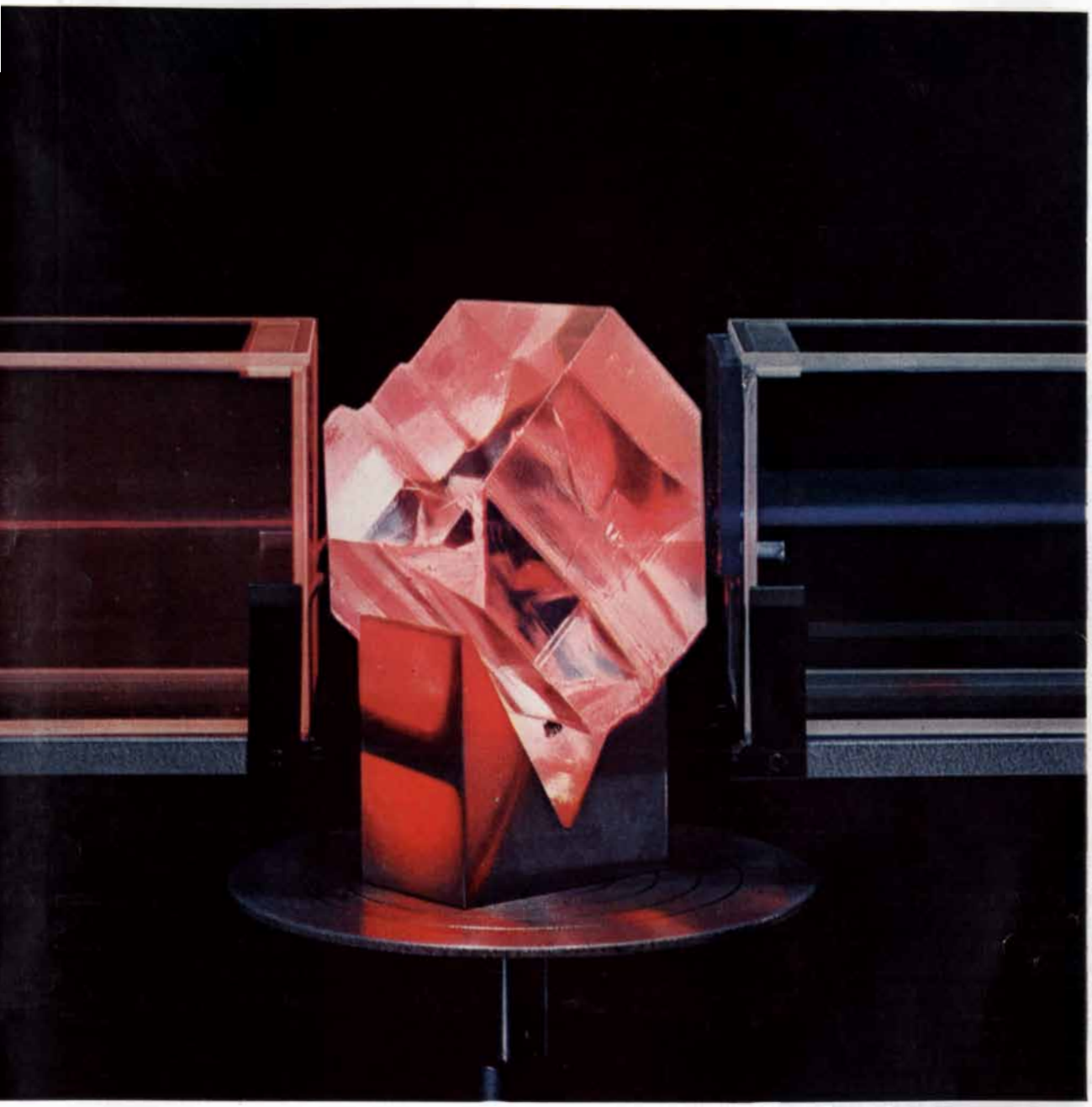
SCIENTIFIC AMERICAN



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July 1963

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Established 1845 **SCIENTIFIC AMERICAN** July 1963 Volume 209 Number 1

ARTICLES

DEPARTMENTS

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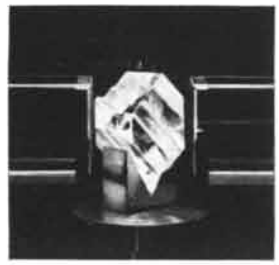

THE COVER

The photograph on the cover shows a beam of red light from a ruby optical maser entering from the left and striking a colorless crystal of ammonium dihydrogen phosphate (see "Advances in Optical Masers," page 34). Inside the crystal a portion of the red beam, which has a wavelength of 6,940 angstrom units, is doubled in frequency and emerges with a wavelength of 3,470 angstroms. The emerging beam is invisible (ultraviolet) but records as blue on color film. The experimental apparatus was built by R. W. Terhune and his associates at the Ford Motor Company's Scientific Laboratory.

THE ILLUSTRATIONS

Cover photograph by William Vandivert

Page	Source
35	General Electric Research Laboratory (*top*), James Egleson (*bottom*)
36	Ford Motor Company (*top and bottom right*), Bell Telephone Laboratories (*bottom left*)
37–41	James Egleson
43	Joan Starwood
44	Sperry Gyroscope Company (*top*), James Egleson (*bottom*)
45	Jarrell-Ash Company
46–47	Stefan Martin
48–49	Sol Baruch
50–51	Stefan Martin
52	Sol Baruch
53	Sol Baruch (*top and third from top*), Choh Hao Li (*second from top and bottom*)
54	Ursula Mittwoch
55	Anthony Bligh
56	Hatti Sauer
57	Anthony Bligh
58	James L. German III
59	B. B. Mukherjee, O. J. Miller, Saul Bader, Columbia University College of Physicians and Surgeons, and W. Roy Breg
60–61	Hatti Sauer
62	Murray L. Barr and E. G. Bertram
71	Irving Geis
72	Dan Todd
73–77	Irving Geis
78–79	Dan Todd
80	Irving Geis
82	Dan Todd
83	Joan Starwood
88	Fairchild Aerial Surveys
90–91	Library of East Asian Studies, Columbia University
92–95	John Langley Howard
96	Aerofilms and Aero Pictorial Limited (*top*), Morton Salt Company (*bottom*)
98	John Langley Howard
101	Heine Hediger and H. Heusser
102–103	Thomas Prentiss
104	K. H. Lüling
106–108	Thomas Prentiss
110–111	Allen Beechel
112	Alex Semenoick
113	Allen Beechel
114–115	Alex Semenoick
116	Allen Beechel
118	A. R. Mackintosh
120	Allen Beechel
122–123	Jack J. Kunz
124	William H. Miller (*top*); Jack J. Kunz (*middle*); Donald Kennedy (*bottom*)
126–130	Jack J. Kunz
132–142	Jerome Kuhl
144–150	Roger Hayward

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LETTERS

Sirs:

In his article "Radiation Belts" [SCIENTIFIC AMERICAN, May] Brian J. O'Brien discusses the experimental data on the natural and artificial radiation belts and then refers briefly to the cosmic ray neutron-albedo theory of the origin of the natural belt. O'Brien states that the theory "remains an attractive one because it can be placed in a mathematical framework, and its proponents die hard."

Aux armes, citoyens! Formez vos bataillons. . . The theory is attractive because it apparently accounts for all the observations of the high-energy protons, and—truer words were never spoken—its proponents are still very much alive and battling; in fact, they form a veritable foreign legion. We boast such old warriors as Vernov and Lebedinski in the U.S.S.R. and more recent recruits such as Galperin and Shklovsky; other veterans are Kellogg and Lenchek, now in France, Haerendel in Germany and quite a number of us in the U.S., including Freden, White, Heckman, Dessler, Hess and Wentworth.

The question of whether or not the neutron-albedo theory would survive has been an exciting one ever since it was first published. The theory was stimulated by the discovery of the trapped radiation, but it then made many predictions that did not seem to be in accord with what was observed. It predicted high-energy protons, of several hundred million volts, when the counters in the early satellites saw none. It predicted a reasonably constant intensity when the data appeared to show time variations. It predicted a maximum of the protons between one or two earth radii at a time when it was believed the belt would increase up to many earth radii, or even up to the sun. Our early strategy was: "Let's wait and see if the data go away." Things looked black, but the first real turning point for the theory came in 1959 with the discovery that there are indeed trapped high-energy protons; it was made in a little photographic emulsion, flown up in a rocket and analyzed by Freden and White. Some of the most significant "victories" have come from other photographic-emulsion experiments, for example those of Armstrong, Harrison, Heckman and Rosen, and of Naugle and Kniffen.

The early faith in the correctness of the albedo theory led, of course, to the hypothesis that there were two belts of fundamentally different origin, and this hypothesis was substantially confirmed in the *Pioneer* flights, as O'Brien explains. The theory gave the distribution-in-energy of the protons and their distribution in space, and showed that the high-energy protons should disappear at higher altitudes; all these results have been verified by observations. The theory even predicts a kink in the intensity around 1,200 kilometers, where the character of the atmosphere changes from a predominantly oxygen atmosphere into a hydrogen and helium atmosphere; this again has been verified.

Now, in the matter of *electrons* the neutron-albedo theory has not been much help. Here O'Brien sets up a straw man and knocks him down. Only a few zealots have tried to maintain that the neutron-albedo theory accounts for the electrons. Most of us conservatives have stuck to protons and have tried to establish our beachhead in as solid a way as possible.

The battle is not over—strange time variations have appeared and have been published by Van Allen and O'Brien. One of our more active recruits, Hess, has taken on this particular fight, and the pages of the *Journal of Geophysical Research* are littered with letters to the editor, back and forth.

Admittedly some of the consequences of the neutron-albedo theory are hard to accept. It is a mechanism that gives a feeble injection of particles, about one particle per cubic centimeter every mil-

Scientific American, July, 1963: Vol. 209, No. 1. 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.

Editorial correspondence should be addressed to The Editors, SCIENTIFIC AMERICAN, 415 Madison Avenue, New York 17, N.Y. Manuscripts are submitted at the author's risk and will not be returned unless accompanied by postage.

Advertising correspondence should be addressed to Martin M. Davidson, Advertising Manager, SCIENTIFIC AMERICAN, 415 Madison Avenue, New York 17, N.Y.

Subscription correspondence should be addressed to Jerome L. Feldman, Circulation Manager, SCIENTIFIC AMERICAN, 415 Madison Avenue, New York 17, N.Y.

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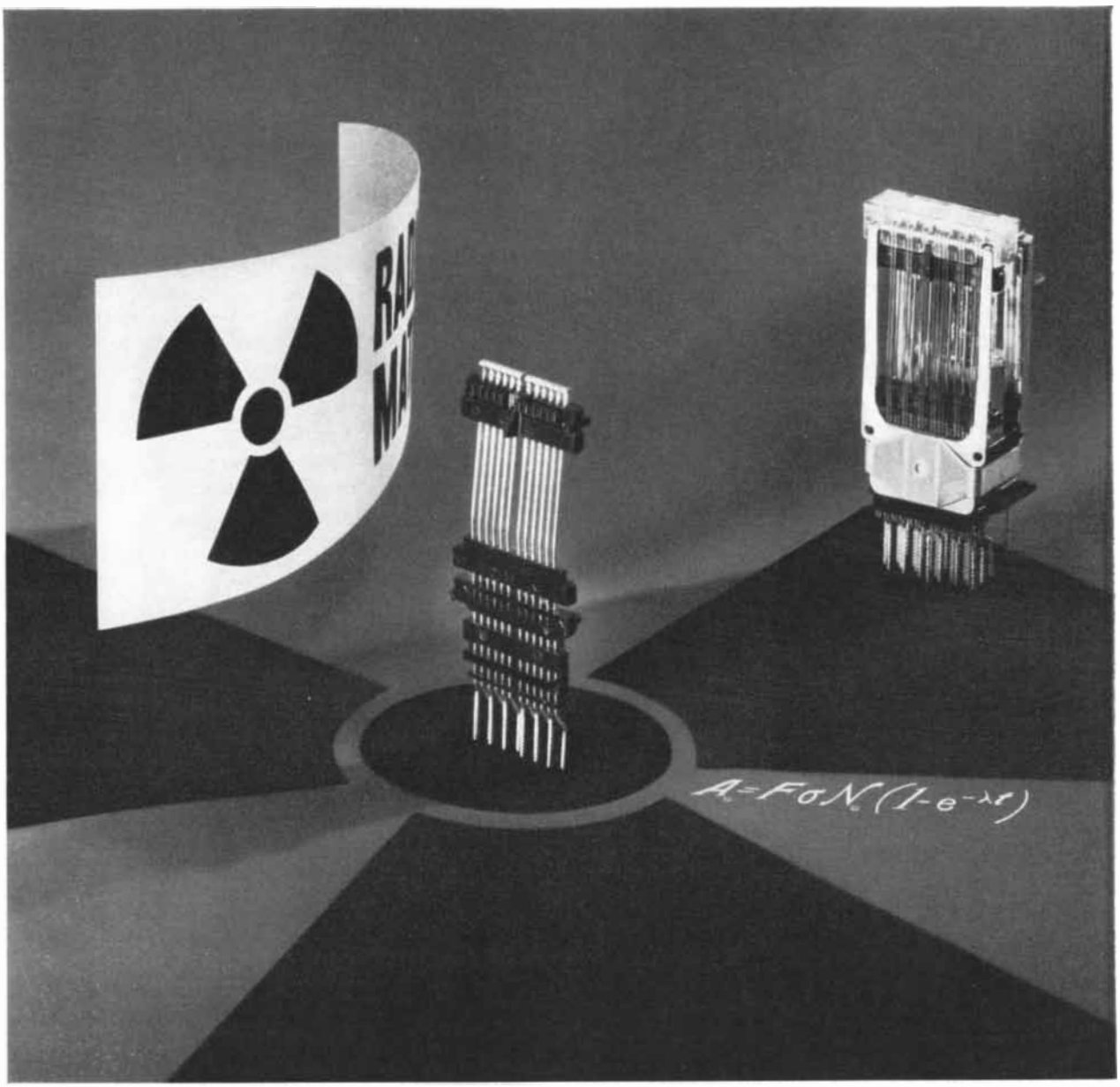
RADIOISOTOPES. To improve measurement accuracy, process control and analysis, Western Electric engineers utilize the unique properties of nuclear radiation. Radioactive isotopes are used as tracers to test for leaks, detect structural weakness, measure thickness and wear. Example: a severe die erosion problem arose in the molding of plastic parts for the wire spring relay, an integral part of equipment for switching calls in the Bell telephone network. W. E. engineers tagged a steel insert in a test die with a radioactive tracer. The amount of steel worn off as various compounds were tested was determined by measuring the radioactivity of the molded parts with a gamma ray spectrometer. Correlations established between the radioactivity of molded parts and formulations of molding compounds made it possible to select a compound with 1/20th the erosiveness of the one previously used, thereby extending die life many times. Another reason why Americans have the finest, most economical communications in the world. **WESTERN ELECTRIC**



