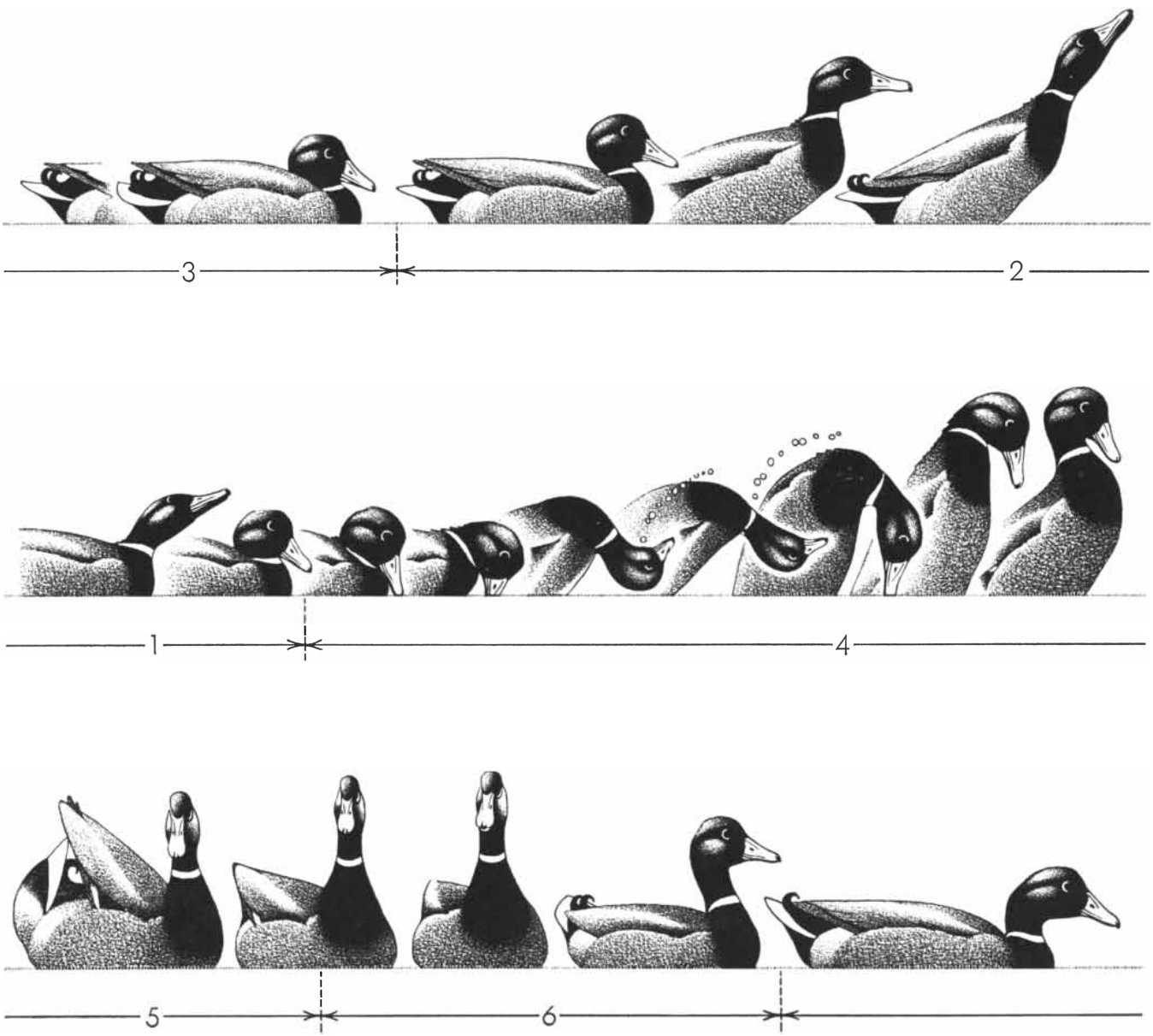
the infant of the species. It is not hard to conceive how selection pressure could have led to this result.

The work of the Tinbergen school has had the important result of placing innate motor habits in their proper setting. He and his co-workers have shown that these traits are highly resistant to evolutionary change, and that they often retain their original form even when their function has diverged considerably. These findings amply justify the metaphor that describes innate patterns as the skeleton of behavior. More work of the Tinbergen kind is badly needed. There is great value in his synthetic approach, uniting the study of the physical nature and environment of animals with study of their behavior. Any such project is of course a tall order. It requires concerted field work by investigators at widely separated points on the globe.

Behavior in the Laboratory

Fortunately it is quite feasible to approach the innate motor patterns as an isolated topic for examination in the laboratory. Thanks to their stability they are not masked in the behavior of the captive animal. If only we do not forget the existence of the many other physiological mechanisms that affect behavior, including that of learning, it is legitimate for us to begin with these innate behavior traits. The least variable part of a system is always the best one to examine first; in the complex interaction of all parts, it must appear most frequently as a cause and least frequently as an effect.

Comparative study of innate motor patterns represents an important part of the research program at the Max Planck Institute for Comparative Ethology. Our



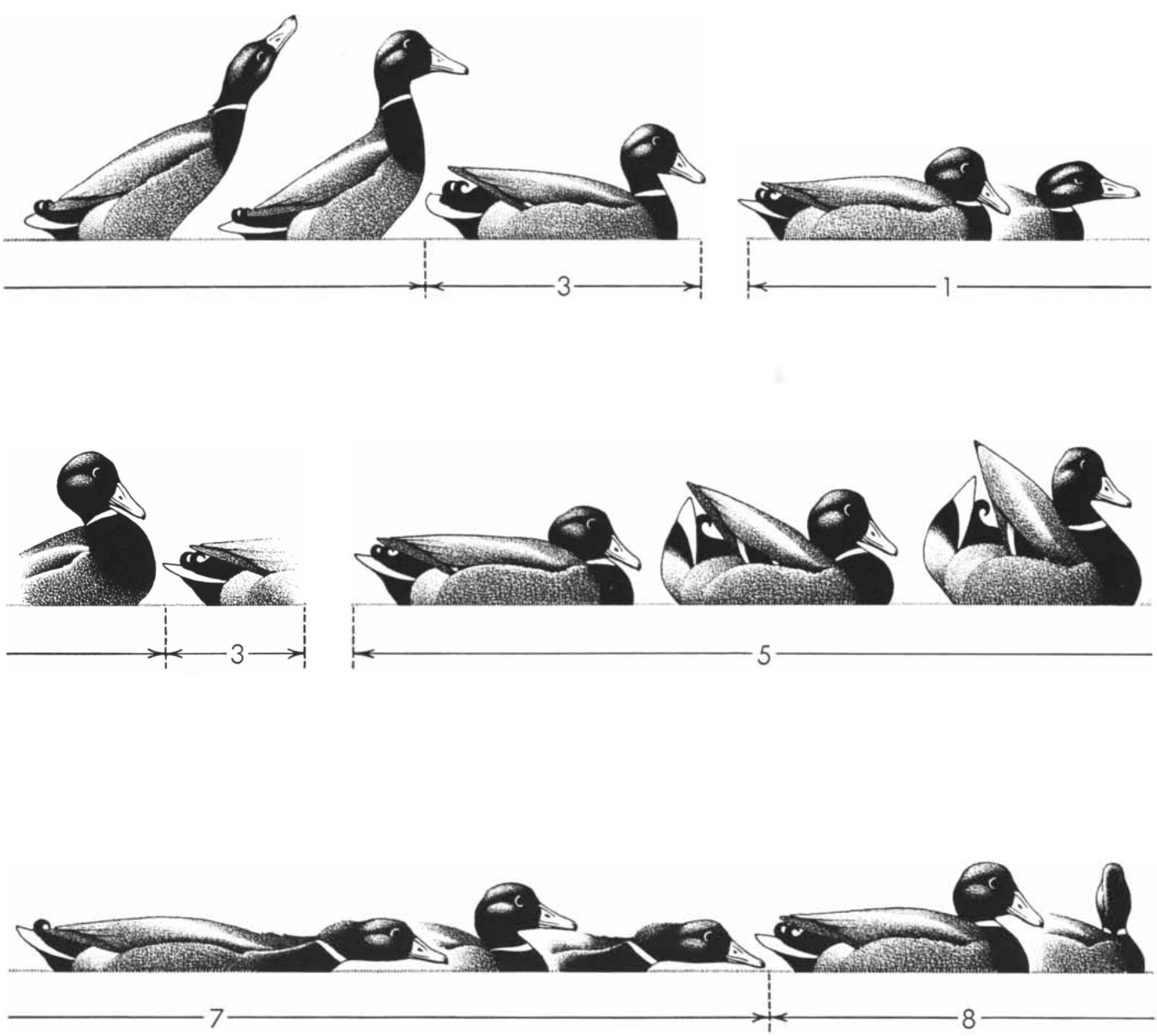
COURTSHIP SEQUENCES OF MALLARD are shown in this series of drawings, based on motion pictures made by the author at his laboratory in Seewiesen, Germany. Each sequence combines in fixed order several of the 10 innate courtship poses illustrated on

subjects are the various species of dabbling, or surface-feeding, ducks. By observing minute variations of behavior traits between species on the one hand and their hybrids on the other we hope to arrive at a phylogenetics of behavior.

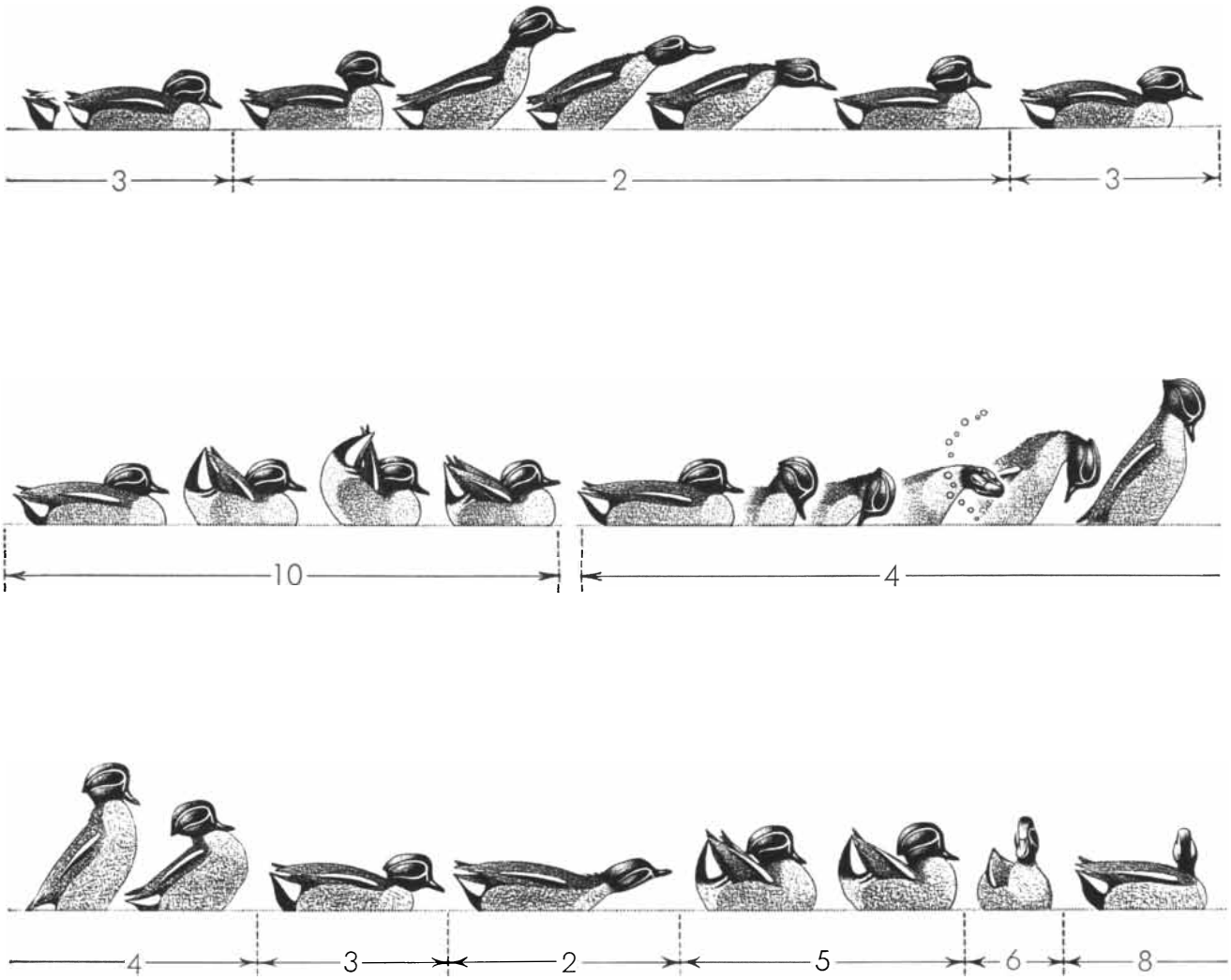
Our comparative studies have developed sufficient information about the behavior traits of existing species to permit us to observe the transmission, suppression and combination of these traits in hybrid offspring. Ordinarily it is difficult to find species which differ markedly with respect to a particular characteristic and which yet will produce fertile hybrids. This is true especially with respect to behavioral traits, because these tend to be highly conservative. Species which differ sufficiently in behavior seldom produce offspring of unlimited fertility. However, closely related species which differ markedly in their patterns of sexual display are often capable of producing fertile hybrids. These motor patterns serve not only to bring about mating within a species but to prevent mating between closely allied species. Selection pressure sets in to make these patterns as different as possible as quickly as possible. As a result species will diverge markedly in sexual display behavior and yet retain the capacity to interbreed. This has turned out to be the case with dabbling ducks.

The first thing we wanted to know was how the courtship patterns of ducks become fixed. Credit is due to Sir Julian Huxley, who as long ago as 1914 had observed this process, which he called "ritualization." We see it clearly in the so-called "inciting" movement of female dabbling ducks, diving ducks, perching ducks and sheldrakes.

To see "inciting" in its original unritualized form, let us watch the female



page 71. The numbers under the ducks refer to these poses. Shown here are the following obligatory sequences: tail-shake, head flick, tail-shake; bill-shake, grunt-whistle, tail-shake; head-up tail-up, turn toward female, nod-swimming, turning back of the head.



COURTSHIP OF EUROPEAN TEAL—another species of surface-feeding duck—includes tail-shake, head-flick, tail-shake (as in the mallard); down-up; grunt-whistle, tail-shake, head-flick, head-up–tail-up, turned toward the female, turning back of the head.

of the common sheldrake as she and her mate encounter another pair of sheldrakes at close quarters. Being far more excitable than her placid companion, the female attacks the "enemy" couple, that is, she adopts a threatening attitude and runs toward them at full tilt. It happens, however, that her escape reaction is quite as strong as her aggressive one. She has only to come within a certain distance of the enemy for the escape stimulus to overpower her, whereupon she turns tail and flees to the protection of her mate. When she has run a safe distance, she experiences a renewal of the aggressive impulse. Perhaps by this time she has retreated behind her mate. In that case she struts up beside him, and, as they both face the enemy, she makes threatening gestures toward them. But more likely she has not yet reached her mate when the aggressive impulse returns. In that case she may stop in her tracks. With her body still oriented toward her mate, she will turn her head and threaten the enemy over her shoulder. In this stance she is said to "incite" an aggressive attitude in her partner.

Now the incitement posture of the female sheldrake does not constitute an innate behavior trait. It is the entirely plastic resultant of the pressure of two independent variables: her impulse to attack and her impulse to flee. The orientation of her head and body reflects the geometry of her position with respect to her mate and the enemy.

The same incitement posture in mallards, on the other hand, is distinctly ritualized. In striking her pose the female mallard is governed by an inherited motor pattern. She cannot help thrusting her head backward over her shoulder. She does this even if it means she must point her bill away from the enemy! In the sheldrake this posture is the resultant of the creature's display of two conflicting impulses. In the mallard it has become a fixed motor pattern.

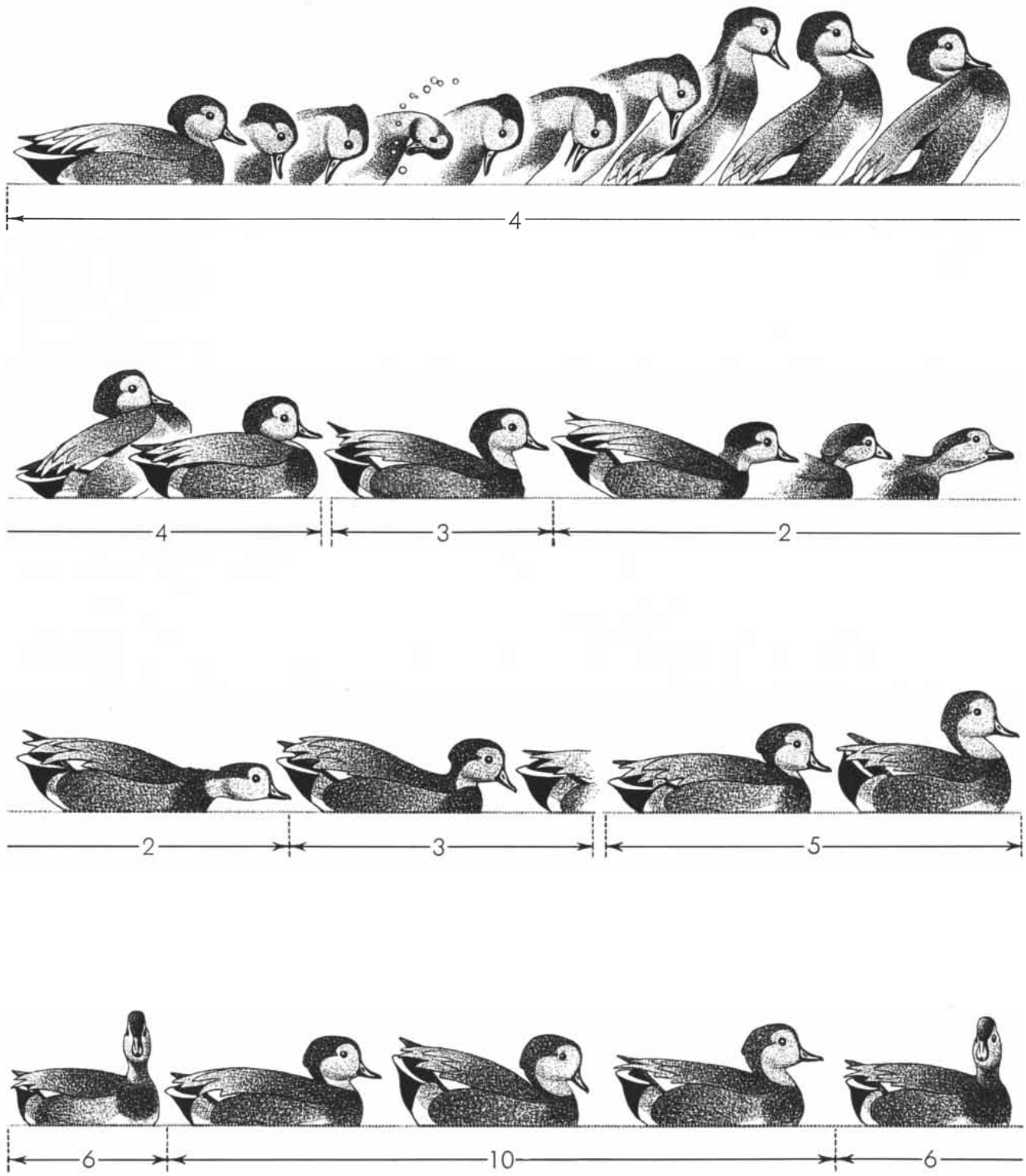
No doubt this motor pattern evolved fairly recently. It is interesting to note that while the female mallard is impelled to look over her shoulder when inciting, the older urge to look at the enemy is still there. Her head travels much farther backward when the enemy is behind her. If you observe closely, it is plain that her eyes are fixed on the enemy, no matter which way her head is turned.

Occasionally a female, impelled by the awkwardness of watching the enemy from the ritualized posture, will swing about and face them directly. In that case one may say that her old and new motor patterns are simultaneously active. Like the sheldrake, the mallard must

once have faced the enemy during incitement. Overlying this instinct is a new one—to move her head backward over her shoulder regardless of the location of the enemy. The old orienting response survives in part. It usually displays itself at low levels of excitement. Especially at the beginning of a response, the female mallard may stretch her neck straight forward. As her excitement mounts, however, the new motor pattern irresistibly draws her head around. This is one of many instances in which the mounting intensity of a stimulus increases the fixity of the motor coordination.

What has happened is that two independent movements have been welded together to form a new and fixed motor pattern. It is possible that all new patterns are formed by such a welding process. Sometimes two patterns remain rigidly welded. Sometimes they weld only under great excitement.

Recently we have been studying be-



GADWALL COURTSHIP includes the grunt-whistle, always followed by the tail-shake, head-flick, tail-shake sequence also found in the other species illustrated. The head-up–tail-up (5) and the down-up (10) are always followed by a turn toward the female (6). During the most intense excitement of the courtship display, these pairs themselves become welded into the invariable sequence 5-6-10-6.

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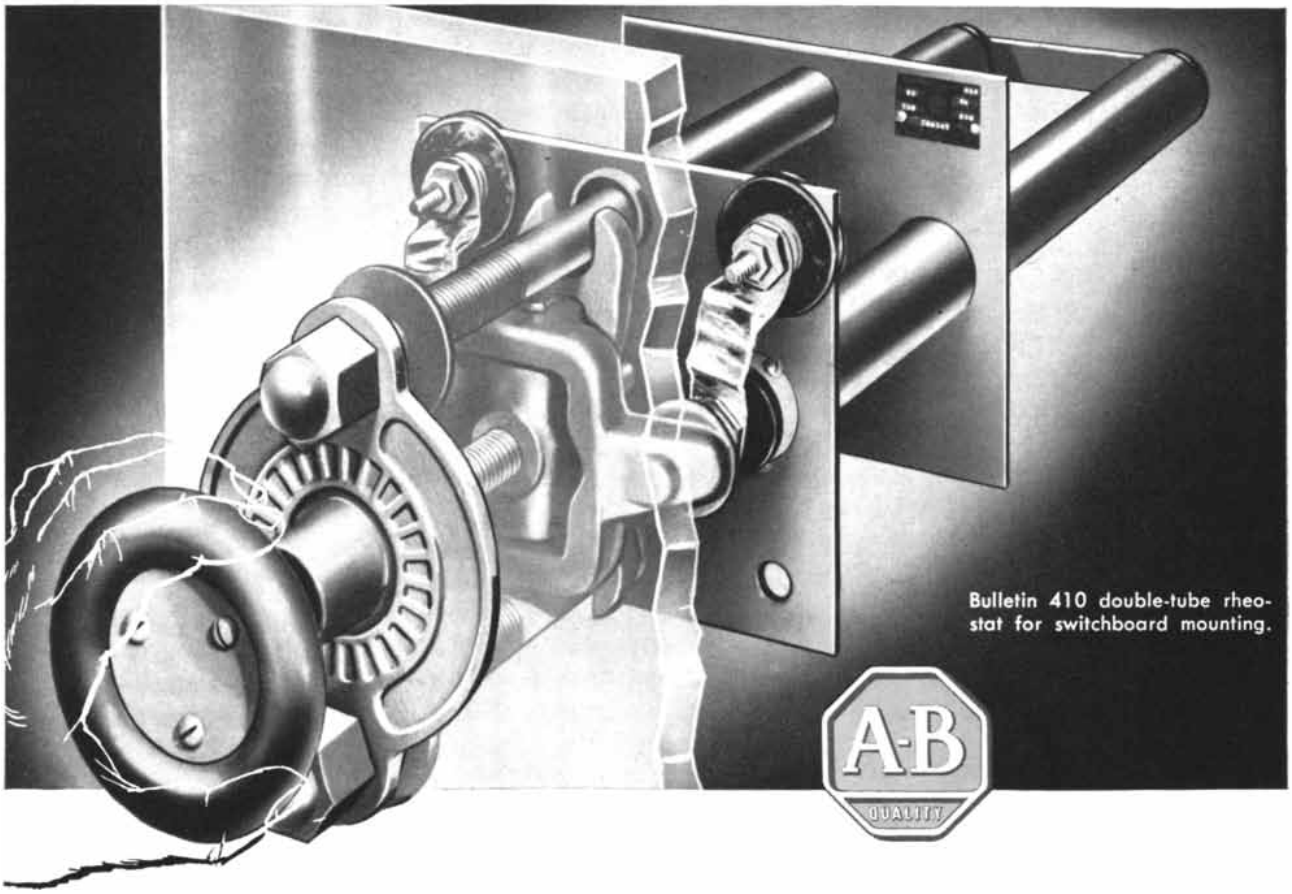

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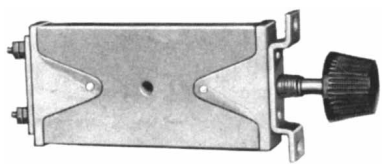

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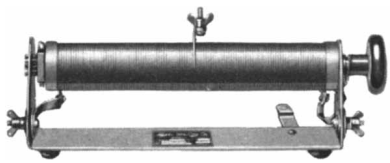

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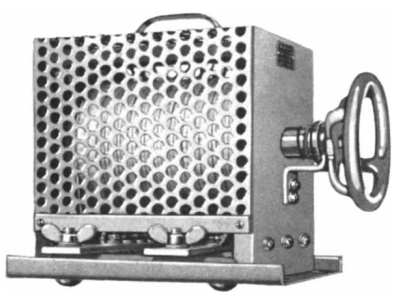

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havior complexes in which more than two patterns are welded. In their courtship behavior our surface-feeding ducks display some 20 elementary innate motor patterns. We have made a special study of three species which have 10 motor patterns in common but display them welded into different combinations. As shown in the illustration on page 71, these patterns are (1) initial bill-shake, (2) head-flick, (3) tail-shake, (4) grunt-whistle, (5) head-up—tail-up, (6) turn toward the female, (7) nod-swimming, (8) turning the back of the head, (9) bridling, (10) down-up movement. Some of the combinations in which these motor patterns are displayed are shown on pages 72 through 76. In some species certain of the patterns occur independently (*e.g.*, 1 and 10 in the mallard). Some simple combinations have wide distribution in other species as well (*e.g.*, 4, 3 and 5, 6 in all the species). Many combinations are more complicated, as the illustrations show.

What happens when these ducks are crossbred? By deliberate breeding we have produced new combinations of motor patterns, often combining traits of both parents, sometimes suppressing the traits of one or the other parent and sometimes exhibiting traits not apparent in either. We have even reproduced some of the behavior-pattern combinations which occur in natural species other than the parents of the hybrid. Study of our first-generation hybrids indicates that many differences in courtship patterns among our duck species may also be due to secondary loss, that is, to suppression of an inherited trait. Crosses between the Chiloe teal and the Bahama pintail regularly perform the head-up—tail-up, although neither parent is capable of this. The only possible conclusion is that one parent species is latently in possession of this behavioral trait, and that its expression in a given species is prevented by some inhibiting factor. So far our only second-generation hybrids are crosses between the Chiloe pintail and the Bahama pintail. The results look promising. The drakes of this generation differ greatly from each other and display hitherto unheard-of combinations of courtship patterns. One has even fused the down-up movement with the grunt-whistle!

Thus we have shown that the differences in innate motor patterns which distinguish species from one another can be duplicated by hybridization. This suggests that motor patterns are dependent on comparatively simple constellations of genetic factors.

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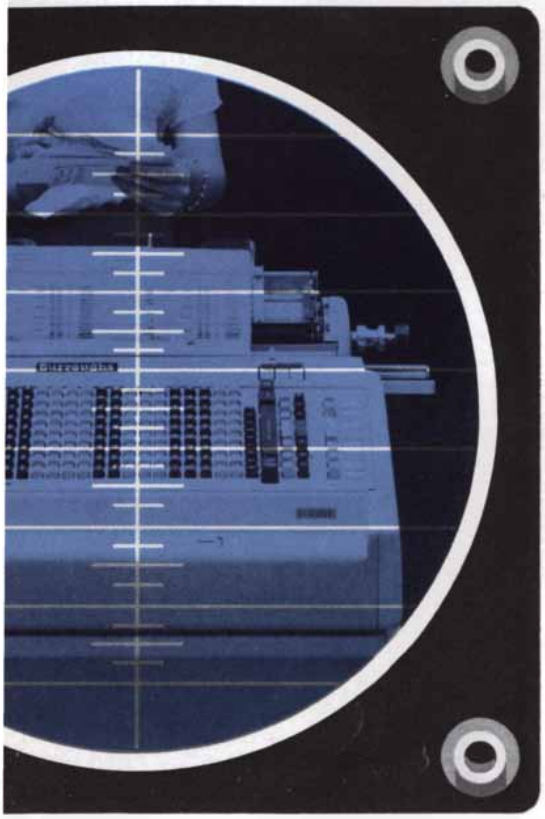

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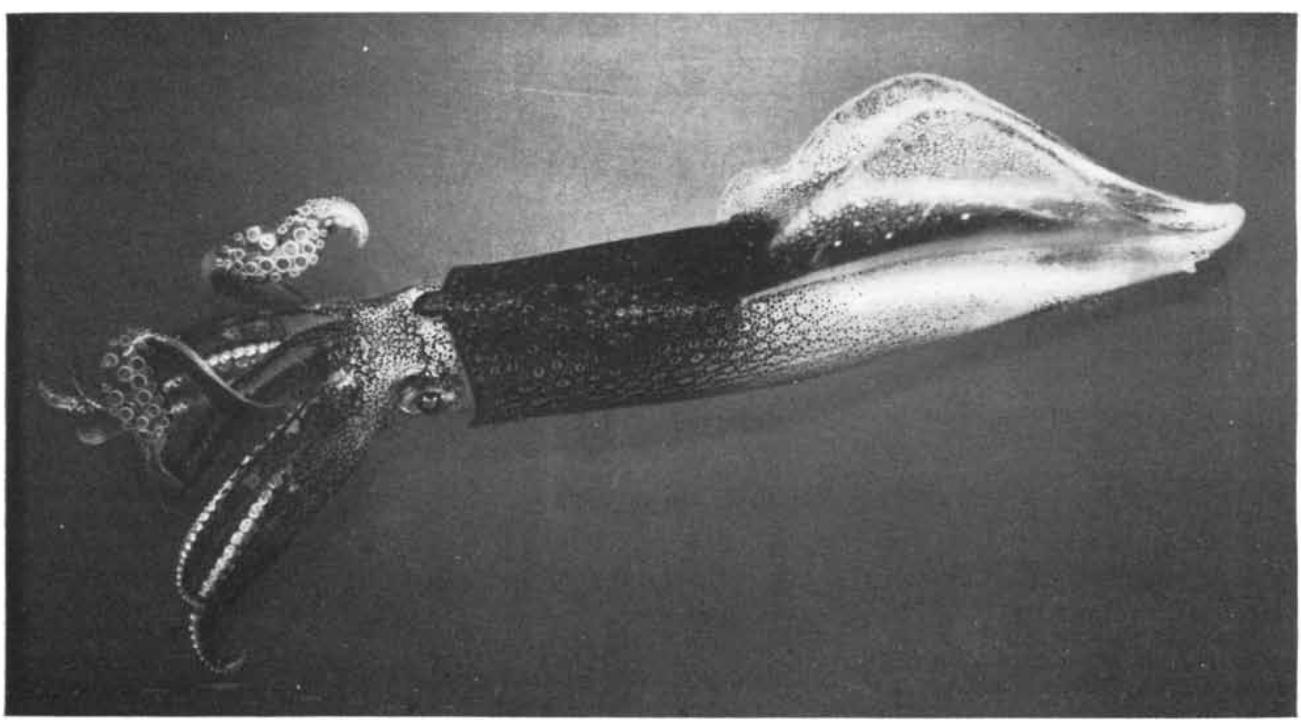
The Nerve Impulse and the Squid

The giant nerve fibers of this common invertebrate are as much as a millimeter in diameter. Their large size has made possible important investigations into the physiology of nerve impulses

by Richard D. Keynes

An invention of nature, once we have learned to appreciate it, may facilitate the progress of knowledge more significantly than a new instrument devised by human ingenuity. Such is the case with the giant axon of the squid. In the living animal the usefulness of this large-sized nerve cable is demonstrated when the creature suddenly changes course and darts away by jet propulsion. An array of giant axons activate the muscles that furnish this auxiliary mode of locomotion. In the laboratory the investigator can easily dissect a convenient length of axon from the tissues of a squid. The transparent tubelike axon, up to a millimeter in diameter, gives him a nerve fiber that he can handle and study with far greater ease than the tenuous fibers, 50 to 1,000 times thinner, available from most animals. In particular the large diameter of the giant axon makes the events that go on at the inner surface of its enclosing membrane accessible to investigation. During the past 20 years work with giant axons has opened the way to the principal advances in our understanding of the generation and propagation of the nerve impulse.

By the beginning of this century, physiologists had shown that the nerve impulse is a transient wave of electrical excitation that travels from point to point down the length of a nerve fiber. They had also established that the fiber may be likened in structure to a cable with a low-resistance core of cytoplasm surrounded by a high-resistance insulating membrane. Outside the membrane the salt-containing tissue fluids provide a low-resistance medium which itself plays an important role in the propagation of the nerve impulse. With the comparatively insensitive instruments of the day, workers had found that there was a steady difference in electrical potential across the membrane when the fiber was in the resting state, the inside of the membrane being charged negative with respect to the outside. They had detected the nerve impulse as a brief wave of external negativity that traveled along the outer sur-



SQUID (*Loligo*) is found in great numbers on both sides of the North Atlantic. It normally swims by moving its fins but can also dart backward or forward by expelling a jet of water. The "jet propulsion" mechanism is controlled by two sets of giant nerve fibers.

face of the membrane with constant amplitude and velocity.

In 1902 Julius Bernstein of the University of Halle in Germany put forward what proved to be for many years the most satisfactory explanation of this phenomenon. As was by then well known, the cells of all the excitable tissues of the body, muscle as well as nerve, contain an appreciably higher concentration of potassium ions than the body fluid, while the body fluid contains a relatively higher concentration of the ions of sodium. Bernstein suggested that the membrane's selective permeability to potassium might account for the resting potential. In the dynamic equilibrium of electrochemical forces, the negative charge on the inside of the membrane opposes the tendency of the positively charged potassium ions to escape. Bernstein further proposed that during the passage of a nerve impulse the membrane momentarily lost its selective resistance to the electrochemical pressure of the ions in the external fluid. With the rush of these ions into the interior of the fiber, the potential across the membrane would collapse to zero. Electric currents generated by the movement of the ions would then spread the loss of selectivity to the next section of the membrane. Thus the impulse was made to travel by self-regeneration down the length of the fiber.

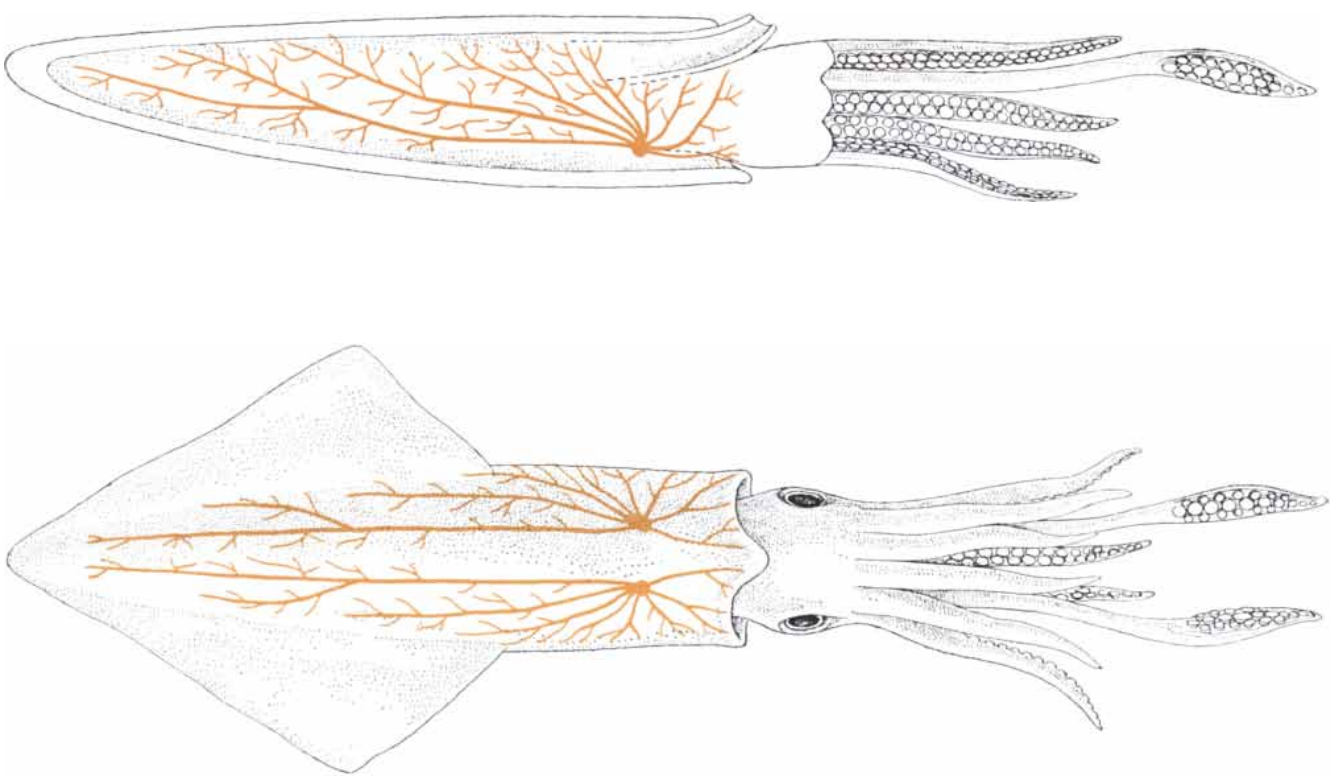
Neurophysiologists long accepted Bernstein's "membrane" hypothesis as the best guess that could be made at the truth. But they could develop little direct evidence to support it. The high speed of the reaction, the minute quantities of material involved and the tiny dimensions of most nerve fibers defied the experimental ingenuity of investigators for the next three decades.

The way around the impasse was discovered in 1933, when J. Z. Young, now at University College London, undertook an investigation of the nervous system in squids and other cephalopods. Young immediately pointed out that the big nerve fibers of these animals would provide exceptionally favorable material for research into the propagation of the nerve impulse. The soundness of this observation is reflected in the degree to which the marine biological laboratories at Plymouth, England, and Woods Hole, Mass., have since figured in the literature of the nerve impulse.

It is difficult to transport living squid any distance from the coastal waters in which they are taken by trapping or trawling; the creatures are most numerous in late summer and early autumn. As a result nerve physiologists are to be found spending their vacations busily dissecting squid by the seaside.