lion years. But these particles apparently live for a long time. The high-energy protons can last for several hundred years, and the artificial radiation belt in essence confirms this. Since the high-energy electrons there can last for a decade, the lifetime of a proton that has a range about 60 times greater will be of the order of 600 years. It is difficult to understand, therefore, why "neutron-albedo theory" is a dirty word in parts of the Middle West.

There is an unrelated but interesting point that can be made in connection with O'Brien's statement that *Sputnik II* confirmed the findings of *Explorer I* and *Explorer III*. In fact, the second sputnik went into orbit in November, 1957, several months before *Explorer I*. In late 1957 the Russians published their first results, showing a rapid rise in intensity between 400 and 700 kilometers. Had they been able to extend their readings to higher altitudes they would have seen a much more startling increase and perhaps guessed its cause. But as it turned out, *Sputnik II*'s perigee remained over the U.S.S.R., whereas its apogee was in the Southern Hemisphere. In fact, the Australians were recording *Sputnik II* and obtaining data up to 1,680 kilometers, but they didn't have the code for interpreting the telemetering. Last year at a conference in Kyoto I asked Professor Messel of Sydney why the Russians never got the high-altitude data from him. He replied: "They wouldn't send us the code, and we were not about to send them the data." The whole episode provides an interesting comment on how Russian preoccupation with secrecy damaged their own scientific program.

S. Fred Singer

University of Maryland
College Park, Md.

Sirs:

Dr. Singer's letter has two main points, first that I did not do justice to the neutron-albedo theory in my article, and second that "Russian preoccupation with secrecy damaged their own scientific program" regarding *Sputnik II* recordings.

On the first point, the theory has been used in attempts to explain the four main features of the inner Van Allen belt, viz., (1) the energy spectrum of the electrons, (2) the spatial distribution of the electrons, (3) the energy spectrum of the protons and (4) the spatial distribution of the protons.

Dr. Singer says only "zealots" have used it to treat items 1 and 2, so I'll ignore these.

I stated in *Scientific American* regarding 3 that "the range of energies of protons found in the [inner] zone agrees with this [neutron-albedo] view." So I gave it due credit for explaining item 3.

Dr. Singer asserts that it also explains item 4, the proton distribution in space. He mentions that it "led, of course, to the hypothesis that there were two belts of fundamentally different origin." Unfortunately for this point of view, Carl McIlwain of the University of California has discovered another "belt" of high-energy protons located midway between the two belts mentioned by Dr. Singer. I was aware of McIlwain's finding when I wrote the article, but he had not released it publicly then. This finding is inconsistent with the predictions of the neutron-albedo theory in its *presently developed and published form*. The theory therefore does not explain item 4.

The theory thus explains item 3 only, and even then the original theory had to be modified to include solar protons as well as cosmic rays as an ultimate source. I gave it credit for what it can explain and indicated some of the features that it does not explain. That still seems to be a reasonable treatment.

Dr. Singer's second point is that the Russians did not get recordings of data from *Sputnik II* at altitudes up to 1,680 kilometers (and hence by implication perhaps they did not recognize the trapped radiation before Van Allen did) because they were preoccupied with secrecy and wouldn't send Messel's team the "code." In fact Messel's team studied *Sputnik III* (not *Sputnik II*), launched about two weeks *after* Van Allen's report in Washington about the discovery of the radiation. The team studied it because "In June, 1958, the ... University of Sydney received a cabled request from the ... U.S.S.R. asking for help with the recording of signals from *Sputnik III* ...." (The quotation is from Herz *et al.*, *Nature*, August 8, 1959.) Part of the story about supply of the code to the Australians is contained in that article. Therefore Dr. Singer's statements concern the wrong satellite and I present the above quotation to show that his conclusions about Russian attitudes are not proved in his letter.

Brian J. O'Brien

State University of Iowa
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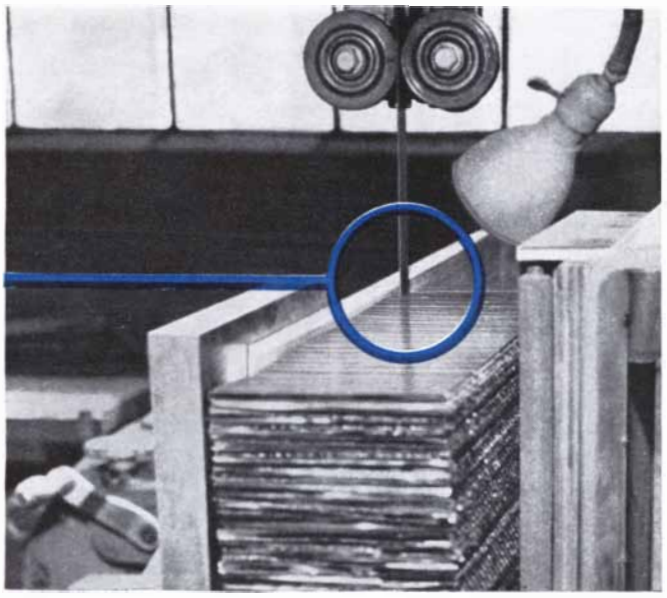
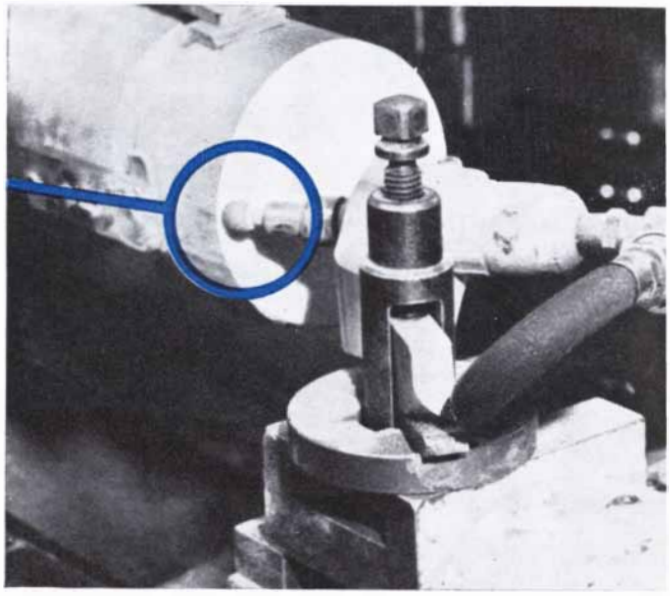
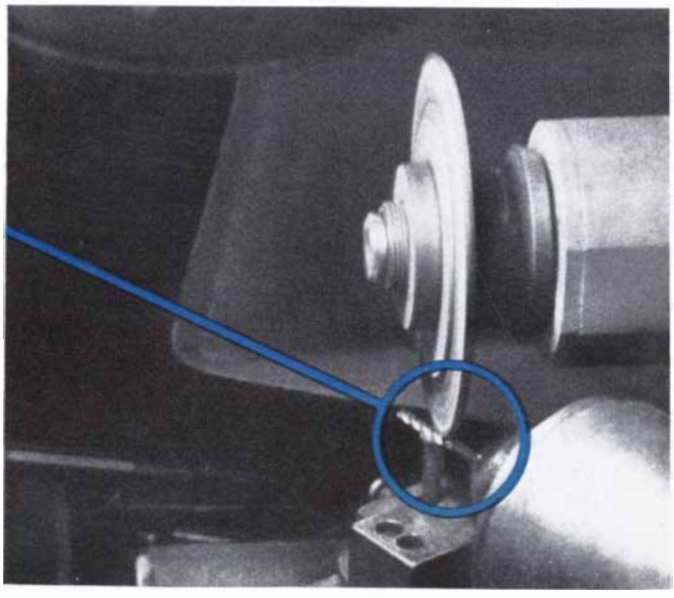


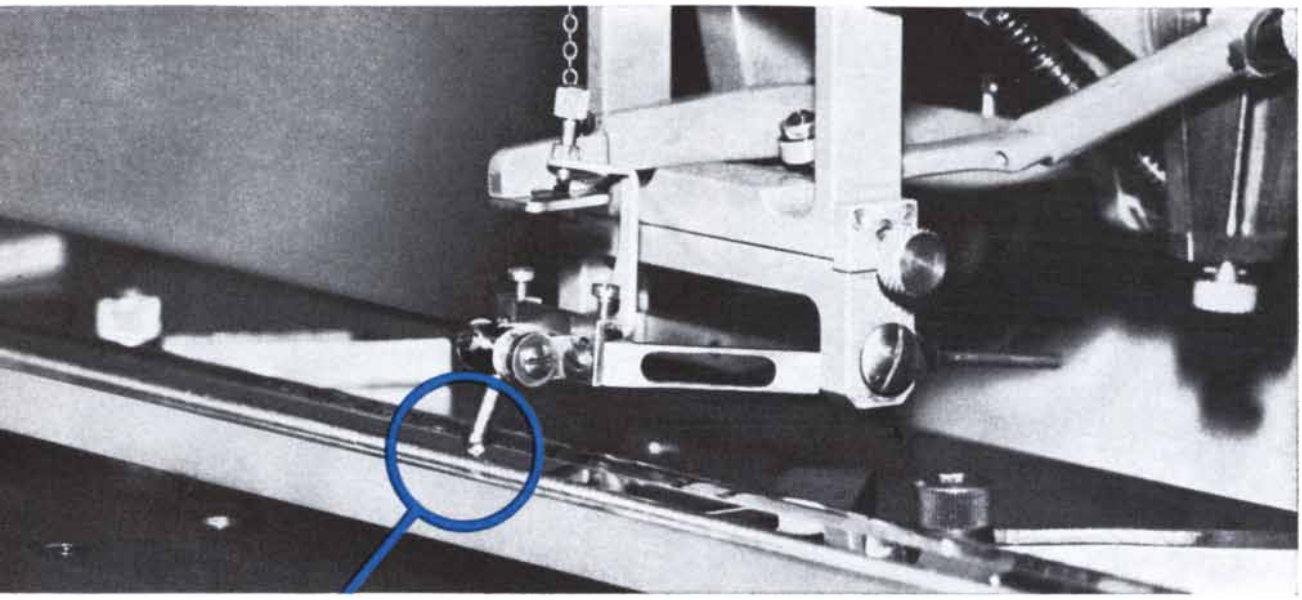
Band saw edged with natural diamonds cuts sandwich core panels from molybdenum alloy honeycomb billets at the Martin Company. The special fixture was designed to hold the billet for parallel cuts. Guide rollers prevent blade vibration. Blade cuts dry at speed of 4000 s.f.m.