The process of freeing the giant axon from the mantle of the squid and then cleaning away the small nerve fibers that run with it requires an hour or two of exacting work with fine forceps and scissors and a binocular dissecting microscope. The axon is then mounted in a bath of sea water which substitutes for the body fluids that bathe it in the living animal. In this state the axon will continue to conduct impulses in an essentially normal fashion for 12 hours or more. The cuttlefish *Sepia officinalis* has the merit of surviving better in captivity, and we have managed to keep ourselves supplied with *Sepia* at the University of Cambridge through several winters. The cuttlefish axon, with a diameter of .2 millimeter, is appreciably smaller than that of the squid, but nevertheless has proved highly satisfactory for our work with radioactive tracers.

The first six years of investigation of the giant axons established firmly the various vital facts about their physical and chemical structure. At Woods Hole in 1936 K. S. Cole and H. J. Curtis mounted single axons as one arm in a Wheatstone bridge, a standard device for determining the electrical properties



GIANT AXONS of the squid (*in color*) are shown from above in the upper drawing and in simplified cross section below. Dissected from the animal and mounted in a bath of sea water, the fibers will continue to conduct nerve impulses for 12 hours or longer.

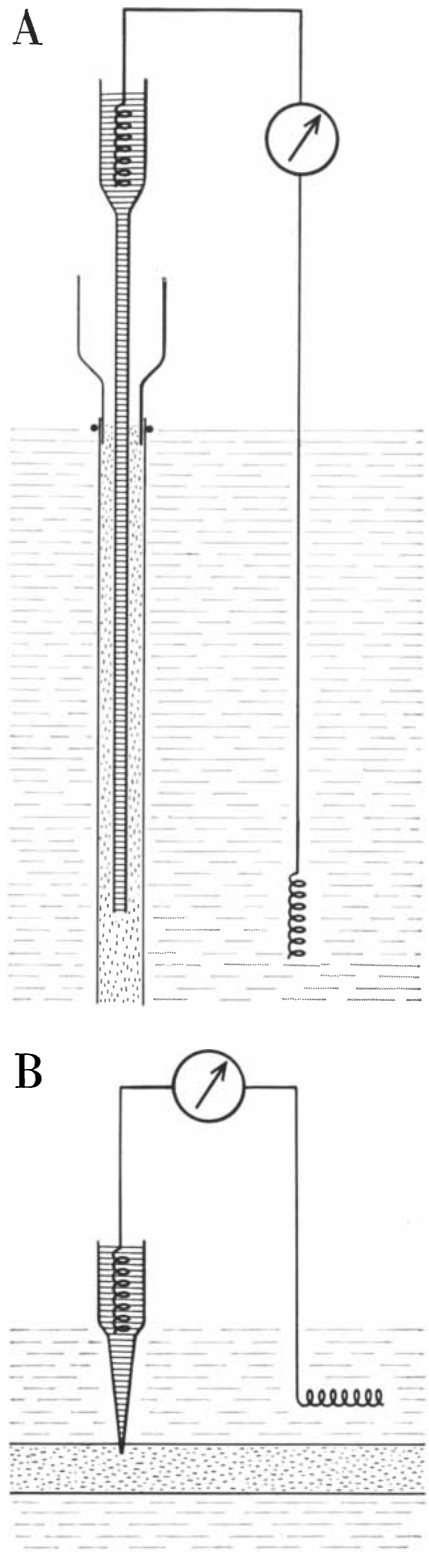
of conductors. They were thus able to measure the resistance across the membrane and to determine its capacitance (its capacity to hold an electrostatic charge) as one microfarad per square centimeter of surface. Later, having perfected the technique, they provided a classical demonstration that the drop in resistance across the membrane, implied by Bernstein's postulated loss of selectivity, does indeed occur. In this connection they found that the inherent capacitance of the membrane does not change, thus confirming the indications that the drop in resistance is associated with increased permeability to the flow of ions. Cole and A. L. Hodgkin of the University of Cambridge investigated the details of the process by which a change in the potential across the membrane spreads passively down the axon, by virtue of its cable-like structure. In another series of experiments Hodgkin demonstrated that the velocity of propagation varies with the resistance of the external medium, the impulse traveling only half as fast in moist air as it does in the more natural environment of sea water, where resistance is low. All this work fitted nicely into the concepts embodied in Bernstein's hypothesis, but it did not yet provide a basis for much extension of the theory.

Work on the chemical composition and activity of the axon made parallel progress when investigators learned to extrude the cytoplasm from squid axons, much as one extrudes toothpaste from a tube. With several milligrams of the material thus isolated from contamination with the external medium, the intracellular concentrations of salts and other materials could be determined without ambiguity.

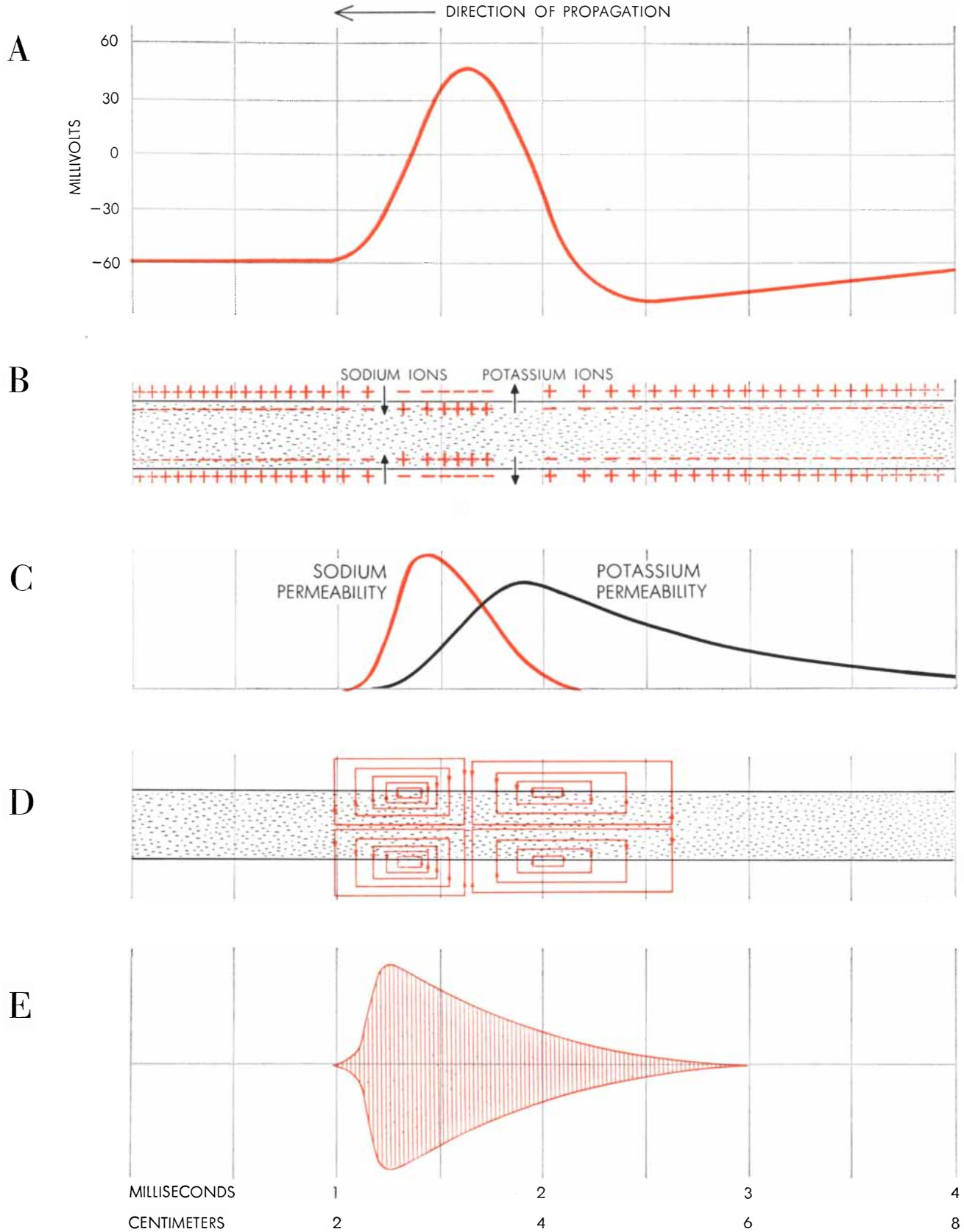
The first really critical test of the Bernstein hypothesis and the first important advance beyond it came in 1939, when workers took advantage of the relatively large diameter of squid axons and slipped micropipettes inside them down their length from the cut end. Up to this time all measurements of nerve potential had been made from the outside. Short-circuiting by the external fluid and the uncertainty of potentials measured at liquid junctions had made it impossible to get a reliable test of Bernstein's key hypothesis: that the potential across the membrane falls to zero at the peak of the "spike," as the recorded nerve impulse is often called. In the summer of 1939, simultaneously and independently, Cole and Curtis at Woods Hole and Hodgkin and A. F. Huxley at Plymouth devised closely similar techniques to measure the membrane potential of the squid axon from the inside. They pushed a micropipette, .1 millimeter in outside diameter, two or three centimeters down the inside of the axon, carefully steering the tip to avoid scraping the membrane at any point. They could then measure the potential difference between the solution inside the pipette and the sea water outside the axon, this being in effect the potential across the nerve membrane at the tip of the pipette.

Their measurements yielded a surprising result. At the peak of the spike the membrane potential did not merely drop to zero, but was reversed. The charge on the inside of the membrane became momentarily positive by 40 millivolts or more. This interior reversal of charge corresponded with the exterior wave of negativity that had been observed so many years before. But it did not tally with Bernstein's ideas. It was some years, however, before further investigation resolved this discrepancy of observation with theory, since the talents of many biologists as well as physicists were temporarily diverted into other channels in the autumn of 1939.

The relevance of the giant-axon work to excitable tissues in general was established soon after the war when Ralph W. Gerard and Gilbert Ling, then at the University of Chicago, devised another form of micropipette with a tip tapering to a point no more than .0005 millimeter across. This tool can be thrust through the membrane to reach the interior of the thin fibers that are found more commonly in nature than the giant axons. The membrane seals off fairly well around the tip of the pipette, making it possible to measure the potential difference between the interior of the fiber and the outside of the membrane. It was not long before these microelectrodes were being used to penetrate every kind of excitable cell, from the nerve cells in the spinal cord of the cat to the specially modified muscle cells which generate the electricity of the electric eel, and they have now become a standard tool in every physiological laboratory. Many, but not all, these cells produce a spike with the same reversal of membrane potential as that first seen in squid axons. The potential change occurs at different rates in different tissues; the spike lasts under one millisecond in the nerve of a mammal and more than half a second in the muscle fibers of a frog's heart. But the potentials have roughly the same magnitude from species to species. In most



TWO METHODS of measuring the internal potential of a nerve fiber are shown here. In A a tube .1 mm. in diameter, filled with potassium chloride, is inserted down the length of a giant axon, the only nerve fiber large enough to accommodate it. In B a micropipette only .0005 mm. across at the tip is thrust through the cell membrane. This fine-drawn tool can be used on the far thinner nerve fibers more often found in animals.



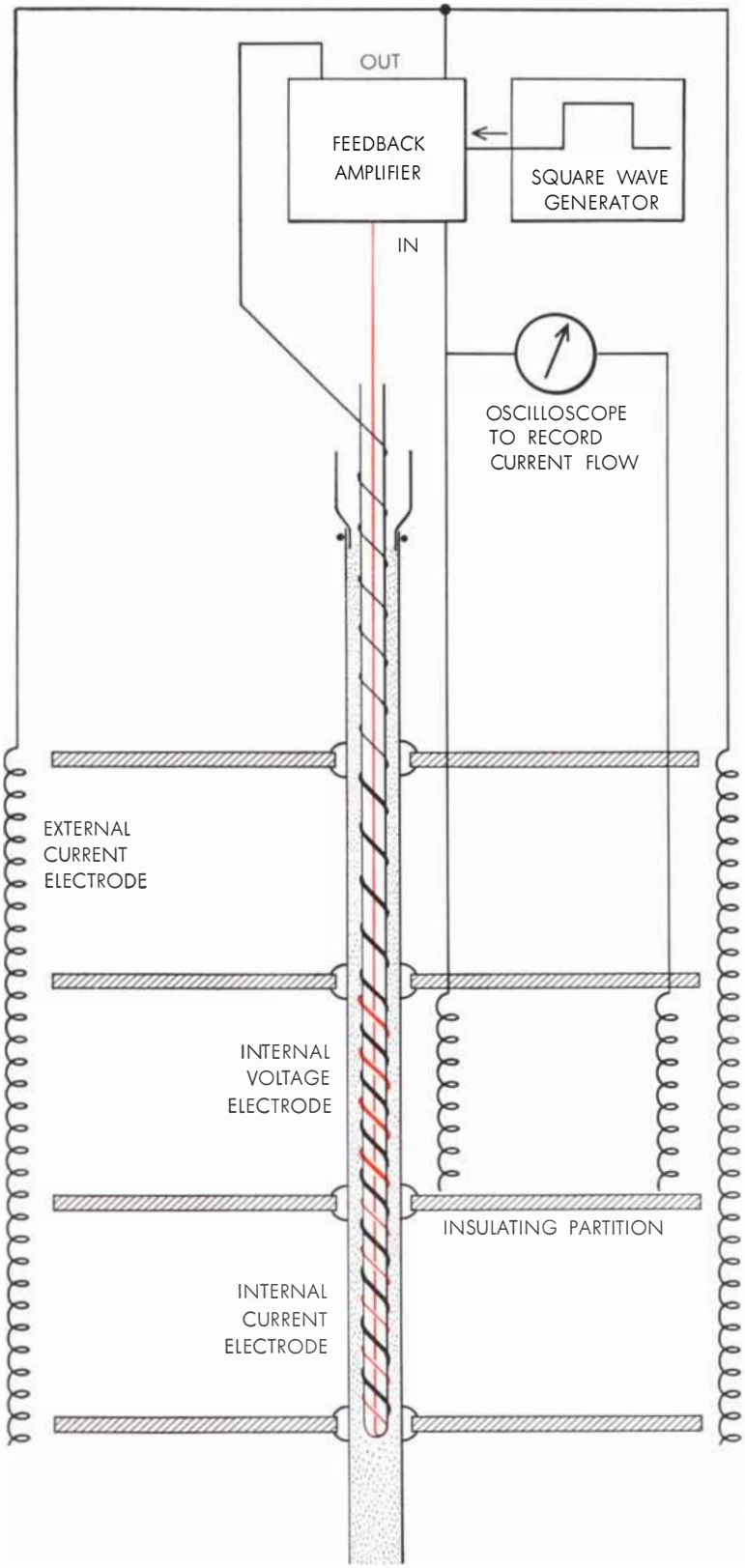
NERVE IMPULSE travels along a nerve fiber as a self-propagating wave of electrical activity. The potential across the outer membrane of the fiber reverses and then returns to normal again (A). These changes are caused by rises in ionic permeability (C), which permit rapid movement of sodium ions into the fiber, followed by an egress of potassium ions (B). The altered potential across the disturbed part of the membrane causes electrical currents to flow in the external medium and within the fiber (D). These depolarize the membrane ahead of the advancing impulse, triggering permeability changes and thus producing a wave of increased conductance (E).

cells the resting potential lies between 50 and 100 millivolts, while at the peak of the spike the potential is reversed by 20 to 50 millivolts.

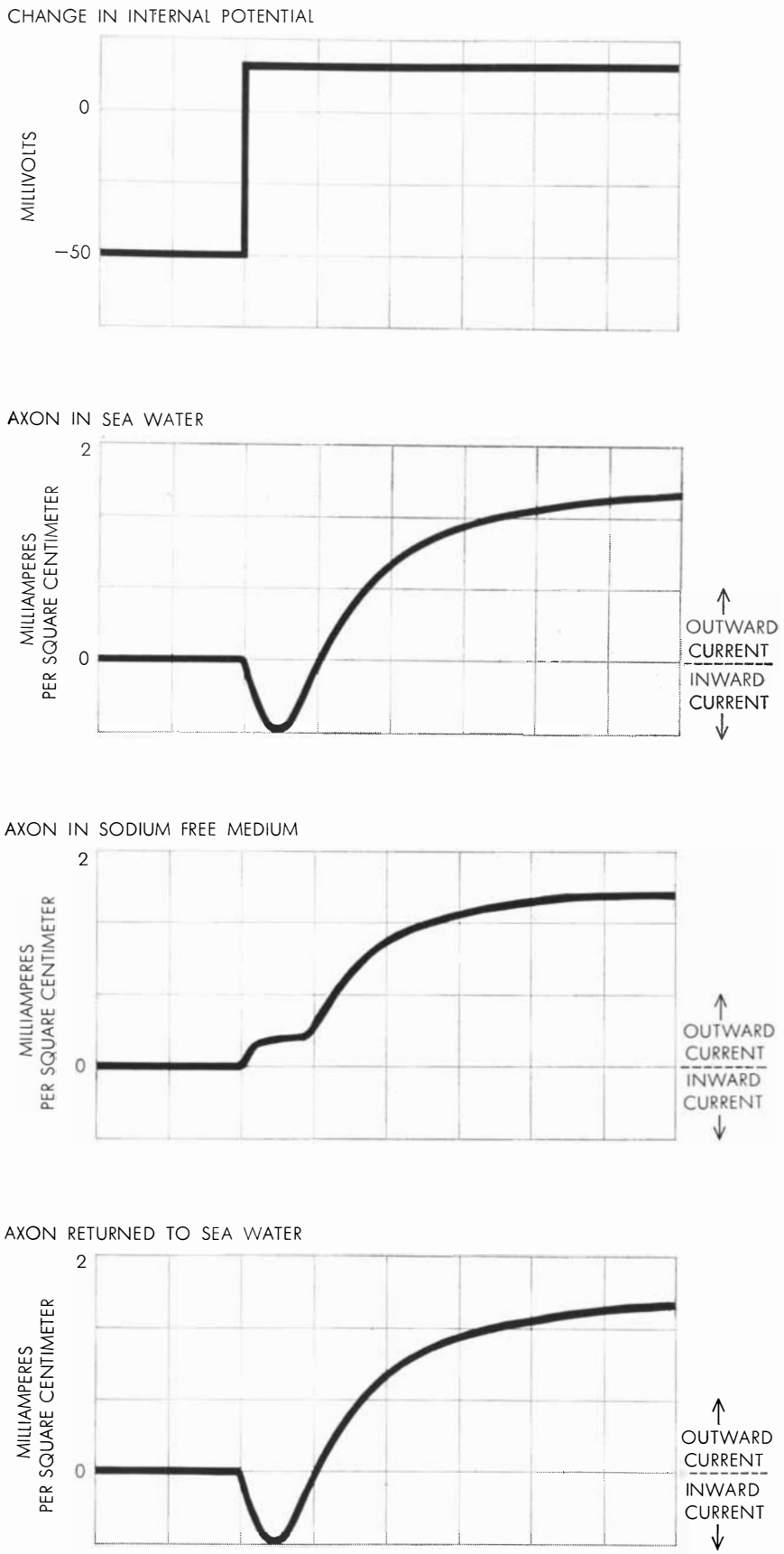
The most satisfactory present explanation for the reversal of the membrane potential was proposed by Hodgkin and Bernhard Katz after they had spent the summer of 1947 working on squid axons at Plymouth. Their "sodium hypothesis" holds that the nerve membrane does not merely lose its selectivity during the rising phase of the spike, as Bernstein supposed, but that it becomes highly and specifically permeable to sodium ions. Since the sodium concentration outside the membrane is about 10 times greater than that inside, this could account, in an idealized case, for a reversal of potential of nearly 60 millivolts. It is further proposed that the original internal negativity of the resting nerve is restored by the subsequent exit of potassium ions from the intracellular fluid.

The sodium hypothesis suggested a whole series of fruitful experiments. An obvious first test of the idea was to find out whether a nerve impulse could be propagated when there was no sodium in the external medium. As a matter of fact, E. Overton of the University of Würzburg had shown in 1902 that frog muscle loses its excitability when immersed in a sodium-free solution; most people, however, had long since forgotten about his work. Hodgkin and Katz, working with squid axons, showed that both the size and rate of rise of the spike vary with change of sodium concentration in the external fluid in a way that fits well with theoretical prediction.

The next step was to determine whether the postulated inward transfer of sodium and outward transfer of potassium actually occur across the membrane of the nerve fiber. Here again giant axons proved invaluable. S. L. Cowan of University College London had shown in 1934 that some potassium leaked from a whole crab nerve during activity, but experiments with whole nerve trunks could not yield sufficiently accurate results to permit a critical comparison between the chemical and electrical information. Working with single giant axons, investigators found that the exchange of sodium and potassium ions is large enough to be detected after reasonably short periods of stimulation. Moreover, it is easy to count the exact number of impulses conducted and to measure the membrane area involved. Using radioactive isotopes of sodium and potassium, Harry Grundfest and David



"VOLTAGE CLAMP" TECHNIQUE measures electrical changes across an isolated part of the membrane. A micropipette bearing two separate electrodes (insulated except where drawn heavily) is thrust into the fiber. A rapid change in the fiber's internal potential, produced by the square wave generator, is measured by the internal voltage electrode (*in color*) and fed back to the feedback amplifier which "clamps" the potential at the given level. The electrical current which flows across the membrane at this potential, measured by the two small electrodes at right, reflects changes in the flow of ions across the membrane.



"VOLTAGE CLAMP" RECORDS show that a change in the internal potential produces a brief inward current before the main flow of current outward. Since the inward flow does not occur in a sodium-free medium, it must be due to the movement of sodium ions into the axon.

Nachmansohn made measurements at Woods Hole on the inflow of sodium and outflow of potassium in squid axons, while I have used these isotopes in similar experiments on cuttlefish axons. P. R. Lewis and I have also employed a special microanalytical method to determine the initial concentration of the elements in the resting fiber; this involves irradiating samples with neutrons in an atomic pile and then measuring the amounts of different radioactive isotopes formed in them. By this means we have succeeded in determining the net gain of sodium and the net loss of potassium in the stimulated fiber. The upshot of all this work is that the measured movements of sodium and potassium are large enough to alter the potential across the nerve membrane to the extent observed. The close fit of the electrical and chemical observations lends strong support to the sodium hypothesis.

Although tracer experiments yield admirably unambiguous results, they represent the cumulative effect of a few thousand impulses. They do not, in consequence, reveal the sequence and the timing of the changes in the permeability of the membrane that take place in the course of a single impulse. The next step in the investigation called for a means of observing the flow of current across a measured area of nerve membrane and for deducing how much the fluxes of sodium and potassium each contributed to this current. The need was met by the so-called "voltage-clamp" technique, first developed by Cole and George Marmont at Woods Hole, and later used extensively by Hodgkin, Huxley and Katz at Plymouth. This experiment involves the insertion of two internal electrodes into the nerve [*see illustration on preceding page*]. One electrode records the internal potential, while the other receives just sufficient current from the output of a feed-back amplifier to "clamp" the potential at the desired level. Two other electrodes in the sea water outside measure the current that flows during the instant after the potential is established. A typical record from one of these experiments shows that, as a result of the reduction of internal potential, there is a brief phase of inward current, followed by a prolonged flow of current in the opposite direction, outward from the fiber [*see illustration at left*].

The disappearance of the inward current when the experiment was repeated in sodium-free solutions demonstrated that this current is carried by sodium ions. Experiments which simultaneously measured the membrane current and the

outward passage of potassium tracer-ions proved that almost all the outward current is carried by potassium ions. The sodium-ion current builds up quickly after the potential change, but switches off after approximately one millisecond; the potassium-ion current then rises and stays high so long as the potential is maintained. After recording the current and ion flow associated with many different sequences of potential change, Hodgkin and Huxley were able to work out the precise curves linking the changes in the permeability of the membrane to the changes in its potential over the duration of a spike [*see illustration on page 86*].

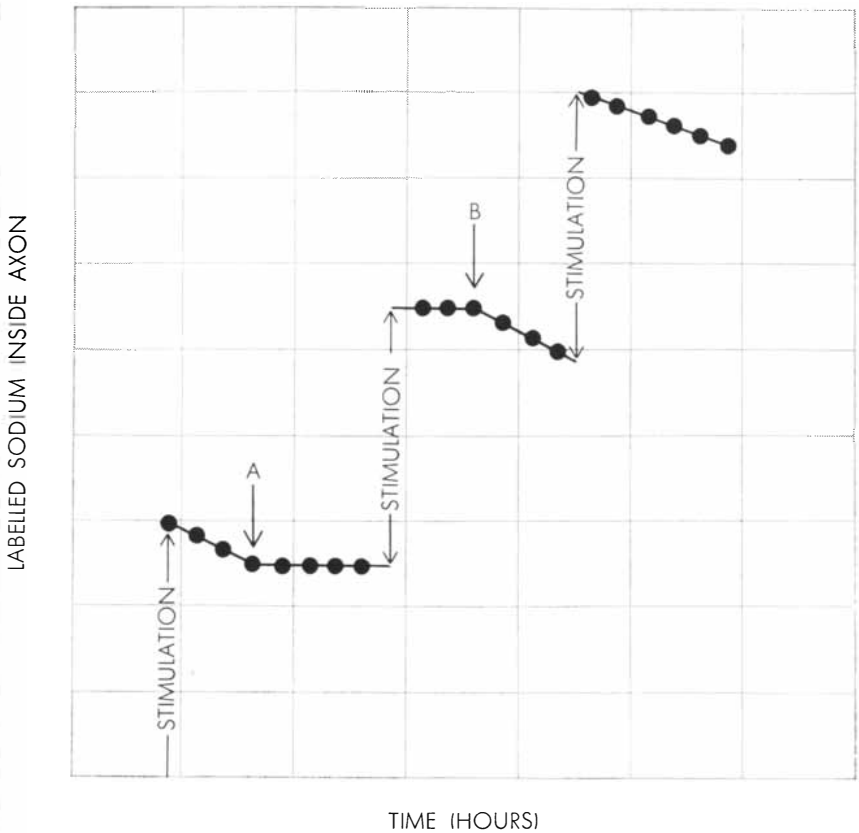
At present we have almost no idea what kind of molecular mechanism underlies the all-important changes in the permeability of the membrane. It is clear that a very small change in potential brings a relatively huge change in permeability; the permeability to sodium increases more than eight times in response to a potential shift of only 10 millivolts. This suggests some rearrangement of charged groups in the structure of the membrane. Nothing is known, however, about the chemical nature of these groups. No chemical compound yet described can discriminate between sodium and potassium so effectively as a nerve membrane. It may be that the membrane mechanism exploits some physico-chemical difference between the two ions, the subtlety of which at present eludes us.

We come now to an interesting new question which is raised by what we have learned about the propagation of the nerve impulse. We have sought for the source of electrical energy that moves the impulse along the fiber. And we have found that source in the electrochemical pressure exerted by the concentration of sodium on one side of the membrane and potassium on the other. This energy is released and electric currents flow across the membrane when the changing permeability of the membrane permits the ions to penetrate it. We are now, therefore, prompted to ask how these concentration gradients are built up in the first place. We must ask also how they are maintained, despite the gain of sodium and loss of potassium that occur every time an impulse travels along the nerve. The question has general importance, for the same concentration gradients of low internal sodium and high internal potassium exist in many other kinds of cells.

The cells must build up these concentrations by forcing the sodium and potassium ions to move uphill against their respective gradients, as contrasted with the downhill transfer that occurs during the spike. Some still-unidentified source of energy in the metabolism of the cell must pump the sodium out of the fiber into the surrounding fluid in which 10 times as much sodium is present, and must take potassium up into the intracellular medium in which potassium predominates. So far we have learned very little about this process of "active transport," but we owe much of what we have learned to work with giant axons.

Using radioactive isotopes, Hodgkin and I have obtained evidence that the outward passage of sodium is normally (but not, it seems, invariably) linked to the uptake of an equivalent quantity of potassium. The working of this coupled "sodium pump" could be interrupted, we found, by treating a squid axon with dinitrophenol, a metabolic poison. The presence of this poison brought the outward passage of labeled sodium to a standstill. It did not, however, reduce appreciably the downhill inflow of sodium during stimulation of the axon. When we washed the inhibitor away, the sodium pump started up again [*see illustration on next page*]. Parallel experiments which measured the movement of labeled potassium proved that metabolic inhibitors cut down the uptake of potassium and the extrusion of sodium to roughly the same extent.

It would be very interesting to know how the energy, which must be derived ultimately from the oxidation of foodstuff, is supplied to the sodium pump. Most biochemists would suspect that the fuel is the energy-rich substance adenosine triphosphate (ATP), produced by the oxidative metabolism of the cell. P. C. Caldwell, working at Plymouth, accordingly set out to analyze the amount of ATP and related phosphates in cytoplasm extruded from squid axons. He found that the rate at which ATP disappeared during treatment with metabolic inhibitors fitted fairly well with the rate at which the sodium pump slowed down and switched off. Moreover, ATP reappeared in the cytoplasm of the axon when the inhibitors were washed away. Recently I have joined forces with him to examine the role of ATP more directly. By means of a microinjection technique made possible by the large diameter of the squid axon, we introduced measured amounts of ATP into cells whose own ATP-synthesizing machinery had been poisoned. We found that injected ATP can indeed restore the rate of sodium extrusion, but only temporarily and never to the level observed



THREE SUCCESSIVE STIMULATIONS increased the concentration of radioactive sodium in a giant axon. The "sodium pump" then caused the concentration to fall slowly. (The sodium measurements are indicated by dots.) Between A and B the pump was blocked by a metabolic poison; axon could take up sodium upon stimulation, but could not eliminate it.

in an unpoisoned axon. However, it would be premature to conclude that the sodium pump is driven by ATP alone.

The active-transport system is even more exact than the spike mechanism in distinguishing between sodium and potassium. It moves sodium outward from the intracellular medium, which is rich in potassium, and draws potassium inward from an environment containing 50 times as much sodium. Lithium can be substituted for sodium in the external medium without causing any perceptible change in the spike. On the other hand, lithium that has entered the cell is extruded very slowly; the sodium pump, unlike the spike mechanism, does discriminate between sodium and lithium.

Several theoretical schemes have been proposed for the sodium pump. Mostly they postulate carrier molecules which move the sodium from inside to outside, there releasing the sodium, and then change their affinity to move back to the inner surface of the membrane carrying potassium. But so far not even a plausible guess has been made at the identity of these carriers. We should not be surprised if it turns out eventually that the sodium pump works on some other principle entirely.

The reader may reasonably ask how much of the work on giant axons is relevant to the properties of other types of nerve fibers. It is always dangerous to extrapolate too slavishly from one species to another. Size is not the only important difference between squid axons and vertebrate nerves. Many of the latter are sheathed in myelin, a fatty material which insulates the membrane except at interruptions (called the nodes of Ranvier) which occur at intervals of about a millimeter. Study of frog nerves, however, indicates that the membrane at the nodes undergoes permeability changes basically similar to those which occur over the whole surface of a squid axon. It is now agreed that the function of the myelin sheath is to force the impulse to skip from node to node in a "saltatory" manner. This confers an important advantage on vertebrates; it provides them at strategic points with nerves able to conduct impulses much faster than nonmyelinated fibers of equal bulk. The conduction mechanisms in vertebrate and invertebrate nerves thus seem to be fundamentally the same.

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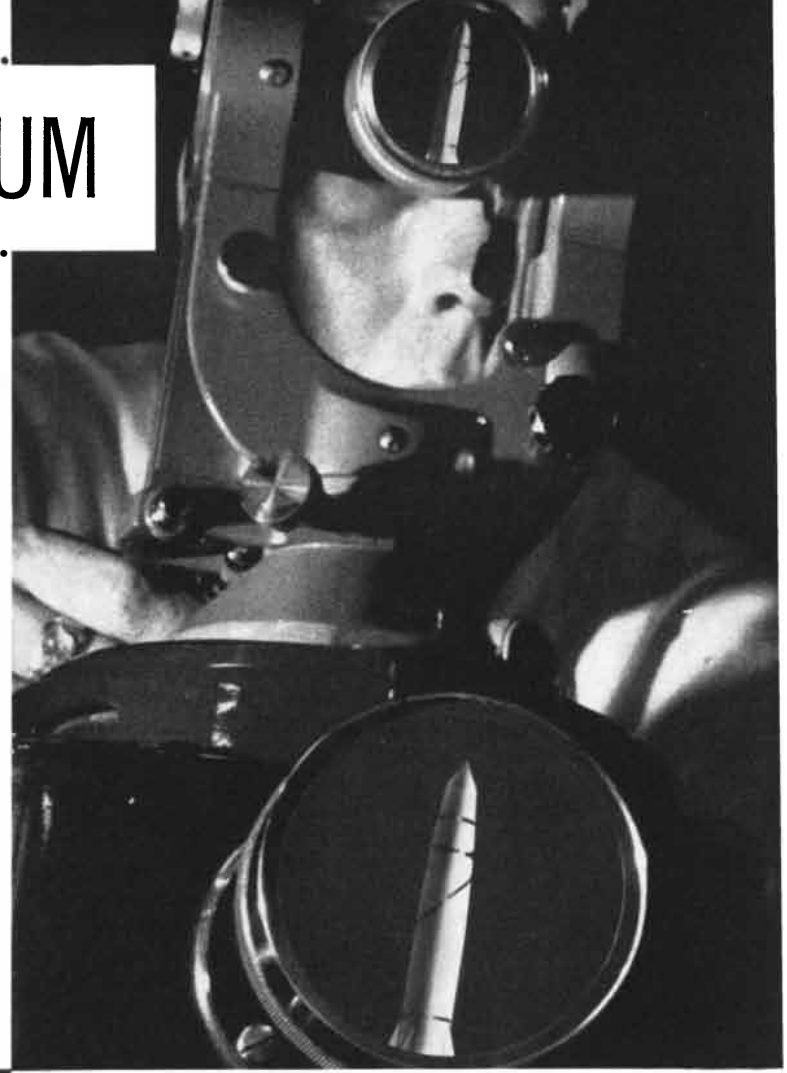

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Essentially, the integrator plots shaft rotation against time, suggesting its wide application in other fields where chart-area measurements are significant. These include: integration of stress-strain curves for determination of cyclic and rupture energies; continuous process weighing, in which the integrator totalizes the amount of material supplied to a conveyor belt; integration of rocket thrust in conjunction with transducers to obtain propulsion efficiency; and obtaining daily totals of process plant flow.

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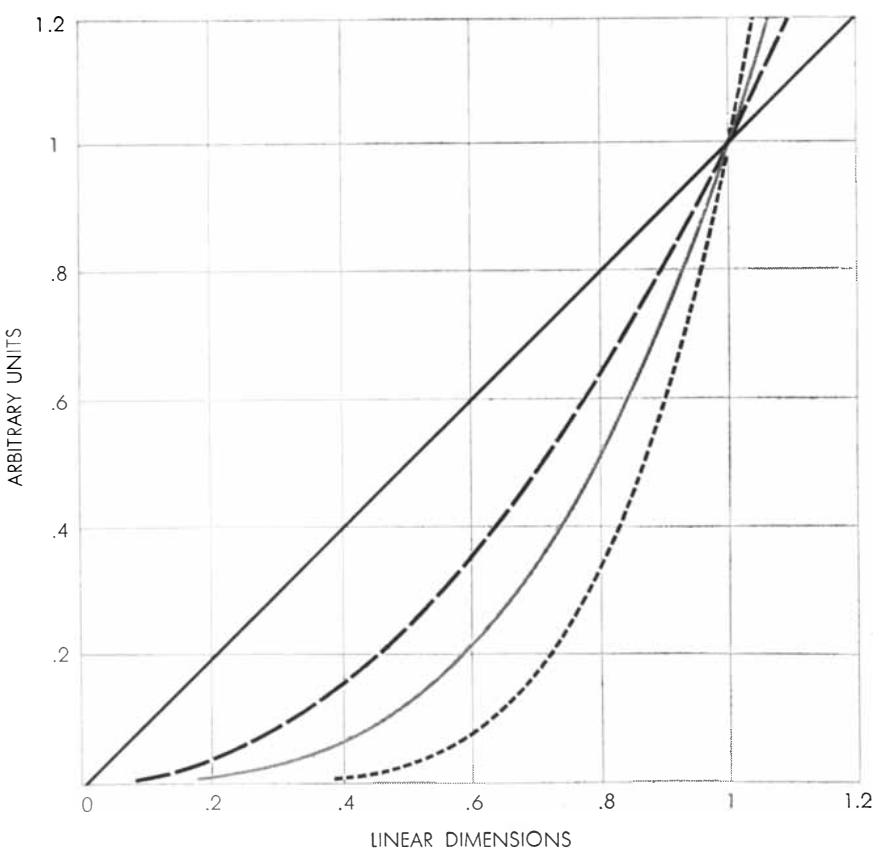
INSECT FLIGHT

Although its speed has sometimes been exaggerated, it is still an impressive biological performance. It appears, for example, that the monarch butterfly can fly nonstop across the Atlantic

by Brian Hocking

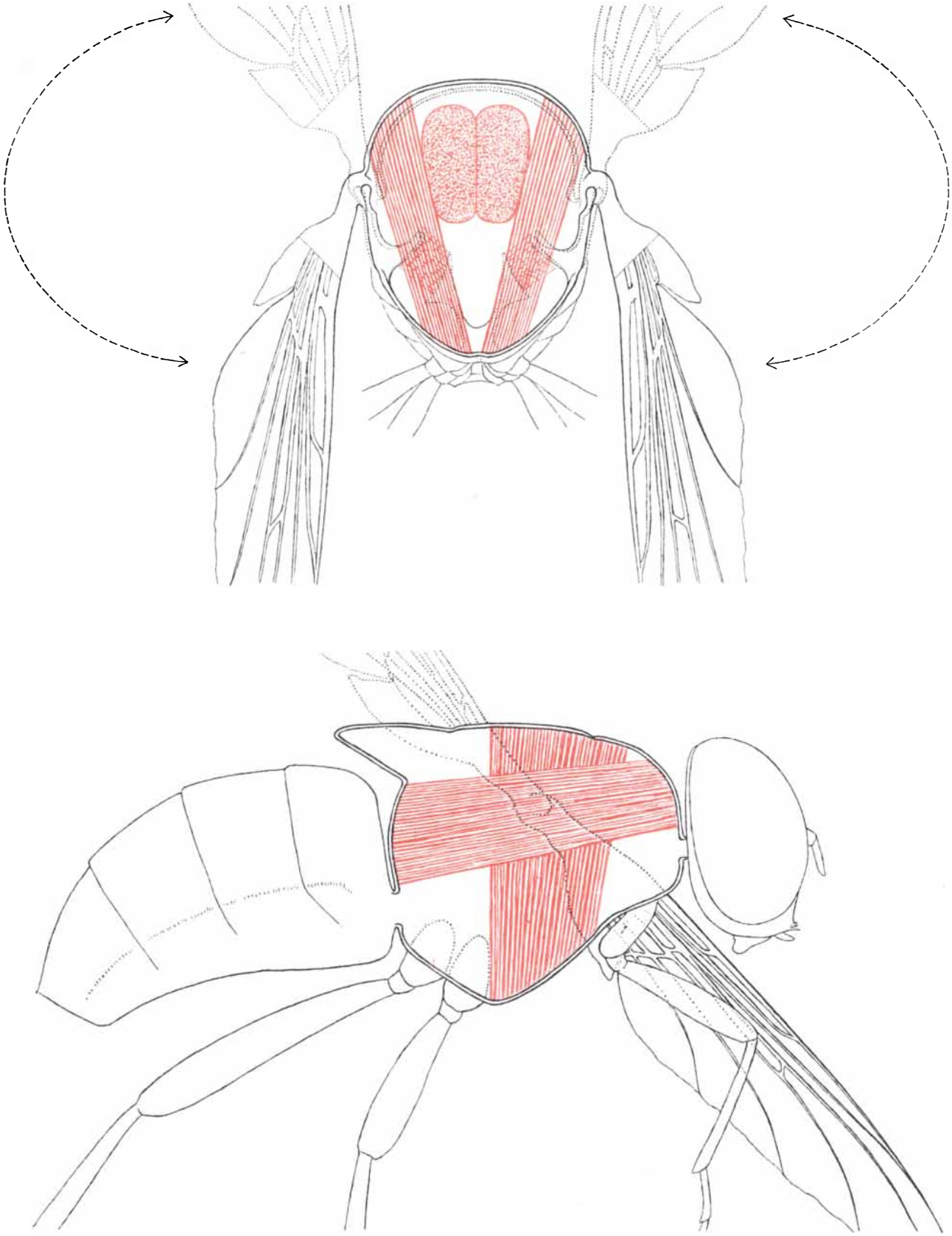
It is obvious that insects fly by flapping their wings. But exactly how the flapping of wings enables an insect to fly is not so obvious. The question first attracted serious attention less than 100 years ago, in connection with man's own efforts to fly. The small size, delicate structure and rapid movements of insects posed serious difficulties for the early investigators, and their publications were filled with acrimonious debate. One careful student, the French zoologist Antoine Magnan, found it impossible to explain the flight of the bumblebee by any known principle; he is the authority so often quoted to the effect that the bumblebee should not be able to fly at all.

Though much of the mystery of flight has been dispelled by man's recent mastery of the art, insect flight continues to present intriguing problems. Insects began to fly some 300 million years ago. Vertebrates did not follow them into the air until 100 million years later; then they went aloft largely in pursuit of insects. The virtuosity and efficiency of insect flight, attained by the evolutionary experience of the numerous insect species, still hold challenge and surprise for the investigator.

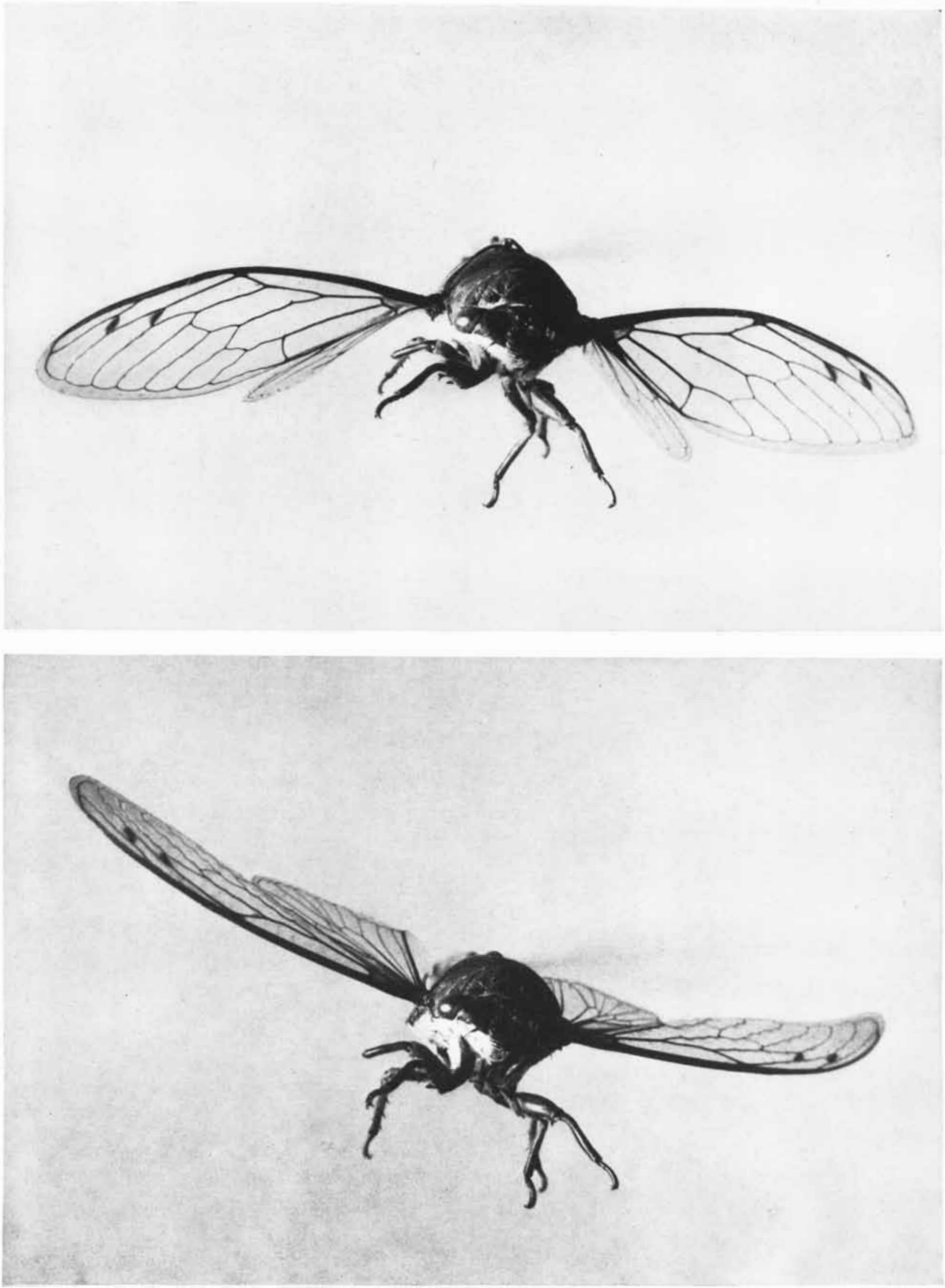


POWER required to keep an animal in the air (*short dashes*) increases with its length (*solid straight line*) and weight (*gray line*). Above a certain point (*1 on the vertical and horizontal scales, both of which are arbitrary*), muscle power (*long dashes*) is insufficient for the job.

The flapping of an insect's wings is no mere up-and-down motion. It is a complex movement designed to supply the lifting force that carries the insect upward and the thrusting force that carries it forward. For most biological flying machines the first of these two forces requires much the greater expenditure of energy. In other words, flying organisms must work harder to overcome the force of gravity than to make their way through thin air. But of course the air does offer resistance to the movement of objects through it. Air has viscosity, and this sets a limit on the velocity with which objects can fall in it. According to Stokes's law, the limiting velocity of fall is proportional to the difference between the density of the object and that of the air, and also to the square of the radius of the object. Thus a mammal 10 inches long will attain a limiting velocity of fall 100 times greater than that of an insect one inch long. This comparison is especially significant because the work an animal must do to remain airborne is equivalent to the energy developed by its weight at the limiting velocity of fall. And the weight of a 10-inch mammal is far greater than that of a one-inch insect; if the linear dimension increases by a factor of 10, the weight (given the same density) increases by a factor of 1,000. As a result the power needed to keep



TWO PAIRS OF MUSCLES (*color*) supply the power for the flight of an insect. In the drawing at the top of this page the muscles are shown in a transverse section of a housefly; the longitudinal section at bottom depicts the muscles which operate the wing on the far side of the fly. The vertical muscle in the longitudinal section contracts to pull the wing up; the horizontal muscle, to pull it down.



FLYING CICADA was photographed with high-speed flash by Harold E. Edgerton of the Massachusetts Institute of Technology. In the photograph at the top the wings of the cicada are on the upstroke; in the photograph at the bottom the wings are on the downstroke.

the 10-inch mammal from falling will be at least 100,000 times greater than that required by an inch-long insect.

As this analysis plainly suggests, flying is not at all the same task for an insect that it is for a bird, a bat or an airplane. The latter must expend most of their energy pushing downward on the air just to stay aloft. The effort needed to push ahead through the air remains comparatively small, except for airplanes traveling at a speed which exceeds their maximum velocity of fall. Insects, on the other hand, need to spend relatively little energy to get into the air. The very viscosity of the air helps keep them aloft.

In recent years we have come to realize that the air supports a considerable and complex population of plant and animal forms, many of which—gossamer spiders, mites, springtails, spores and pollen grains—have no wings at all. The smallest insects, about the size of the largest protozoa, are not the smallest airborne creatures, but they are probably the smallest which have control of their progress through the air. They have such a low velocity of fall that they can remain aloft by gliding, and need flap their wings only to propel themselves forward.

The wings of insects, unlike those of other flying animals, arise not from limbs but from the body wall; the insects acquired wings and yet kept their legs—all six of them. This development was possible only for animals with an exoskeleton, which combines skin with skeleton in the body covering. Such a construction scheme economizes on weight and imposes limitations on growth; this, as we have already seen, confers important aerodynamic advantages. Most of the more specialized insects (flies, mosquitoes, beetles) have only one pair of wings. Where there are two pairs, they are usually synchronized to function as one, with the rear pair often hooked onto the hind margin of the front pair. In this discussion our model will be the fly, whose hindwings have been modified into stabilizers called halteres.

Insect wings are stiffer at the front edge, where the veins are concentrated and power is applied, and more flexible at the trailing edge. They are driven by muscles that occupy most of the thoracic box. One set of muscles runs from the back of the thorax around to the front; these contract to bring the wings upward and backward. Another set runs longitudinally and upward to the back of the thorax; these move the wing forward and downward. The alternate contractions of the two sets of muscles distort the back of the thorax. A series of plates and pivots translates this distortion into the motion of the wings.

The tracing-out of the true motion of insect wings inspired some keen ingenuity among 19th-century investigators. We owe the stroboscope to Joseph Plateau, the blind Belgian physicist who invented this device in the 1860s in his effort to visualize insect wing motion. His son Felix made interesting determinations of the lifting power of flying insects by attaching small weights to them.

The essential scheme of insect wing motion was at last resolved in 1868 by Etienne Jules Marey of France. He attached a bit of gold leaf to the wingtip of a fly which he had fixed to a stationary mounting. Observing the gleaming pathway traced by the wingtip as the fly buzzed under a bright light, he saw for the first time that the wing moves through a figure eight. He determined the direction in which the wing moves around the figure eight by poking thin, soot-blackened glass filaments into the trajectory and observing from which side the wing brushed the soot. The results of these two experiments were elegantly confirmed by a third. Marey mounted a fly on a pivoted arm which permitted it to fly in a circle. Its outer wingtip, brushing against the smoke-blackened inner surface of a cylinder of paper, made a complete record of its motion in flight. Spread out in such a record, the figure eight becomes a somewhat asymmetrical wave.

The figure eight actually traced in flight is elongated, somewhat bent and inclined forward at the bottom [*see illustration on next page*]. As the pattern suggests, the work of lifting and propelling is done on the downward and forward stroke, while the upward and backward stroke effects the recovery of the wing for the next cycle. As the wing moves, it twists about its long axis as the result partly of its own variable flexibility from leading edge to trailing edge, and partly of the articulation of the levers and muscles that move it. Thus the wing is made to push against the air during the working portion of its travel and to minimize resistance during recovery, as in the feathering of an oar.

With this compound motion the wing draws air from above and ahead and pushes it below and behind. In doing so it imparts an equal and opposite—upward and forward—push to the insect.

In normal flight the long axis of the figure eight is inclined at an angle of about 45 degrees. This suggests that the power needed to lift the insect just about equals the power applied to move it forward. This surmise is supported by the observation that the two sets of muscles which move the wing are of comparable size. And it has been confirmed by direct measurement of the two components of force developed by the wings.

The figure eight can be seen plainly with the unaided eye when the common black-and-yellow-banded hover fly is observed against the light. With the insect hovering and no forward thrust applied, the long axis of the figure eight appears roughly horizontal. If we could observe the insect during a burst of speed, with maximum forward thrust applied, the axis would presumably rotate toward the vertical. The wings of a healthy insect move with large amplitude when it is in full and vigorous flight. If we could see the cross section of wing motion from in front or behind, we would doubtless find that each wing moves through more than a half circle. The alarming note that enters the peaceful hum of a bumblebee when it comes in on an attack apparently arises from the beating of the wingtips as they meet at the top of their swing.

Insects generally fly rather close to the ground. The insect population thus thins out rapidly with height. Smaller insects may, however, be carried by winds to altitudes as high as 5,000 or 6,000 feet and for very great distances. An insect, like an airplane, usually takes off into the wind, so that its air speed is made to exceed its ground speed. Many insects, especially the larger species, must warm up before they can take off. Some hawk moths and other species flutter their wings for a few minutes, thereby raising the temperature of the thorax and speeding up the generation of the muscular power required for flight. Other insects, especially some butterflies, warm up merely by sitting in the sun.

Curiously, an insect usually continues flying straight into the wind unless an outside stimulus makes it turn. If the wind speed increases above its air speed, the insect will usually be stimulated by its backward motion with respect to the ground to turn and fly downwind. Around large bodies of water this idiosyncrasy can lead insects into trouble. During the hours after sunrise the land warms up faster than the water, and the warm air, rising above the land, draws cooler air from over the water in the familiar morning onshore breeze. At the

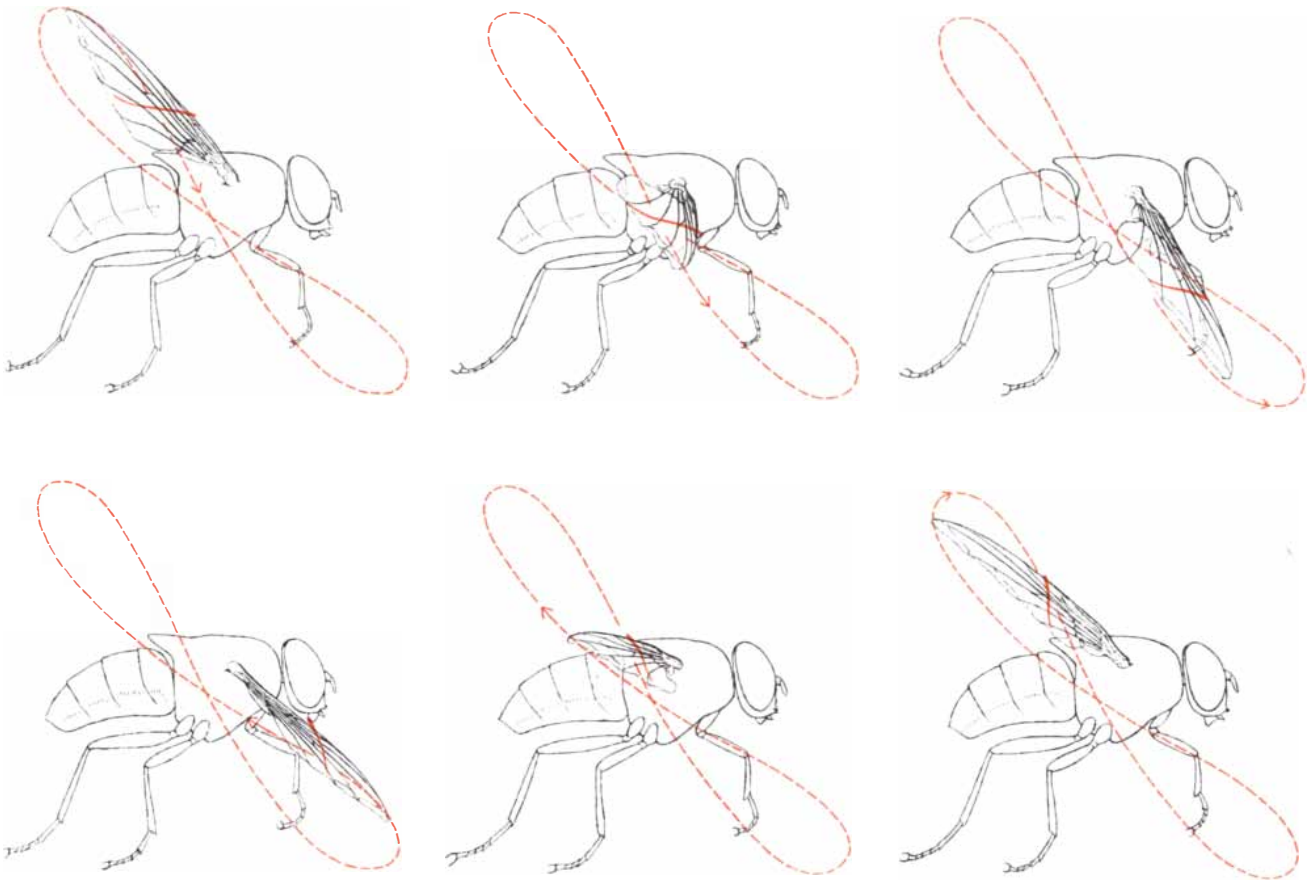
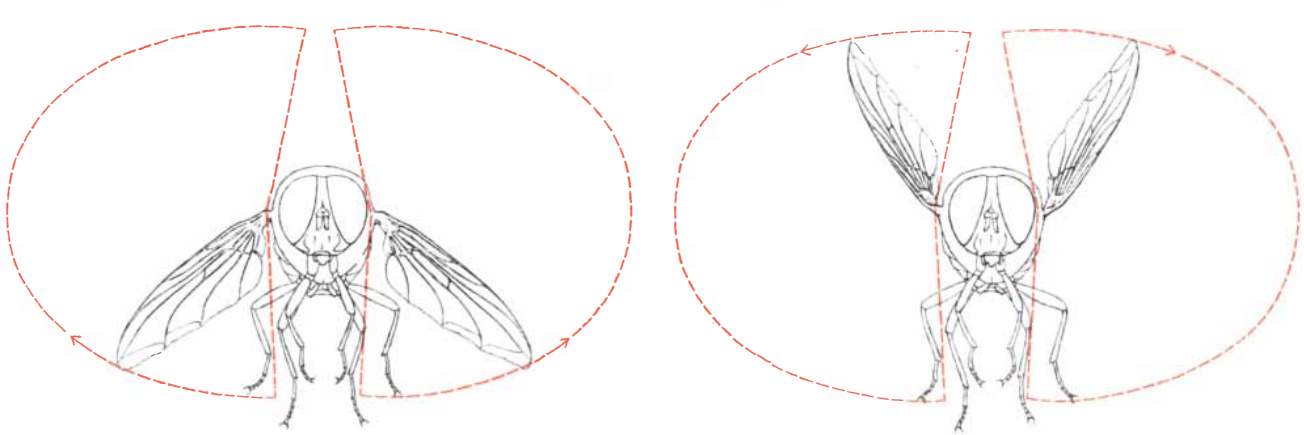


FIGURE-EIGHT PATTERN is traced by each wingtip as an insect flies. These drawings illustrate several positions of the wing on the downstroke (*top row*) and on the upstroke (*bottom row*). The line across the middle of the wing (*solid color*) is horizontal on the downstroke, but on the upstroke the line is vertical. Here the wing is "feathered" to decrease its air resistance.

same time insects on the shore are absorbing heat from the sun before they take to the wing. As the breeze begins to blow, they take off into it and soon find themselves over water. With no ground pattern to orient them, they are likely to continue to fly into the wind. They will do so even if the wind freshens and exceeds their air speed, for the only regularly visible pattern, that of clouds and waves, moves with the wind. The appearance of an island or a ship, apparently moving at a rate different from that of the wind-cloud-wave system, may provide a visual cue that will evoke a "homing" response. This may help to explain the peculiar make-up of the insect population of some islands. If an insect exhausts its energy reserves before a haven appears, it must come down in the water. Few insects are equipped to survive in water for long, and most are eaten by fish. It would seem that this sort of thing happens frequently and on a large scale, for windrows of insects are often observed on lake or ocean shores.

Some insects are capable of extraor-



AMPLITUDE OF WING MOVEMENT is more than a half circle. The colored lines show the extent of the wing movement upward (*left*) and downward (*right*). Note the pattern of veins of the fly's wings; the veins are more concentrated toward the leading edge.

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dinary long flights. The most famous long-range flier is the handsome monarch butterfly. Enormous numbers of these insects migrate from the region around the Gulf of Mexico to eastern Canada during the summer and back to the Gulf states in the fall. Individual monarch butterflies have appeared from time to time in England and are believed to have crossed the Atlantic with no assistance other than a tail wind. Calculations based on the monarch butterfly's supply of energy and rate of energy consumption indicate that it is capable of traveling about 650 miles in still air at a speed of about six miles per hour. With a modest following wind it should certainly be able to cross the Atlantic.

Locusts, in swarms weighing thousands of tons, can fly up to 300 miles without stopping. Even smaller insects travel surprising distances. Aphids regularly cross the North Sea between England and the Continent, a distance of several hundred miles; in Africa black flies may ignite an epidemic of cattle disease 200 miles from their nearest breeding site, having traveled 100 million times their body length without being able to stop for food.

In recent years the rapid and convenient transportation provided for insects as well as for man by modern aircraft has overshadowed the importance of the insects' own power of flight. In the past, however, the spread of insect species has been accomplished largely through their own capacity. The white cabbage butterfly crossed North America in 28 years; it took modern human settlers much longer. Man has a practical stake in the mobility which flight gives to the insect, for it determines the spread of insect pests and insect-borne diseases of plants and animals.

Speed is an aspect of insect flight that has excited many wild guesses and tall stories. At least one distinguished U. S. naturalist, whose knowledge and good sense should have availed him better, went on record with an estimate that the deer fly is capable of a speed of 820 miles per hour. Irving Langmuir took the trouble to show the impossibility of this estimate on purely physical grounds. This led me to consider the limitations of insect capacity from a physiological point of view.

We encounter at once a strange paradox. In general, the larger the insect, the faster it should be able to fly. For various reasons a very big insect must fly fast to stay aloft. Yet there is a size limit above which an insect would be unable to fly at all. It is all too easy to overestimate the speed of insect flight. One may see various insects, notably horseflies, holding their own with a car moving at 50 miles per hour. But the insect may actually be aided by a 20-m.p.h. tail wind, by gravity on a downhill run, by air currents carried along with the car, or by periodic rests on the car—or one may really be seeing not one insect but relays of insects. Flight speed must be measured under more controlled conditions.

On the basis of the specific power of insect muscle, the weight of the flight muscles, the efficiency with which they operate and the drag of air, I have calculated that the fastest insects are probably the large dragonflies and hawk moths. They should be able to cruise at speeds up to 24 m.p.h., and to attain 36 m.p.h. in a short burst. No direct measurements in the scientific literature conflict with these figures, and my own observations tend to confirm them. Such speeds are impressive with respect to the insects' small size. Traveling at a comparable multiple of his body length, a man would jog along at 800 m.p.h. and sprint 1,200 m.p.h. The speed of insect flight bespeaks a type of muscular activity not encountered elsewhere in the animal world.

The power required for insect flight, as for airplane flight, increases steeply with speed. Speeds higher than my estimates would require power outputs which insect muscles could not possibly maintain for more than a few seconds. There are fossil records of a dragonfly with a 29-inch wing span; this huge insect might conceivably have attained 43 m.p.h. In full flight it must have presented quite a spectacle, though of course no man was around to see it. I am assuming that the giant dragonfly was built on the same lines as present-day species. If it were not, it could not have flown at all.

Insects seem to have good control over their flight, and we have a long way to go to understand how they manage some of their aerobatic feats. A hover fly, for instance, can remain completely stationary in flight, even in a breeze; it can fly sideways and backwards and spin on its tail or on either wingtip. Some insects, it seems, can even fly upside down, but again we know not how. Fairy flies, which feed on aquatic insects, emulate the penguin and "fly" under water to attack their prey. Unlike the penguin they can also fly through the air.

All in all, insect flight is a complex and controlled action which has served insects well, as is testified by their survival in this man-infested world.

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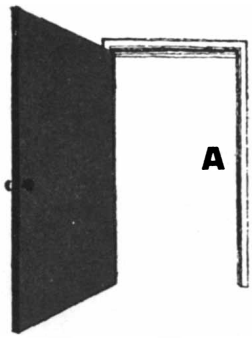

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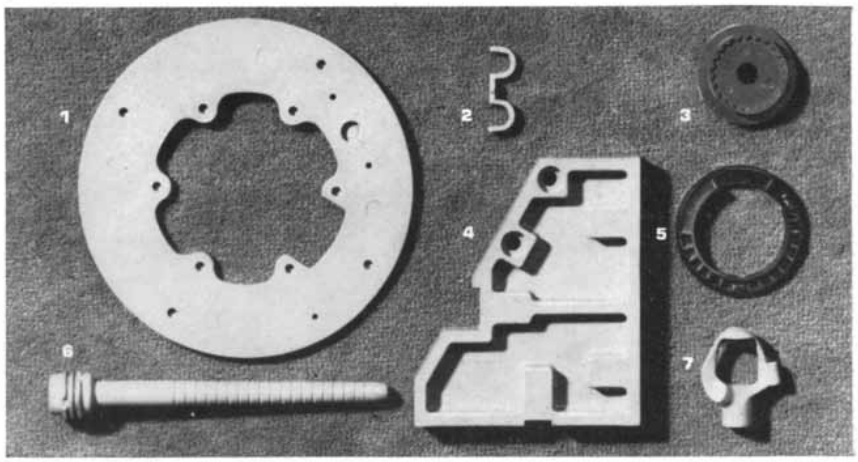

NEW USES FOR PLASKON ALKYD MOLDING COMPOUNDS: 1. Motor guard; 2. Cable bracket; 3. Fishing reel part; 4. Support bracket; 5. Azimuth ring; 6. Textile bobbin; 7. Fire sprinkler head.

Our headline doesn't mean that we are going to tell you about a revolutionary new *kind* of plastic material. Instead, what follows is more in the nature of a letter from some old friends—namely, Alkyd, Urea and Nylon. It tells you what these characters are up to these days and may contain a hint or two about why it may pay *you* to keep in touch with *them.*

ALKYDS. Developed some years ago, alkyd molding compounds began their career in a specialized field—electrical and electronic insulating components. They did a fine job, too—and why not? They have the best electrical properties of any plastic molding compound we know. Their arc and heat resistance are excellent, and they are extraordinarily strong and dimensionally stable.

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It's not hard to account for the present popularity of alkyds. Besides excellent electrical properties, these compounds offer a combination of strength, dimensional stability and rapid cure that can "open a door" to many profitable new applications for those who make or use plastic parts.

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IF YOU WOULD LIKE INFORMATION *or literature on any of these plastics developments from our* PLASTICS AND COAL CHEMICALS DIVISION, *just write us on your company letterhead. In addition to* Plaskon *alkyd, urea, nylon and melamine molding compounds, we make polyester, industrial and coating resins. Perhaps information on one or more may "open a door" to profits or progress in* your *business. Address: Allied Chemical, Dept. 128-S, 61 Broadway, New York 6, N.Y.*

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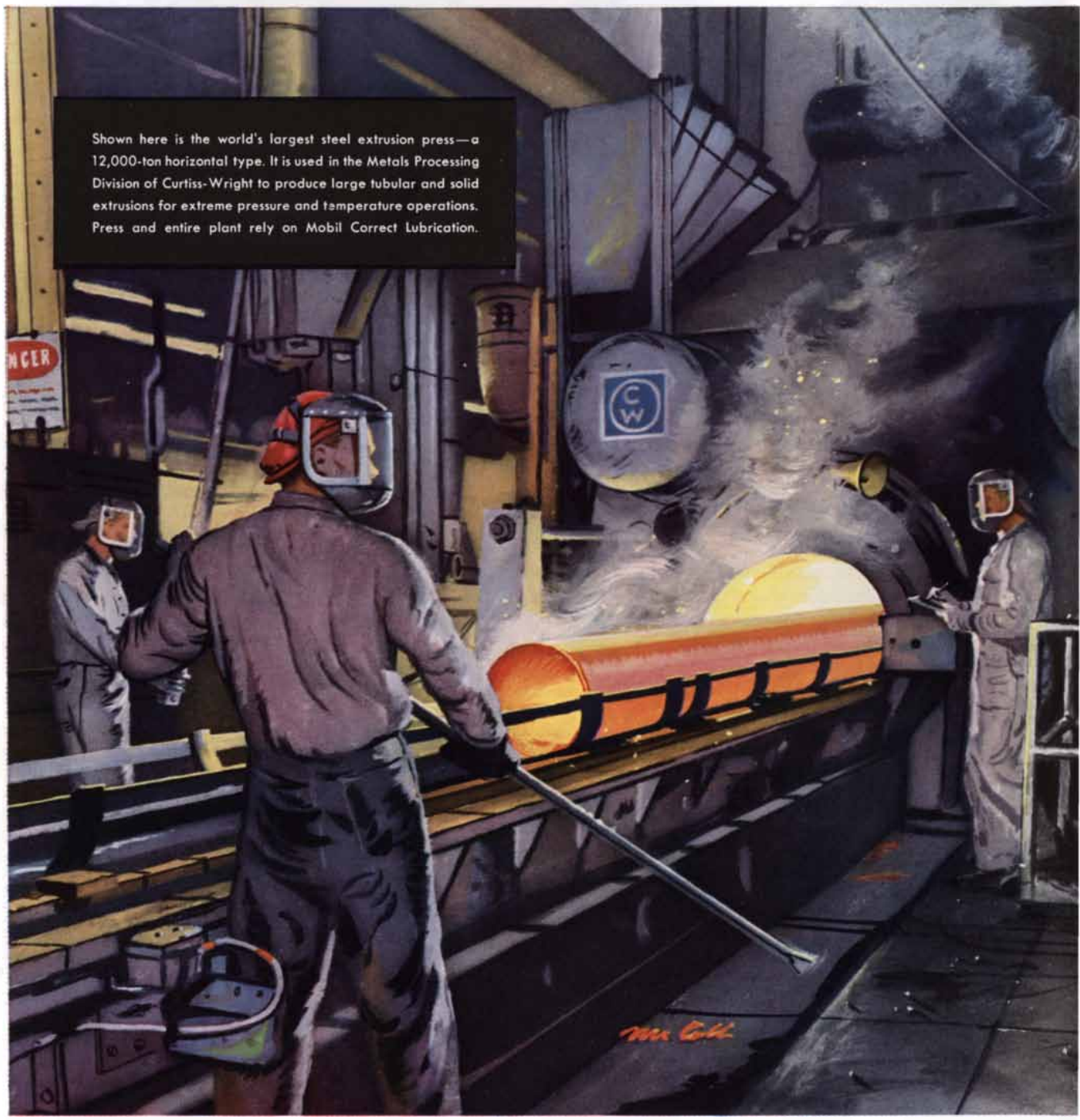

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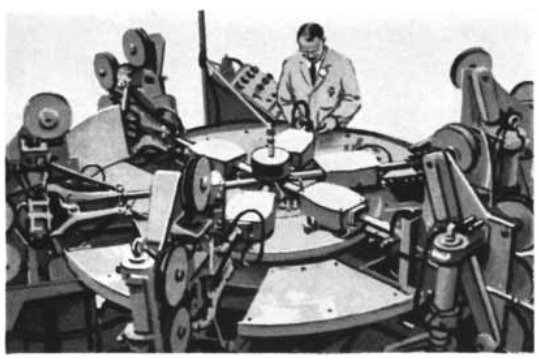
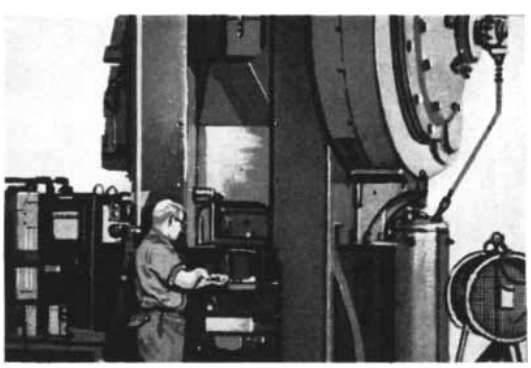
Bearings on drop hammers in Curtiss-Wright's forging shop failed after ten months. Mobil recommended a grease that extended bearing life five years . . . saved $1,152 every ten months.



Curtiss-Wright saves by re-using hydraulic oil as coolant for polishing machine. This saving is part of oil reclamation program organized by Mobil and plant lubrication supervisor. Altogether savings total $5,392 annually.



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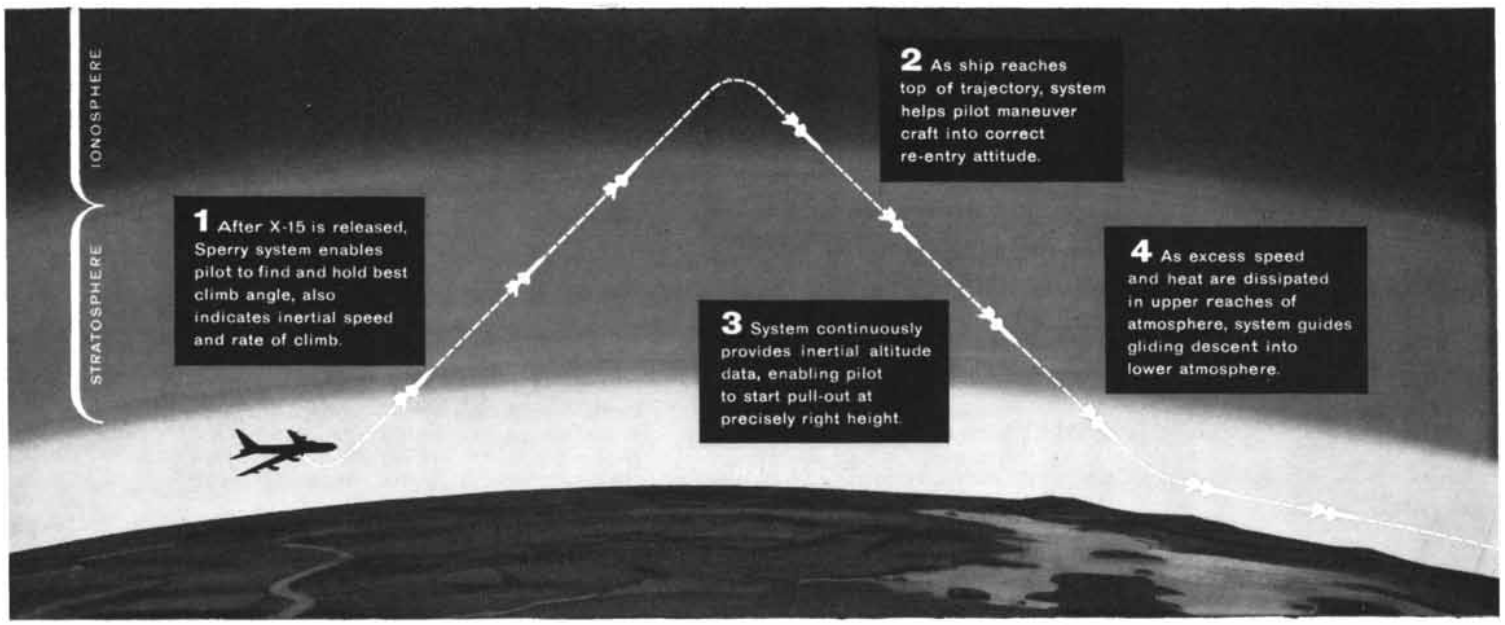

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Mathematical Sieves

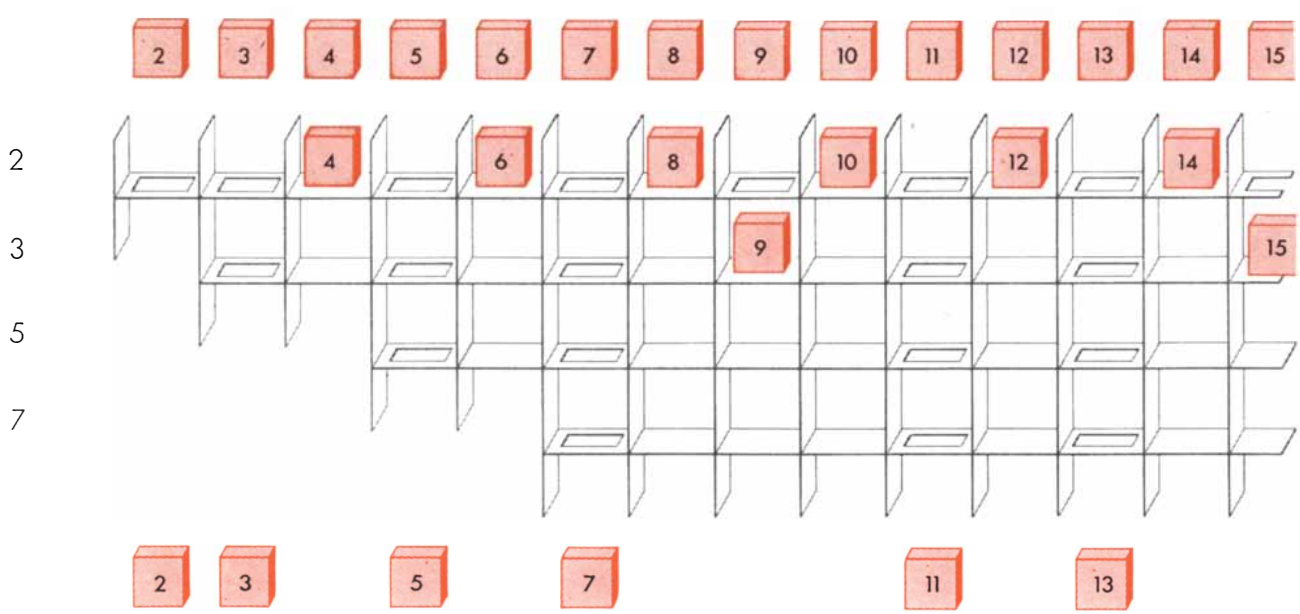
They sift out prime numbers and similar series of integers. Recent research into their properties suggests that a kind of uncertainty principle may exist even in pure mathematics

by David Hawkins

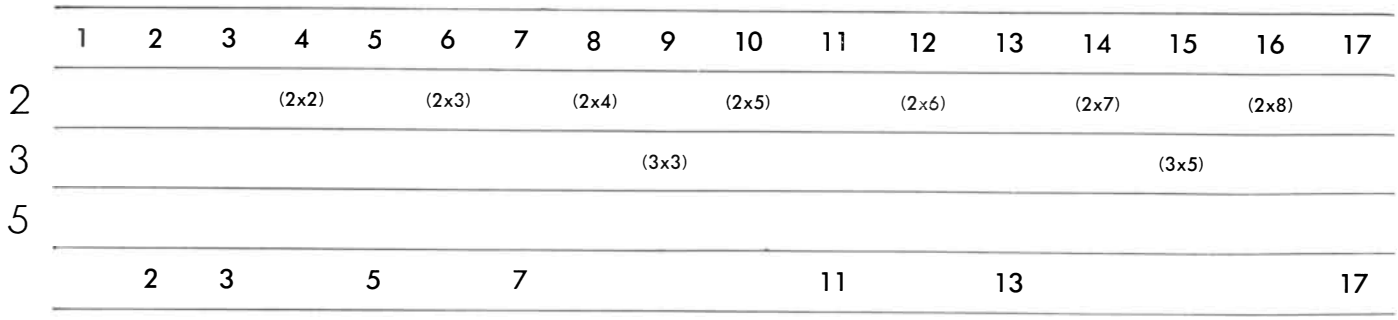
It is no accident that the theories of probability and statistics are among the most rapidly growing branches of modern mathematics. Science demands them. Faced with problems too complex, or too little understood, to solve exactly, it falls back on laws or facts that are true only probably, or on the average. And from physics, considered the most exact of sciences, we learn that at bottom nature is inescapably uncertain and chancy.