Ball cutter, a steel sphere coated with particles of natural diamonds, grinds alumina ceramic to proper curvature for rocket heat-shield nose cap. The cutter rotates at 30,000 r.p.m., and is set to remove 3/32 inch of stock on roughing and 1/32 inch on finish cut.



Natural-diamond wheels (vitrified bond) grind small-diameter carbide drills to half-thousand tolerances at Raymac Division, Dexco Corp., Detroit. More delicate fluting operations are done between 3600 and 5400 s.f.m. Finally, diamond micron powders finish flutes to within 4 to 8 micro-inches.



Natural-diamond scribing tool marks graduations on a linear scale for Hilger & Watts Ltd., London, England. Material being scribed is steel with chromium coating. The diamond tool makes V-shaped lines in the scale which appear black on the bright surface, making them easily read under magnification. For marking some instruments, the width of the diamond wedge must be as narrow as .0001 inch.

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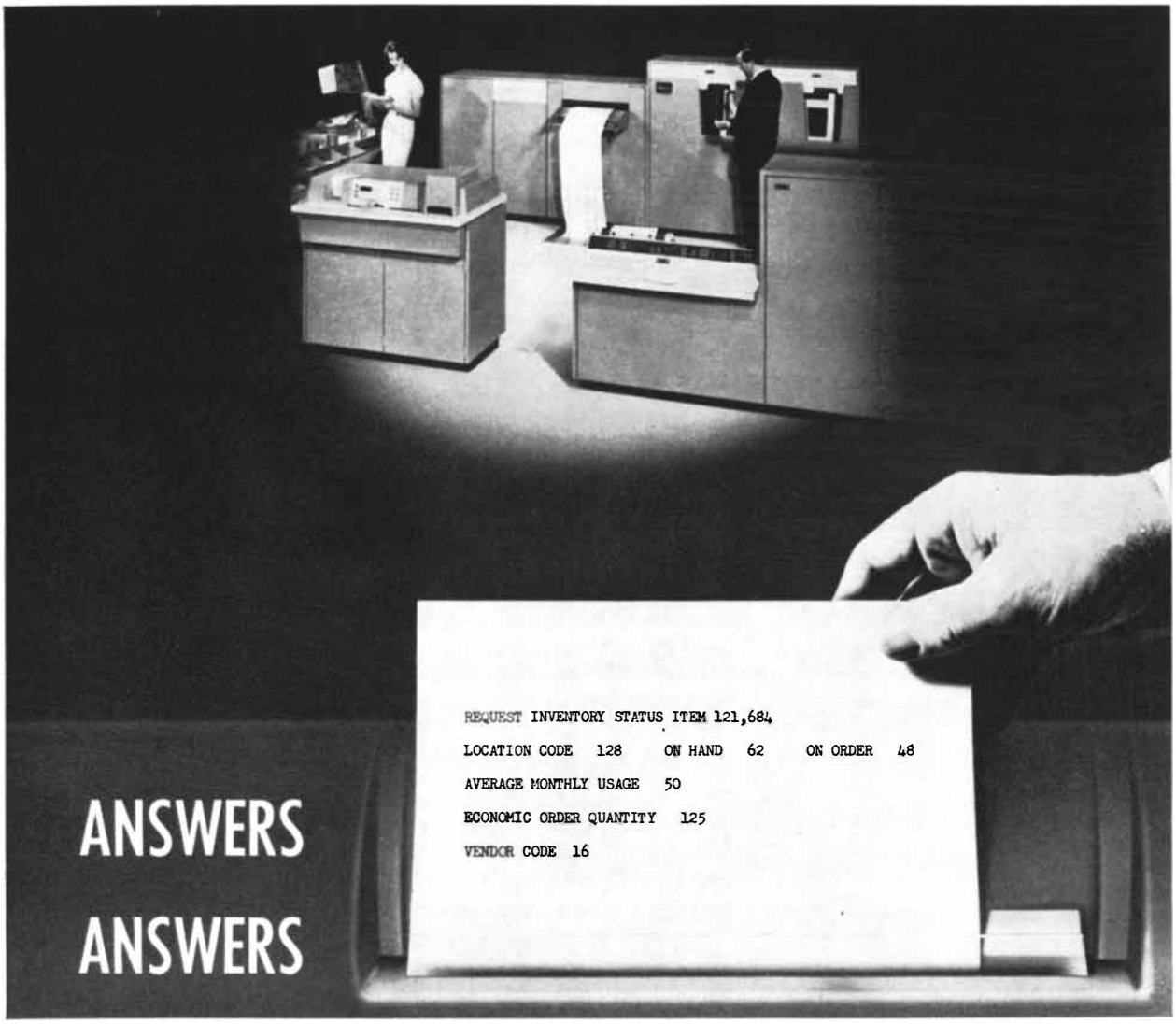

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50 AND 100 YEARS AGO

SCIENTIFIC AMERICAN

JULY, 1913: "The International Aeronautic Federation has recently published its annual bulletin, and it contains a list of aeronauts in all countries who are regularly entered. Up to the end of last year the number of aeroplane pilots was as follows: France, 968; Great Britain, 376; Germany, 335; United States, 193; Italy, 189; Russia, 162; Austria, 84; Belgium, 68; Switzerland, 27; Holland, 26; Argentina, 15; Spain, 15; Sweden, 10."

"It is reported that the Russian government has lately granted the rights to English interests for the construction of electric stations, using the power of the Terek River and Lake Gökcha, together with long power lines running to distant points. First, a temporary plant will be erected on the Terek River, which is to furnish 20,000 horse-power, then a permanent turbine station on the same stream near the railroad station of Lars, so as to secure as much as 50,000 horse-power. Current from these plants will be taken over power lines to Tiflis and Vladikavkaz. One or two hydraulic plants will also be erected on Lake Gökcha near the Tarstcha and Akstafa rivers, and these are expected to provide at least 40,000 horse-power."

"The experiences and achievements of Mr. Frank Wild and his seven companions, who formed the second base of the Australian Antarctic Expedition, have just been made public. After leaving Mawson and the main party at Adélie Land the second detachment sailed westward along the Antarctic coast, under orders to form a base on Sabrina Land or Knox Land. The former land was found not to exist, and ice prevented access to Knox Land. Finally the party was landed on a lofty moving glacier, which Wild thinks was mistaken by Wilkes for 'Termination Land.' It was named 'Shackleton Glacier.'"

"During the year 1912, 20,275,120 tons of shipping passed through the Suez Canal, an increase of nearly 2,000,000 tons over the year of 1911. The total receipts of $27,300,000 were the greatest in the history of the canal. During the year 5,373 ships passed through the canal and of these 3,335 flew the British flag. Such figures as these give ground for the hope that the Panama Canal may become self-supporting and even profitable sooner than some of our statisticians have predicted."

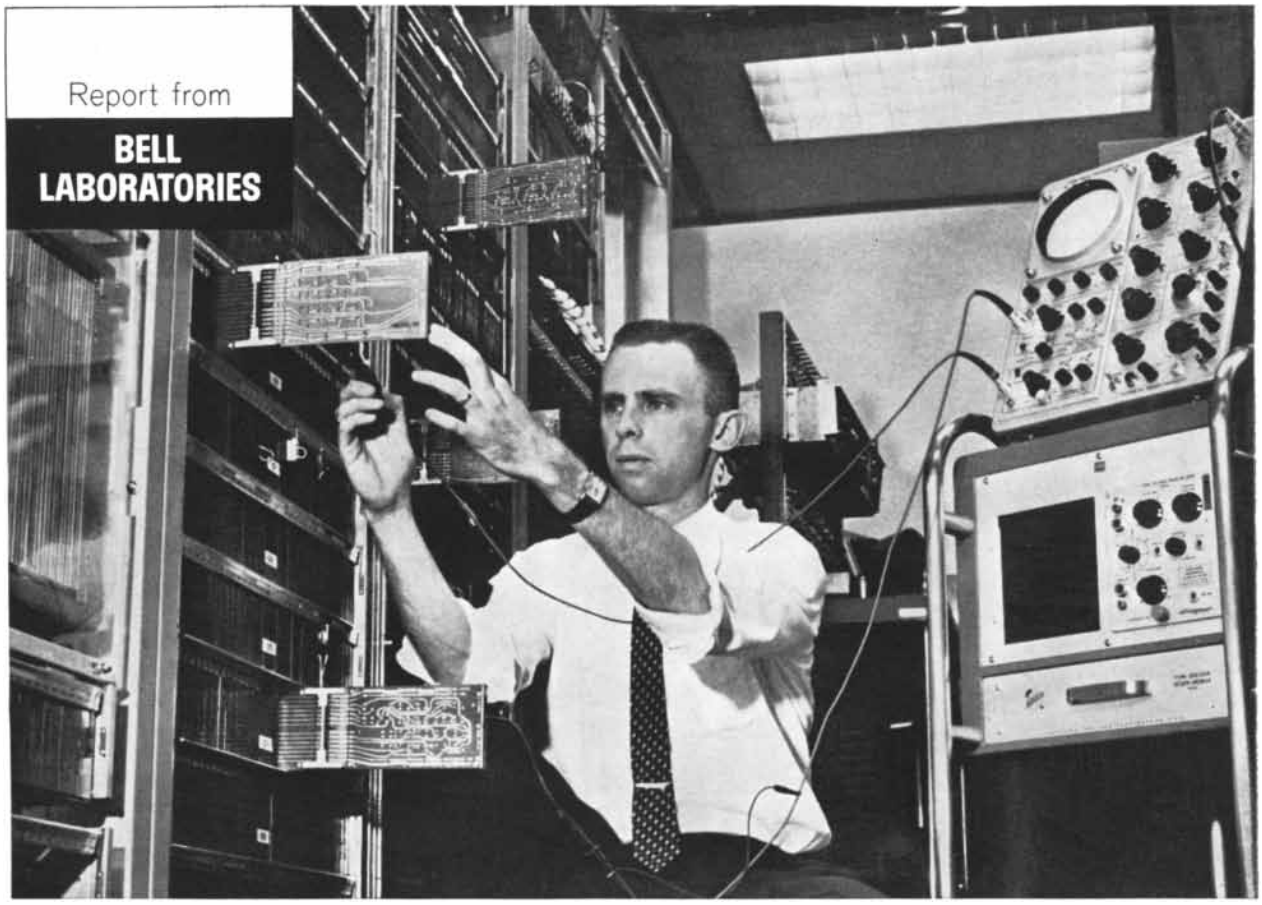
"Count von Zeppelin is building his largest dirigible with a view to crossing the Atlantic to the United States in the late summer. He expects to make the trip in from 30 to 60 hours' time. German warships are to be distributed along the course to assist the airship in case it is obliged to descend."

"On June 7 Archdeacon Hudson Stuck, accompanied by Robert G. Tatum, Harry P. Karstens and Walter Harper, reached the top of the south peak of Mount McKinley. Barometric observations which were made by Dr. Stuck are said to indicate that the height of the mountain is 20,500 feet. The expedition, which left Fairbanks on March 13, expected to reach the summit of Mount McKinley early in May but was delayed three weeks in cutting a passage three miles along ice, thrown across the ridge last summer by an earthquake."

"The territory in northern Africa recently conquered by Italy from Turkey has been divided into two distinct colonies, viz., Tripolitania and Cirenaica, with capitals at Tripoli and Bengasi respectively. A governor for each colony is to be appointed by the King of Italy upon the joint recommendation of the ministers of Colonies and of War."

Scientific American.

JULY, 1863: "On the 28th day of June, Major-General George Gordon Meade was ordered by the President to take command of the army of the Potomac. He at once issued a modest yet soldierly order to his army and put it in rapid motion toward Gettysburg, Pa., at which place the rebels under General Lee were in large force, 'flushed with the pride of successful invasion.' In a series of brilliant and sanguinary battles fought under the eye of the Commanding General and continuing three days, desperate charges were repeatedly made by the enemy; but as often as they were made, so often did the brave



Bell Laboratories' E. G. Hughes tests printed circuit boards in experimental central office control equipment for 101-Electronic Switching System. The system automatically detects trouble, switching out a defective unit and switching in a duplicate unit so service is not interrupted.

High-Speed Switching System Provides New Telephone Services for Business

A new electronic switching system designed to meet the special needs of business customers has been developed at Bell Telephone Laboratories. This system provides many new telephone services such as a way for reaching a seven- or ten-digit number by dialing only three digits, setting up conference calls by dialing other customers into the conversation, and automatically transferring incoming calls from your phone to another by predialing special codes.

A notable feature of the new system is a high-speed control unit. Operating from a telephone switching center, the unit scans—thousands of times per second—all the telephone connections in dozens of business offices that may be located many miles apart. It spends only two-thousandths of a second in each office, but in that time it determines what has to be done and arranges for the necessary actions.