But if we must settle for a gambler's view of the real world, can we not console ourselves with the thought that in the abstract realm of mathematics certainty is always possible? As this article will indicate, the answer is by no means clear. Some provinces of mathematics are so difficult that, for the present at least, they must make do with rules which are only probably true. Even in mathematics there may be an uncertainty principle not utterly unlike the uncertainty principle of physics.

The text of this sermon derives not from some new and exotic kind of mathematics but from arithmetic. We shall discuss the classical problem of prime numbers. These are the positive integers—2, 3, 5, 7, 11 and so on—which cannot be represented by multiplying two smaller numbers. (Numbers which can be represented by such multiplication—4, 6, 8, 9, 10, 12 and so on—are called composite numbers.) Prime numbers have fascinated mathematicians for centuries. It was Euclid who proved there is an infinite number of them. Since then many brilliant minds have turned to primes and have discovered a number of remarkable theorems concerning them. Even more remarkable is what has not been discovered. For example, what is the 34th prime number? What is the billionth? The *n*th? To this day there is no general formula to answer these questions. The only way to find the billionth prime would be to write down all of the first billion and take the last. As another example, consider the famous twin-prime problem. Pairs of primes such as 11 and 13 or 29 and 31, which are separated by only



SIEVE OF ERATOSTHENES, a small part of which is shown here, was devised more than 2,000 years ago to separate prime and composite numbers. The first "layer" of the sieve screens out multiples of 2 from the series of integers at the top. Since 3 passes through this layer, it screens out its own multiples in the next layer. Numbers at the bottom are primes which have passed through all previous layers; they will become screening numbers in their turn. No simpler method of deriving primes has yet been devised.

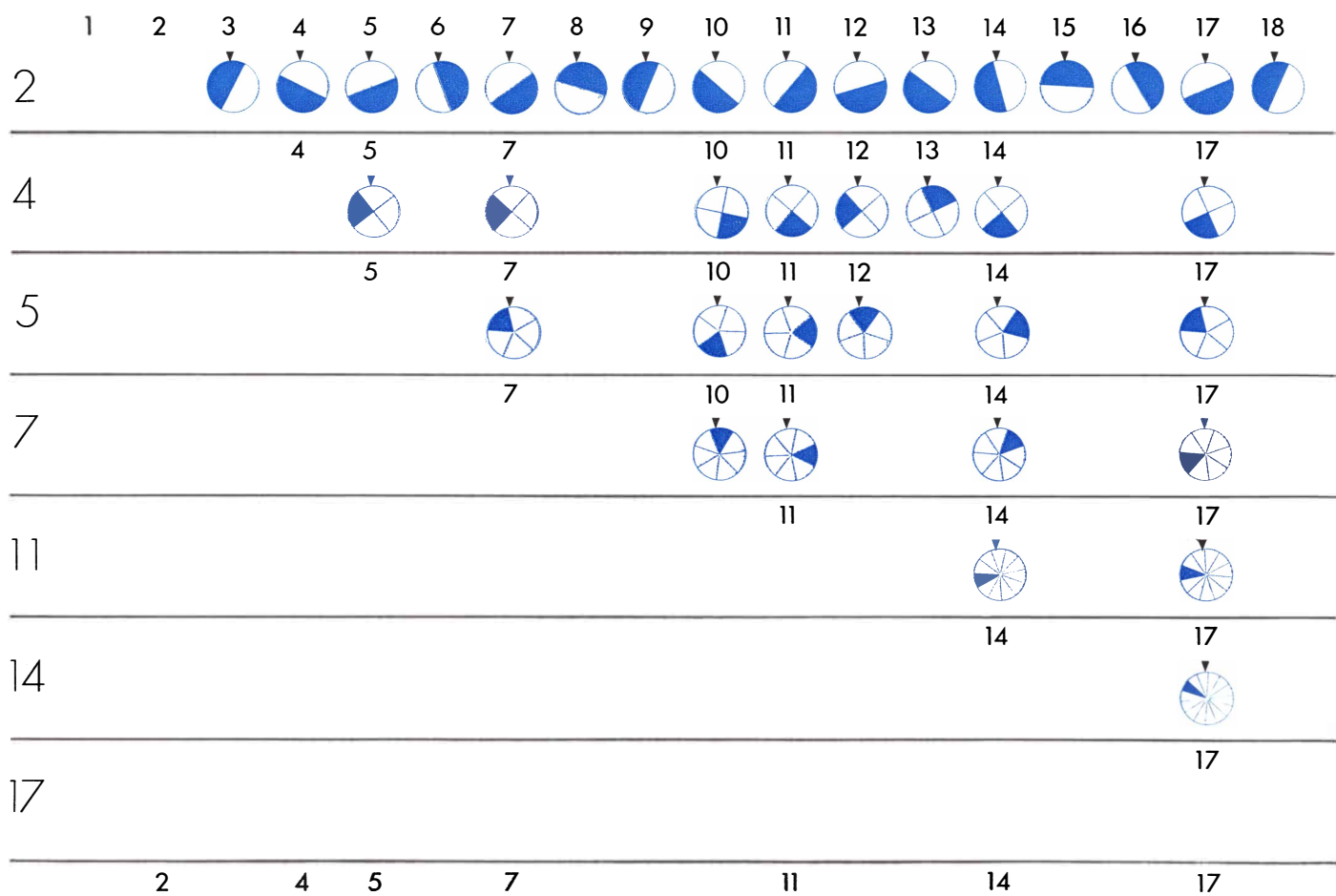


PRIME-NUMBER SIEVE shown here is a larger portion of the sieve on the preceding page. Primes appear on the bottom line. Each prime in turn becomes a sieving number which eliminates its own multiples, beginning with its square (lower multiples have

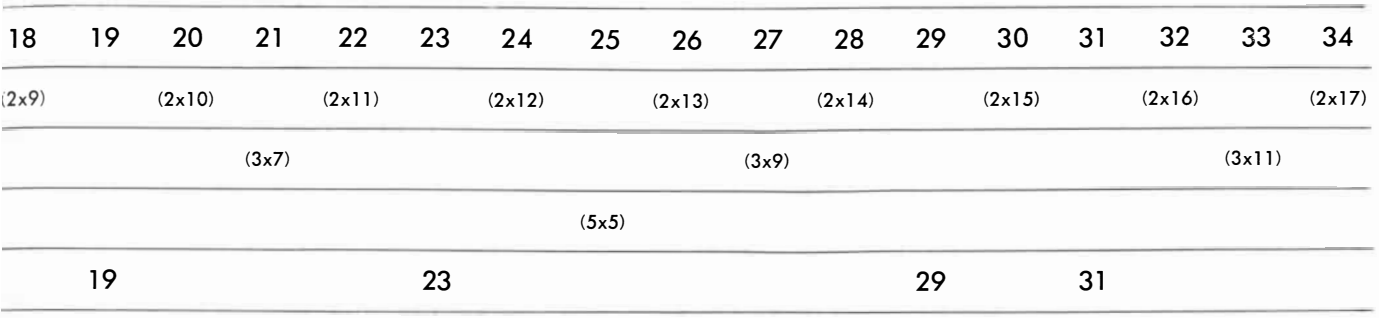
one other number, are known as twins. They keep turning up in the longest series of primes that have yet been listed. Will they continue to recur indefinitely? Is their number infinite? It seems probable, but no one has been able to prove it.

The study of prime numbers has been quite literally as much an experimental as a theoretical investigation. Most of the facts that have been proved began as conjectures, based on the inspection of an actual series of primes. Many conjectures remain, seeming more or less probably true. Thus an indispensable tool of the number theorist is a long list of primes.

One of the best known, now found in every well-equipped mathematics library, was compiled by **D. N.** Lehmer of the University of California in 1914. The volume contains a table of the 664,580 prime numbers smaller than 10,000,000, plus a few more to fill the last column, ending with the prime 10,006,721. Lehmer's work was completed before the age of automatic computation; today there are even longer lists, the longest being "published" only on magnetic tape.



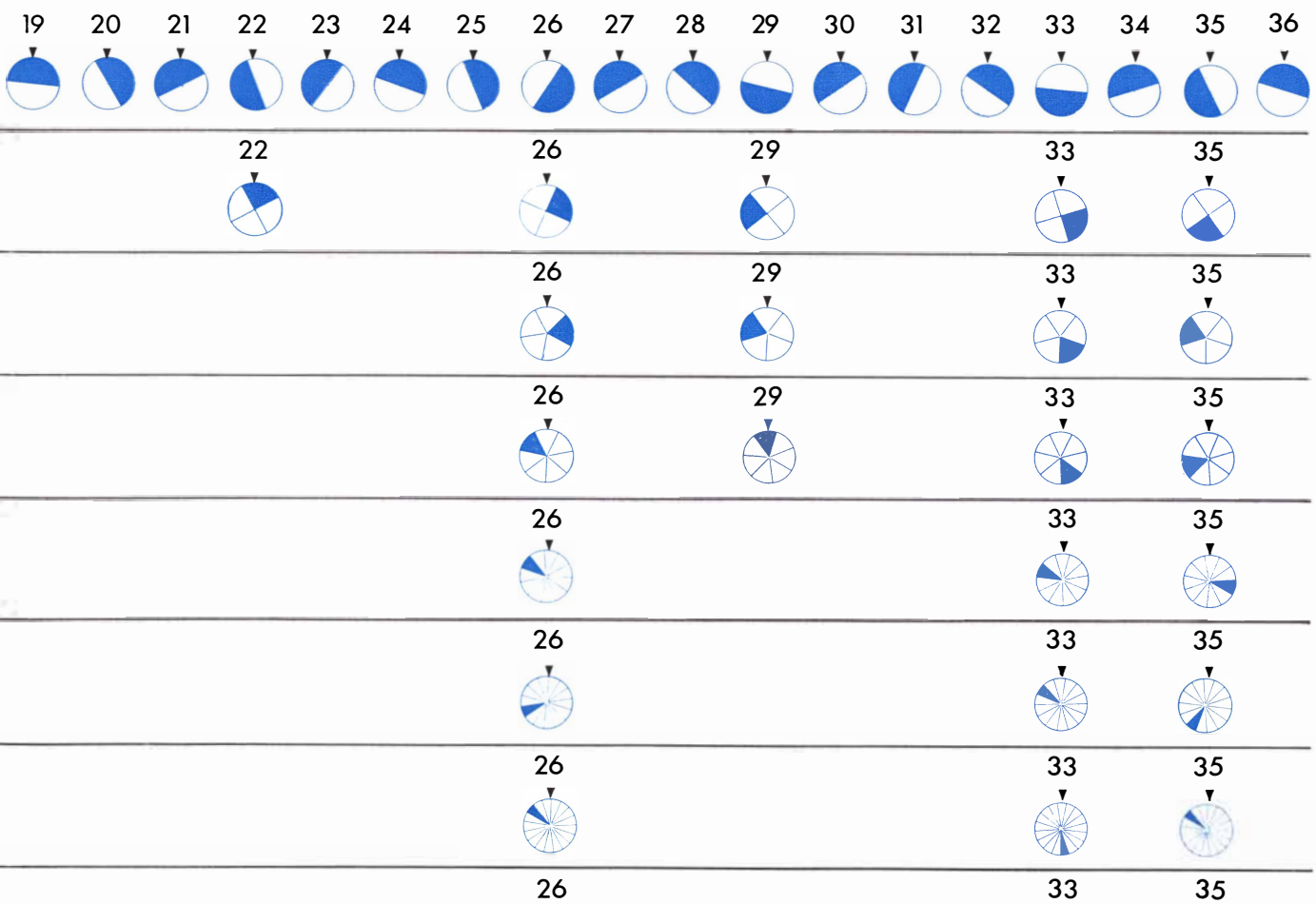
RANDOM-NUMBER SIEVE is statistically similar to the prime sieve but differs from it in detail. In both cases numbers not previously eliminated become sieving numbers; these screen out a proportion of the remaining numbers equal to their reciprocals.



already been removed by lower primes). Thus each prime eliminates a proportion of the remaining numbers equal to its reciprocal (*e.g.*, 3 removes 1/3, 5 removes 1/5). The steps shown here in part yield all primes up to 49, the square of the next sieving number.

Modern tables of primes are prepared by a method, essentially unaltered for 2,000 years, which is called the sieve of Eratosthenes. Its inventor was one of those great figures of the Hellenistic Age who seem today, across the intervening centuries, so clairvoyant of the spirit of modern science. Eratosthenes of Alexandria is best known for his feat of measuring the size of the earth. But he was a man of universal learning who wrote also on geometry, the measurement of time, and the drama. In his own day he was nicknamed "Beta" because, it was said, he stood at least second in every field. Modern electronic computers can make far longer lists of primes than Eratosthenes could have, but his principle of computation has not been much improved.

The method is almost obvious [*see illustration on page 105*]. Simply write down a series of positive integers and proceed systematically to eliminate all the composite numbers. The numbers that remain—that fall through the "sieve"—are primes. We begin by knocking out the even numbers, which are multiples of the first prime number: 2. (One is not usually called a prime.) When we have



In the random sieve, however, the specific numbers to be eliminated are chosen by a random process symbolized by the colored wheels. Thus the random sieve produces a different set of numbers each time it is used, while the set of prime numbers is invariant.

done this, the smallest of the remaining numbers is the second prime: 3. Now we eliminate the multiples of 3 from the numbers which survived the first sieving operation. Five is the next number remaining, so its multiples drop out next; then the multiples of 7, and so on.

The reader may wish to try a somewhat longer version of the sieve than the one shown in the illustration, where 7 is the largest sieving number. In number theory the distance from the obvious to the profound is sometimes very short, and any amateur willing to play the game is on the verge of some first-class mysteries. At any rate, a little manipulation of the sieve will make clear some of its properties. Every sieving number is a prime. The first number sieved out by each one is its own square: the first number eliminated by 2 is 4; by 3, 9; by 5, 25 and so on. In addition, the fraction of the remaining integers eliminated by each sieving number is its own reciprocal: 2 sieves out half of the remaining numbers, 3 sieves out a third, 5 sieves out a fifth.

By carrying out the sieving operation through the prime number 31, we can obtain all the primes in the first 1,368 integers. (The first number sieved out by 37, the next prime, is 37^2, or 1,369.) For purposes of illustration we have arranged the first 1,024 of the integers in a 32×32 array, with the prime numbers shown in color [*upper illustration at right*]. The list is short, but it does demonstrate that the frequency of primes slowly decreases in a rather irregular way. From considerably longer tables Adrien Marie Legendre, and later Karl Friedrich Gauss, were able to guess one of the most important facts about primes—the celebrated Prime Number Theorem. This tells how many primes we may expect to find by carrying the list out to any given number. It states that if the number is n, then there are about n divided by the logarithm of n (n/log n) primes before it. As n grows larger, the error in the formula becomes a smaller and smaller proportion of the exact number of primes. Gauss, whose skill in computing belied the myth that mathematicians cannot add and subtract, arrived at the theorem by a combination of arithmetical insight and purely empirical study. It was not proved for almost another century. In the 1890s the Belgian mathematician Charles de la Vallée Poussin and the French mathematician Jacques Hadamard independently found a proof, but it made use of concepts outside simple whole numbers. It was not until 1950 that the Norwegian mathematician Atle Selberg discovered a purely arithmetical proof. In the quaint vocabulary of number theory his proof is called elementary, but it is not easy.

The difficulties of the Prime Number Theorem are connected with the puzzlingly irregular way in which the primes are distributed. Indeed, the theorem itself does no more than state a statistical average. Outrageous as it may seem, the sequence of primes is just as "random" as many of the natural phenomena on which we make bets. Sometimes we think that if we knew enough about the individual events of which such phenomena are composed, we could predict their outcome with certainty. This is surely true of the primes. The sieve will eventually tell us about the primality of any given number. But it cannot tell us about all numbers, because the sequence is itself an infinite, unending process.

From the time of Gauss mathematicians have talked, perhaps rather shamefacedly, about the "probable" behavior of primes, and this kind of reasoning has been very helpful. No mathematician, however, seems to have gone the whole way and made a purely statistical model of the prime-number distribution. Recently I was led to try it, and I found that the model helps clarify the Prime Number Theorem. Furthermore, it places the whole subject in a new perspective. In particular, the theorem no longer appears as a special fact about the sequence of numbers which cannot be produced by multiplying two smaller numbers, but rather as a common feature of all sequences of numbers generated by sieves of a certain type.

The model is called the random sieve, and it works like this [*see illustration at bottom of preceding two pages*]. Start with 2 as the first sieving number, just as in the method of Eratosthenes. Now make a kind of roulette wheel that is divided into two equal parts, black and white. Go down the list of integers

PRIME SERIES

1	2	3	4	5	6	7	8	9
33	34	35	36	37	38	39	40	41
65	66	67	68	69	70	71	72	73
97	98	99	100	101	102	103	104	105
129	130	131	132	133	134	135	136	137
161	162	163	164	165	166	167	168	169
193	194	195	196	197	198	199	200	201
225	226	227	228	229	230	231	232	233
257	258	259	260	261	262	263	264	265
289	290	291	292	293	294	295	296	297
321	322	323	324	325	326	327	328	329
353	354	355	356	357	358	359	360	361
385	386	387	388	389	390	391	392	393
417	418	419	420	421	422	423	424	425
449	450	451	452	453	454	455	456	457
481	482	483	484	485	486	487	488	489
513	514	515	516	517	518	519	520	521
545	546	547	548	549	550	551	552	553
577	578	579	580	581	582	583	584	585
609	610	611	612	613	614	615	616	617
641	642	643	644	645	646	647	648	649
673	674	675	676	677	678	679	680	681
705	706	707	708	709	710	711	712	713
737	738	739	740	741	742	743	744	745
769	770	771	772	773	774	775	776	777
801	802	803	804	805	806	807	808	809
833	834	835	836	837	838	839	840	841
865	866	867	868	869	870	871	872	873
897	898	899	900	901	902	903	904	905
929	930	931	932	933	934	935	936	937
961	962	963	964	965	966	967	968	969
993	994	995	996	997	998	999	1,000	1,001

RANDOM SERIES

1	2	3	4	5	6	7	8	9
33	34	35	36	37	38	39	40	41
65	66	67	68	69	70	71	72	73
97	98	99	100	101	102	103	104	105
129	130	131	132	133	134	135	136	137
161	162	163	164	165	166	167	168	169
193	194	195	196	197	198	199	200	201
225	226	227	228	229	230	231	232	233
257	258	259	260	261	262	263	264	265
289	290	291	292	293	294	295	296	297
321	322	323	324	325	326	327	328	329
353	354	355	356	357	358	359	360	361
385	386	387	388	389	390	391	392	393
417	418	419	420	421	422	423	424	425
449	450	451	452	453	454	455	456	457
481	482	483	484	485	486	487	488	489
513	514	515	516	517	518	519	520	521
545	546	547	548	549	550	551	552	553
577	578	579	580	581	582	583	584	585
609	610	611	612	613	614	615	616	617
641	642	643	644	645	646	647	648	649
673	674	675	676	677	678	679	680	681
705	706	707	708	709	710	711	712	713
737	738	739	740	741	742	743	744	745
769	770	771	772	773	774	775	776	777
801	802	803	804	805	806	807	808	809
833	834	835	836	837	838	839	840	841
865	866	867	868	869	870	871	872	873
897	898	899	900	901	902	903	904	905
929	930	931	932	933	934	935	936	937
961	962	963	964	965	966	967	968	969
993	994	995	996	997	998	999	1,000	1,001

DISTRIBUTION of random "primes" between 1 and 1,024 (*lower table*) resembles that of true primes in the same number sequence (*upper table*). Both sets of numbers (*in color*) thin out irregularly as the sequence progresses (*see totals at right*). Another "run" of the random sieve might yield an even more similar distribution. The resemblance of the two series tends to intensify as they are increased in length.

																								ROW TOTAL	CUMULATIVE TOTAL
10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32		11	11
42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64		7	18
74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96		6	24
106	107	108	109	110	111	112	113	114	115	116	117	118	119	120	121	122	123	124	125	126	127	128		7	31
138	139	140	141	142	143	144	145	146	147	148	149	150	151	152	153	154	155	156	157	158	159	160		6	37
170	171	172	173	174	175	176	177	178	179	180	181	182	183	184	185	186	187	188	189	190	191	192		6	43
202	203	204	205	206	207	208	209	210	211	212	213	214	215	216	217	218	219	220	221	222	223	224		5	48
234	235	236	237	238	239	240	241	242	243	244	245	246	247	248	249	250	251	252	253	254	255	256		6	54
266	267	268	269	270	271	272	273	274	275	276	277	278	279	280	281	282	283	284	285	286	287	288		7	61
298	299	300	301	302	303	304	305	306	307	308	309	310	311	312	313	314	315	316	317	318	319	320		5	66
330	331	332	333	334	335	336	337	338	339	340	341	342	343	344	345	346	347	348	349	350	351	352		4	70
362	363	364	365	366	367	368	369	370	371	372	373	374	375	376	377	378	379	380	381	382	383	384		6	76
394	395	396	397	398	399	400	401	402	403	404	405	406	407	408	409	410	411	412	413	414	415	416		4	80
426	427	428	429	430	431	432	433	434	435	436	437	438	439	440	441	442	443	444	445	446	447	448		6	86
458	459	460	461	462	463	464	465	466	467	468	469	470	471	472	473	474	475	476	477	478	479	480		6	92
490	491	492	493	494	495	496	497	498	499	500	501	502	503	504	505	506	507	508	509	510	511	512		5	97
522	523	524	525	526	527	528	529	530	531	532	533	534	535	536	537	538	539	540	541	542	543	544		3	100
554	555	556	557	558	559	560	561	562	563	564	565	566	567	568	569	570	571	572	573	574	575	576		5	105
586	587	588	589	590	591	592	593	594	595	596	597	598	599	600	601	602	603	604	605	606	607	608		6	111
618	619	620	621	622	623	624	625	626	627	628	629	630	631	632	633	634	635	636	637	638	639	640		4	115
650	651	652	653	654	655	656	657	658	659	660	661	662	663	664	665	666	667	668	669	670	671	672		6	121
682	683	684	685	686	687	688	689	690	691	692	693	694	695	696	697	698	699	700	701	702	703	704		5	126
714	715	716	717	718	719	720	721	722	723	724	725	726	727	728	729	730	731	732	733	734	735	736		4	130
746	747	748	749	750	751	752	753	754	755	756	757	758	759	760	761	762	763	764	765	766	767	768		5	135
778	779	780	781	782	783	784	785	786	787	788	789	790	791	792	793	794	795	796	797	798	799	800		4	139
810	811	812	813	814	815	816	817	818	819	820	821	822	823	824	825	826	827	828	829	830	831	832		6	145
842	843	844	845	846	847	848	849	850	851	852	853	854	855	856	857	858	859	860	861	862	863	864		5	150
874	875	876	877	878	879	880	881	882	883	884	885	886	887	888	889	890	891	892	893	894	895	896		4	154
906	907	908	909	910	911	912	913	914	915	916	917	918	919	920	921	922	923	924	925	926	927	928		3	157
938	939	940	941	942	943	944	945	946	947	948	949	950	951	952	953	954	955	956	957	958	959	960		5	162
970	971	972	973	974	975	976	977	978	979	980	981	982	983	984	985	986	987	988	989	990	991	992		5	167
1,002	1,003	1,004	1,005	1,006	1,007	1,008	1,009	1,010	1,011	1,012	1,013	1,014	1,015	1,016	1,017	1,018	1,019	1,020	1,021	1,022	1,023	1,024		5	172

																							ROW TOTAL	CUMULATIVE TOTAL
10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32		8	8
42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64		6	14
74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96		7	21
106	107	108	109	110	111	112	113	114	115	116	117	118	119	120	121	122	123	124	125	126	127	128		8	29
138	139	140	141	142	143	144	145	146	147	148	149	150	151	152	153	154	155	156	157	158	159	160		7	36
170	171	172	173	174	175	176	177	178	179	180	181	182	183	184	185	186	187	188	189	190	191	192		6	42
202	203	204	205	206	207	208	209	210	211	212	213	214	215	216	217	218	219	220	221	222	223	224		4	46
234	235	236	237	238	239	240	241	242	243	244	245	246	247	248	249	250	251	252	253	254	255	256		4	50
266	267	268	269	270	271	272	273	274	275	276	277	278	279	280	281	282	283	284	285	286	287	288		7	57
298	299	300	301	302	303	304	305	306	307	308	309	310	311	312	313	314	315	316	317	318	319	320		6	63
330	331	332	333	334	335	336	337	338	339	340	341	342	343	344	345	346	347	348	349	350	351	352		3	66
362	363	364	365	366	367	368	369	370	371	372	373	374	375	376	377	378	379	380	381	382	383	384		4	70
394	395	396	397	398	399	400	401	402	403	404	405	406	407	408	409	410	411	412	413	414	415	416		3	73
426	427	428	429	430	431	432	433	434	435	436	437	438	439	440	441	442	443	444	445	446	447	448		5	78
458	459	460	461	462	463	464	465	466	467	468	469	470	471	472	473	474	475	476	477	478	479	480		4	82
490	491	492	493	494	495	496	497	498	499	500	501	502	503	504	505	506	507	508	509	510	511	512		3	85
522	523	524	525	526	527	528	529	530	531	532	533	534	535	536	537	538	539	540	541	542	543	544		3	88
554	555	556	557	558	559	560	561	562	563	564	565	566	567	568	569	570	571	572	573	574	575	576		4	92
586	587	588	589	590	591	592	593	594	595	596	597	598	599	600	601	602	603	604	605	606	607	608		3	95
618	619	620	621	622	623	624	625	626	627	628	629	630	631	632	633	634	635	636	637	638	639	640		8	103
650	651	652	653	654	655	656	657	658	659	660	661	662	663	664	665	666	667	668	669	670	671	672		3	106
682	683	684	685	686	687	688	689	690	691	692	693	694	695	696	697	698	699	700	701	702	703	704		4	110
714	715	716	717	718	719	720	721	722	723	724	725	726	727	728	729	730	731	732	733	734	735	736		5	115
746	747	748	749	750	751	752	753	754	755	756	757	758	759	760	761	762	763	764	765	766	767	768		5	120
778	779	780	781	782	783	784	785	786	787	788	789	790	791	792	793	794	795	796	797	798	799	800		4	124
810	811	812	813	814	815	816	817	818	819	820	821	822	823	824	825	826	827	828	829	830	831	832		3	127
842	843	844	845	846	847	848	849	850	851	852	853	854	855	856	857	858	859	860	861	862	863	864		5	132
874	875	876	877	878	879	880	881	882	883	884	885	886	887	888	889	890	891	892	893	894	895	896		3	135
906	907	908	909	910	911	912	913	914	915	916	917	918	919	920	921	922	923	924	925	926	927	928		0	135
938	939	940	941	942	943	944	945	946	947	948	949	950	951	952	953	954	955	956	957	958	959	960		1	136
970	971	972	973	974	975	976	977	978	979	980	981	982	983	984	985	986	987	988	989	990	991	992		5	141
1,002	1,003	1,004	1,005	1,006	1,007	1,008	1,009	1,010	1,011	1,012	1,013	1,014	1,015	1,016	1,017	1,018	1,019	1,020	1,021	1,022	1,023	1,024		4	145

DERIVATION OF THE PRIME NUMBER THEOREM FOR THE RANDOM SIEVE

Let us consider the fate of any two consecutive numbers, say 127 and 128, on a run through the random-sieving operation. We shall compare their probabilities of getting through the sieve; *i.e.*, of becoming sieving numbers or "random primes" themselves.

Call these probabilities P_{127} and P_{128}. Now it is obvious that 128 runs the same risk of being eliminated by previous sieving numbers as does 127, except for one possibility. If 127 becomes a sieving number, it can eliminate 128, but not *vice versa*. The probability that 127 is a sieving number is P_{127}. If it is a sieving number, the probability that it will eliminate 128 (or any other following number) is 1/127. The chance that the two events will occur and that 127 will eliminate 128 is the product of their probabilities: $P_{127} \times 1/127$. The probability that this will not happen is $1 - P_{127}/127$. Except for this factor the chance of survival for 128 is the same as that for 127. Its net probability is therefore the product of the two: $P_{128} = P_{127}(1 - P_{127}/127)$.

At this point it will be more convenient to shift from the probabilities to their reciprocals. The reciprocal of a probability has itself a clear statistical meaning: it gives the average interval, or range, between two events. (Instead of saying that the probability of double six in dice is 1/36, we can as well say that the average interval between throws of double six is 36.) Denote the reciprocal of P_{127} by X_{127}, and of P_{128} by X_{128}. X_{127} measures the average interval between sieving numbers in the neighborhood of 127 and X_{128} measures the same interval in the slightly shifted neighborhood of 128.

By a little algebra we can show that if $P_{128} = P_{127}(1 - P_{127}/127)$, then $X_{128} = X_{127} + 1/127 + r$, where r is a negligibly small remainder. For practical purposes we can say that $X_{128} = X_{127} + 1/127$. Now a similar argument would show that $X_{127} = X_{126} + 1/126$, and so on. Eventually we arrive at the result that $X_{128} = 1 + 1/2 + 1/3 + 1/4 \ldots + 1/127$, or, in general, $X_n = 1 + 1/2 + 1/3 + 1/4 \ldots + 1/n$, with a remainder that is still negligibly small. In calculus books we discover that the series $1 + 1/2 + 1/3 + 1/4 \ldots + 1/n$ is nearly equal to $\log n$ for fairly long series. The difference can be made as small as we like by making n large enough. Therefore we can say that, in the long run, $X_n = \log n$, or $P_n = 1/\log n$.

The graph on the opposite page shows the values of $1/\log n$ (and, for comparison, the reciprocal of the actual values of the series $1 + 1/2 + 1/3 + 1/4 \ldots + 1/n$). Thus the curve is also a graph of P_n. Suppose we now want to know how many random primes, on the average, there should be before any number n. We simply add the probabilities that each smaller number becomes a sieving number. Graphically this is the same as taking the area under the curve. But if n is very large, then the difference between the area under the curve and the area of the shaded rectangle, which is $n \times P_n$, is negligible. Hence we can say that the average number of random primes out to n is $n \times P_n$. But $P_n = 1/\log n$, so the number becomes $n/\log n$. And this is the Prime Number Theorem!

Having completed the proof, we may reexamine our reasoning to see why the result is plausible. The essential step was to find that $X_n + 1 = X_n + 1/n$. This equation says that on the average, over many repetitions of the sieve, any number n removes enough of the numbers following to lengthen the interval between them by $1/n$. Take a specific example. Suppose that P_{127} is 1/5 and X_{127} is 5. Then 127 will be a sieving number 1/5 of the time. When it is, it will eliminate about 1/127 of the remaining numbers, lengthening the average interval between them from 5 to $5 + 5/127$. Since it only does this about one time out of every five trials of the sieve, its average effect will be to lengthen the interval from 5 to $5 + 1/127$.

The same chain of reasoning is plausible for the prime-number sieve. following 2, and for each one spin the wheel. If the black part of the wheel stops at the pointer, strike the integer out; if white stops at the pointer, leave the integer in. Note what you have accomplished. In the long run you will have sieved out half of the integers, just as the first step in the prime-number sieve does. But just which ones go out is a matter of chance, and the list will be different each time you try it.

Next take the first number that was not removed. Suppose it was 4. Make a new wheel of which a fourth is black and three fourths is white. Spin the wheel for each succeeding number left after the first sieving. When black comes up, strike the number out; when white comes up, leave the number in. This time you have removed a fourth of the remaining numbers. Proceed again to the first number not removed—say 5. Repeat the procedure using a sieving probability of 1/5, and so on. After any number of steps you will be left with a series of integers which might be called "random primes."

If you want to try the sieve yourself, you need not actually make roulette wheels. A table of random numbers or, failing that, a telephone book will do. Express each sieving probability as a four-digit decimal (*e.g.*, 1/4 = .2500). For each "spin of the wheel" read successive telephone numbers. If your probability is 1/4, then any number whose last four digits are 2499 or less tells you to eliminate the integer in question; 2500 or more means to leave it in.

One run of the random sieve for the first 1,024 integers is summarized in the table on the preceding two pages. Comparing the distribution of these random primes with the actual ones, we can see that our sieve acts something like the sieve of Eratosthenes. This is partly in spite of the random element, but partly because of it. For a much longer series the general statistical similarity would be even closer.

It may seem paradoxical that we can take a statistical model, involving an infinity of random choices, as *ersatz* for the straightforward and perfectly defined sieve of Eratosthenes. The paradox is the same as the one which underlies statistical mechanics: the average behavior of an assembly of molecules is easier to describe than the actual behavior of any one of them. Of course the random sieve preserves only the general features of the prime-number sieve. The eccentricities of the latter are averaged out by randomizing them. In either case

any number not sieved out becomes in turn a sieving number. It starts a process by which a proportion of later numbers is removed, equal to the reciprocal of that sieving number. Every wave of sieving in the prime-number sieve, except the first, is determined strictly by the result of previous waves. At every corresponding point the random sieve makes probability choices, partly determined by its own earlier statistical behavior.

How closely the random sieve actually approximates the sieve of Eratosthenes is demonstrated by the fact that the Prime Number Theorem holds for random primes. This can be proved by some elementary mathematics, which in this case is also fairly easy [*see box on opposite page*].

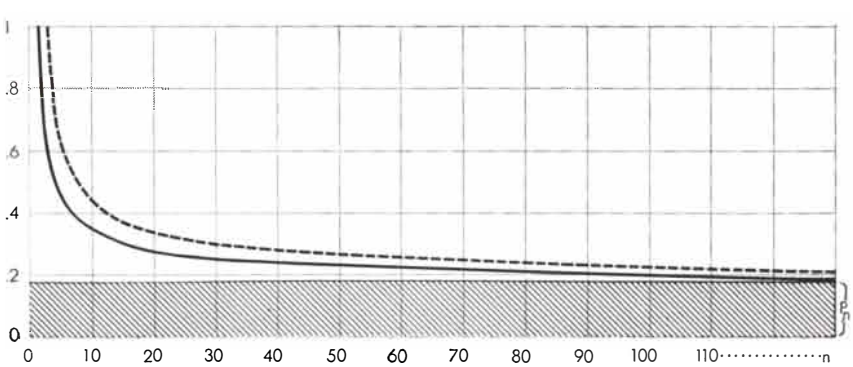
Perhaps the parallel between the two sieves is not so surprising. We might say, indeed, that the prime-number sieve would have to be remarkably abnormal in its detailed behavior not to lead to the same general result as the random sieve. This statement implies that the random sieve can be taken as a criterion of normality.

If so, there must be other sieves—in fact, an infinite number of other sieves—that have the same general characteristics as those of the sieve of Eratosthenes, but which differ somewhat in the details of their definition. They will not yield the prime numbers in general, but numbers having some other special property. In 1956, as it happens, Stanislas M. Ulam and his associates at the Los Alamos Scientific Laboratory published some results of a new type of sieve which yields what they called "lucky" numbers. Their sieve begins by removing the multiples of 2, leaving 3 as the first number not sieved out. Instead of removing next the multiples of 3, the Ulam sieve removes every third remaining number. Since 5 is the third number in the list of remaining numbers, it drops out, but 7 remains. Hence in the next wave every seventh number of those still remaining is eliminated, and so on [*see illustration at top of next page*]. The numbers that escape are "lucky." It has been proved that the analogue of the Prime Number Theorem holds for lucky numbers. Thus the random sieve is a model for the lucky numbers as well as for the primes.

So far the random sieve has only duplicated results that can be obtained independently and rigorously for the sieves of Eratosthenes and of Ulam. The mathematics of it, however, is mostly easier. Therefore many additional theorems can be obtained from the random sieve and conjectured to be true of the other two. Such conjectures are not proofs, but we can say that unless the prime number and lucky sieves are vastly abnormal, the results must hold for them.

Let us look at a couple of examples. As we go to larger and larger numbers in the table of integers, the spacing between successive primes (or luckies or random primes) grows greater in an irregular way. In the neighborhood of any number, n, the average interval is about the logarithm of n. What is the greatest interval? We do not know the answer for primes or luckies. But for the random sieve we can prove that, with only a finite number of exceptions, the interval is never greater than the square of the logarithm of n, that is, $(\log n)^2$. The chance that there will be any further exceptions can be made as small as we please by taking a sufficiently large n. No upper boundary to the interval between successive primes or successive luckies has been found which is anywhere nearly as small, although from the existing tables it looks as though the formula should hold for them too.

Another example is the twin-prime problem mentioned earlier. In the ran-



AVERAGE NUMBER OF RANDOM "PRIMES" in the first n integers is shown by the area under the solid curve, roughly approximated by the hatched rectangle (drawn here for $n = 130$). The area under the broken curve gives the approximate number of true primes. Since the two curves approach each other as n increases, the two sets of primes are very like.

"LUCKY" NUMBER SIEVE resembles the prime and random sieves already described. Here, also, numbers which are not eliminated become sieving numbers and remove a proportion of the remaining numbers equal to their reciprocals. Elimination is by counting: thus 3 removes every third remaining number, 7 every seventh. Like primes, the "lucky" numbers form an invariant series.