Another feature of the new system is the high-capacity memory. From this, the control unit can draw, in eight-millionths of a second, such specific instructions as how to handle a certain call.

The new switching system operates compatibly with existing electromechanical switching systems in the Bell System. Such Bell Laboratories inventions as the transistor are indispensable to its compactness and the high reliability of its operation. The system was developed for use by businesses as a private branch exchange, and a model has been installed by Western Electric for trial by two New Brunswick, New Jersey, companies.

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army of the Potomac withstand the shock, until the rebels were everywhere repulsed and commenced a rapid retreat toward the Potomac. All the accounts which we have read satisfy us that for skillful generalship and dauntless bravery no other battles since the war began can compare with these."

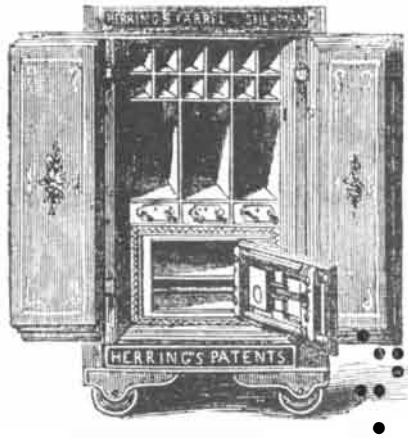
"After the reading of a paper on Borneo at a late meeting of the Royal Geographical Society of London, Mr. Crawford related some particulars respecting the volcanic eruption of Timboro Mountain in 1814, of which he witnessed some of the effects. At a distance of 300 miles it was pitch dark for three days; the ashes were carried by the monsoon to a distance of 1,200 miles from the mountain, and for 10 days he was obliged to write by candle-light."

"An elaborate statistical article on railways appears in a late number of the London *Engineer,* from which we select a few results. The actual extent of railway now open throughout the world is probably about 70,000 miles, and the capital expenditure nearly £1,170,000,000. This vast sum has almost wholly been raised and expended within 25 years. The share of this immense capital which Great Britain and its colonies have expended appears to be upwards of £417,000,000, and the miles of open railway amount to 14,277. On the North and South American continents, exclusive of British possessions, about £257,250,000 have been laid out on 32,102 miles of open railway."

"The ship *Resolution,* in which Captain Cook left England on his second voyage round the world in 1772–91 years since—is now at Demerara waiting a cargo of sugar."

"The immense amount of capital invested in the commerce of our Great Lakes is hardly realized by the public outside of business circles immediately interested in the trade. The following statement of sail and steam vessels now engaged in this business is compiled from the *Marine Register* for 1863, just issued by the Board of Lake Underwriters:—Steamers, 134; propellers and tugs, 253; barks and barkentines, 191; brigs and brigantines, 79; schooners, 1,030; sloops, 14; barges, 60. Total, 1,761."

"Upwards of £300,000 has been subscribed in England to the Atlantic telegraph, and it is said that the work is to be prosecuted immediately."



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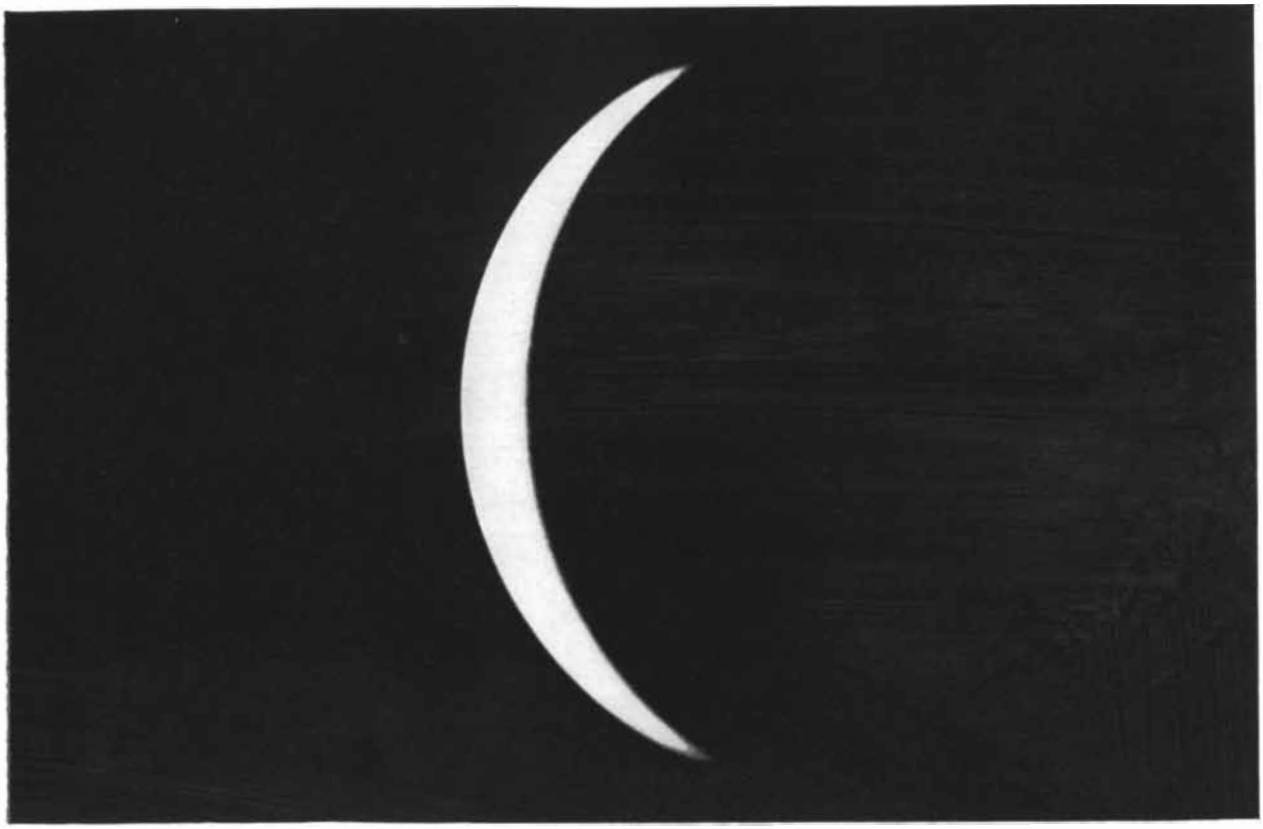
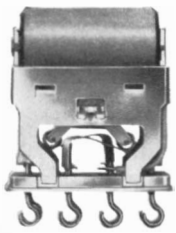


This is Venus



85 of these Sigma Relays went there on Mariner II

Sigma Relays were specified for Mariner II because the designers knew they'd have no second chance. What had to be done, had to be done right the first time. Opening the solar panels, for example. Switching on the scanning devices as Venus was approached. Initiating timing sequences. Sampling data for telemetry. The designers of Mariner II needed assured reliability in spite of adverse operating conditions—both predictable and unpredictable. And they came to Sigma to get it.□ Working together, Sigma Application Engineers and Mariner's designers specified the Sigma Series 32's and 33's which performed so reliably on the Venus probe.

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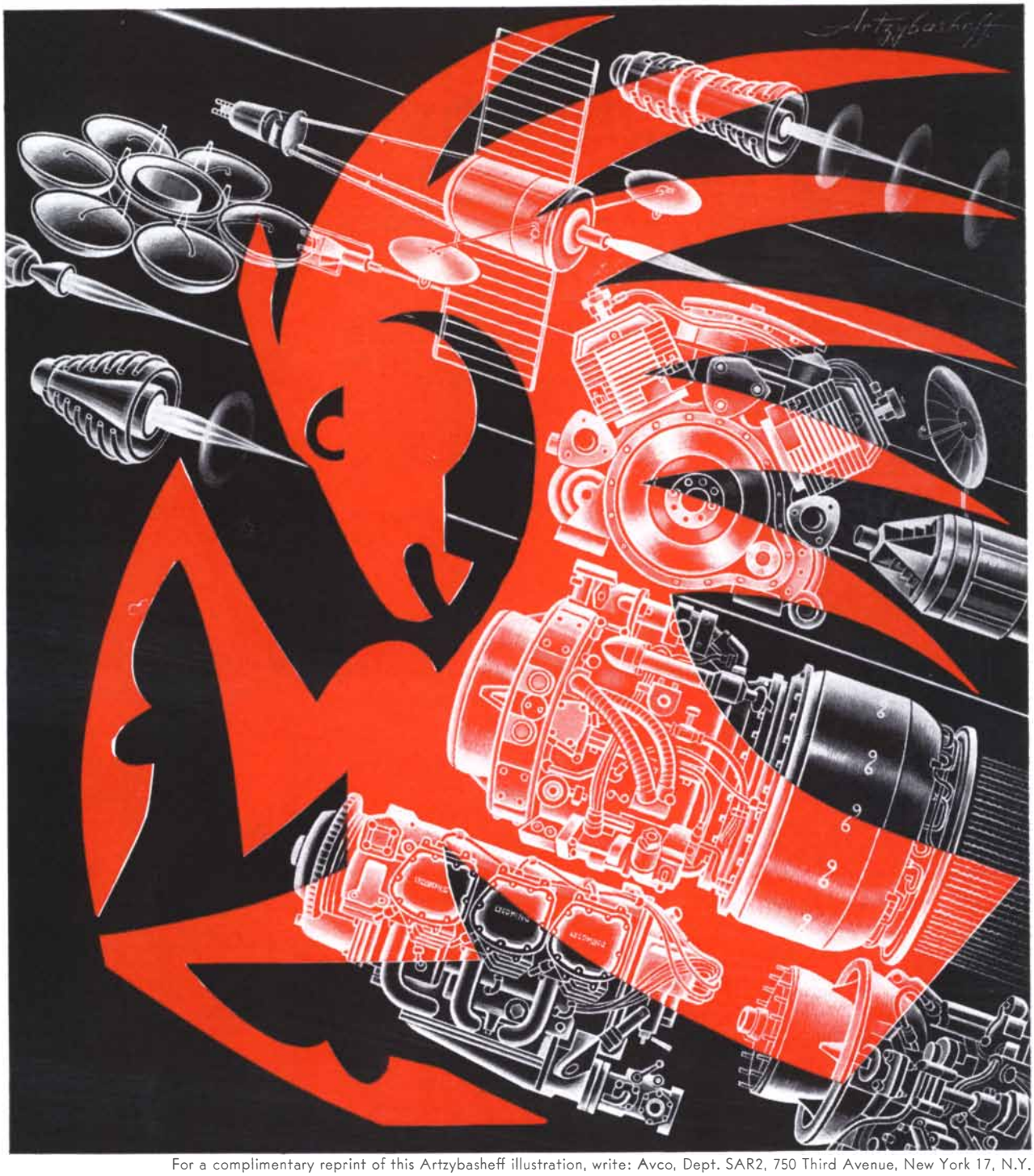

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That's why we make such a variety of printed circuit connectors. Each type and style has its own special bailiwick. They're all "perfect" when they're applied properly.

OUR NEW BELLOWS-TYPE

Take the new Amphenol 225-series. This bellows-type connector has the smoothest, gentlest, most efficient mating action you'll find anyplace. Even after thousands of insertions, the delicate conductive surfaces of the printed board are unscathed by the 225.

The 225-series has remarkably low contact resistance, too. For the solder terminated style, it's under 25 millivolts at 5 amperes.

The bellows-type contact on the 225-series is split down the middle. You get two contact points for every interconnection. This helps keep the contact resistance low, of course, but it also conforms readily to irregular mating surfaces.

The 225 is convex. It meets and mates the printed circuit board with a wiping action that assures contact.

AND, FURTHERMORE

The 225-series contact is self anchored in the connector body. Contact faces will not distort at the slightest pull on the terminals.

The 225-series has twice the flexing range that you'll find on other bellows-type contacts. This means you can rock the board twice as far with no danger of contact distortion.

The 225-series does not waste valuable contact space with a polarizing key. The key is sandwiched in between contacts.

The 225-series can be terminated with solder lugs, taper pins, removable crimps, or Wire-Wrap* terminals.

Contact styles? Contact positions? Mounting provisions? Well, let's just say that there are over 100,000 combinations available in the Amphenol 225-series bellows-type connector.

WHO NEEDS IT?

And now for the facts of life. Some people simply don't need the 225-series. Some printed circuit boards are inserted once and never disturbed again. Some printed circuits are never subjected to pull on the terminations. Some printed circuits are not really so delicate that they must be protected from contact wear. Some printed circuit boards never get rocked. And in some applications, the space taken up by a conventional polarizing key is of no consequence. And so forth.

And that is why Amphenol makes Prin-Cir® connectors, Micro-Edge® connectors, Micro-Min® connectors, and specials that haven't been named yet. They are all printed circuit connectors. They are all "right" where the need dictates their use.