2	3	7	9	13	15	21	25	31	★	33	37	43	49	51	63	★	67	69	73	75	79	87	93	★	99
105	111	115	127	★	129	133	135	141	151	159	★	163	169	171	189	★	193	195	201	205	211	219	223	★	231	235
237	241	★	259	261	267	273	283	285	★	289	297	303	307	319	★	321	327	331	339	349	★	357	361	367	★	385	391
393	399	409	415	★	421	427	429	433	★	451	463	475	477	★	483	487	489	495	511	★	517	519	529	535	537	541	★
553	559	★	577	579	583	591	601	★	613	615	619	621	631	639	★	643	645	651	655	★	673	679	685	693	699	★	717
723	727	729	735	★	739	741	745	★	769	777	781	787	★	801	805	819	823	831	★	841	855	★	867	873	883	885	895	★
897	903	925	927	★	931	933	937	957	★	961	975	979	981	991	★	993	997	1009	1011	1021	1023	★						

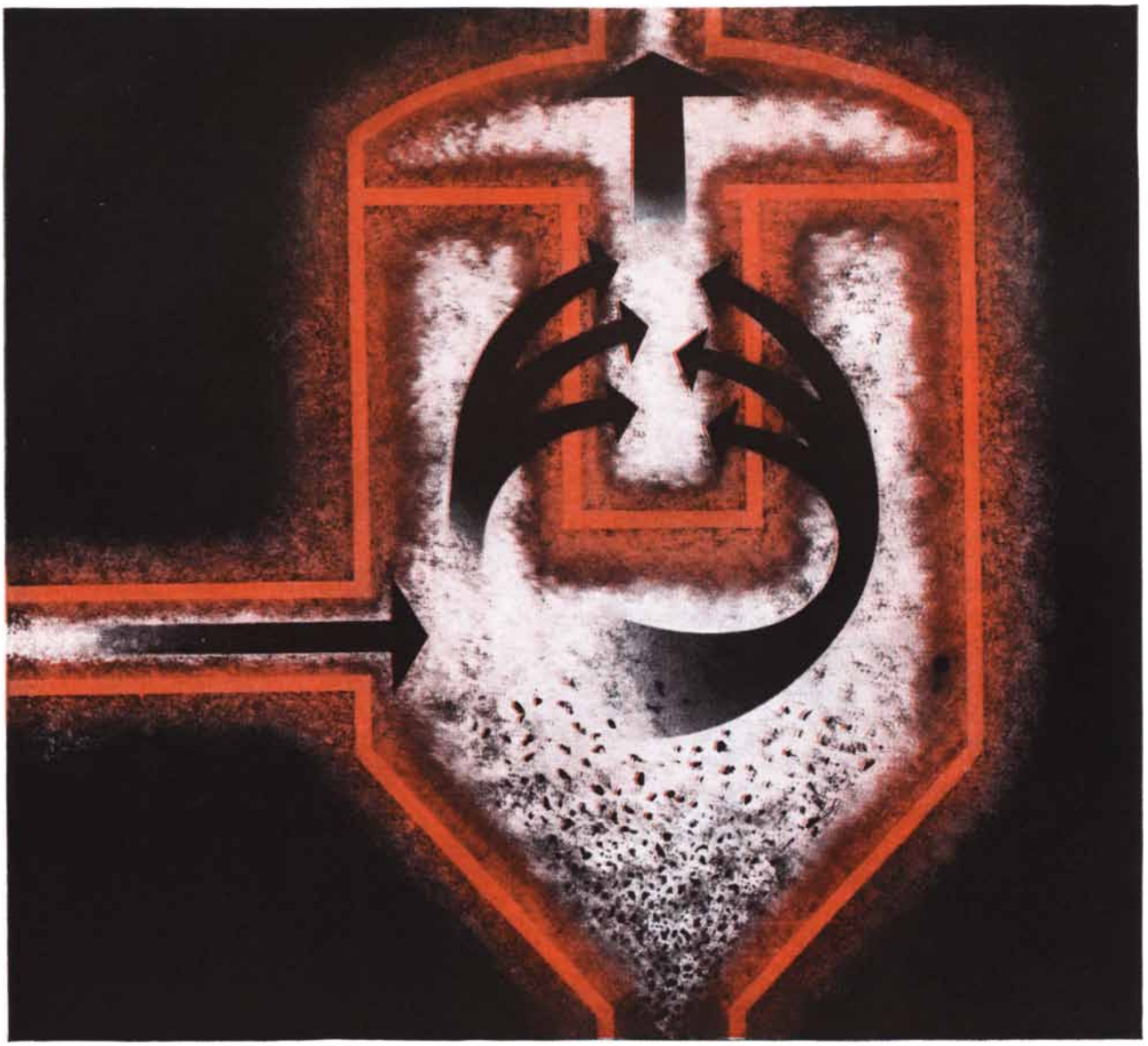
DISTRIBUTION OF "LUCKY" numbers between 1 and 1,024 resembles that of primes and random primes, thinning out gradually but irregularly as the list increases. This table shows only the "luckies"; the intervening numbers are omitted. Stars set off luckies within successive series of 32 integers; each of these groups corresponds to a single line of the tables on pages 108 and 109.

dom sieve there is almost certainly an infinite number of twins. Indeed the average interval between twins ought to be about $(\log n)^2$, and the maximum interval between them, with only a finite number of exceptions, ought to be $(\log n)^3$. Again the tables suggest that these results are also true for primes and luckies, but no one has any idea how to prove such results.

Although the random sieve does not solve any classical problems concerning primes, it does enable us to reformulate such problems. We may ask: "Are the prime numbers normal in such and such a respect?" The random sieve, or certain modifications of it, defines what we mean by normality. If the properties we are talking about depend on the exact fine structure of the sequence of primes, the answer will obviously be no. Thus all primes except the number 2 are odd, while this is infinitely improbable in the sequences of random primes. But average properties such as those we have discussed do not seem to depend on the fine structure, and those may be presumed to be normal for primes or luckies. Can anyone find a major abnormal property, in this sense, of the sequence of primes? Or the sequence of luckies?

In the opinion of the author the concept of normality raises some very deep questions about numbers and the theory of numbers. Sieves as a class are a type of feedback mechanism: the output of one stage of the process determines the input of the next stage. Now in any such mechanism the nature of the coupling between output and input is crucial; the result may be stable and predictable for one type of coupling and unstable for another. So far as the outcome of the random sieve is concerned, it is in one respect extremely stable. If by chance there are relatively few sieving numbers in the early stages, they will remove relatively few later on, and so there will be an increase in the later stages to compensate for the initial deficit. The sieves of primes and luckies share this characteristic. But this is a statistical stability.

When we look at other aspects of the prime or the lucky sieve, however, we find elements of instability. The detailed ordering of primes or luckies depends upon the individual sieving numbers that precede them, and this involves a growth of complexity without apparent limit. Some easily defined properties of normal sequences, for example the two described, may depend strongly enough on this complexity to make it impossible, in a finite number of steps, to prove that they hold. Here is the analogy, if it be one, with the uncertainty principle of physics: An infinite complexity requires infinite time to resolve it. If our suggestions have substance, we will have examples of mathematical statements which are almost certain, but which cannot, in principle, be proved. Examples of undecidable propositions are known in modern arithmetic [see "Gödel's Proof," by Ernest Nagel and James R. Newman; SCIENTIFIC AMERICAN, June, 1956], but so far none of the unproved conjectures about prime numbers has been shown to be undecidable. Perhaps none of them is. If any are, however, the random sieve will be a model for the primes in a deeper sense than any we have exploited in this article. We cannot distinguish an infinitely complex order from a random one, and so we might be forced to admit that there is a certain background of noise even among the eternal verities.



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Operating at a temperature so high (over 1200°F) that the filter and its housing are red hot, this specially designed and constructed Purolator frameless metal edge filter reclaims fines from the highly corrosive gas.

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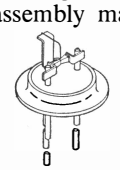
AUTOMATIC ASSEMBLY OF TRANSISTOR ACHIEVED AT WESTERN ELECTRIC

Some impressive obstacles have long blocked efforts to mechanize assembly of transistors. Among them: the tiny, closely spaced parts involved, the extreme material purity required and, especially, the constant changes in transistor design.

Yet the advantages of mechanized assembly are enticing – large volume production of a quality product at lower cost.

Recently an automatic assembly machine, at Western Electric's Allentown (Pa.) Works, began producing high quality grown junction type transistors. The only machine of its kind, it is doing what was considered – not so very long ago – practically impossible.

The grown junction transistor was chosen for automatic assembly because it promised to be fairly stable in design, making development of an assembly machine worthwhile.



Grown junction type transistor

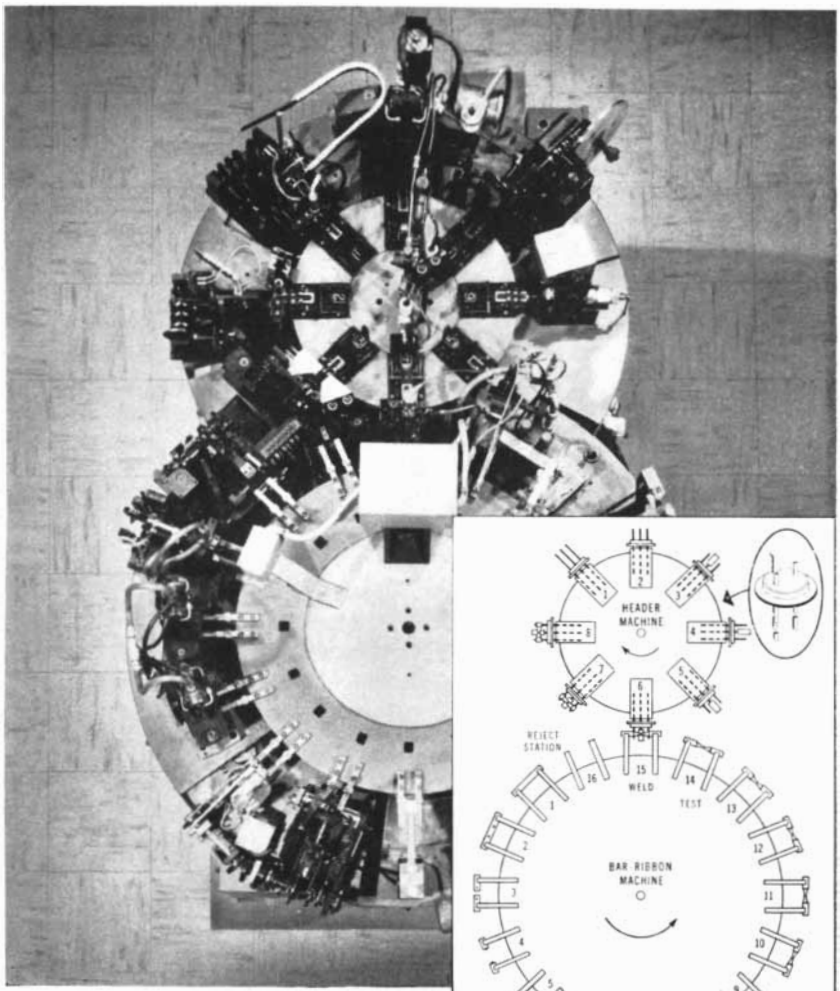
Our engineers began by collaborating with the Bell Telephone Laboratories (our Bell System teammate and inventor of the transistor) in modifying the design of this transistor, to make it more suitable for automatic assembly.

The many assembly operations could be naturally divided into two phases: processing of headers; fabrication of the bar-ribbon assembly composed of an NPN germanium bar, supported between two .005-inch thick Kovar ribbons. So a two-part machine was devised by a team of Western Electric engineers. (See schematic.)

Problems of Mechanization

Each of the individual mechanized operations making up the overall unit had to be separately designed and synchronized with the rest. Many problems came up in designing these stations.

For example, how to save expensive headers from being welded to bar-ribbon assemblies which may not meet strict Western Electric quality standards. To solve this, our engineers added a station to test each bar-ribbon assembly prior to welding it to a header. The test compares the photoelectric properties of the subassembly to those of a standard quality transistor.



Automatic transistor assembly machine

Schematic of unit shown above

When the bar-ribbon assembly passes this test, an electrical signal actuates a relay on the header machine, allowing a header to be moved to the welding position common to the two tables (station 15). If a substandard bar-ribbon is detected at the test station, the welding operation does not occur and the assembly, without header, is moved to a subsequent station (number 16) where it is ejected.

Though it is entirely possible that the grown junction type transistor – and, in part, this machine–will soon be obsolete, much has been gained. The feasibility of automatic transistor assembly has been proved, representing a long step forward in transistor manufacture and a substantial contribution to the field of automation. This is one more example of the inventive engineering that is constantly brought to bear on Western Electric's job as manufacturing and supply unit of the Bell System.

If you desire additional information on the automatic transistor assembly machine, a reprint of a semi-technical article may be obtained by writing to Western Electric Co., Room 1630, 195 Broadway, New York 7, N. Y.

Western Electric

MANUFACTURING AND SUPPLY UNIT OF THE BELL SYSTEM

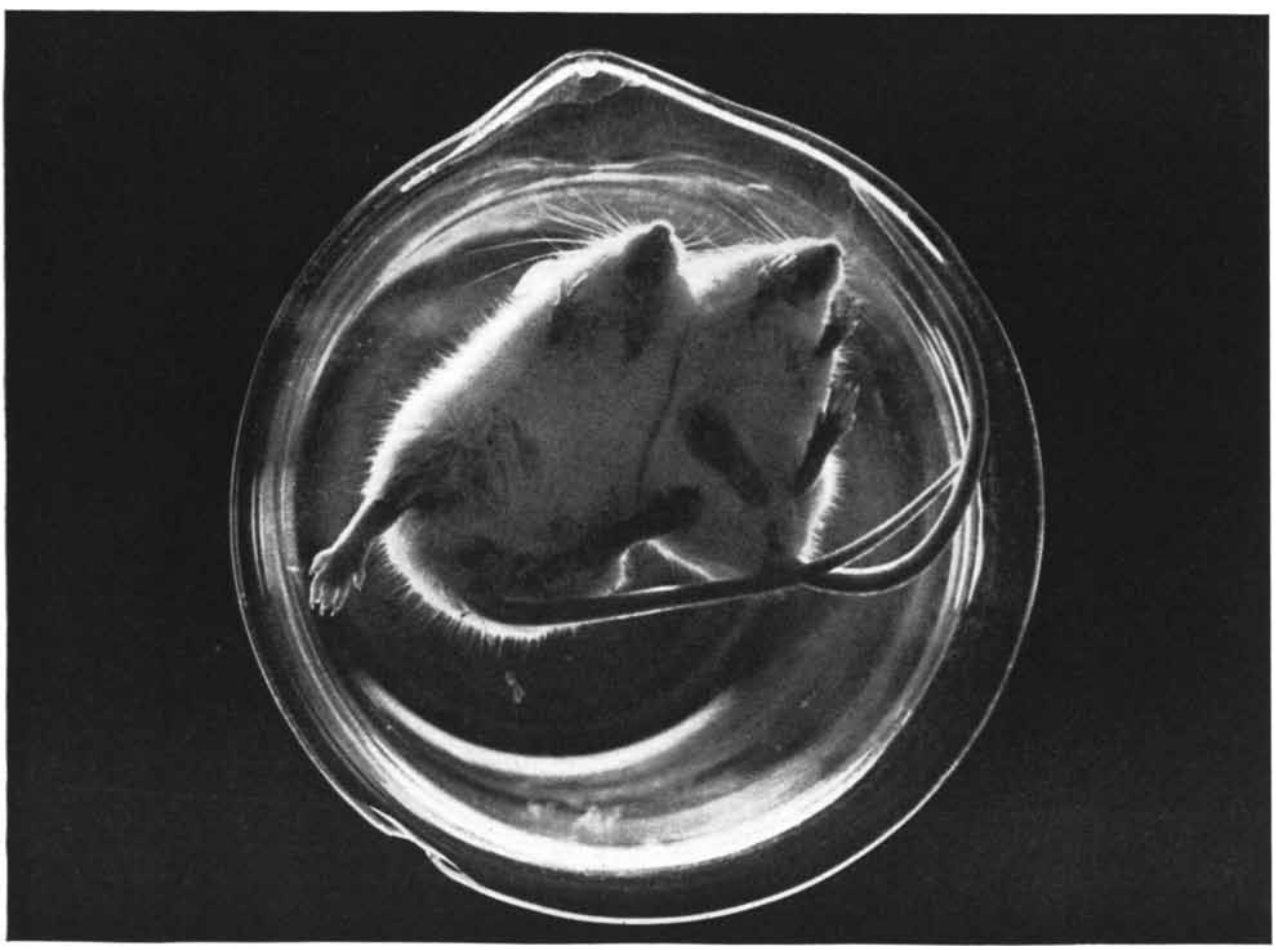
WOUND SHOCK

This state of collapse brought on by severe injuries can cause death in a few hours. Extensive research has begun to clarify its physiology and has developed a simple emergency treatment

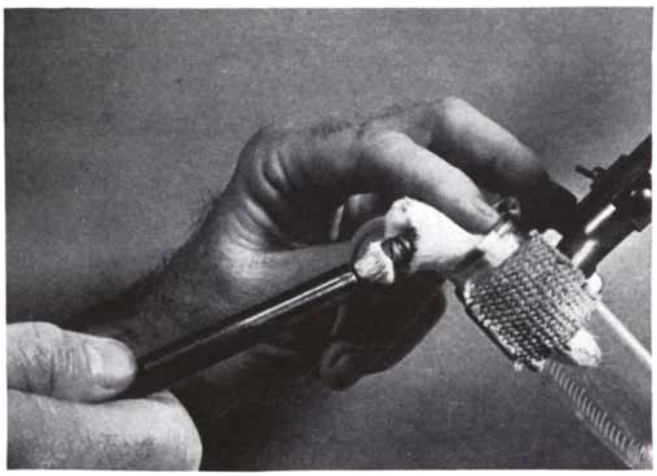
by Sanford Rosenthal

Every first-aid manual teaches us to beware the ashen pallor, the clammy skin and the enfeebled pulse that are the signs of shock in the severely injured. If shock is not promptly treated the victim may die in a few hours, even though the injury that brought on the condition might not involve a vital organ. As the symptoms dramatically proclaim, shock is attended by a lowering of the volume of blood in circulation in the body. The treatment, once a physician arrives, is the restoration of the blood volume by the infusion of whole blood, blood plasma, a synthetic plasma substitute, or just plain saline solution. But no therapy for shock is certain. Efforts to develop surer measures of control have been hampered by our even less certain understanding of the physiological mechanism that induces it.

Our group at the National Institutes of Health has been engaged in an extensive laboratory and clinical investigation of this difficult problem since 1942. At that time the project was motivated by the emergency need to do something



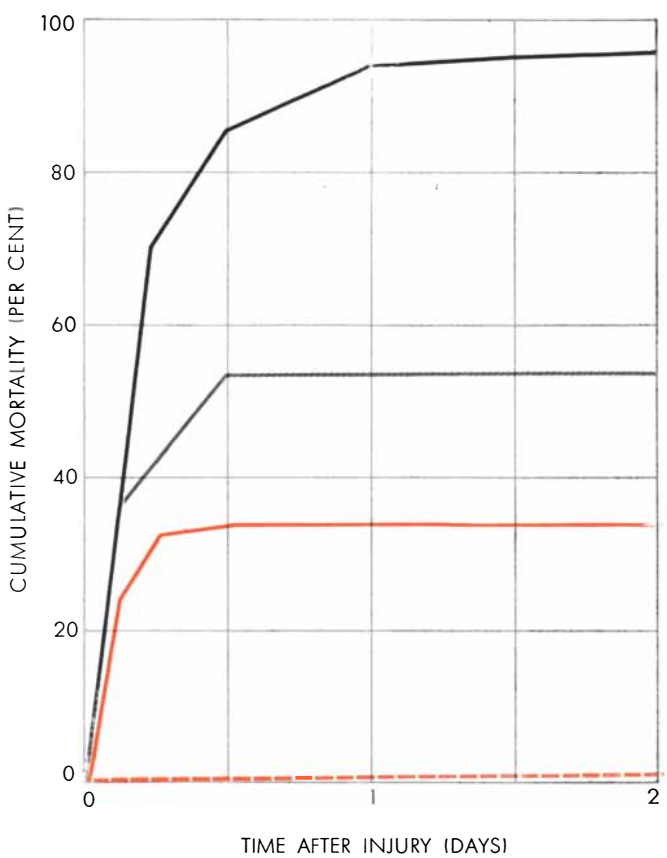
SHOCKED MOUSE at left is larger than an unshocked animal because of the swelling around its legs due to injury and to the large volume of saline solution with which it has been treated. Salt water in quantity seems as effective as any other known therapy.

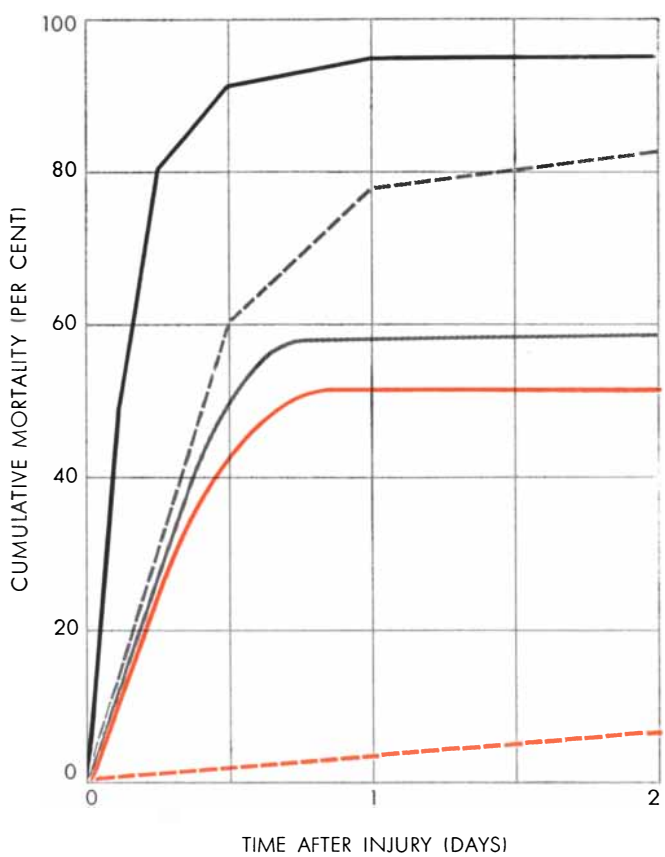


SHOCK EXPERIMENT involved cutting off circulation in the legs of mice with rubber bands, as at left. Two hours after the bands were removed, the legs showed the large swellings which are characteristic of shock-producing injuries (*center*). Saline solution

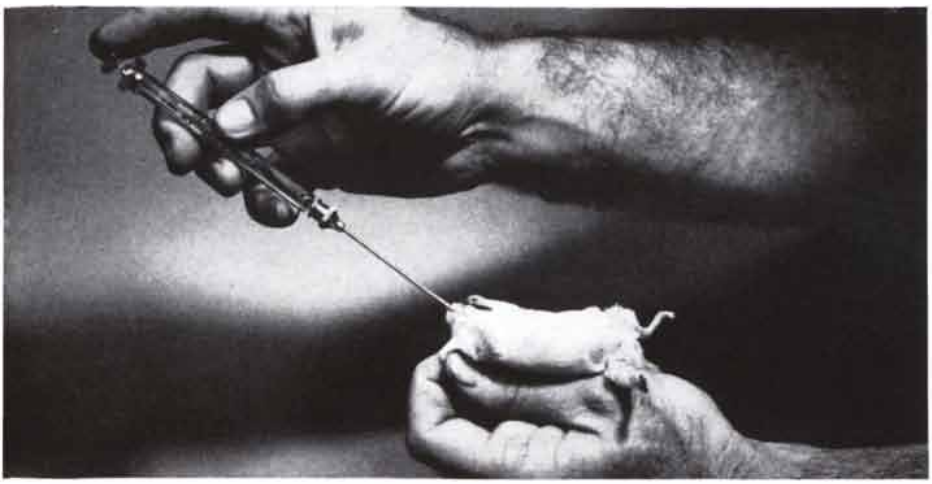
about the high incidence of shock among battlefield casualties. Our work continues, with most of the troublesome questions still unanswered. But our investigation has succeeded at least to the extent of gaining a better understanding of some of the underlying mechanisms of shock. And we have developed an emergency treatment which can be administered by laymen, and which may greatly improve on the effectiveness of the first-aid measures it has been possible to recommend hitherto.

There is no doubt that the loss of fluid from the circulatory system plays a central role in wound shock. (The shock produced by electricity, brain injury or bacterial toxins is another story; it does not involve this large loss of fluid.) In cases of severe hemorrhage the loss is plainly accounted for. Animal experiments indicate that a loss of half of the blood—5 per cent of the body weight—will result in fatal shock. For a long time, however, it was difficult to explain the fall of blood volume in severe burns and in other injuries not attended by hem-





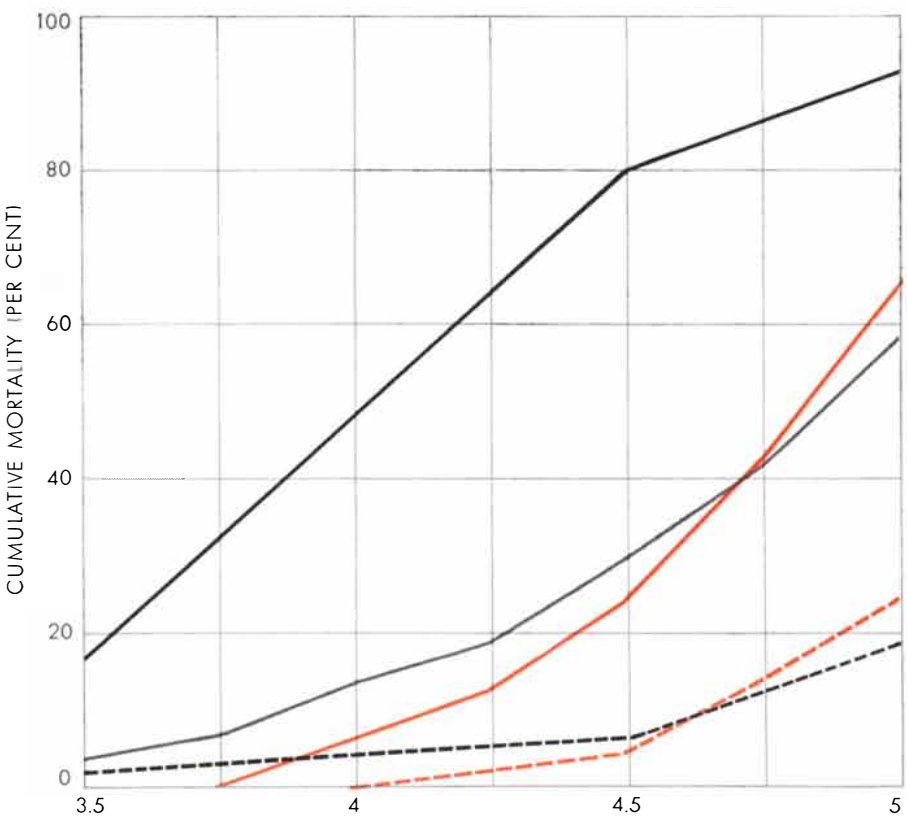
DIFFERENT TREATMENTS for shock are compared in these graphs; solid black lines represent untreated animals. In tourniquet shock (*left*) saline solution equal to 10 per cent of the animal's weight (*solid color*) reduced mortality more than an equal amount of plasma (*gray*) did; 15 per cent body weight of saline solution (*broken color*) prevented almost all deaths. In burn shock (*center*) 15 per cent of saline was again the most effective therapy; 5 per cent of saline (*solid color*) or plasma (*gray*) was less effective.



proved an effective treatment, even when given by mouth, as at right. Similar experiments were carried out on mice shocked by burns and suffering from extensive hemorrhage.

orrhage. Then, in 1931, animal experiments showed that the fluid which accumulated in the swelling (edema) at the site of a fatal injury amounted in volume to the same 5 per cent of body weight lost in fatal hemorrhage.

Since the composition of the edema fluids closely resembles that of blood plasma, investigators and physicians began to attribute the profound systemic disturbance of shock to the loss of plasma from the bloodstream. This deduction was supported by the finding that plasma could serve in the treatment of shock (where no severe hemorrhage occurred) just about as effectively as whole blood. During World War II the freeze-drying of plasma made it possi-



Salt-free plasma (*broken gray*) was of little value. In hemorrhage (*right*), where loss of red blood cells is a serious problem, 3 per cent body weight of whole blood (*broken black*) was most effective, with 10 per cent of saline (*broken color*) a close second. Three per cent of saline (*solid color*) or plasma (*gray*) were both moderately effective.

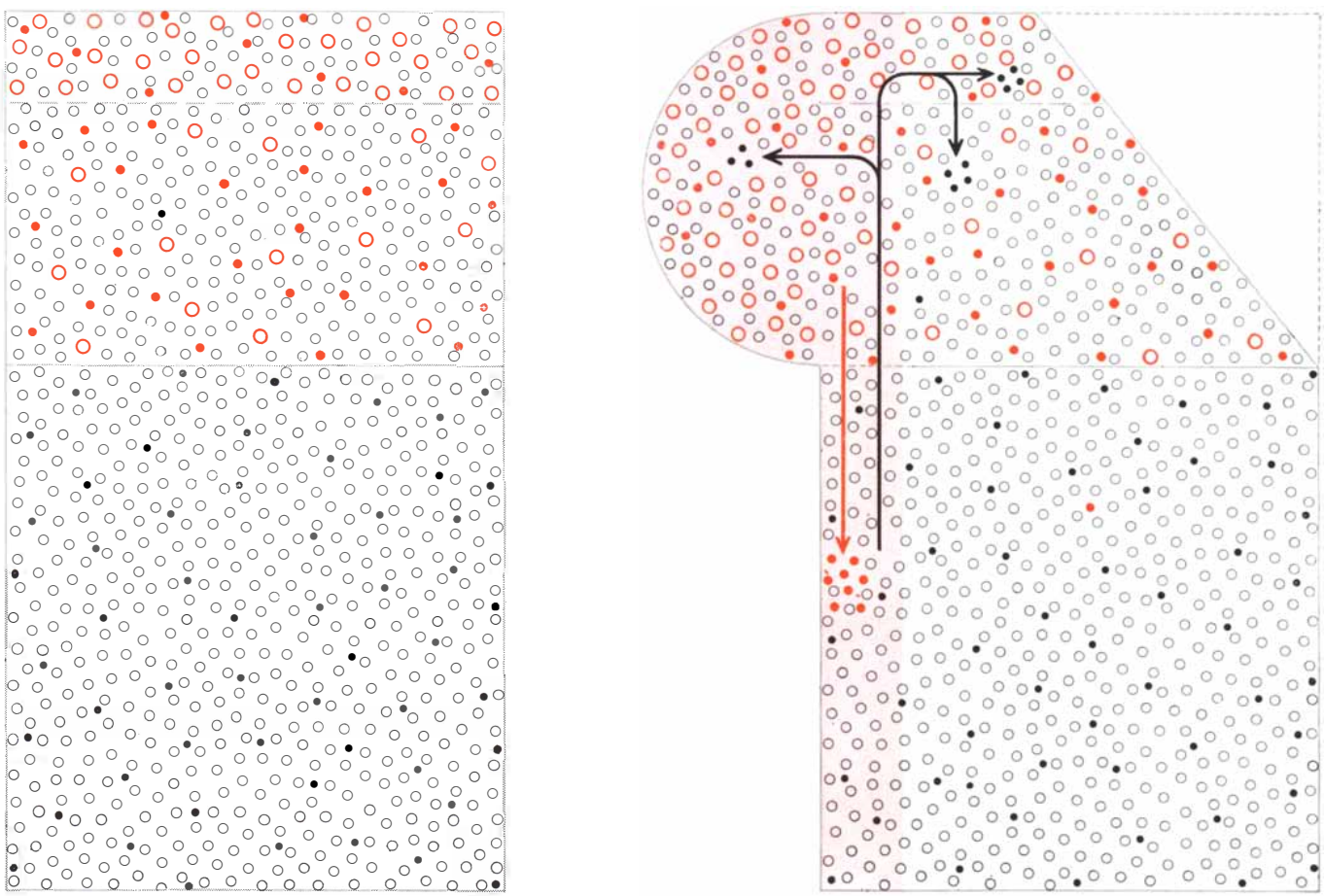
ble for medical corpsmen to administer this therapy at battalion-aid stations and on the battlefield itself in circumstances where it was impossible to deliver whole blood. Thanks to the control of shock by plasma (and the control of infection by drugs) 96.7 per cent of the U. S. casualties who reached battalion-aid stations survived their wounds.

Plasma consists chiefly of water, proteins and sodium chloride. The search for plasma substitutes led investigators to inquire what role the loss of each of these constituents might play in shock. The eminent British physiologist E. H. Starling had shown long ago that the large protein molecules in plasma play an important part in establishing the blood's osmotic pressure, and thus in balancing the distribution of fluid between the bloodstream and the tissues. Following this lead, investigators found that solutions containing other large molecules, such as gelatin and even the synthetic substance PVP (polyvinylpyrrolidone), could substitute successfully for plasma. It seemed apparent that shock must be induced principally by the loss of the plasma proteins.

Subsequent work has cast doubt on this conclusion, though the observations which led to the conclusion have been confirmed. The history of science offers many instances of honest error in interpretation; it is much harder to disprove an interpretation than to show that an observation is wrong. That is why for so many centuries the earth was thought to be flat.

When we began our work, however, we were struck by the numerous conflicts of observation in previous animal experiments on shock. Investigators had found it difficult to standardize experimental injury, and since no treatment for shock is infallible—even for injuries of the same degree—they often could not duplicate one another's results. At the outset, therefore, we sought ways to induce objectively comparable injuries in large numbers of small animals, principally mice. To produce burn shock we immersed mice (shaved and anesthetized) to a measured depth in water at 158 degrees Fahrenheit for an exact number of seconds. We simulated the muscle trauma of crushing injuries by cutting off with rubber bands the circulation in the limbs of anesthetized animals. To produce measured degrees of hemorrhage we snipped the ends of their tails and immersed them in warm anticoagulant solution, where the amount of bleeding was measured. We then established the extent of injury by each technique which would kill 90 to 100 per cent of the mice within 48 hours. To minimize random variations we experimented only on large groups of mice of the same sex and of uniform heredity and size, fed them the same diet, and held the laboratory temperature constant. As a consequence of these precautions, we began to get reproducible results in the testing of various therapies for shock.

Our attention was soon attracted by the results we obtained with saline solution, that is, .85 per cent sodium chloride in distilled water. Physicians had been

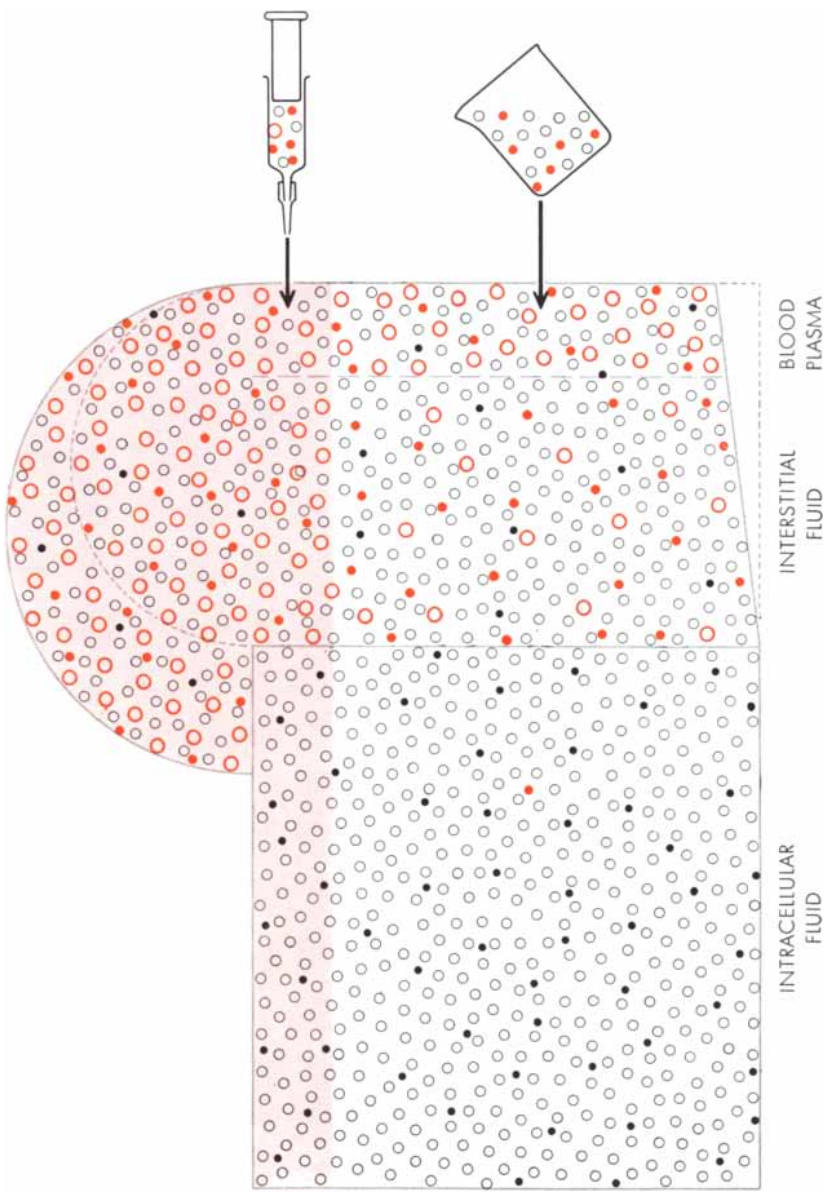


CHANGES IN BODY FLUIDS, shown in these highly schematic drawings, are important factors in shock. The fluids consist chiefly of water (*black circles*), potassium ions (*black dots*), sodium ions (*colored dots*) and plasma proteins (*colored circles*). Normally (*left*) potassium is mostly inside the cells, sodium outside; plasma proteins tend to remain in the bloodstream. In shock (*center*) injury to part of the body (*shaded*) produces swelling which absorbs fluid from the blood and uninjured tissues. Cells in the injured

using saline solution to treat shock for nearly half a century, but its value was much in dispute. Some proponents of the role of plasma proteins in shock considered it useless, since it leaves the bloodstream rapidly; some held it to be actually harmful, on the theory that it "washes out" the proteins.

Under our standard conditions, however, we found that saline solution was almost as effective as equal quantities of plasma and whole blood in the therapy of shock from burns and trauma. Then, to our surprise, we discovered that when we administered saline solution in larger quantities it resulted in the survival of nearly all the animals. Plasma or whole blood could not be administered in these large doses. In hemorrhage, where the loss of red blood cells is an important additional factor, whole blood of course proved superior. Yet even in hemorrhage sufficient quantities of saline solution produced highly favorable results when administered during the hemorrhage.