The hero of this story is the Amphenol Sales Engineer. He's the only man who has access to a complete line. Thus he's the only man who can look you in the eye and tell you exactly which printed circuit connector you need. Objectivity.

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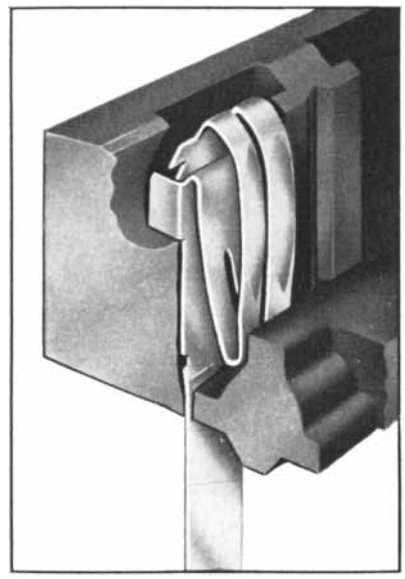
If you're *really* interested in seeing what a complete line of printed circuit connectors looks like, we invite you to write for our new 20-page catalog PC-1. Just contact your local Amphenol Sales Engineer, or write to Dick Hall, Vice President, Marketing, Amphenol Connector Division, 1830 South 54th Avenue, Chicago 50, Illinois.



Problem: To make contacts that give an extremely low millivolt drop, yet do not mar printed circuit conductors, even after thousands of insertions.

Solution: Bifurcated, convex faces for sure contact. Double spring action with wide flexing range. Then double-plate and polish so smooth they caress the mating surface.

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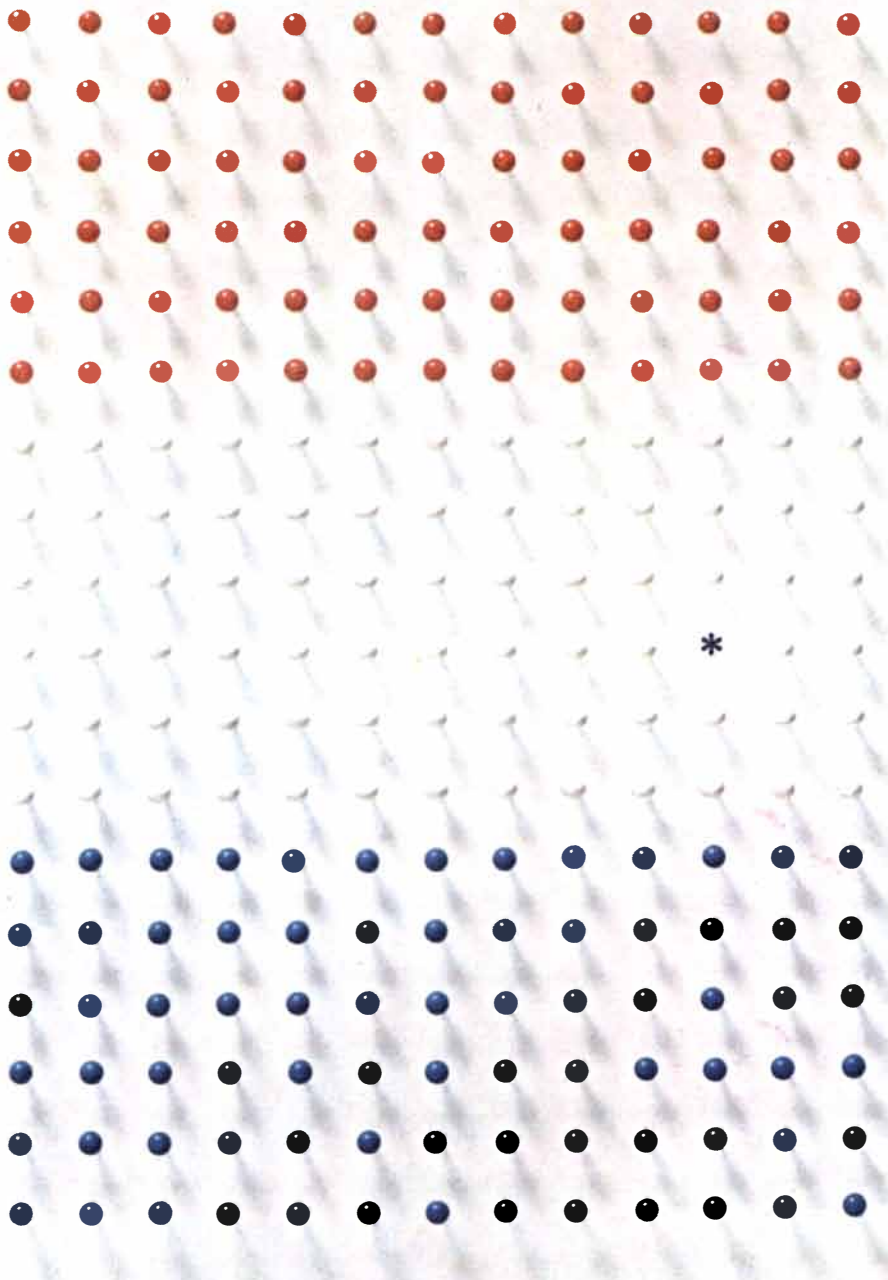

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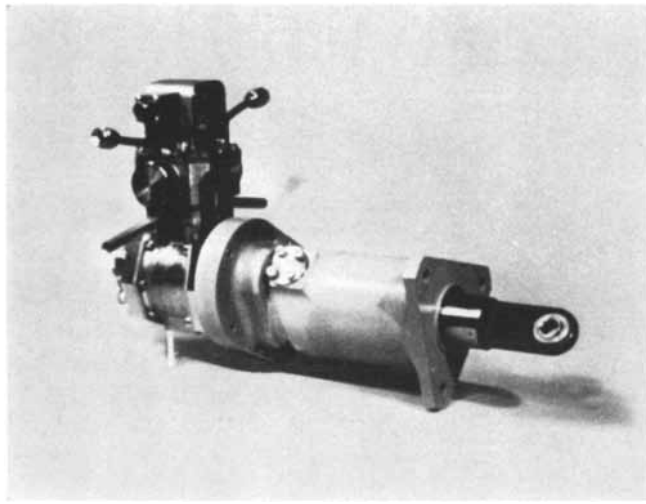


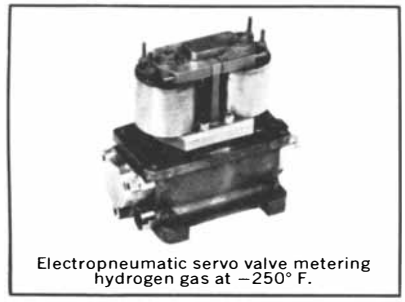
Missile control servo utilizing 2000° F. solid propellant gas.

Dynamic Controls: Integration of Electrical, Mechanical, Hydraulic, Pneumatic, and Hybrid Servo Techniques

The capabilities demanded of recent aerospace dynamic controls have been difficult to satisfy. Conditions such as extreme temperatures and intense nuclear radiation have imposed new limitations on materials, configurations and modes of operation. These limitations and the need for maximum performance and reliability prevent the use of conventional devices.

The control systems engineer must now work towards an optimum design through direct integration of all available dynamic control techniques with propulsive and/or non-propulsive power sources, with environmental conditions and with critical design parameters of the vehicle. We have tackled these new control problems in projects ranging from materials research to the development of complete, integrated systems.

Take one system component, the servo valve. This precision element directs fluid flow to an actuator in response to electrical input signals. A variety of these devices has been developed. One is capable of metering hydrogen gas at −250° F. At the other end of the scale is a unit which controls the flow of solid-propellant combustion products at over 1500°F. Although these two devices fulfill the same function, they differ in materials, configuration, and even in the phenomena used for controlling flow.



Electropneumatic servo valve metering hydrogen gas at −250° F.

Bendix has established research and development programs in bearings, seals, fluid mechanics, electromechanics, and control techniques. Through integration of these efforts a wide range of control concepts and components is being devised. The available techniques for controls include electrical, hydraulic, mechanical, pneumatic and hybrid. In the future, control systems engineers will no longer be limited to a few alternate approaches to system design, such as hydraulics and pneumatics. Instead, an optimum solution to any dynamic controls problem should be sought using any one or a combination of techniques and integration opportunities available. For example, the control actuation requirements of vehicles for deep space application, where direct energy conversion techniques appear most promising, may be better satisfied by electromechanical control techniques than by fluid power control techniques.

Bendix research embraces a wide range of technology including acoustics, nuclear, solid state physics, quantum electronics, mass spectrometry, photoelectronics, electron beam and tube technology, measurement science, applied mechanics, energy conversion systems, dynamic controls, systems analysis and computation, navigation and guidance, microwaves, digital techniques, data processing and control systems. Motivation:—to develop new techniques and hardware for The Bendix Corporation to produce new and better products and complete, integrated, advanced systems for aerospace, defense, industrial, aviation, and automotive applications. Inquiries are invited. We also invite engineers and scientists to discuss career position opportunities with us. An equal opportunity employer. Write Director, Bendix Research Laboratories Division, Southfield, Michigan.

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THE AUTHORS

ARTHUR L. SCHAWLOW ("Advances in Optical Masers") is professor of physics at Stanford University. Although born in Mount Vernon, N.Y., Schawlow grew up in Toronto, where his family had moved when he was three years old. He acquired a B.A. and an M.A. at the University of Toronto in 1941 and 1942 respectively before interrupting his studies to do research on wave guides and antennas in World War II. Schawlow resumed graduate work under the direction of M. F. Crawford at Toronto and received his Ph.D. in 1949. As a postdoctoral fellow and research associate at Columbia University for the next two years, he began the collaboration with C. H. Townes that resulted in the formulation of the basic principles of optical masers. From 1951 to 1961, when he joined the Stanford faculty, Schawlow was a member of the staff in the Physical Research Department of the Bell Telephone Laboratories. The present article is a sequel to one titled "Optical Masers" by Schawlow in the June 1961 issue of SCIENTIFIC AMERICAN.

CHOH HAO LI ("The ACTH Molecule") is professor of biochemistry and director of the Hormone Research Laboratory at the University of California at Berkeley. Born in Canton, China, Li received a B.S. in 1933 from the University of Nanking, where he stayed to teach chemistry for the next two years. Coming to the U.S. in 1935, he studied chemistry at Berkeley and obtained his Ph.D. in 1938. He joined the Berkeley faculty the same year. Li served as a civilian with the Office of Scientific Research and Development in 1944. In 1950 he was appointed professor of biochemistry and experimental endocrinology at Berkeley; he became director of the Hormone Research Laboratory in 1959. Li, whose chief research interests are protein chemistry, the biochemistry of protein hormones and in particular the chemistry and biology of pituitary hormones (of which ACTH is one), was the author of "The Pituitary" in the October 1950 issue of SCIENTIFIC AMERICAN.

URSULA MITTWOCH ("Sex Differences in Cells") is a senior research assistant at University College London. Dr. Mittwoch was born in Berlin and completed her schooling in London. On leaving school she went to work at the John Innes Horticultural Institution under the direction of Kenneth Mather. There she became interested in genetics and later she took a degree in biology at University College London. For her Ph.D. Dr. Mittwoch did research on the genetics of fungi under the direction of J. B. S. Haldane. She began to study human genetics at University College London under L. S. Penrose and made a study of white blood cells, which led her into research on the sex differences in these and other cells.

J. N. JAMES ("The Voyage of *Mariner II*") is a member of the Jet Propulsion Laboratory of the California Institute of Technology, which he joined in 1949 as a group leader in guidance radar. James received a B.S. in electrical engineering from Southern Methodist University in 1942 and an M.S. from Union College in New York in 1948. James's service with the Navy during World War II included—in addition to his studies at Bowdoin College and the Massachusetts Institute of Technology—duty as a radar officer aboard the U.S.S. *South Dakota* and as an instructor in radar. At the General Electric Company from 1946 to 1949 James worked on rocket motors, the use of captured V-2 rockets for upper-atmosphere research, and radar command and tracking systems. From 1955 to 1959 he was responsible for the systems design and field operations of the Sergeant missile as well as for certain parts of the *Explorer I* and *Pioneer IV* satellite projects. In 1960 he became deputy director of the Sergeant program and at the same time undertook the technical direction and execution of the *Mariner II* flight.