As the first unexpected result of our investigation we thus found that quantity is decisive in the effectiveness of saline solution. In burn and tourniquet experiments, saline solution equivalent to 5 per cent of the body weight—approximately equal to the fluid lost—saved less than half the animals. Twice as much saline brought about two thirds of them through, and three times as



area release potassium and take up sodium in exchange; plasma proteins escape from the blood. Treatment (*right*) by plasma injections (*syringe*) or saline solution (*beaker*) restores the blood volume and corrects dehydration and sodium loss in the tissues. Since most of the therapeutic effect is lost in additional swelling, large quantities must be administered.

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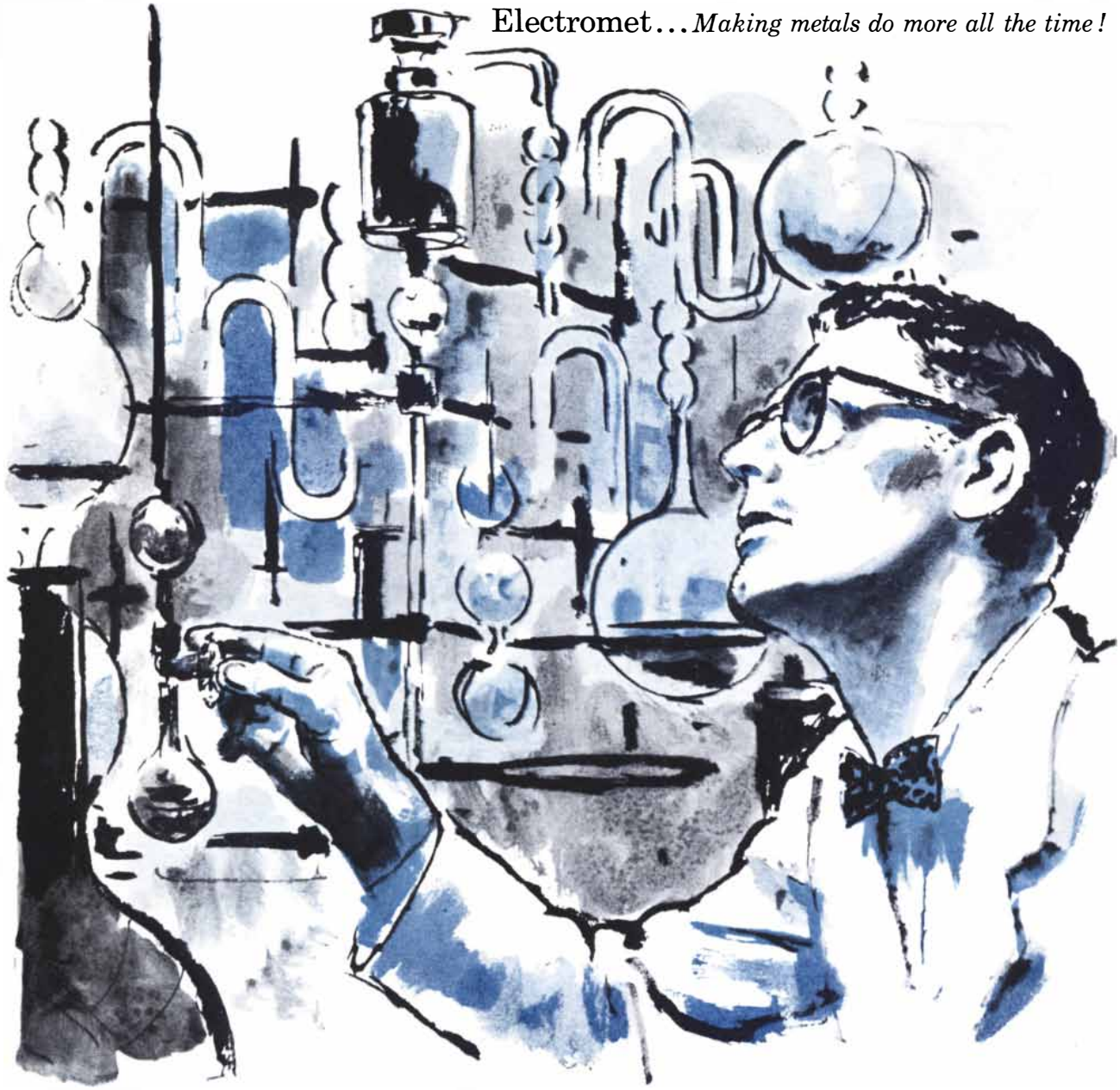

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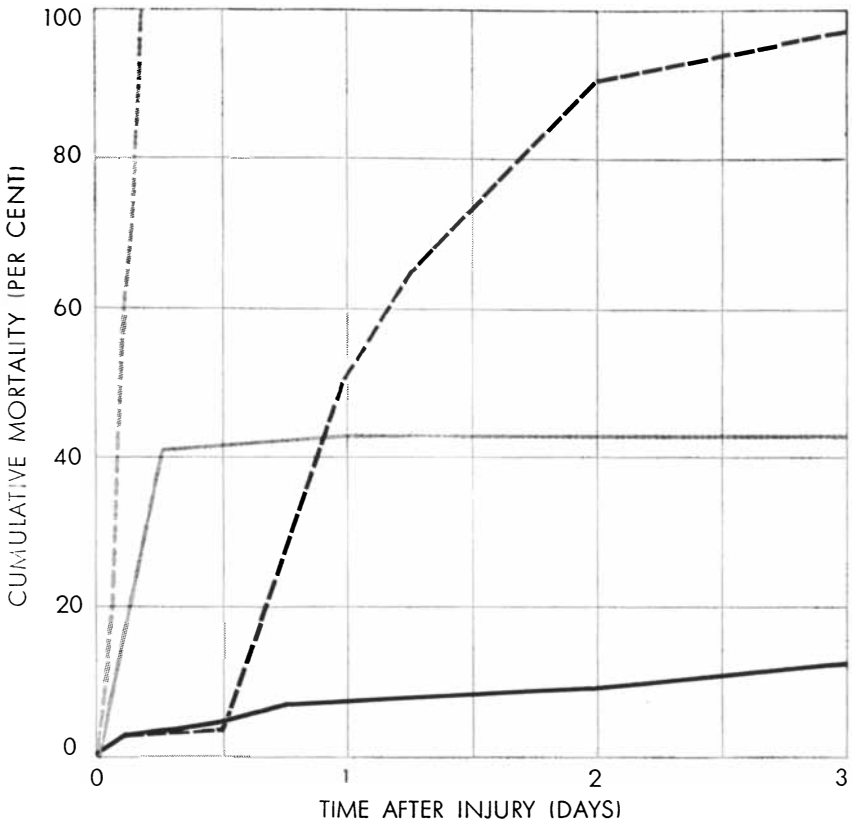


PROPER ENVIRONMENTAL temperature radically improved survival among shocked mice treated with saline solution. At 77 degrees F. (*solid black curve*) nearly 90 per cent survived; at 88 degrees (*solid gray*), less than 60 per cent. At 98.6 (*broken gray*) all died rapidly. At 65 degrees (*broken black*) most animals survived the first few hours but died later.

much produced survival rates of 80 to 97 per cent [*see illustrations on pages 116 and 117*]. This heroic dose, equal to three times the volume of plasma in the body, would in a human adult amount to eight to 10 quarts of liquid!

From the clinical standpoint our next surprise may prove to be even more significant. We found that the administration of saline solution by mouth is just as effective as direct infusion into the bloodstream. Here, it seemed, we had come upon an excellent emergency treatment for shock. A solution of table salt and water can be mixed and administered by any layman so long as the patient can swallow.

Preliminary clinical trials with human shock patients gave promising results. With the plasma protein theory of shock prevailing, however, most physicians continued to look askance at our experiments, saying in effect: "Mice are not men." We concluded that we should seek a better understanding of our results before pressing for a full-scale clinical trial.

We set out first to compare the action of saline solution and plasma throughout the course of therapy in mice. It turned out that saline solution had little immediate effect upon the volume of circulating blood. The concentration of red cells, raised by the loss of plasma, remained high; the concentration of proteins dropped, suggesting that the saline solution had indeed washed some proteins out of the blood. By standard clinical criteria the treatment was worthless. But most of the animals survived! Twenty-four hours later their blood volume had returned to normal. Plasma and other colloid solutions secured an immediate increase in blood volume. This improvement did not, however, ensure the survival of the animals. In fact, when we tried "salt-free" solutions of plasma protein all the animals died, though the blood volume increased at the outset.

Further experiment showed that the sodium ion is the active ingredient. Other salts of sodium gave results comparable to sodium chloride; solutions of glucose or of various proteins without salt had no more effect than water alone. These experiments cast serious doubt on the plasma protein theory. They also indicated that wound shock is something more than a circulatory disturbance.

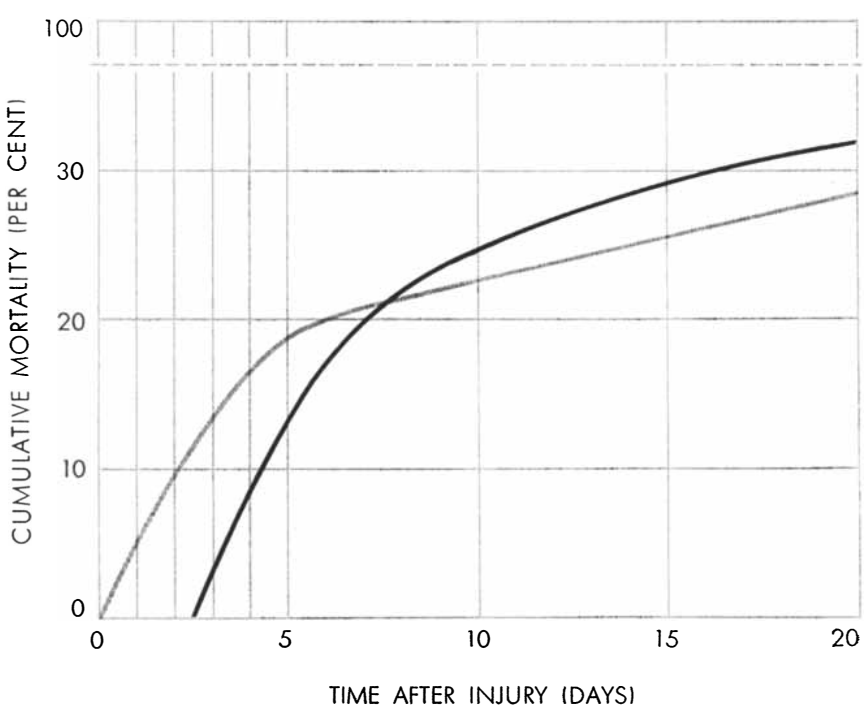
To get a clearer picture of the noncirculatory factors, we set out to trace what happens to fluids, sodium and pro-

teins in shock. Herbert Tabor and R. C. Millican assayed the injured and uninjured tissues of mice that had succumbed to shock without treatment. Their measurements confirmed the older observations that the fluid lost to the edema amounted to 4 or 5 per cent of body weight. Only half of this fluid, however, came from the blood; the remainder was drawn from the uninjured tissues and thus produced a general tissue dehydration along with the lowering of blood volume. Analysis showed further that the injured tissues had accumulated 30 per cent more sodium than the size of the swelling would indicate.

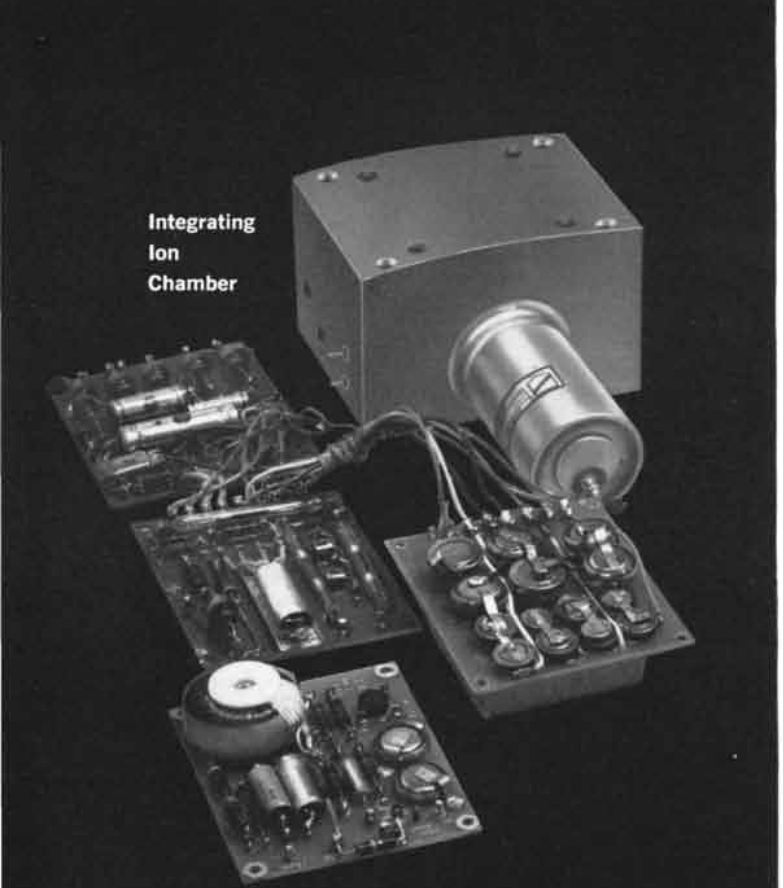
We then found that an equivalent amount of potassium had escaped from the injured area into other parts of the body. Normally almost all the body's potassium is found inside the cells, while sodium remains outside [see "The Nerve Impulse and the Squid," by Richard D. Keynes; page 83]. In the injured tissues the physiological barrier which maintains these concentrations had evidently broken down. The damaged cells had absorbed sodium ions and given up potassium ions in osmotic exchange. This "wandering" potassium helped to explain an earlier finding which had puzzled us: the extraordinary sensitivity of mice in shock to potassium. Potassium injections are normally toxic, but shocked mice succumb to doses which normal mice would easily survive. These results suggest that potassium poisoning may play a part in death from shock.

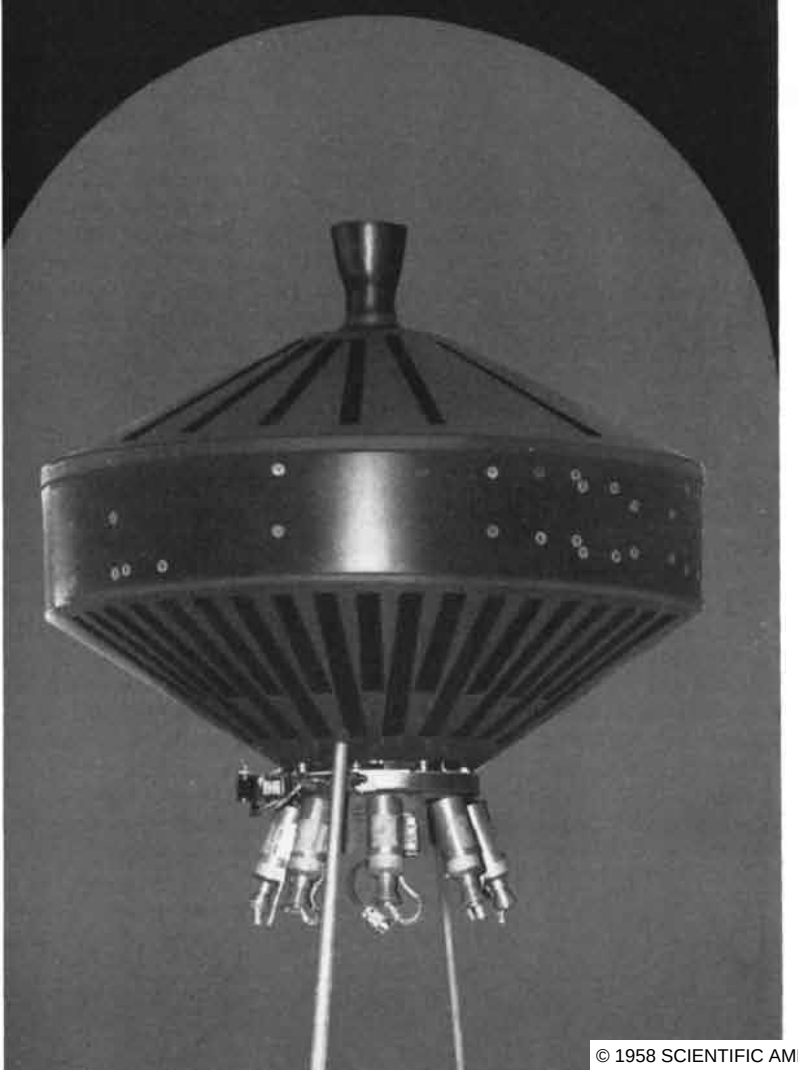
For a time we were puzzled by a discrepancy between these assays of salt and fluid distribution in untreated animals, and our experience with the saline-solution treatment. If the edema took up 5 per cent of the body weight in fluid, what became of all the saline solution—three times as much by volume—which was needed for maximum effectiveness? Moreover, when we analyzed the urine of mice under treatment we found that they retained three times more sodium than we calculated they had lost in the edema fluid. Where had all this sodium gone? Potassium exchange accounted for some of the missing sodium, but not all. It then occurred to us that the 5 per cent figure came from analysis of the edema in untreated animals. We promptly discovered that the edema in treated mice increased beyond 5 per cent in direct proportion to the amount of fluid we administered to the animal. In fact, a full 70 to 80 per cent of the first saline infusion showed up in the edema, thus explaining our earlier finding that saline solution does not secure an immediate increase in the volume of circulating fluid. With the radioactive isotope sodium 22 as a tracer we confirmed that the sodium as well as the water was "lost" in this manner.

Clearly the inordinate capacity of injured tissues to swell and absorb fluids at



CLINICAL TRIAL in three Lima, Peru, hospitals showed that burn-shocked adults treated with saline solution (*black curve*) or plasma (*gray curve*) have similar recovery rates. Only deaths during the first few days are due to shock; causes of later deaths are under study.





Concerning Radiation Theories in Interplanetary Space

Aptly called **Pioneer,** the terminal stage of Able-One's space probe reached into the fringes of the universe to telemeter data that will help solve the problems of interplanetary travel. **Pioneer** successfully carried 39.6 pounds of Space Technology Laboratories' developed instrumentation for the gathering and transmission of data.

The ion chamber and associated equipment provided information concerning the radiation intensity in space. This experiment was carried on in connection with the Department of Physics, State University of Iowa.

In conjunction with the U. S. Air Force Ballistic Missile Division, and under the sponsorship of the National Aeronautics and Space Administration, **STL's** explorations and developments in seeking energy spectra of the radiation belt are continuing at an accelerated pace. Increased knowledge in the fields of interplanetary magnetism and the distribution of interplanetary matter are being sought. Related fields of astrophysics provide additional areas in which advanced experimentation may be expected to add substantially to man's knowledge of the universe.

These programs at **STL** open a whole new vista in analytical and experimental areas for the advanced technical person whose interests and experience qualify him for work in the following fields: electrodynamics, nuclear physics, communication theory, and the design and execution of physical experiments in interplanetary space. Inquiries are invited.

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the expense of the blood and uninjured tissues is one of the basic mechanisms in shock. An effective treatment must supply sufficient fluid to fill up the stagnant "puddle" and leave enough to correct dehydration and sodium deficiency in the rest of the body. Derangement of the body's fluid and ionic balance are evidently at least as important in shock as the more easily observed disturbance of circulation. Indeed D. C. Darrow and his associates at Yale University have produced conditions resembling shock in animals simply by lowering the sodium concentration in their body fluids.

We had clarified the role of sodium in shock. What of the plasma proteins? To answer this question, Millican prepared radioactive mouse plasma by feeding mice a yeast cultured in a medium containing the radioactive isotope sulfur 35. When this plasma was infused in the bloodstream of shocked mice, it migrated into the injured tissues along with the sodium and water. Evidently the osmotic barrier which keeps plasma proteins in the blood under normal conditions breaks down at the site of injuries. This experiment gave the *coup de grâce* to the plasma protein theory of shock.

The tracer experiments also showed that, once the swelling stops, the proteins which have accumulated in the edema do not get back into the blood. In other words, the osmotic barrier is reestablished after some hours. If plasma is infused at this time, the new protein tends to remain in the circulation and acts to restore blood volume more effectively than it does when injected soon after injury. Thus plasma has some special virtues in the treatment of shock, though in most cases it can be partly or wholly replaced by saline solution.

Anyone who has ever taken a first-aid course will remember the first rule for treating shock: Keep the patient warm. The patient himself feels cold, and his temperature and metabolic rate are down. Physicians and first-aiders alike try to treat symptoms by getting the patient warm. Animal experiments, however, show that excessive warming may be harmful. Our mice showed the best survival rate when kept at 77 degrees Fahrenheit; at 98.6 F., the normal body temperature of mice, the animals died [*see illustration on page 121*]. Low body temperature and metabolic rate in shock seem analogous to fever and high metabolic rate in infection; they are mechanisms of defense. We should not try to correct all of the abnormalities brought on by illness and injury; some may serve a useful purpose.

In 1951 we decided that our observations were ready for a full-scale clinical test. We found it difficult, however, to justify trying our saline-solution treatment on patients to whom plasma and whole blood were available. How could we urge their physicians to set aside proven treatment in favor of a procedure supported so far chiefly by animal experiment? We had to find patients for whom our saline solution would represent rescue from their desperate condition. Thanks to the mediation of Alberto Hurtado of the University of San Marcos, we found them in the hospitals of Lima, Peru. There plasma and whole blood were in short supply, with not even enough to treat emergency patients.

It was a true *Arrowsmith* adventure. At three Lima hospitals we arranged to treat all the victims of serious burns, choosing this type of injury because its relative severity can be expressed in objective measurement of area and depth. Under the supervision of Kehl Markley of the U. S. Public Health Service the patients were to be treated in strict alternation, one receiving saline solution and the next plasma. We heard many predictions of failure. The patients would not drink quarts of salt solution, and if they did so it would sicken or kill them. Besides, how could a foreign physician get the cooperation of three different hospitals on an experiment in which they had no faith?

The beginning was not auspicious; the first patient treated with saline solution died in shock. The project, however, continued; scheduled at first to run for three years, it has continued for seven. The doctors have found their patients quite willing to swallow quarts of the fluid, for the dehydration which attends burns brings on severe thirst. (Volunteers who were not dehydrated found saline solution by the quart highly distasteful.) Patients unable to swallow have been given saline intravenously.

As the number of cases multiplies, the clinical record lends increasing confirmation to our laboratory findings. Experience with a now substantial number of patients shows that large quantities of saline solution, administered principally by mouth, are in most cases as effective as plasma in the treatment of shock arising from severe burns. Our research continues at Lima. But now, at the very least, we can recommend the administration of salt water by mouth, or the direct infusion of saline solution into the bloodstream, as effective therapy for shock on those occasions of accident and disaster when plasma and whole blood are not readily available.

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MATHEMATICAL GAMES

Diversions which involve the five Platonic solids

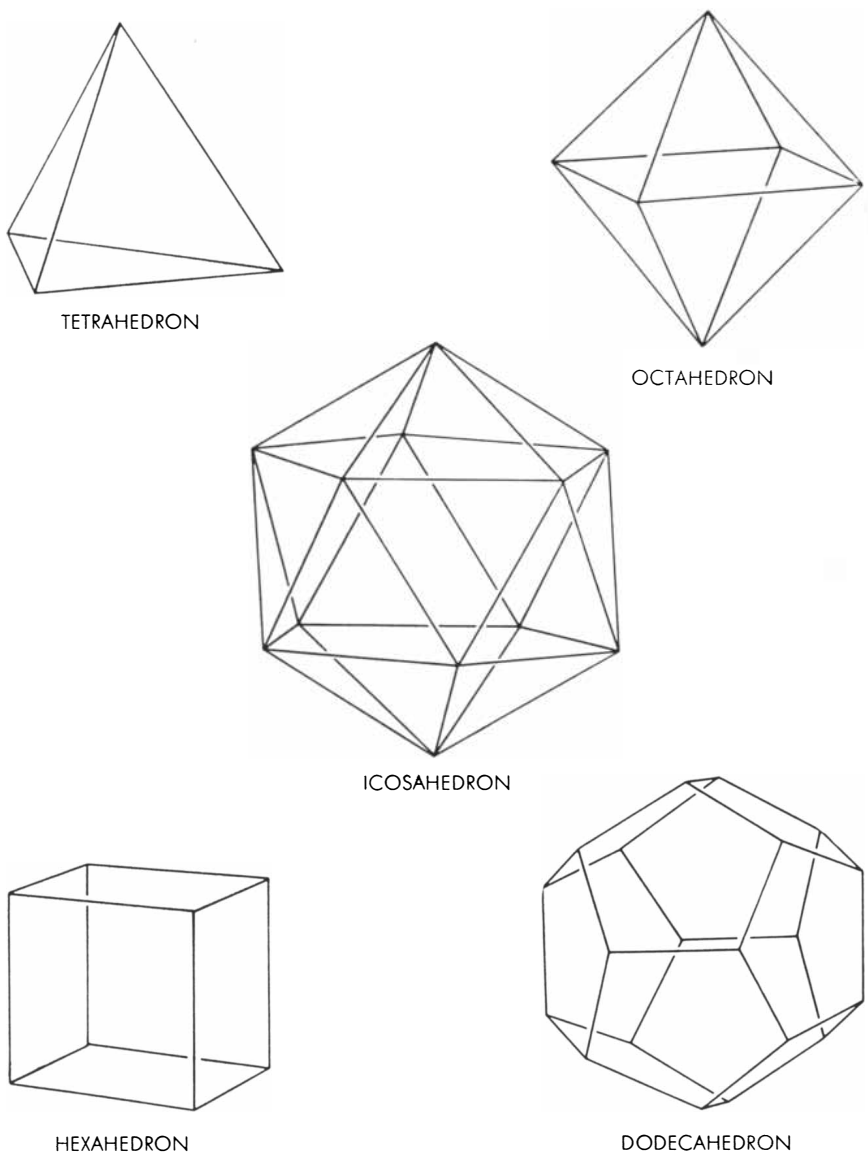
by Martin Gardner

A regular polygon is a plane figure which is bounded by straight lines and has equal sides and equal interior angles. There is of course an infinite number of such figures. In three dimensions the analogue of the regular polygon is the regular polyhedron: a solid which is bounded by regular polygons and has congruent faces and congruent interior corner angles. One might suppose that these forms are also infinite, but in fact there are only five: the regular tetrahedron, hexahedron (cube), octahedron, dodecahedron and icosahedron [*see illustration at right*].

The first systematic study of the five regular solids appears to have been made by the ancient Pythagoreans. They believed that the tetrahedron, cube, octahedron and icosahedron respectively underlay the structure of the traditional four elements: fire, earth, air and water. The dodecahedron was obscurely identified with the entire universe. Because these notions were elaborated in Plato's *Timaeus*, the regular polyhedrons came to be known as the Platonic solids. The beauty and fascinating mathematical properties of these five forms haunted scholars from the time of Plato through the Renaissance. The analysis of the Platonic solids provides the climactic final book of Euclid's *Elements*. Johannes Kepler believed for a time that the orbits of the six planets known in his day could be obtained by nesting the five solids in a certain order within the orbit of Saturn. Today the mathematician no longer views the Platonic solids with mystical reverence, but their rotations are studied in connection with group theory, and they continue to play a colorful role in recreational mathematics. Here we shall quickly examine a few diversions in which they are involved.

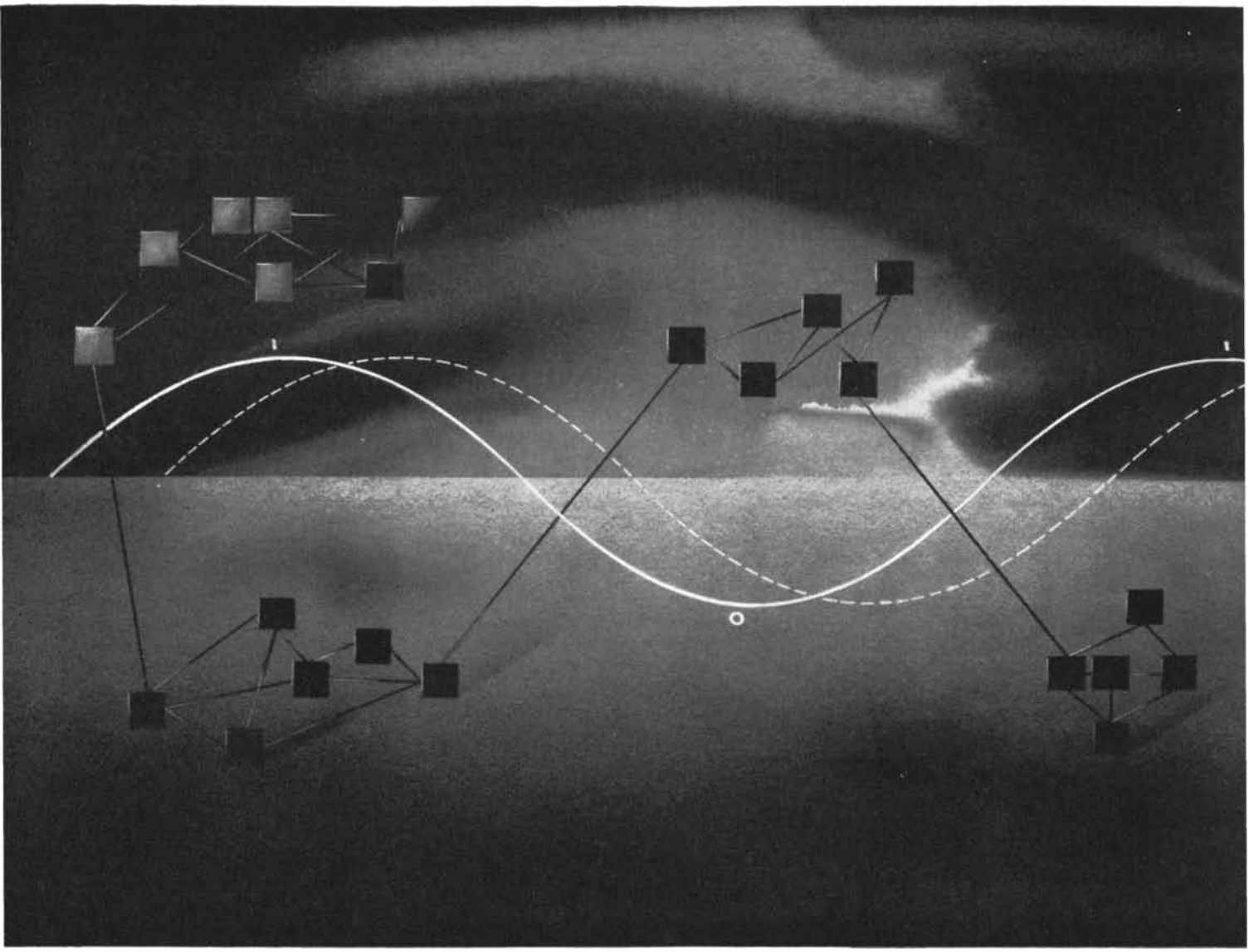
There are four different ways in which a sealed envelope can be cut and folded into a tetrahedron. The following is perhaps the simplest. Draw an equilateral triangle on both sides of one end of an envelope [*see illustration at top of page 128*]. Then cut as indicated by the broken line, and discard the upper piece. By creasing the paper along the sides of the front and back triangles, points A and B are brought together to form the tetrahedron. The illustration at the bottom of page 128 shows the pattern for an amusing puzzle currently marketed in plastic. You can make the puzzle yourself by cutting two such patterns out of heavy paper. (All the line segments except the longer one have the same length.) Fold each pattern along the lines and tape the edges to make the solid shown. Now try to fit the two solids together to make a tetrahedron. A mathematician I know likes to annoy his friends with a practical joke based on this puzzle. He bought two sets of the plastic pieces so that he could keep a third piece concealed in his hand. He displays a tetrahedron on the table, then knocks it over with his hand and at the same time releases the concealed piece. Naturally his friends do not succeed in forming the tetrahedron out of the three pieces.

Concerning the cube I shall mention only an electrical puzzle and the sur-



The five solids

REPORT FROM IBM YORKTOWN RESEARCH CENTER, NEW YORK

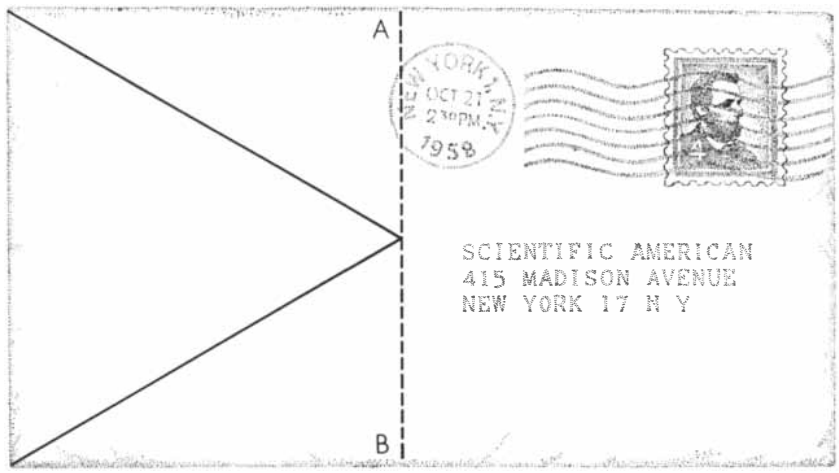


Using high-frequency waves to perform computer logic

Using refined techniques, the exciting new field of microwave spectroscopy is being explored by scientists at the Poughkeepsie unit of the IBM Yorktown Research Center. Preliminary results indicate that these studies may point one way to improved computers of tomorrow.

In one experiment, a small, single crystal of magnesium oxide is placed in a magnetic field of a few thousand oersteds, and microwave radiation of, say, three centimeter wave length is directed at it. When the magnetic field is varied, the crystal will absorb energy at many different magnetic fields. Each absorption is characteristic of the various impurities present, although the amounts are less than one tenth of one percent in the crystal. When microwave power into the crystal is increased, new absorption lines appear at high power that are "forbidden" at low power. Because of the marked power dependence of the absorption, one may logically consider the impurities as small nonlinear circuit elements within the crystal itself.

Scientists at IBM have several reasons for these studies. There is the contribution to the basic understanding of crystal structures. Also, by studying time constants and nonlinearities of the microwave interactions with the impurity ions, important data is being uncovered. Already these tiny circuit elements are used in the maser amplifier of the radio astronomer. Their descendants may open the way to the ideal, small-size, high-speed computer we are striving to make a reality.

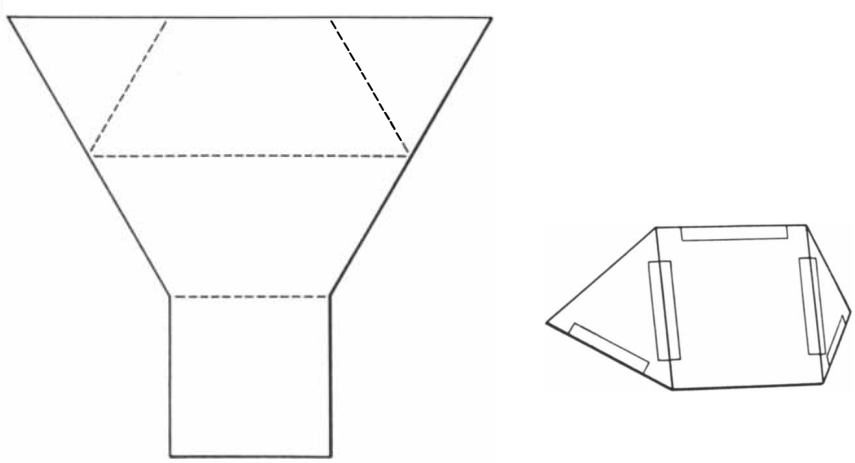


How a sealed envelope can be cut for folding into a tetrahedron

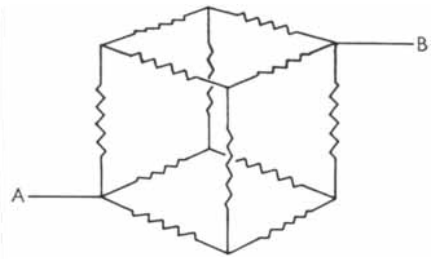
prising fact that a cube can be passed through a hole in a smaller cube. If you will hold a cube so that one corner points directly toward you, the edges outlining a hexagon, you will see at once that there is ample space for a square hole that can be slightly larger than the face of the cube itself. The electrical puzzle involves the network depicted in the illustration at the top of page 130. If each edge of the cube has a resistance of one ohm, what is the resistance of the entire structure when current flows from A to B? Electrical engineers have been known to produce pages of computations on this problem, though it yields easily to the proper insight.

All five Platonic solids have been used as dice. Next to the cube the octahedron seems to have been the most popular. The pattern shown in the illustration at the bottom of page 130, its faces numbered as indicated, will fold into a neat octahedron whose open edges can be closed with transparent tape. The opposite sides of this die, as in the familiar cubical dice, total seven. Moreover, a pleasant little mind-reading stunt is made possible by this arrangement of digits. Ask someone to think of a number from 0 to 7 inclusive. Hold up the octahedron so that he sees only the faces 1, 3, 5 and 7, and ask him if he sees his chosen number. If he says "Yes," this answer has a key value of 1. Turn the solid so that he sees faces 2, 3, 6 and 7, and ask the question again. This time "Yes" has the value of 2. The final question is asked with the solid turned so that he sees 4, 5, 6 and 7. Here a "Yes" answer has the value of 4. If you now total the values of his three answers you obtain the chosen number, a fact that should be easily explained by anyone familiar with the binary system. To facilitate finding the three positions in which you must hold the solid, simply mark in some way the three corners which must be pointed toward you as you face the spectator.