M. R. BLOCH ("The Social Influence of Salt") is scientific adviser to the Negev Institute for Arid Zone Research in Beersheba, Israel. Bloch was born in Aussig, Austria (now part of Czechoslovakia), and studied chemistry at the universities of Prague and Leipzig. He then studied physical chemistry at the University of Berne, where he received a Ph.D. for a thesis on the absorption spectra of rare-earth compounds. In 1936 he began working for the Palestine Potash Company (located on the Dead Sea) and developed a method for speeding up the solar evaporation of brines in the production of salt. Bloch is now assistant to the managing director for research and development of the Dead Sea Works, Ltd. From 1948 to 1960 he served as a member of the Research Council of Israel. In addition to his other work Bloch is a member of the

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K. H. LÜLING ("The Archer Fish") heads the department of ichthyology at the Zoological Research Institute and A. Koenig Museum in Bonn, Germany. Lüling studied zoology at the universities of Bonn and Kiel, receiving his Ph.D. from the latter institution in 1940. From 1947 to 1950 he was scientific assistant at the Institute for Fishery Biology at the University of Hamburg. A research fellowship enabled Lüling for the next two years to do research on eyes of fish, including the archer fish. In 1959 the Peruvian Government invited him to serve for a year as a consultant on problems of fisheries biology, particularly on the ecology of *Arapaima gigas*, the largest fresh-water fish in the world. Lüling took up his present job in 1954.

A. R. MACKINTOSH ("The Fermi Surface of Metals") has just joined—as a visiting member of the physics department—the research establishment of the Danish Atomic Energy Commission in Riso, Denmark. Born in Nottingham, England, in 1936, Mackintosh did research on the absorption of ultrasonic waves in metals at the Royal Society Mond Laboratory at the University of Cambridge, where he received his Ph.D. in 1960. From 1960 until this month he was assistant professor of physics at Iowa State University of Science and Technology and a physicist in the Ames Laboratory of the U.S. Atomic Energy Commission.

DONALD KENNEDY ("Inhibition in Visual Systems") is associate professor of biology at Stanford University. Having spent much of his childhood watching birds and collecting butterflies, Kennedy was primarily interested in ecology when he was graduated from Harvard University in 1952. But graduate work at Harvard, where he was influenced by Donald R. Griffin and George Wald, soon shifted his interests from ecology to sensory physiology. After receiving his Ph.D. in 1956 Kennedy joined the department of zoology at Syracuse University, where he remained until he went to Stanford in 1960.

EDWIN G. BORING, who in this issue reviews *The World of Psychology*, an anthology edited by G. B. Levitas, is professor emeritus of psychology at Harvard University.

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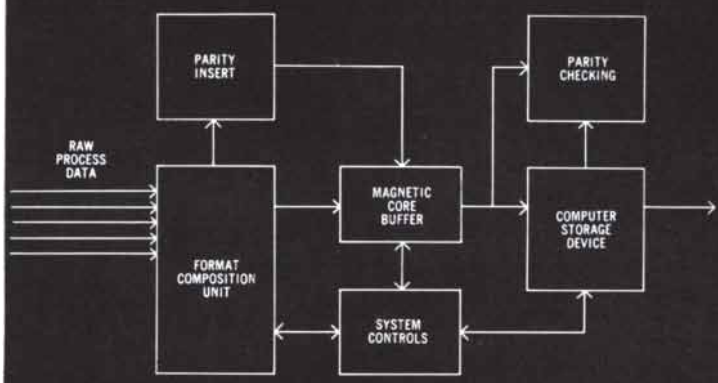

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Established 1845 SCIENTIFIC AMERICAN July 1963 Volume 209 Number 1

Advances in Optical Masers

Just three years ago this month the first optical maser, or laser, was announced. Today about 500 U.S. groups are engaged in laser development. The prospects are dazzling, the technical choices hard

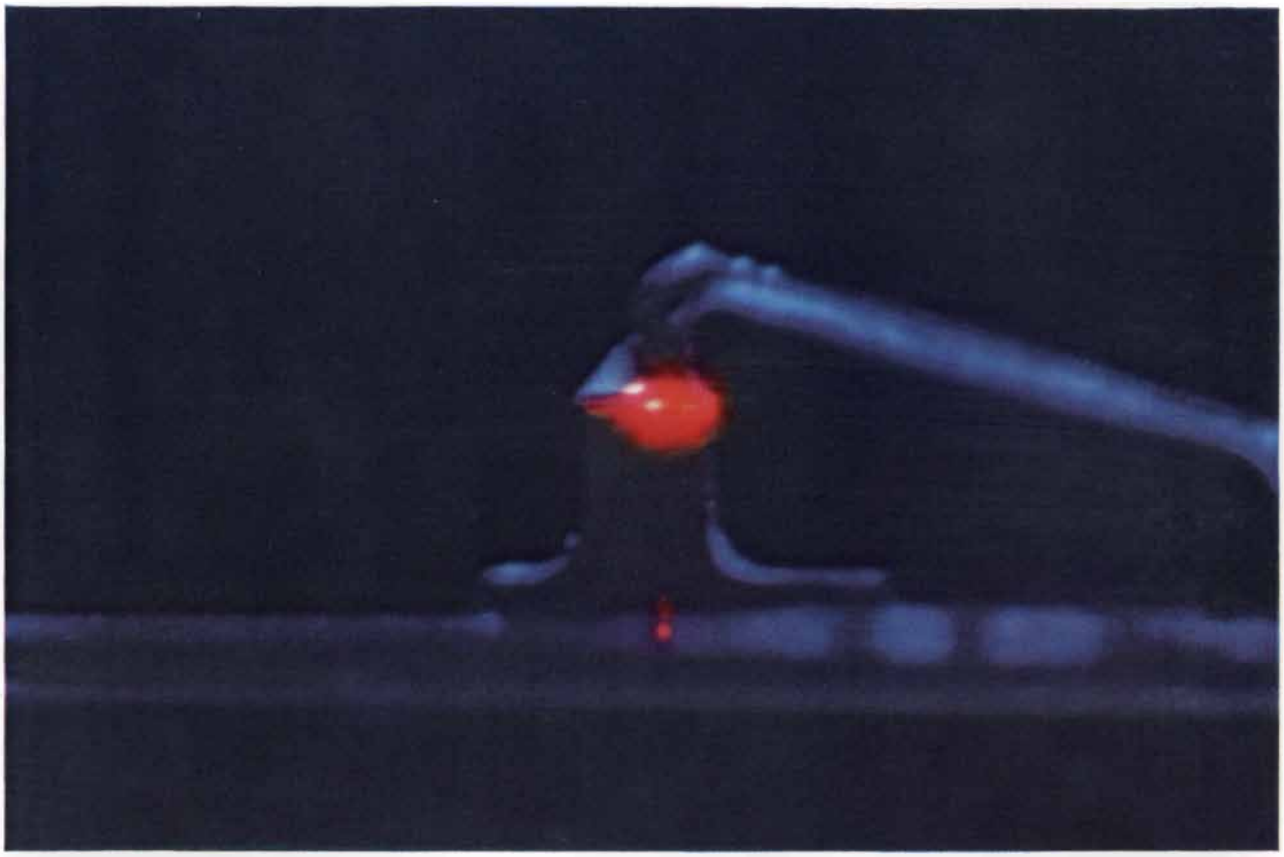
by Arthur L. Schawlow

It is never possible to predict when a development in technology will fire the imagination of the scientific and engineering community. Fifteen years ago it was the transistor, which stimulated a worldwide flowering of solid-state physics. The latest device to fascinate the technical community is the optical maser, or, as it is now often called, the laser. The term is an acronym for "light amplification by stimulated emission of radiation." (In "maser" the "m" stands for "microwave.") The laser is a device for producing a powerful monochromatic beam of light in which the waves are coherent, or in step. The waves emitted by ordinary light sources, such as incandescent and fluorescent lamps, are incoherent and nonmonochromatic.

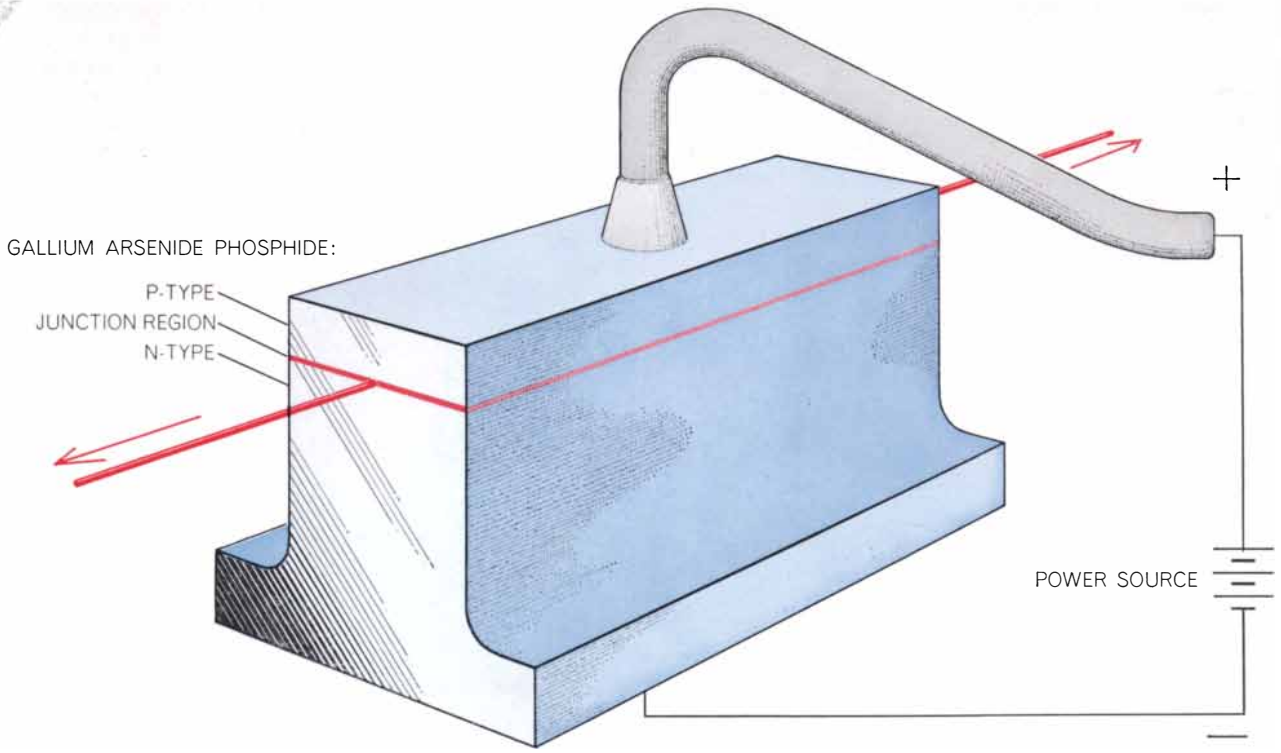
By conservative estimate about 500 research groups are engaged in laser development and exploitation in the U.S. alone. Much of this effort is directed toward the use of laser beams in communication systems. The amount of information that can be carried by a communication channel is proportional to its frequency, and in principle the visible region of the spectrum between the wavelengths of 4,000 and 7,000 angstrom units could accommodate 80 million television channels. The realization of this potential is still far in the future. Outside the field of communications—in chemistry, medicine and several other disciplines—many possible uses of a strong beam of monochromatic laser light are being intensively explored.

The first theoretical analysis showing that it should be possible to build an optical maser was published in 1958 by C. H. Townes, then at Columbia University, and the author. Several years earlier Townes had worked out the principle of microwave amplification by stimulated emission of radiation. Our analysis showed that a device working in the optical region could be made using the same principles. Its structure, however, would be different, and many of its properties and uses would be quite different from those of its microwave ancestor. The first announcement of a working model of an optical maser was made just three years ago this month by T. H. Maiman, then at the Hughes Aircraft Company [see "Optical Masers," by Arthur L. Schawlow; SCIENTIFIC AMERICAN, June, 1961].