There are other interesting ways of numbering the faces of an octahedral die. It is possible, for example, to ar-



A pattern (left) *that can be folded into a solid* (right), *two of which make a tetrahedron*

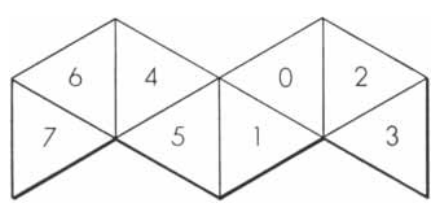


An electrical-network puzzle

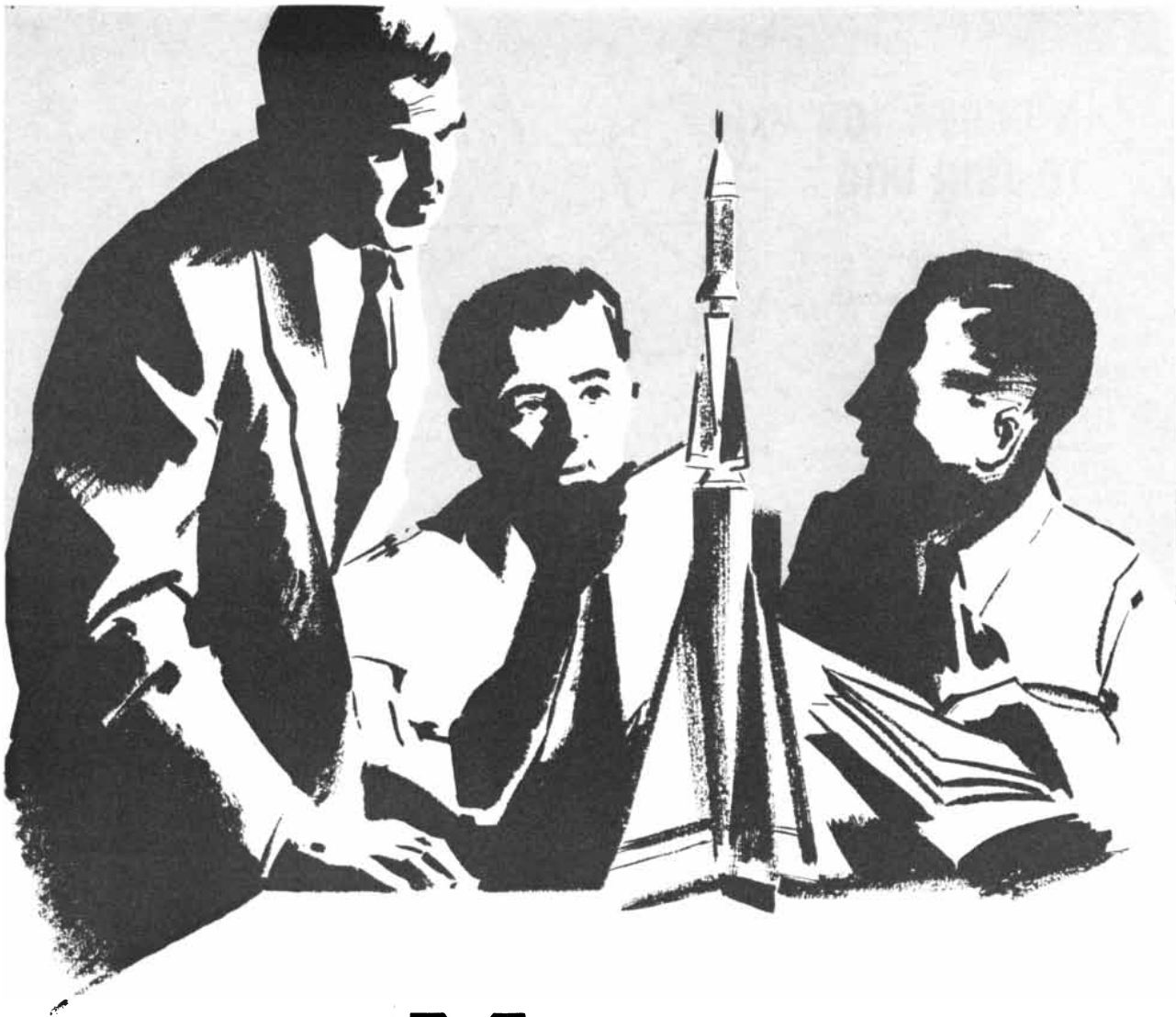
range the digits 1 through 8 in such a manner that the total of the four faces around each corner is a constant. The constant must be 18, but there are three distinct ways (not counting rotations and reflections) in which the faces can be numbered in this fashion.

An elegant way to construct a dodecahedron is explained in Hugo Steinhaus's book *Mathematical Snapshots*. Cut from heavy cardboard two patterns like the one pictured at left in the illustration at the top of page 132. The pentagons should be about an inch on a side. Score the outline of each center pentagon with the point of a knife so that the pentagonal flaps fold easily in one direction. Place the patterns together as shown at right in the illustration so that the flaps of each pattern fold toward the others. Weave a rubber band alternately over and under the projecting ends, keeping the patterns pressed flat. When you release the pressure, the dodecahedron will spring magically into shape.

If the faces of this model are colored, a single color to each face, what is the minimum number of colors needed to make sure that no edge has the same color on both sides? The answer is four, and it is not difficult to discover the four different ways that the colors can be arranged (two are mirror images of the other two). The tetrahedron also requires four colors, there being two arrangements, one a reflection of the other. The cube needs three colors and the octahedron two, each having only one possible arrangement. The icosahedron calls for three colors; here there are no less than 144 different patterns, only six of



A strip to make an octahedral die



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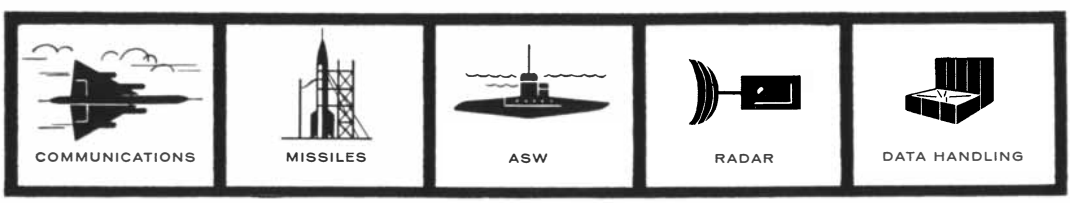
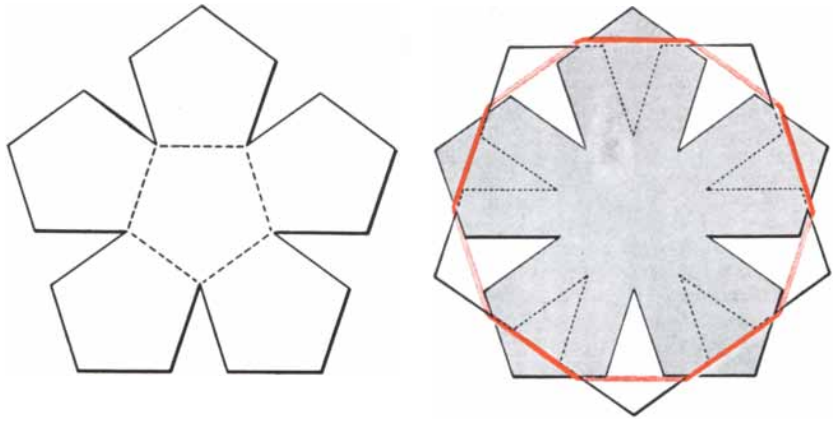




Two identical patterns are fastened together with a rubber band to make a dodecahedron

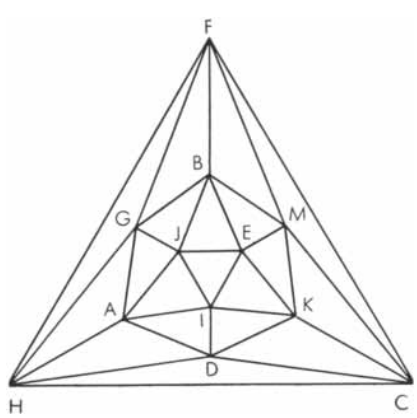
which are identical with their mirror images.

If a fly were to walk along the 12 edges of an icosahedron, traversing each edge at least once, what is the shortest distance it could travel? The fly need not return to its starting point, and it would be necessary for it to go over some edges twice. (Only the octahedron's edges can be traversed without retracing.) A plane projection of the icosahedron [*illustration at bottom of this page*] may be used in working on this problem, but one must remember that each edge is one unit in length. (I have been unable to resist concealing a laconic Christmas greeting in the way the corners of this diagram are labeled. It is not necessary to solve the problem in order to find it. The greeting, and the answers to some of the questions raised earlier, will be given in this space next month.)

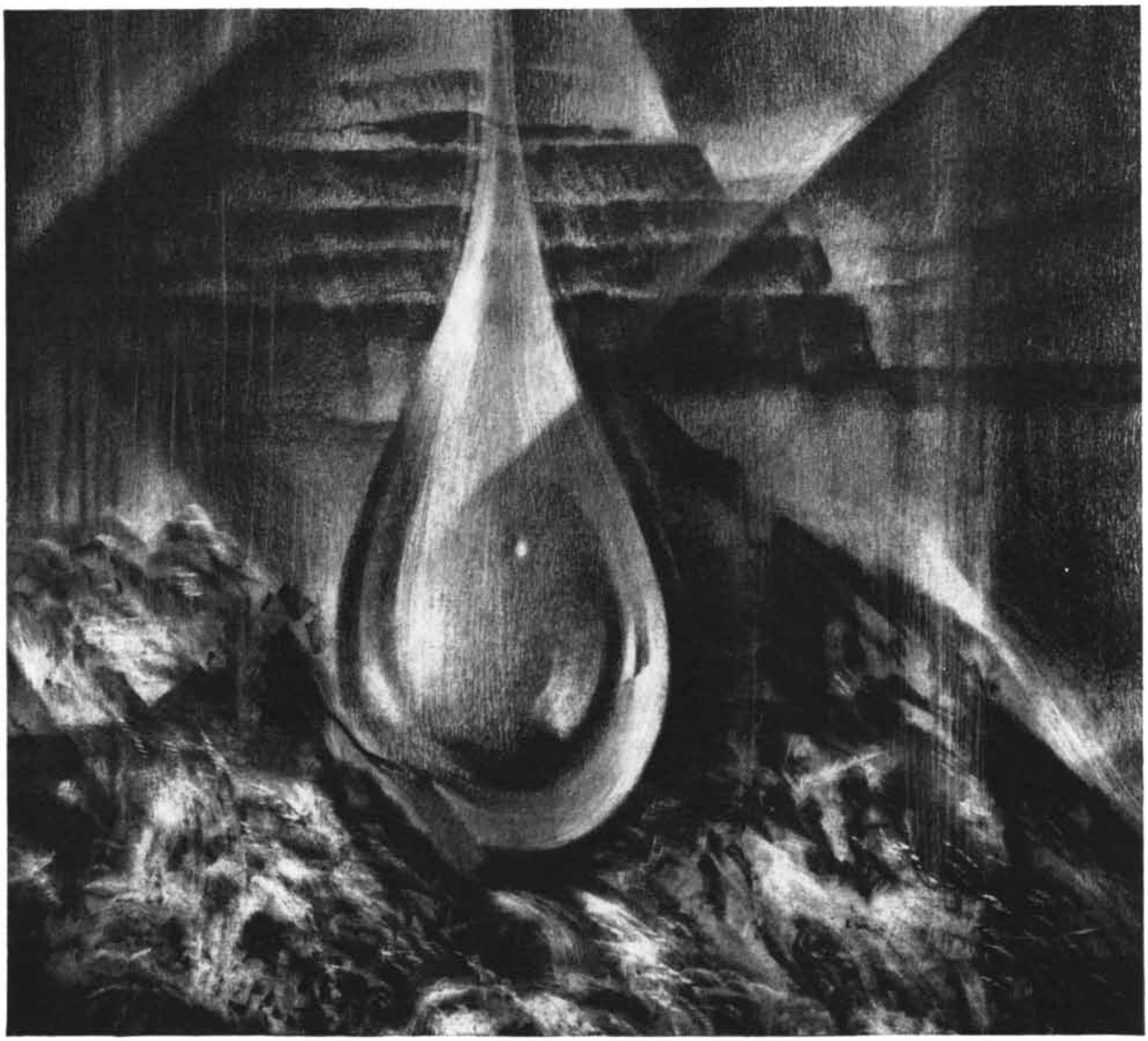
In view of the fact that cranks persist in trying to trisect the angle and square the circle, long after these feats have been proved impossible, why has there been no comparable effort to find more than five regular polyhedrons? One reason is that it is quite easy to "see" that no more are possible. The following simple proof goes back to Euclid. A corner of a polyhedron must have at least three faces. Consider the simplest face: an equilateral triangle. We can form a corner by putting together three, four or five such triangles. Beyond five, the angles total 360 degrees or more and therefore cannot form a corner. We thus have three possible ways to construct a regular convex solid with triangular faces. Three and only three squares will similarly form a corner, indicating the possibility of a regular solid with square faces. The same reasoning yields one possibility with three pentagons at each corner. We cannot go beyond the pentagon, because when we put three hexagons together at a corner, they exceed 360 degrees.

This argument does not prove that five regular solids can be constructed, but it does show clearly that no more than five are possible. More sophisticated arguments establish that there are six regular polytopes, as they are called, in four-dimensional space. Curiously in spaces of more than four dimensions there are only three regular polytopes: analogues of the tetrahedron, cube and octahedron.

A moral may be lurking here. There is a very real sense in which mathematics limits the kinds of structures that can exist in nature. It is not possible, for example, that beings in another galaxy gamble with dice that are regular polyhedra of a shape unknown to us. Some theologians have been so bold as to contend that not even God himself could construct a sixth Platonic solid in three-dimensional space. In similar fashion, geometry imposes unbreakable limits on the varieties of crystal growth.



A plane projection of an icosahedron



THE WASH THAT STOPPED THE DRAIN

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On experiments with gibberellic acid, which stimulates the growth of plants

Conducted by C. L. Stong

When young rice plants are infected with the fungus *Gibberella fujikuroi*, they grow extraordinarily tall. Some 30 years ago a Japanese plant physiologist discovered that an extract of the fungus produced the same effect, and shortly before World War II workers at the University of Tokyo isolated the active substance in the extract. The substance, called gibberellic acid, is now the subject of intense study by plant physiologists all over the world. It has been found to exert striking influences in a wide variety of plants. When young citrus trees, for example, are treated with gibberellic acid, their stems elongate more than six times!

Gibberellic acid is now commercially available. It should interest amateurs because it is inexpensive, produces spectacular effects and offers an unusual opportunity for original experiments. Among those who have worked with it are Robert Lawrence and Henry Soloway, who are students in the College of Medicine of the State University of New York.

"A speck of gibberellic acid smaller than a grain of sugar," they write, "has turned our window box into an Alice-in-Wonderland jungle. The compound causes most plants to grow at record speed, flower in half the usual time and bear fruit that will win first prize in any county fair. In view of these effects and their implications it is not surprising that gibberellic acid is now bringing many strange bedfellows together: the florist seeking to produce larger flowers, the farmer trying to double the production of his land and the cancer researcher who hopes in some manner to find clues to the dynamics and pathology of growth.

"The amateur who experiments with gibberellic acid is likely to reap satisfying rewards because the field is still wide open. Most of the research now under way is centered on crop plants and flowers cultivated by commercial greenhouses. Amateurs can avoid duplicating these experiments by selecting less common plants. For example, to our knowledge no work is being done with molds, mushrooms, mosses, ferns or fresh-water algae. Aside from the fascination of producing freakish plants, experiments with gibberellic acid also provide the amateur with the opportunity of gaining experience with the scientific method—of forcing answers from nature with a minimum of guesswork.

"The experiment which follows is designed to demonstrate certain basic reactions of plants to gibberellic acid. The approach is not limited to this compound; it will prove equally effective with any substance suspected of being a growth stimulator or inhibitor. Thus it can serve as a steppingstone to other investigations.

"You will need a quantity of the acid, a set of identical plants, some inexpensive apparatus and, last but not least, a notebook. Gibberellic acid is sold under the name of Brellin 10 (order No. 450A590) by General Biological Supply House, 8200 South Hoyne Avenue, Chicago, Ill. A 28-gram bottle ($2.95) will be more than sufficient for this experiment. A convenient plant for the experiment is the common garden pea, although many other plants are equally rewarding. It should be said, however, that gibberellic acid is known to have no effect on the white pine, the gladiolus or the onion.

"The modern scientific method requires that at least two plants be used in the experiment. One, called the control, is treated with tap water. The other, the experimental specimen, is treated with dilute gibberellic acid. By comparing the subsequent reaction of the experimental specimen with the control the experimenter draws conclusions about the effect of the acid. The method requires that the experimenter make all comparisons on the basis of precise measurements. The elements selected for measurement may consist in the height of the plant, the number of its leaves and its weight. The selection of these particular elements for measurement is not dictated by any hard and fast rule, so the experimenter may choose others. But once selected, the elements should not be changed during the experiment. Less obvious effects should also be selected for observation, such as the rate at which the plant consumes oxygen and the percentage of water in the plant with respect to the percentage of organic matter and inorganic ash. Again no hard and fast rules apply. Other factors may be selected for observation.

"We suggest the use of 32 germinated peas as experimental plants. It is well to place 45 or 50 seeds in a germinating medium, which may consist of thoroughly moistened filter paper, a few layers of cotton cloth, or wet sawdust. The medium should be kept warm and should be covered with an inverted glass bowl to prevent evaporation. Some of the seeds may not germinate, but virtually all of those that do will mature. Do not use ungerminated seeds. This experiment seeks to measure the effects of gibberellic acid on a growing plant, not its influence on the sprouting time of seeds. The latter experiment can be equally fascinating and, incidentally, it is one which is of great interest to commercial growers.

"While the seeds are incubating, the experimenter should start his notebook. Every detail, however self-evident, should be entered along with the entry date. It is well to reserve the first few pages for a running summary, including the date on which the acid was received (for information in case the compound should deteriorate with time), the date on which the peas were set for germination, the temperature, the date of planting, when the acid was first administered, the date of the second treatment and so on. It is in this information

that explanations will ultimately be found of how the acid does its work.

"When the peas have germinated, 32 paper drinking cups are filled to within a quarter-inch of the rim with sifted topsoil moistened just enough to form a fragile lump when a pinch of it is squeezed. One sprouted pea is then planted in each cup with the tip of the shoot pointing up and flush with the surface of the soil. The cups are arranged in groups of four and labeled according to the concentration of gibberellic acid the group is to receive. One group of four cups is reserved as a control and receives only tap water.

"The gibberellic acid comes mixed with an inert filler. If the experiment were ideally controlled, another group of cups would be reserved for treatment with the filler alone. For this experiment, however, we assume that the manufacturer's filler is really 'inert.'

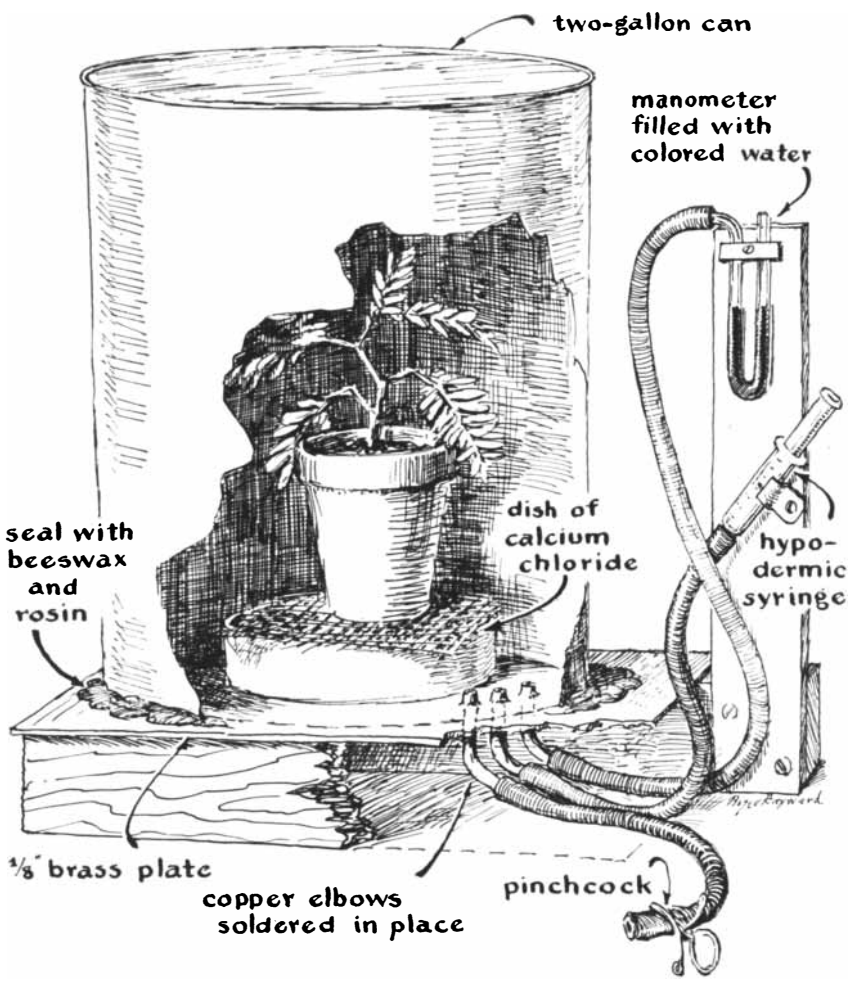
"A set of seven small bottles with a capacity of three or four fluid ounces will be required for storing dilutions of the acid. These may be purchased for a few cents at most drugstores. The kind which has a scale of cubic centimeters molded in the glass is convenient. If bottles with such scales are not available, the experimenter must either make or buy a graduate.

"The dilutions are prepared by first dissolving one teaspoon (2.5 grams) of Brellin 10 in 50 cubic centimeters of tap water. Each teaspoon contains five milligrams of gibberellic acid; hence each cubic centimeter of this solution will contain a 10th of a milligram of acid. The second dilution is prepared by pipetting 5 c.c. of the first dilution into another container and adding enough tap water to make 50 c.c. Each cubic centimeter of this solution contains one 100th of a milligram of acid, and each dose of 10 c.c. contains a 10th of a milligram. A dilution containing one 100th of a milligram per 10 c.c. is made by pipetting 5 c.c. of the second dilution into a third container and adding water to make 50 c.c. The process is continued until seven dilutions are prepared so that 10 c.c. of each contains, respectively, 1 milligram, .1 mg., .01 mg., .001 mg., .0001 mg., .00001 mg. and .000001 mg. of the acid. Each bottle is labeled to indicate the dilution it holds, and is refilled only with the dilution for which it is marked. Fresh dilutions must be prepared for each treatment, because the acid gradually loses its activity in solution.

"To eliminate the influence of variations in environment during the experiment, the growing plants should be placed in a dark room in which the temperature does not vary appreciably from 70 degrees Fahrenheit, and should be exposed daily for 11 hours to a fluorescent lamp of at least 40 watts placed lengthwise above the cups at a height of two feet. Each experimental plant receives 10 c.c. of the appropriate acid dilution, as indicated by its label, every 48 hours. No water or other solution should be administered to them. The four control plants receive 10 c.c. of tap water at the same time. The acid should always be administered in a uniform manner. Ideally it is applied as a spray by means of an atomizer, which assures that all the exposed parts of the plant receive the solution. If desired, however, the dilutions may be poured on the soil near the base of the plant. Reaction between the acid and the soil tends to lower the activity of the acid somewhat.

"The height of each plant is recorded daily, beginning with zero inches on the day the experiment starts, when the shoots are flush with the top of the soil. A table is ruled in the notebook with a column for recording the height of each plant. From these data graphs may be plotted either for the individual plants or as averages of the groups. Similar tables should be constructed for the remaining indices of growth, such as the number of leaves. Weight need not be measured daily. This is a tedious operation. But the plants should be weighed individually at the conclusion of the experiment.

"Gibberellic acid appears to increase the rate of the metabolism of plants. It is possible to investigate metabolism by measuring the rate at which the plants consume oxygen. This is accomplished



A homemade apparatus to measure the oxygen consumption of plants

by means of an apparatus similar to the one described in this department for August, 1957, and October, 1957. The plant is enclosed in a vessel to which air can be admitted in accurately measured amounts. The vessel contains a small quantity of calcium chloride (soda lime) to absorb carbon dioxide liberated during respiration. Plants take up oxygen from the air and give off carbon dioxide only during intervals when photosynthesis is not taking place. In determining oxygen consumption, therefore, all measurements must be made when the plant is in the dark. The enclosing vessel may be opaque or, if it is made of glass, should be kept in a dark room.

"An adequate vessel can be made by upending a two-gallon tin can on a plate of flat metal. Hose connections can be introduced through the metal bottom. After the plant and calcium chloride are in place, the assembly is made airtight by applying a ring of wax (made of equal parts of beeswax and rosin) between the can and plate as shown in the accompanying drawing [*preceding page*]. The wax, which should be applied smoking hot with an eyedropper or a small brush, adheres strongly to cold metal. It may be scraped off at the end of the measurement and reused. One hose connects the vessel with a U-shaped length of glass tubing which serves, when partially filled with colored water, as a manometer for measuring the difference in pressure between the closed vessel and the room. A second hose terminates in a calibrated hypodermic syringe by which air is admitted to the vessel in measured amounts. The third hose serves as a vent for the vessel and is normally kept closed by means of a pinchcock. The potted plant may be supported on a sheet of stiff wire screening placed over the dish of calcium chloride. Unless the seams of the can are airtight they should be coated with wax. A coating of Vaseline will seal the piston of the syringe to the walls of the cylinder.

"To make a measurement, a fresh supply of calcium chloride is placed in the dish, the plant is set on top of the screen and covered by sealing the tin can in place. The piston of the hypodermic syringe is placed at the 10 c.c. graduation. The pinchcock is opened until the columns of colored water in the arms of the manometer stand at the same height, which indicates that the air pressure in the vessel and the room are equalized. The pinchcock is then closed and the time is recorded. After an interval which depends on the size of the plant and the rate of its respiration, the plant will take up enough oxygen from the air to cause an appreciable drop in the pressure indicated by the

Plant is treated with gibberellic acid

Carrot plant at right was treated

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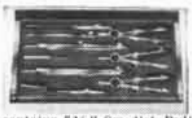

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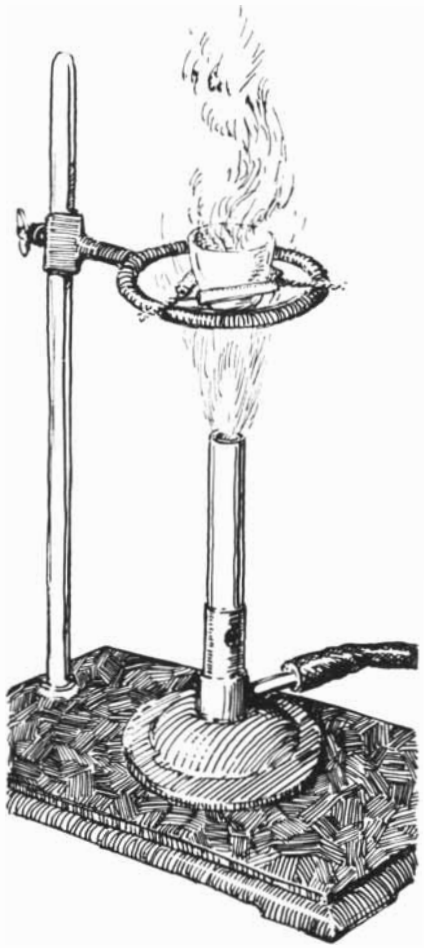
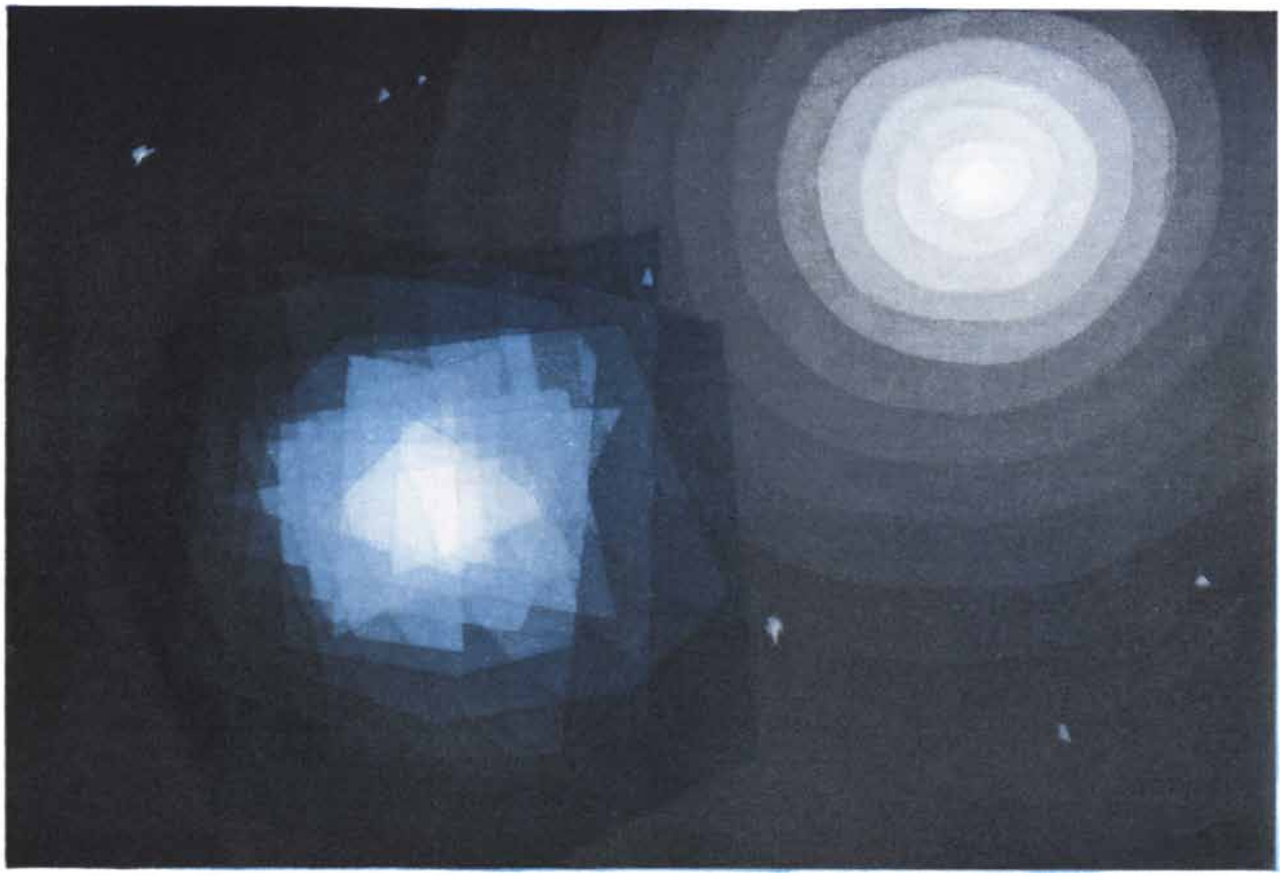
manometer. The piston of the syringe is then pushed in until the columns of water in the arms of the manometer again stand at the same level. The time is then recorded along with the volume of air admitted to the vessel from the syringe. The volume of air required to equalize the pressure is proportional to the oxygen consumed during the interval, and is an index of the metabolic rate of the plant. The rate of oxygen consumption is computed by dividing the volume of air admitted from the syringe into the vessel by the elapsed time in minutes. Accuracy can be improved by making three successive tests of the same plant and averaging the consumption rate of the three runs. The experiment may extend over several weeks, during which atmospheric conditions as well as the temperature change; for this reason tests made on different days may not be comparable. It is therefore necessary to add a correction which adjusts the figure to the value it would have if the test were made at 'standard' temperature (20 degrees centigrade) and barometric pressure (760 millimeters of mercury). To make this adjustment, the average amount of air admitted from the syringe to the vessel is multiplied by the barometric pressure (measured in millimeters of mercury) and divided by 760. This quotient is then multiplied by 273 and divided by 273 plus the temperature of the room in degrees centigrade. The result is entered in the notebook for the plant and dated.



How a plant is reduced to inorganic ash

"The oxygen consumption of plants varies as a logarithmic function of their surface area. Hence, for strictest accuracy, only plants of identical surface area can be compared. It is not easy to determine the surface area of a plant, but by making the assumption that all plants of equal height have comparable surface areas one can make comparisons which are interesting and useful even though approximate. We have assumed in this experiment that all the plants which are three inches high have the same surface area. The oxygen consumption of the group receiving the highest concentration of gibberellic acid is measured when these plants reach a height of three inches. A day or so later the next group will have reached the same height and can be similarly measured. The test is repeated as each of the more slowly growing groups reaches the height arbitrarily selected. The rate of consumption is plotted (on the vertical coordinate of a graph) against the logarithm of the dose (on the horizontal axis). The logarithm of one milligram per day equals zero, the log of .1 mg. per day equals –1, of .01 mg. per day equals –2, and so on.

"At the conclusion of the growth period, when, say, the most slowly growing group reaches a height of three inches, all the plants are carefully removed from the paper cups and gently agitated in a large pan of water until the soil adhering to the roots sinks to the bottom of the pan. Care should be taken not to tear away any of the roots. The plants are then rinsed, blotted dry and promptly weighed. Any delay may introduce error because the plants will lose water through evaporation. The weight of each plant is recorded. Then the leaves and roots are cut from the stem and weighed separately. The combined weight of the parts should nearly equal the total weight of the plant. Evaporation may account for a slight difference, but any substantial disagreement may indicate an error in procedure. Graphs of the weight are then drawn, in which the total weight is plotted against the logarithm of the dose, as in the case of oxygen consumption. Similar graphs should be made showing the percentage



"EARTH IN SPACE," one of a series of paintings of the planets by Simpson-Middleman, painters who have been finding their subject matter in science. To quote them: "Earth is distinguished among the planets by its oceans of water and its single moon. From these as a starting point, earth in this painting has been imagined as a configuration of intersecting planes—layer on layer of blue—until it becomes a transparent crystal, glowing in space." Painting courtesy John Heller Gallery, Inc.

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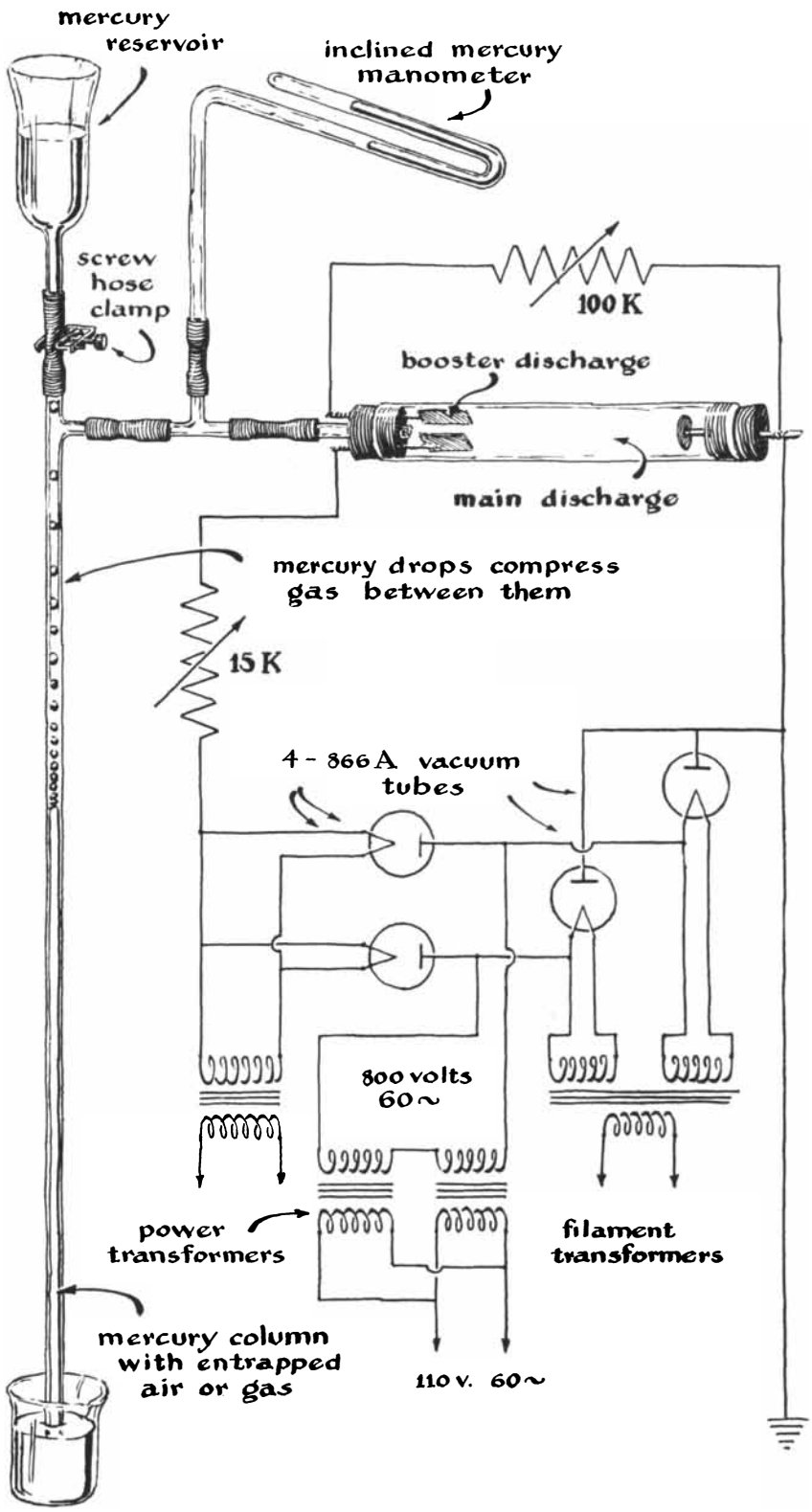

An apparatus to evacuate and excite a gas-discharge tube

of weight as a function of dose represented by the leaves, stems and roots respectively.

"Most plants consist mainly of water, and it is important to discover if the growth induced by gibberellic acid represents an increase in the solids or merely an increase in water. This can be determined by thoroughly drying the plants and comparing the dry weight with the total weight previously recorded. Separate tests should be made of the leaves, roots and stems to disclose the effects of the acid on the several parts of the plant. Plants may be dried in about three days by placing them on top of a radiator or under a 100-watt incandescent lamp. To find the percentage of water, multiply the dry weight by 100, divide by the wet weight and then subtract the quotient from 100.

"How does gibberellic acid affect the rate at which plants take up inorganic substances? This can be investigated by burning the dried remains and weighing the ash. In making this test it is again interesting to measure the leaves, stems and roots separately. An accurately weighed sample is placed in a crucible supported in the flame of a Bunsen burner [*see illustration on page 138*]. Set the crucible somewhat obliquely in an asbestos triangle to allow for the expansion of the heated parts, and close it with a loosely fitted cover. The crucible is then maintained at a red heat until the contents turn to a white, powdery ash. When cool, the ash is transferred to a balance and weighed. Multiply the weight of the ash by 100 and divide by the weight of the dried material placed in the crucible. This gives the percentage of inorganic ash.

"From the accumulated data it is now possible to answer the following questions: Does gibberellic acid increase the rate at which the experimental plant stores energy or merely cause it to absorb an abnormal amount of water? How does gibberellic acid affect the plant's consumption of oxygen? What further experiments do the results suggest?"