Maiman found that a suitable active component for a laser could be made from a single crystal of pink ruby: aluminum oxide colored pink by the addition of about .05 per cent chromium. A description of a typical early ruby laser will illustrate the atomic basis of laser action. For this purpose I will describe lasers built by Robert J. Collins, Donald F. Nelson, Walter L. Bond, C. G. B. Garrett and the author at the Bell Telephone Laboratories in the summer of 1961. The ruby was machined into a rod about four centimeters long and half a centimeter across. Its ends were polished optically flat and parallel and were partially silvered. A powerful electronic flash tube was coiled around the ruby to provide an intense source of "pumping" light. Normally the chromium atoms in the ruby absorb ultraviolet radiation and a broad band of green and yellow light. The light raises the atoms to an "excited" state, from which they drop back to the "ground" state in two steps. In the first drop, to a metastable state, the atoms give up some of their energy to the crystal lattice and no light is emitted. The second drop, however, is accompanied by emission of energy in the form of photons, or quanta of light, with a wavelength (at room temperature) of 6,943 angstroms, which is a deep red. The drop to the metastable state is almost instantaneous, but the drop from there to the ground state occurs at random over a period of a few thousandths of a second. This delay is helpful in achieving maser action. An atom in the metastable state can be stimulated to emit a photon and fall to the ground state instantaneously if it absorbs a photon carrying the same energy it would normally release in its fall. Conversely, an atom in the ground state can be raised to the metastable state by the same sort of photon. To obtain laser action, then, there must be more atoms in the upper state than in the lower, otherwise absorption will predominate over emission. If the required population inversion can be attained, the first few photons released (at random) by atoms dropping to the ground

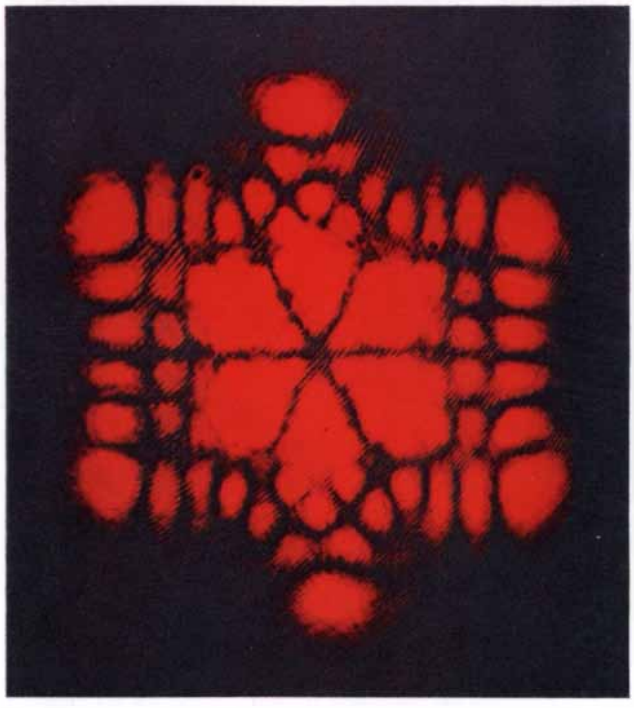


JUNCTION-DIODE LASER built by Nick Holonyak, Jr., and S. F. Bevacqua of the General Electric Company is the first such device to operate in the visible region of the spectrum; this makes it possible to photograph its beam in color. The wavelength of the red light, aimed at the camera, is about 7,000 angstrom units. The center of the beam looks yellow owing to its intensity, which has overexposed the film. The laser and its supporting structure appear blue because blue light was used for general illumination.

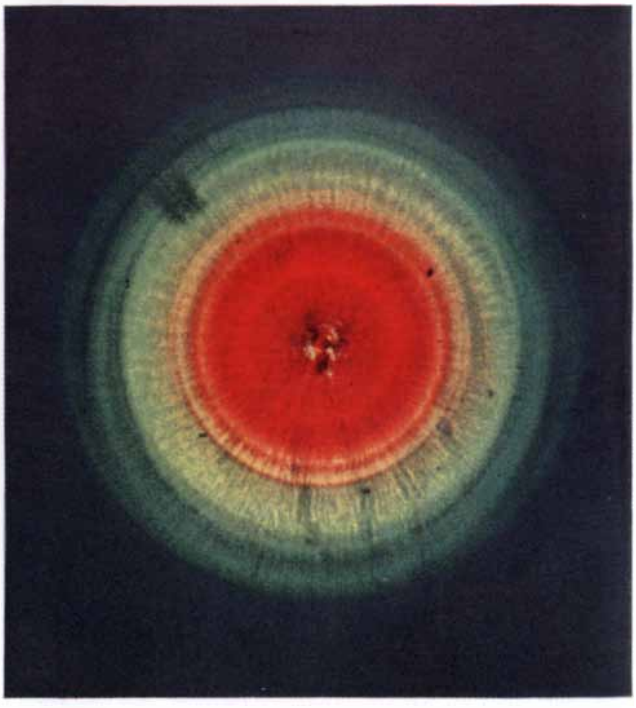


STRUCTURE OF DIODE LASER resembles that of ordinary junction diodes. The active material is a crystal of gallium arsenide phosphide. Small amounts of impurities create *p* (positive) and *n* (negative) regions. At the junction electrons drop into "holes," emitting photons in the process. Front and rear faces of the diode are polished to favor build-up of light emission along one axis.

ELECTRICAL BREAKDOWN OF AIR is produced by the focused beam of a giant-pulse ruby laser. Such lasers incorporate a shutter to postpone stimulated emission, thereby raising beam intensity. When the shutter is opened, a giant pulse of millions of watts is delivered for 10 to 25 billionths of a second. The photograph was made at the Scientific Laboratory of the Ford Motor Company.



OSCILLATION MODES of a gas-discharge laser yield vivid symmetrical patterns. The emerging beam is about half a centimeter in diameter. Patterns show where light waves reinforce or cancel. The photograph was made by Bell Telephone Laboratories.



STIMULATED RAMAN EFFECT is seen when the output of a giant-pulse laser is focused in benzene. The vibration frequency of the benzene molecule adds to the laser frequency, yielding the colored rings. The photograph is by R. W. Terhune of Ford.

state will trigger off a cascade of photons all the same wavelength and all in step. This inversion is achieved by making the pumping light suitably intense. Because the ends of the ruby rod are partially silvered, photons are reflected back and forth parallel to the long axis of the laser, forcing the cascade to develop in a single direction. At the peak of the cascade an intense beam of red light flashes out from the ends of the rod.

Since Maiman's first announcement in July, 1960, many new laser materials have been discovered. They include crystals other than ruby, glasses, plastics, liquids, gases and even plasmas (the state of matter in which some of the atomic electrons are dissociated from the atoms). New materials are being discovered almost weekly. The only general requirement for a laser system is that it provide an upper energy state into which atoms can be pumped and a lower state to which they will return with the spontaneous emission of photons. The system must also allow a population inversion between the two states. Since the emission wavelength is controlled by the characteristic resonances of the particular material used in the laser, only a limited number of wavelengths can be generated by a given material. Consequently in order to cover the full spectrum of optical frequencies new materials will be needed unless some radically different approach can provide a device that is tunable over a wide range.

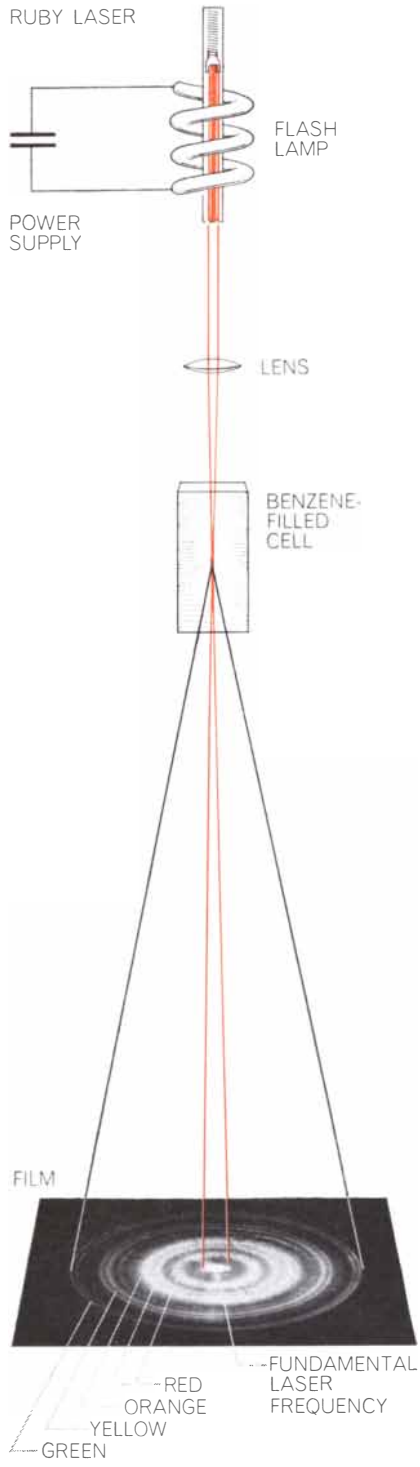
At present optical masers exist with output wavelengths from about 5,900 angstroms (.59 micron) in the yellow-orange portion of the spectrum out to 35 microns in the middle of the infrared. There have been observations of stimulated emission at wavelengths as short as 3,100 angstroms (.31 micron) in the ultraviolet, but no one has yet reported true maser action as indicated by the production of a well-defined beam. The ratio between the longest optical-maser wavelength (35 microns) and the shortest (.59 micron) is almost 60 to 1. Between 35 microns and the beginning of the microwave region at about one millimeter, where conventional electronic oscillators can take over again, there is a gap in which there is as yet no means for producing coherent radiation. Since this gap represents a wavelength ratio of only about 30 to 1, it is smaller than the region now covered by optical masers.

The search for new laser materials is essentially a search for elements that possess an atomic state with a suitable range of energy levels. As we have seen, the active ion in the first optical maser was chromium. Its chief drawback is that its terminal level for laser action is identical with the ground state. Because the ground state is normally fully populated, its depopulation requires a great expenditure of energy. This means that it is very difficult to operate a ruby laser except in pulses. Continuous operation, however, has been achieved at Bell Laboratories by Willard S. Boyle and Nelson.

Several recent masers, operating in the 6,100-angstrom region, use trivalent (triply charged) ions of the rare-earth element europium, whose suitability was recognized in the original 1958 paper by Townes and the author. Europium ions fluoresce in sharp, strong spectral lines, and some of the strongest lines end on a terminal level well above the ground level. This terminal level is almost empty at moderate temperatures; any atoms put into it fall quickly to the ground state. Thus if relatively few atoms can be raised to the upper state, emission can be stimulated without competitive absorption by atoms already in the terminal state. Unfortunately it is hard to excite even a few atoms to the upper state because in most crystals the europium ion has no broad absorption bands to intercept the pumping radiation. Most of the light from the pumping lamp passes uselessly through the material.

One way around this difficulty is to put the europium ion into an organic compound known as a chelate, which acts as a kind of molecular cage. The chelate has strong, broad absorption bands in the near ultraviolet, and much of the energy that is absorbed is quickly transferred to the trapped europium ion, exciting it to the state required for maser action.

The possibility of combining europium with a chelate to produce a laser has been recognized for at least three years. The first success was reported only this February by Alexander Lempicki and H. Samelson of the General Telephone and Electronics Research Laboratories. The successful material was europium benzoylacetonate and it was used not as a crystal, or even a glass, but as a liquid solution in alcohol. The achievement was particularly surprising because one would expect the molecules in a liquid to be so buffeted by thermal agitation that the spectral emission lines would be broadened too much to sustain laser action. The europium ion, however, is not very sensitive to such buffeting, and it is somewhat shielded by the outer portions of the chelate molecule.



RAMAN LASER EFFECT is created by focusing an intense laser beam in benzene and recording the result directly on film (*see picture at bottom right on opposite page*). The frequency of the laser beam is both downshifted and upshifted by multiples of the vibration frequency of the benzene molecule. The downshifting yields infrared frequencies, which do not show on color film. The upshifting by one, two, three and four multiples of the benzene molecular vibration frequency produces respectively the red, orange, yellow and green rings.

LASER FREQUENCIES now extend from 5,940 angstrom units, in the yellow-orange part of the visible spectrum, to 350,000 angstroms (35 microns) in the far infrared. The colored bars indicate the minimum and maximum frequencies for different types of lasers. To date, gas-discharge lasers have produced the greatest number of different wavelengths: over 160. Although it is believed that semiconductor lasers can generate the whole range of frequencies from 6,500 to 31,000 angstroms, this is still to be demonstrated.

Almost simultaneously N. E. Wolff and R. J. Pressley at the RCA Laboratories announced operation of another europium chelate laser in which the chelate was suspended in an acrylic plastic. The plastic laser can be made to operate either in the usual rod configuration or in the form of long fibers. Both the liquid and the plastic are pumped optically with a strong lamp and produce coherent laser light at the characteristic europium-ion wavelength near 6,100 angstroms.

Other materials that respond with optical-maser action when optically pumped include many crystals and glasses and at least one gas: cesium vapor. The cesium has two output wavelengths, one near three microns and the other near seven microns. Because of their high density of active ions, the solids usually produce more intense beams than gases do.

The attractive feature of gas lasers is that they can be designed to produce output beams over a wide range of wavelengths. Except for the cesium-vapor laser, gas lasers are pumped electrically rather than optically. It turns out that the conditions for amplification by stimulated emission, at some wavelength or other, are satisfied in an electric discharge through almost any gas. Moreover, such masers operate continuously rather than intermittently. The noble gases—helium, neon, argon, krypton and xenon—have been the most thoroughly investigated, and each has provided maser action at more than one wavelength. The longest optical-maser wavelength generated so far—35 microns—was produced by xenon; this result was obtained in a series of studies conducted at Bell Laboratories by W. R. Bennett, Jr., W. L. Faust, R. A. McFarlane and C. K. N. Patel.