W. H. Bond, a mechanical engineer of Del Mar, Calif., suggests the Sprengel pump as an inexpensive means of exhausting glow tubes like the one which was described in this department last February.

"About 10 years ago," he writes, "I participated in a glow-tube experiment with A. R. Perl, A. J. Savard and C. S. Brandt of San Diego. Our tube was constructed with rubber stoppers and sealed with vacuum grease. We were interested in examining discharge tubes as

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(Positions are filled in accordance with Aeronautical Research Scientist Announcement 61B)

NASA National Aeronautics and Space Administration

a possible means of producing very high-speed streams of gas to study flows at extreme velocities. To obtain high positive-ion currents we inserted a little booster discharge at the anode end of the tube, hoping this would create more local ions. The apparatus is depicted in the accompanying drawing [*page 140*].

"Of more interest to other experimenters than the ion booster, however, may be the simple and inexpensive vacuum pump we used. Falling drops of mercury were employed as multiple pistons to entrap the gas and force it from a capillary tube. By adjusting the pinch clamp on the hose connecting the upper reservoir to the capillary tube the mercury can be made to fall as discrete drops. Our capillary had a bore of about two millimeters. The manometer used to measure the pressure of the system was a simple U-tube which we inclined at a slope of 10 to 1 to increase the range through which the mercury moved with changes in pressure. It is necessary to tap the manometer gently to obtain good equilibrium levels and to 'break' the mercury away from the sealed end of the U-tube. Incidentally, serious error will result if any gas other than mercury vapor remains in the manometer. Some effort was made to eliminate such gas by heating the sealed end of the U-tube gently when the system was at low pressure. I hasten to point out, however, that this is a tricky and somewhat dangerous operation, because if the tube should break, highly poisonous mercury vapor would be released.

"For a power supply we used two 110- and 440-volt transformers with the primary windings in parallel and the secondaries in series. The secondary output of 800 volts was converted to direct current by means of a full-wave rectifier which used four 866A vacuum tubes, as shown in the drawing. The variable-shunt resistor connected across the ends of the glow tube supplies voltage to the auxiliary discharge plates and has a resistance of about 100,000 ohms. At a rating of only one watt it was somewhat overloaded because it maintained some 400 volts across itself. The ballast resistor in series with the glow tube was a makeshift affair and a source of some difficulty. We tried wet resistors, using various concentrations of contaminants in water to vary the resistance, and were about to try a bank of resistors made of Christmas-tree lamps when our attention was diverted to other matters. Perhaps this is the 'weak link' in the setup. We did produce some mighty pretty glows, however, with all the characteristics shown in the textbooks."

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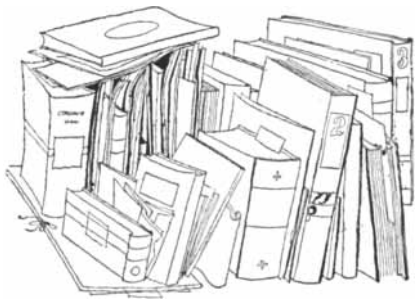

BOOKS

Robert Jungk's lively but debatable history of the scientists who made the atomic bomb

by Robert R. Wilson

BRIGHTER THAN A THOUSAND SUNS: A PERSONAL HISTORY OF THE ATOMIC SCIENTISTS, by Robert Jungk. Harcourt, Brace and Company ($5).

The title of Robert Jungk's *Brighter than a Thousand Suns* is adapted from the epic poem of India, the Bhagavad-Gita. Jungk's book is also a kind of epic, complete with tragically flawed heroes and a broad scene extending from the Old World villages of Göttingen and Cambridge to the pink and purple desert of New Mexico. Indeed, the birth of nuclear energy and the atomic bomb—its effect upon the men who developed it, upon the political environment which determined it and then was determined by it, upon a world which does not quite know what to do with it—is surely a subject fit for an epic.

The subtitle of the book is *A Personal History of the Atomic Scientists.* There is no doubt that the account is personal, but though Jungk is trained as a historian it is not history. It is marred by inaccuracies on nearly every page. Jungk has gone deep enough into his subject to catch something of the spirit of physics and of physicists (he has dug up a wealth of amusing anecdotes), but he has not gone sufficiently deep to acquire the understanding necessary to qualify him for the kind of analysis he attempts of awesome events and of complex personalities.

Although Jungk has interviewed quite a number of people and read quite a few documents, there is little new material in the volume except for the anecdotes. What is new is the synthesis of many stories, the tying up of many strands—a job so artfully done that the account reads like a novel and is as exciting as a murder mystery. What is also new is the interpretation of events and the analysis of the actors in the atomic drama. It is here that Jungk's subject is too big for him; his conclusions are frequently irresponsible, sensational and in questionable taste.

It is all to the good that Jungk comes to grips with the heart of the matter: the moral dilemma faced by those scientists attending the birth of the bomb. I cannot censure the author for concluding that his heroes are less than perfect; it may be the decision of history that they were evil personified. It is still too early to view the matter in its true perspective. Inasmuch as I, along with so many others, played my own role in this real-life epic, due allowance must be made for my defensive bias. Reading this book was an emotional experience for me; I found many old doubts, questions and uncertainties awakened. Sometimes Jungk touched old sores (he also succeeded in opening a few new ones), but usually I was moved not by remorse but by indignation.

Jungk takes us on a journey through the years to the quiet times when physics was a pleasant, intellectual subject, not unlike the study of Medieval French in its popular interest. At that time physicists were nonentities for the man on the street. In presenting rather carefully selected but sharply drawn vignettes of the period, Jungk is at his best. He has picked the right people and the right places at the right time to portray the beginnings of modern physics and modern physicists. He also shows a remarkable talent for discussing in adult but simple language some of the actual physics that was involved. Having sketched these idyllic times and then, I might add parenthetically, neglecting to give any account of the exceedingly important American work which bridged the period between early atomic physics and the later flowering of nuclear physics, Jungk comes directly to the atomic bomb. One of his main themes is the contrast between the wartime work of nuclear physicists in this country and of their counterparts in Germany. His extraordinary thesis seems to be this: Physicists in Germany managed, by their great diligence, *not* to build a bomb; physicists in the U. S., on the other hand, failed—they did *not* manage *not* to build a bomb. It is at this point that my indignation is aroused. Jungk's argument involves relationships of fact and moral value that are beyond the wisest of us to perceive at this stage of history. Furthermore, there is considerable artificiality about a discussion of the moral aspects of a scientific and technological development such as the atomic bomb. In the first place, there is no single-minded group which may be called "American physicists." Physicists do not look alike or think alike, nor are they of the same political persuasion. In the second place, important though physicists may have been in the making of the atomic bomb, there were a host of others—chemists, engineers, technicians, industrialists, military men—all of whom played important roles, and without whose cooperation and interaction the bomb would never have been built. Consequently it is presumptuous for me, a physicist, to discuss the ethics of the physicists who built the bomb. Obviously, however, each individual who participates in such a project does have a personal moral problem. One might also assign a measure of responsibility to each group of men in the project. If the physicists, for example, had decided not to build the atomic bomb, the bomb would probably not have been built. We physicists cast our lot with building it. We therefore bear the responsibility for our choice. Were we moral? Jungk thinks not, and by contrast praises the virtue of physicists working in Germany.

Let us consider the case of the Ger-

EDITOR'S NOTE

Each December since 1949 this department has reviewed a number of books about science for younger readers. The reviews begin on page 149.

man physicists. Because I take the optimistic view of human nature I should like to accept Jungk's views, but I cannot. The willing suspension of disbelief can go just so far. Jungk is the first person to make a serious case for the German physicists, and he makes it badly. A very different view of the matter has been presented by the Dutch-born U. S. physicist Samuel A. Goudsmit in his well-documented book *Alsos,* the result of his wartime study of German progress in developing nuclear energy. He has commented there, and elsewhere, on the conversations of the German physicists, temporarily in custody after the war, when they learned of the explosion of the atomic bomb. They were surprised. They had not believed that it was technically feasible. Goudsmit describes the German failure in terms of ineptitude, political interference and lack of support. Even if we choose not to believe this and accept Jungk's tale of a moral sit-down strike, the comparison is grossly unfair. Although it is now 15 years after the event, I still feel there is no comparison between physicists working for Nazi tyranny, which was hostile to intellectualism, and our activities in a desperate defense of a decent world. We are asked to believe that German nuclear physicists sabotaged the war effort while German rocket physicists worked enthusiastically, and successfully delivered to their armed forces what might have been a crucial weapon. Do blunted ethical perceptions go hand in hand with an interest in classical physics, and does morality march only with nuclear physics? It seems more logical that political and economic support was given to one field rather than another, and that this was decisive.

The other side of the argument, namely our failure not to make the weapon, is more complex. One should recall the atmosphere when work on the bomb began. The Germans were successful on all fronts; they were ruthless; there was a good chance that they would win the war. We knew that they were working on nuclear energy. I held pacifist views at the time, but in the light of the Nazi danger I felt that I had little moral choice. I suspect that the lines of the children of light and of the children of darkness were drawn as clearly as they ever will be. Neutrality would have been a selfish luxury.

Even if it was right to work on the Manhattan Project when the Germans were winning, was it right to continue the work after the Germans surrendered? In retrospect this question has bothered me greatly. Not at the time, however! Perhaps I should now respect myself more if I had left the work on V-E Day. The possibility simply did not occur to me. Events tumbled upon each other too quickly; the German surrender coincided with our preparations for the critical first test of the bomb in the New Mexico desert. We were the heroes of our epic, and there was no turning back. We were working on a problem to which we were completely committed; there was little time to re-examine our moral position from day to day.

In this connection I do remember calling in 1944 a meeting of my cyclotron group at Los Alamos. The subject of the meeting was rather pretentiously announced as "The Impact of the Gadget [the bomb] on Civilization." The meeting was advertised to other groups at Los Alamos, and between 50 and 100 scientists attended. We discussed what the world might be like as a result of our endeavors. At the time our work was not going very well; it was not at all evident that the bomb would be finished before the war was over. Secrecy was a necessary evil with which we lived uneasily. We imagined a world of conventional weapons and conventional world politics where the military kept the atomic bomb a secret. The best thing that we could think of—and we were all in agreement—was that it was absolutely essential to finish the bomb before the meeting in San Francisco at which the United Nations was formed. Then, it was our hope, the new world organization would be able to deal with the atomic bomb from the beginning. We failed that rendezvous. There was no consideration given at San Francisco to nuclear energy.

Those who criticize us for making the bomb might reflect on the kind of world which would have resulted had we not finished the bomb before the war was over. It seems almost certain that if we on the Manhattan Project had not built the bomb, the job would have been done by others within five or 10 years, either in this country or elsewhere. Nuclear energy was a time bomb set for the human race, and eventually the human race would have had to reckon with it. Was it not for the best that the public demonstration of the bomb, which ended World War II, came at a time when new relationships among nations were being established?

Jungk goes to considerable lengths to demonstrate the international origins of nuclear physics. Yet by implication he would have U. S. physicists bear the full responsibility for the bomb. During the war Los Alamos was as international a community of scientists as has ever existed. Our agreement in recognizing the hazards of nuclear energy was as complete as our agreement in purely scientific matters.

If Jungk is critical of the physicists who made the bomb, he is positively censorious of the decision to drop the bomb on Hiroshima and Nagasaki. There are many who share this view; I count myself among them. It is only with his conclusion that I am in agreement, however, for here, as usual, Jungk oversimplifies and distorts history. I recognize that my own feeling about the military use of the bomb was and remains largely sentimental rather than rational. I felt betrayed when the bomb was exploded over Japan without discussion or some peaceful demonstration of its power to the Japanese. More common, and possibly as rational, is the opinion held by many of my colleagues: that the war was ended by the atomic bomb and that more lives, both American and Japanese, would have been lost had the war been permitted to continue. Henry L. Stimson, who had more to do with the decision to drop the bomb than anyone else, perhaps expressed their sentiments when he wrote: "The face of war is the face of death; death is an inevitable part of every order that a wartime leader gives. The decision to use the atomic bomb was a decision that brought death to over 100,000 Japanese. No explanation can change that fact and I do not wish to gloss it over. But this deliberate, premeditated destruction was our least abhorrent choice. The destruction of Hiroshima and Nagasaki put an end to the Japanese war. It stopped the fire raids and the strangling blockade; it ended the ghastly specter of a clash of great land armies. The bombs dropped on Hiroshima and Nagasaki ended a war. They also made it wholly clear that we must never have another war. This is the lesson men and leaders everywhere must learn, and I believe that when they learn it they will find a way to lasting peace. There is no other choice."

Brighter than a Thousand Suns, like the Bhagavad-Gita, has its Krishna—Robert Oppenheimer. Although the author has never interviewed his subject, he has evidently discussed him at length with some physicists and has attempted what amounts to a skeletal biography. Oppenheimer is of course a fascinating figure, but one so complex and with such depths that I, who worked intimately with him during the war, would quail before the task that Jungk approaches so capriciously. It is not a flattering portrait, nor is it a true one. Once more the

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author stoops to what must be deliberate distortion by selecting what conforms to his thesis and ignoring the rest. Unfortunately he has been aided here by the more professional efforts of those who revoked Oppenheimer's clearance in 1954 and published the proceedings. Here were indecently exposed all manner of irrelevant private details about the life of a fine scientist who had devoted his best years to serving his country. The trial of Oppenheimer was one of the last great *autos-da-fé* of the McCarthy era. Perhaps a European journalist like Jungk cannot be blamed too much for his erroneous judgment so long as this ungrateful nation's verdict, made during hysterical times, stands unrescinded.

In view of Jungk's profound errors of judgment, it is perhaps pedantic to add that he has mangled the names of many minor characters of his epic, and that he has a positively abandoned manner with dates. He has not been able to copy with any degree of accuracy a simple list from *Atomic Energy for Military Purposes,* the classic history of the Manhattan Project. He indicates that liquor was banned at Los Alamos, when in fact the only fluid in short supply there was water. (When Klaus Fuchs was arrested, many of us not only asked ourselves, "Why did he do it?," but also, "How did he dare to drink so much at Los Alamos?") Oppenheimer was not educated at the Los Alamos Ranch School for Boys. It is simply not true that "barely a dozen physicists on the bomb projects had an over-all view." Robert Serber did not collect the pool money for the most accurate prediction of the energy released by the first atomic explosion, nor was he a "visitor" to Los Alamos. I. I. Rabi won the pool, and Serber was a regular member of the Los Alamos staff. The Wilsons lived across the hall from the Serbers, and often said: "The Serbers are our nerbers." The Serbers now live across the hall from the Rabis in New York. The world of nuclear physics is rather chummy, and anyone who confuses Robert Serber and I. I. Rabi has not studied that world very carefully.

All this is not, of course, particularly important. It suggests, however, that even Jungk's anecdotal history is weak. What is more to the point, the factual errors do indicate a lighthearted and uncritical approach toward his material, which becomes serious when he attacks men and interprets events. The book lacks the documentation one expects of a historian; one never knows whether Jungk obtained some particular fact from someone's lips or from an unpub-

lished paper or from his own vivid imagination.

Although I have criticized Jungk's book, I respect his motives in attempting to understand the forces that shape science and scientists. Assuming that civilization survives the invention of this ultimate weapon, the human spirit will be challenged often and perhaps even more seriously by future developments in science and technology. For me the question is: Are scientists to attain the heightened sense of moral values which will enable them to determine the direction of these developments with humanistic and humanitarian ends in view, or will humanists and humanitarians attain an understanding of scientific values that will allow them to determine the wise direction of science? I suspect that civilization will best be served by a true fusion—or at least a close mutual understanding—of science, the humanities and politics. There are many who are presently preoccupied with exactly this problem. Jungk has struck out boldly, if not carefully, in this direction by his provocative analysis of this case history of science, scientists and civilization.

Children's Books

THE WONDERFUL WORLD OF FOOD: THE SUBSTANCE OF LIFE, by John Boyd-Orr. Garden City Books ($3.45). At least a 21-gun salute for what is unquestionably one of the best designed, most intelligent of popular-science books in many years. Lord Boyd-Orr, first Director-General of the UN Food and Agricultural Organization and a Nobel peace prize winner, gives a lively, immensely knowledgeable account of the food problems of the world from the Old Stone Age to the present. He deals with primitive man's ways of scratching a living; the changes of time, climate and culture which led to herding, flock-keeping and farming; the development of agriculture in antiquity; the diet of medieval peasants, townsfolk and the rich; the gradual increase in the variety of crops and foods brought about by exploration, trading and contact between the New World and the Old; the effect of enclosure, industrialization, blight, harvest failures and wars upon food supply; the enlargement of the larder by inventions and advances in scientific agriculture; the use, abuse and conservation of farmlands; the methods of dealing with pests, weeds, and other plant and animal enemies; the nature of selective breeding; the fishing, canning and processing industries; food storage and transportation; areas of food shortage; world diet habits; the relation between food and fitness; research on nutritional diseases and on organisms that infect foods; the study of vitamins; different ways of preparing food; the continuing dangers of famine and their social and economic consequences. Boyd-Orr writes from broad knowledge and experience; his book is informed by his courage, kindliness and humanitarianism. But it is not only the text which makes this work outstanding: there are more than 200 illustrations, many in color, which add immeasurably to the richness and clarity of the story. They consist of photographs, attractive paintings especially done for this book, simple and enlightening graphs and diagrams, reproductions of old woodcuts, handbills and the like. Every page is a treat for the eye. This beautiful and exciting book, produced and printed in Great Britain, sets a new standard. For readers of 12 and older.

THE WONDERFUL WORLD OF ENERGY, by Lancelot Hogben ($2.95); THE WONDERFUL WORLD OF MEDICINE, by Ritchie Calder ($3.45). Garden City Books. These two volumes, in the same series as Boyd-Orr's study of food, are superior science primers, ably written and handsomely illustrated. Hogben's story of man's conquest of power presents some of the highlights of physics and chemistry. He describes the early use of simple machines such as the slope and sledge; the principle of the lever, pulley and capstan; the introduction, in different forms, of water power; the discoveries of Galileo and Torricelli; the history of clocks; the invention of the steam engine and locomotive; the work of Guericke, Franklin, Galvani, Volta; applications of the chemical, magnetic and heating effects of electric current; the foundations of modern chemistry; the advances of Boyle, Charles, Avogadro, Gay-Lussac, Faraday; the rise of atomic energy. His account is a little too ambitious and diffuse, but there is much in it to give pleasure and to prompt further reading. Calder, a very able British science journalist, unfolds in brief compass the story of man's quest for health. An introductory chapter deals with the growth of knowledge of human physiology—muscles, blood circulation, glands, the brain and nerve network, the role of the genes. There follow sections on the battle against disease in ancient and medieval times; the achievements of Virchow, Jenner, Pasteur, Lister, Koch, Ehrlich, Domagk, Fleming and others; modern medical therapy; the development of hospitals and clinics; medical aid in remote and backward areas; the

activities of the World Health Organization; the cooperative efforts to produce healthy living conditions. Both these books and Boyd-Orr's are ideal Christmas gifts and are essential to any science bookshelf, however modest.

KANGAROOS AND OTHER ANIMALS WITH POCKETS, by Louis Darling. William Morrow and Company ($2.50). At birth a baby kangaroo is less than an inch long, naked, blind and almost helpless. It has just enough strength to make a single vital journey. Immediately after it is born it gropes its way up its mother's broad tail, "scrambling like a little swimmer in a furry sea," to her pouch. There it attaches itself to a nipple and settles down for a continuous three- or four-month draught of milk. The mother pays no attention, and the baby drinks, sleeps and grows. By the time it is four months old it emerges from the pouch for brief inspection trips. It hops about, nibbles at grass and dives back into the pouch at the slightest alarm. After a while it takes only occasional drinks while standing at the milk bar, and when it is six months old it is fully weaned and ready to take care of itself. One day the mother cuffs it away when it tries to enter her pouch. At six months the young kangaroo is still a bluish gray; at one year it is four feet high and its coat begins to turn yellowish-orange and finally the color of old brick. Kangaroos are peaceful vegetarians that spend their days grazing, browsing, resting among groves of trees; they make shallow pits where they sleep and occasionally toss a pawful of dust into the air to drive away the flies. When they are young the males spar with each other in their inimitable style of boxing; later the fights grow sterner and bloodier, especially when a grown male who is the ruler of a kangaroo "mob" defends his sovereignty and tries to drive pretenders and claimants away. A good-sized male weighs 200 to 300 pounds and can cruise at 15 miles per hour, using his large hindlegs and feet to hop along and his broad tail for balance. Pressed, he can make 20-foot leaps and do 30 m.p.h. Red kangaroos are confined to Australia, which also houses wallabies, rat- and tree-kangaroos, rock wallaroos, jerboas, marsupial tiger cats, Tasmanian wolves, marsupial moles, wombats, gliders, opossums, slow lorises, pottos, and other marsupials. Louis Darling tells and illustrates this natural-history story pleasantly. For 8- to 12-year-olds.

SPACE BOOK FOR YOUNG PEOPLE, by Homer E. Newell, Jr. Whittlesey House ($2.95). Most space books, may

their tribe decrease, are likely to persuade the reader to stay in Brooklyn. This one, by a mathematician who works on rockets, is somewhat better than average. It wanders among a number of subjects which may be thought to prepare the way for understanding the central problem: big and small numbers, exponential notation, the earth and its atmosphere, the moon, sun and planets, comets, galaxies, radio astronomy. The last three chapters are on rockets and space flight. For readers of 12 and over.

FIRST CAME THE FAMILY, by Ruth M. Underhill. William Morrow and Company ($3). Dr. Underhill, an anthropologist and former Supervisor of Indian Education for the U. S. Indian Bureau, presents an excellent account of the role of the family in different societies and at different times in the evolution of human culture. She explains the family concept among the Papago Indians of Arizona, the herders of Siberia, the peasants of the Balkans, the Zulus of South Africa, the Eskimos, the Trobriand Islanders, the Hopis, the Zuñis and other peoples. She discusses patrilineal and matrilineal descent, the clan, the distinction between cross cousins and parallel cousins, the absolute role of the father among the Romans and the Anglo-Saxons, the courting customs of many cultures. A feast is the culminating act of the marriage ceremony in many religions, but the Papagos' ceremony and feast consist of taking the bride to the groom's house, giving him a basket of beans and receiving a basket of corn in return. A Creek Indian bride's father says to his new son-in-law: "There is your bed. Lie in it." A Mohammedan bride need not even be present at her wedding. Other chapters deal with polygamy, the institution of the harem, married life in different societies, the raising of children, the giving of names (Gourd Head, Young-Men-Are-Afraid-Even-of-His-Horse, Big Crazy are choice examples), the child's and the adolescent's place, the attitude towards old people. A wise, human and appealing introduction to social anthropology. For readers of high-school age.

CONSERVATION IN AMERICA, by Dorothy Childs Hogner. J. B. Lippincott Company ($3.75). Mrs. Hogner's story is in two parts. The first recounts the reckless consumption and wasting of resources from the discovery of America to the present; the second describes the efforts of public and private groups to arrest this profligate trend by preserving

animal life, restoring the land, renewing the forests, husbanding water supply, and applying other conservation measures. Some species of animals, as everyone knows, have been exterminated, while others are in grave danger of extinction. The passenger pigeon and the flightless great auk have vanished from the earth; the ivory-billed woodpecker (the rarest American bird), the much-publicized whooping crane (the second rarest bird), the California condor, the everglade kite, are among the animals very likely to die out despite all our exertions. The bison and the grizzly bear are showpieces preserved in pitifully small numbers; many other species are able to survive only because of wildlife refuges and other forms of protection. The sea otter is a happy exception to the fate of species that for one reason or another roused man's rapacity. For decades it was thought that fur-traders had entirely killed off the southern herds, while the northern herds were known to be dwindling rapidly. Then suddenly, half a century ago, a few sea otters were seen in the kelp beds off the coast of Monterey. Thanks to conservation statutes the southern tribe has now increased from 100 to 500, and the herds of Alaska and the Aleutians, guarded by international treaty, again number in the thousands. Mrs. Hogner describes the shrinking of unrenewable resources, such as oil, coal and various metals; the working of the Federal and state conservation laws; the elaborate program directed against the great Western dust bowl; river-basin planning and flood control; reforestation; the protection of fish and other forms of sea and inland-water life. A good book for adolescents.

ALL ABOUT SATELLITES AND SPACE SHIPS, by David Dietz; ALL ABOUT THE HUMAN BODY, by Bernard Glemser; ALL ABOUT FAMOUS SCIENTIFIC EXPEDITIONS, by Raymond Holden; ALL ABOUT MONKEYS, by Robert S. Lemmon; ALL ABOUT ANIMALS AND THEIR YOUNG, by Robert M. McClung. Random House ($1.95 each). The chief merit of these formula books, addressed to children from 9 to 12, is that they never fall below a reasonable standard. On the other hand, they rarely rise above it either in originality, style or scientific content. Dietz's report is mainly composed of material that can be got out of the newspapers. Glemser's primer of anatomy and physiology is sensible. Various scientific expeditions—Beebe's bathysphere descents, the climbing of Mount McKinley, the discovery of Tut-Ankh-Amen's tomb, the Burden dragon-hunting expedition

to Komodo Island, the 1913-18 Canadian Arctic Expedition—are described by Holden in a clumsily written book. Monkeys are nicely classified and portrayed by Lemmon. McClung collects odds and ends about different kinds of animal babies, how they are fed and reared.

UNDERSTANDING TIME, by Beulah Tannenbaum and Myra Stillman. Whittlesey House ($3). On the science of clocks and calendars. There are chapters on sundials, fire-, water- and sand-clocks, the evolution of the escapement mechanism and mechanical clocks, measuring the year, standardizing time, the relativity of time. The story is well told and full of diverting facts. For example, when clepsydras or water clocks were used in the law courts of ancient Rome and Greece, a certain number of clepsydras (which usually held about 30 gallons of water and emptied in about 20 minutes) were allowed for each speaker—two, say, for the prosecution, two for the judge, three for the defense. A special court officer stopped the flow of water when documents were read so as not to cut into the speaker's time. The people of Rome called wasted time *aquam perdere*, which means "to lose water."

THE TOOLS OF SCIENCE, by Irving Adler. The John Day Company ($3). The scientist looks at, listens to, counts and measures the physical world with many tools from a ruler to a cyclotron. From this book one can learn a little about the purpose and use of a number of these tools. Adler discusses lenses and microscopes, cloud chambers, microphones and other devices for bringing our senses in line with our imagination. He writes plainly and sensibly but tries, as he often does, to cover too much ground. For readers of 12 and older.

DUST BOWL: THE STORY OF MAN ON THE GREAT PLAINS, by Patricia Lauber. Coward-McCann, Inc. ($2.50). An exceptionally clear, sympathetic and readable account of the terrible dust storms that scourged the Southern Great Plains a quarter-century ago. Cattle, railroads and sheep were the effective causes of the black blizzards that first struck Kansas and other Plains states in 1933, ruined the crops, suffocated the livestock and drove farmers from their land. Overgrazing and overplowing had stripped the Plains of their protective grass cover; high winds and drought, inevitable in this region, tore up the soil and brought catastrophe. In a true sense man reaped the whirlwind of his folly. Miss Lauber tells this dramatic story and

describes the measures taken with the help of the U. S. Soil Conservation Service—replanting grass and trees, contour plowing, strip cropping and terracing—to make farming of the Plains possible once again. The drought of the 1950s did less damage than that of the 1930s. Farmers suffered, but their land did not blow away, and there is hope that improved conservation methods and prudent use of the land will finally overcome the dangers of the dust bowl. Good photographs. For ages 12 to 15.

PREHISTORIC ANIMALS, by the Editorial Staff of *Life* and Lincoln Barnett; THE SEA, by the same authors; FAMOUS AMERICAN SHIPS, adapted from *American Heritage* by Walter Franklin; INDIANS AND THE OLD WEST, adapted from the same source by Anne Terry White; WILDLIFE OF THE WEST, by Robert Louvain and the staff of the Walt Disney Studio; WHITE WILDERNESS, by the same authors; BIRDS OF THE WORLD, by Eunice Holsaert; BUTTERFLIES AND MOTHS, by Richard A. Martin. Simon and Schuster (50 cents each). These eight volumes, the first in a new series called the Golden Library of Knowledge, are clearly written and attractively illustrated. A surprising amount of material is contained in each 56-page book, and the pace and variety of the presentation are just right for youngsters of 10 or 11 and older. The volumes on prehistoric animals and the sea are familiar packages adapted from articles in *Life;* the books taken from the *American Heritage* articles are colorful, and Mrs. White's adaptation has conspicuous merit; the Disney material is smoothly executed; the bird and butterfly primers are accurate and interesting. If the new series gives as much satisfaction to young readers as other Golden Books have done, it should have a long career.

STRANGE PLANTS AND THEIR WAYS, by Ross E. Hutchins. INSECTS: HUNTERS AND TRAPPERS, by Ross E. Hutchins. Rand McNally and Company ($3.95 each). These two books by a Mississippi zoologist and entomologist concentrate on some of the more fantastic members of the plant and insect world. In the repertory are flowers that capture insects, moths that lay eggs in yucca pods, parasitic plants such as the mistletoe and dodder, mangroves that walk, creeping slime-molds, Mexican jumping beans (a built-in caterpillar is the secret), vampire wasps, beetles that can lift 850 times their weight, water scorpions and striders, cicada killers, cricket-eating aphids, ant lions, robber flies, assassin bugs. Many photographs. For children of 10 and up.

THE SEA AROUND US, by Rachel Carson. Simon and Schuster ($4.95). A special edition for young readers, adapted by Anne Terry White, illustrated with 150 photographs, maps and drawings in color and black and white. Mrs. White has done a good job in combing out some of the excess rapture of Miss Carson's full-length original, without diminishing the intrinsic fascination of the story, and the illustrations range from so-so to stunning. An excellent gift for readers of high-school age.

EXPLORING CHEMISTRY, by Roy A. Gallant. Garden City Books ($2.95). A large-format, colorfully illustrated sketch of the history of chemistry from the early gropings to the present sophisticated state of the science. A reasonable sampler for 10- to 12-year-olds.

LOUIS PASTEUR, by Nesta Pain. G. P. Putnam's Sons ($2). An acceptable, straightforward young people's biography of the immortal microbe hunter. One of the best features of this unassuming little book is that there are no imaginary conversations.

OSTRICHES, by Herbert S. Zim. William Morrow and Co. ($2.50). About the bird that cannot fly, has no wishbone, weighs up to 300 pounds, once decorated ladies' hats, has been ridden in races and been used as a beast of burden, and lays large eggs whose shells were valued as cups and vases in Mesopotamia and Mycenae of 3000 B.C. For 8- to 12-year-olds.

DEEP TREASURE: A STORY OF OIL, by Elizabeth Olds. Houghton Mifflin Company ($3). How oil was formed in the earth, its discovery by man and its early uses, the beginning of oil-drilling and the growth of a huge industry from Edwin Drake's first derrick in Titusville. For 7- to 10-year-olds.

EXPERIMENTS WITH LIGHT, by Nelson F. Beeler and Franklyn M. Branley. Thomas Y. Crowell Company ($2.75). A sound, unpretentious little book on elementary optics by a pair of experienced writers and teachers. Experiments showing that light "travels in the dark" (which explains why outer space is dark); on the nature of light; on measuring light's wavelength; on light and color, lenses, polarized light, phototropism, microscopes, kaleidoscopes and related topics. For youngsters of 12 to 16.

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ANNUAL INDEX

The following index lists all the articles and authors that appeared in SCIENTIFIC AMERICAN *during 1958. The index also lists the principal book review in each issue.*

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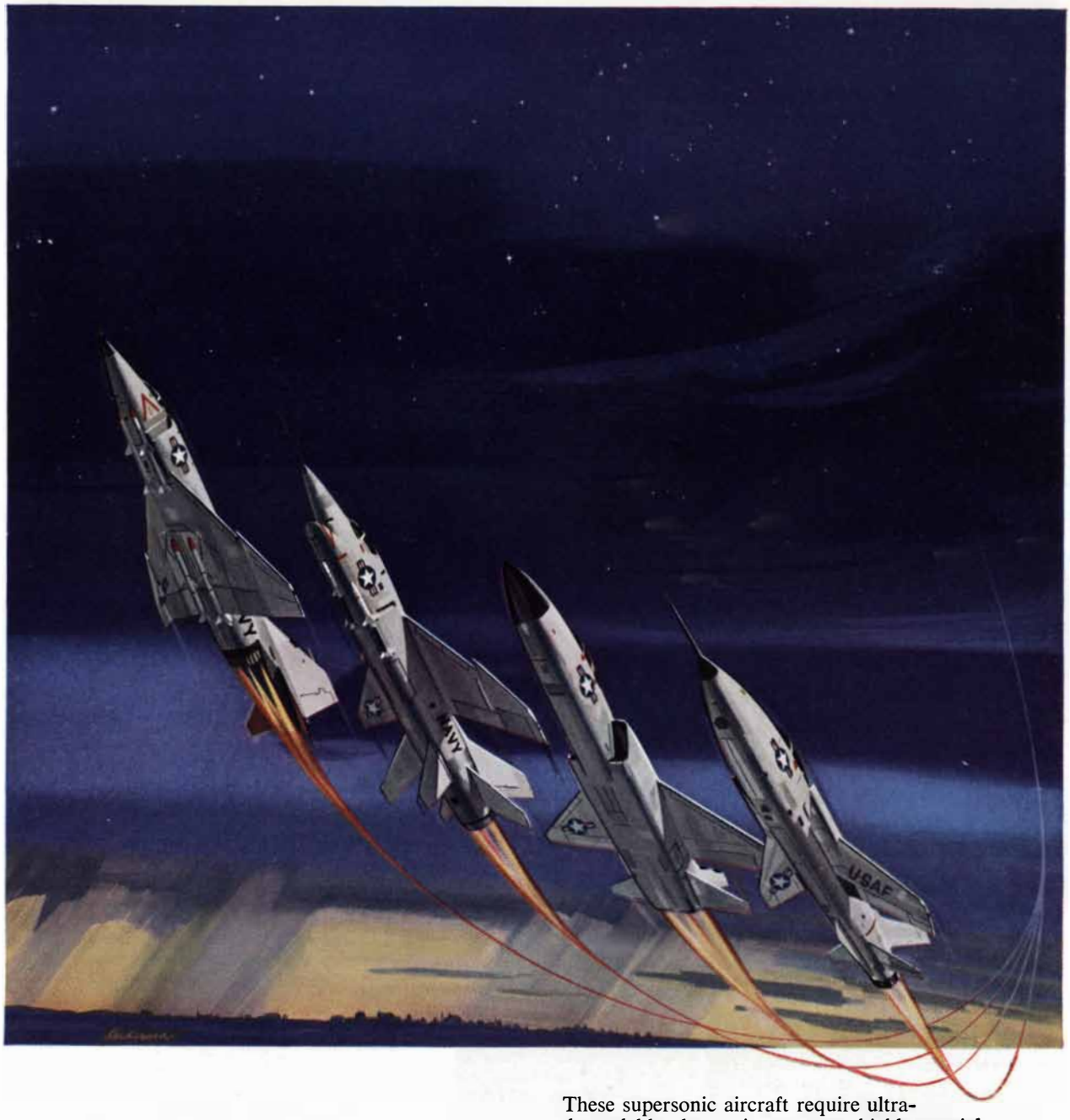

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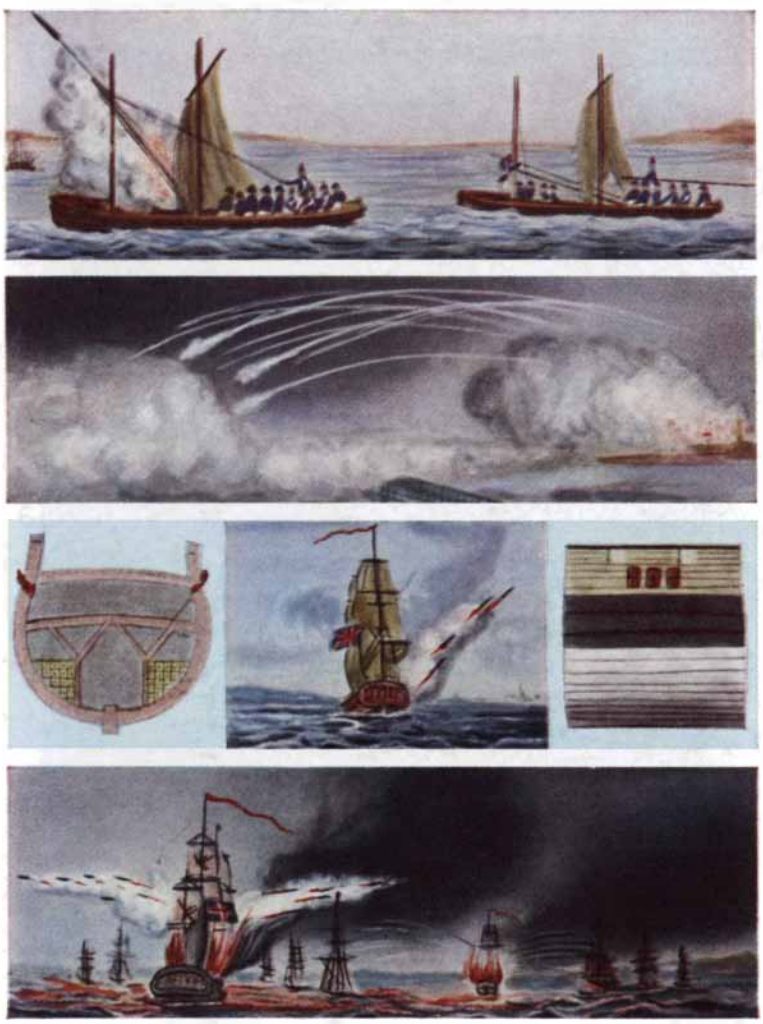

"Their explosion will clear the way for the boarders, both by actual destruction and by the powerful operation of terror among the crew."

The experiments of Sir William Congreve led to the deadly rocket bombardments by the British of Boulogne in 1806 and Copenhagen in 1807. Congreve's warhead-bearing rockets helped break Napoleon's power in 1813 at Leipzig, made possible the capture of Washington in 1814 and, the same year, inspired Francis Scott Key's memorable line, "the rocket's red glare," during the attack on Fort McHenry. Congreve ultimately worked out a complete "system" for the employment of rockets on land and sea, including rocket types, equipment, organization, tactics—forerunner of today's weapons systems. Modern counterpart of Congreve's "Rocket System" is Convair's surface-to-air missile *Terrier*, now operational at sea with vessels of the United States Navy and on land with units of the United States Marine Corps.

From "Dynamic America," a history of 420 pages and 1500 illustrations to be published soon by Doubleday & Company and General Dynamics Corporation, 445 Park Avenue, New York 22, N. Y.