These studies reveal that, in the process of collision with fast electrons in the discharge, atoms are likely to be excited to some atomic states more than to others. These favored states can then serve as upper levels for maser transitions to lower terminal states. If the atoms are allowed to linger in the terminal states, however, they can absorb radiation of the same frequency and return to the upper state. Therefore they must be forced to lose energy so that they will fall from the terminal state to a still lower ground state. Since this transition is promoted if the atoms collide frequently with the walls of the discharge tube, it generally helps to use tubes with rather small diameters. By reducing the diameter to about six millimeters and using mirrors with high reflectivity in the visible, but not in the infrared, J. D. Rigden and A. D. White of Bell Laboratories have designed a gas laser with an output of 6,328 angstroms. This particular laser should provide a simple and convenient source of continuous monochromatic light, with a sharply defined beam, for many laboratory applications.

Neither the gas-discharge masers nor the optically pumped solid-state masers are very efficient. Their output energy is usually less than 1 per cent of the input. Last fall, however, this limitation was unexpectedly lifted by the discovery of a class of semiconductor junction lasers. They promise conversion efficiencies well above 10 per cent and possibly even approaching 100 per cent. The new class of laser was reported almost simultaneously by three groups of workers: Robert N. Hall, G. E. Fenner, J. D. Kingsley, T. J. Soltys and R. O. Carlson of the General Electric Company; T. M. Quist, R. H. Rediker, Robert J. Keyes, William E. Krag, Benjamin Lax, Alan L. McWhorter and Herbert J. Zeiger of the Lincoln Laboratory of the Massachusetts Institute of Technology; and M. Nathan, W. P. Dumke, Gerald Burns, F. H. Dill and Gordon Lasher of the International Business Machines Corporation.

For some years there had been discussion and speculation about the possibility of obtaining maser action from a semiconductor. According to quantum theory the electrons in a solid can occupy two broad energy levels: a lower level called the valence band and an upper level called the conduction band. To carry an electric current a solid must be well supplied with electrons in the conduction band; a semiconductor is less well supplied. Any electron in the conduction band possesses an excitation energy at least equal to the energy gap between the two bands. In principle the electron could be stimulated to radiate this energy in the form of a photon. In the commonly used semiconductors such as germanium and silicon, however, the electrons in the conduction band have crystal momentum, which must also be given up in the transition. Since this requires the co-operation of lattice vibrations, it is a relatively unlikely process. For this reason such semiconductors—known as indirect-gap semiconductors—emit light feebly and so far have not produced maser action.

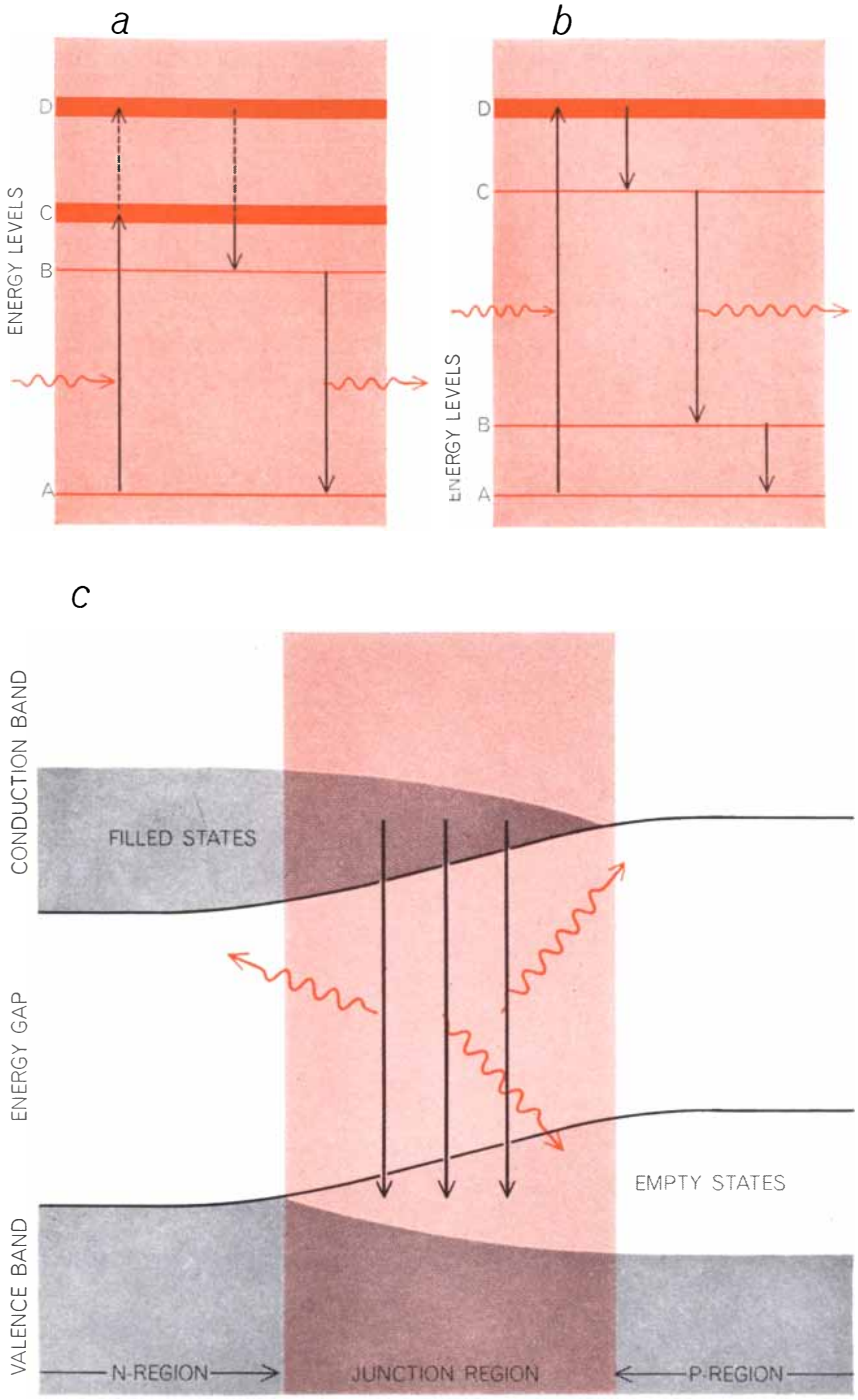
There is another class of direct-gap

semiconductors, typified by gallium arsenide, in which the transition can take place without help from lattice vibrations. In these an electron can drop from the conduction band and occupy, or recombine with, a "hole" in the valence band. This recombination can take place spontaneously with the emission of a photon. When there is sufficient density of excited, or conduction-band, electrons, the spontaneous emission gives way to stimulated emission and maser action can result. The required electron densities can be achieved in the junction region of a "*p*-*n*" junction diode [*see illustration "c" at right*]. In the *p* (positive) region there is an excess of electrons in the valence band. In the *n* (negative) region there is an excess of electrons in the conduction band. If free electrons are fed into the *n* region, they travel to the junction region; there they drop into the holes of the *p* region, emitting photons. Since most of the free electrons lie near the plane of the junction, recombination radiation grows if it propagates along this plane, and the light emerges strongly where the junction meets the side walls of the crystal [*see illustrations on page* 35].

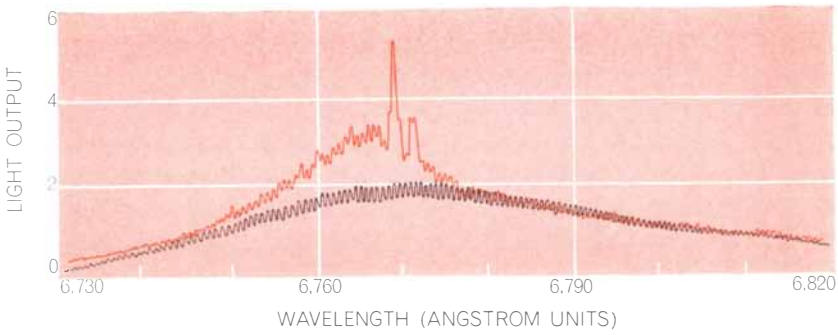
To impart directionality to the emitted light it is necessary only to provide parallel reflecting mirrors on two opposite sides of the crystal. This can be done by polishing two faces of the crystal: the crystal-air boundary provides a natural reflecting surface. The natural cleavage faces of the crystal also make excellent mirrors. Only two opposite faces need be mirror-like; the other faces are left roughly ground or are deliberately etched.

Because large numbers of excited electrons are produced in a junction diode when a current flows, only a small diode is needed to produce laser action. Typically the area of the junction is about one square millimeter. Junction-diode lasers are very efficient because nearly every electron injected across the junction contributes a useful photon, and the losses are mainly the electrical-resistance losses in the rest of the diode. The devices built to date have been small and output has been limited to less than one watt, but there seems nothing to prevent the building of much larger units.

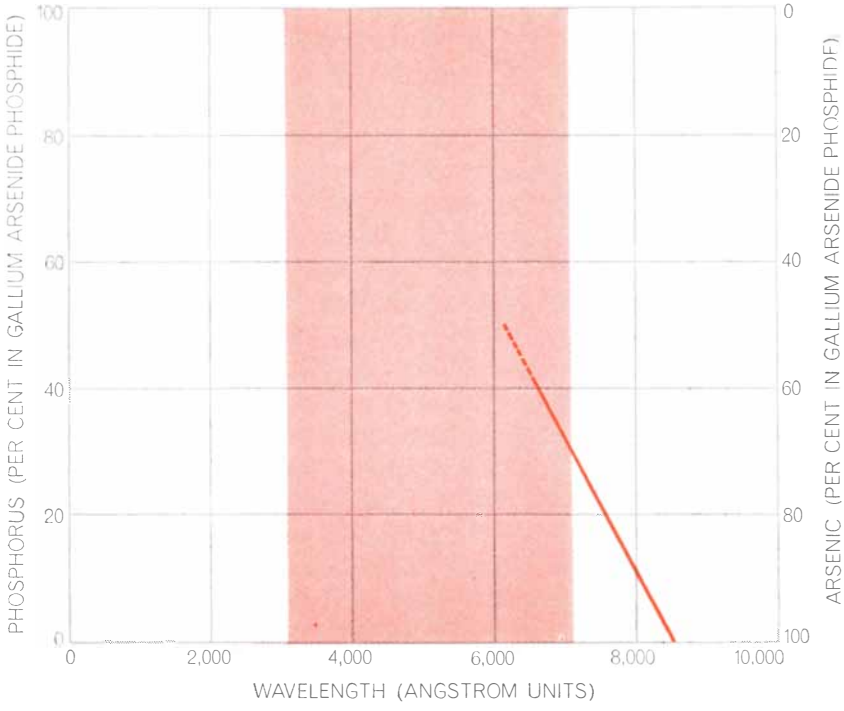
In pure gallium arsenide at room temperature the laser light has a wavelength around 9,000 angstroms, in the near infrared. At lower temperatures the output wavelength decreases to around 8,400 angstroms. The output can therefore be tuned over a considerable range



LASER ACTION depends on the fact that photons (*wavy arrows*) are often emitted when electrons drop from higher to lower energy states. In solid and gas-discharge lasers the electrons are bound to "excitable" atoms. In semiconductor lasers the electrons are unbound. In the original ruby laser (*a*) "pumping" light raises an atom from "ground" state *A* to *C* or *D*. The atom falls promptly to metastable state *B*. The final fall to *A*, which is normally a random process, can be stimulated if the atom is struck by a photon like the one it would emit. When *B* contains more atoms than *A*, stimulated emission predominates over absorption. In other solid lasers and in gas-discharge lasers (*b*) the terminal state *B* is slightly above the ground state, hence is normally lightly populated. Thus an excess of atoms in *C* is readily attained. In the semiconductor, or junction-diode, laser (*c*), electrons are injected at a higher level and fall to a lower level in a crystal "sandwich" containing *p* and *n* regions. The pumping energy is supplied by electricity. At the junction, electrons drop into holes, empty states at edge of the *p* region. This recombination of electron and hole, which leads to the emission of a photon, can be stimulated by another photon of the same energy. Spontaneous photons travel in all directions. But those traveling in the plane of the junction are most likely to stimulate recombination and produce laser action.



SPECTRAL OUTPUT of a gallium arsenide phosphide diode laser is shown near threshold (*black curve*) and just after a single mode of oscillation has begun to predominate (*colored curve*). The curves are for one of the lasers constructed by Holonyak and Bevacqua of G.E.



OUTPUT *V.* COMPOSITION is shown for the ternary mixture of gallium arsenide phosphide. Percentages refer just to the arsenide-phosphide fraction of the mixture; gallium is always present. When phosphorus exceeds arsenic in the mixture, laser action begins to fail.

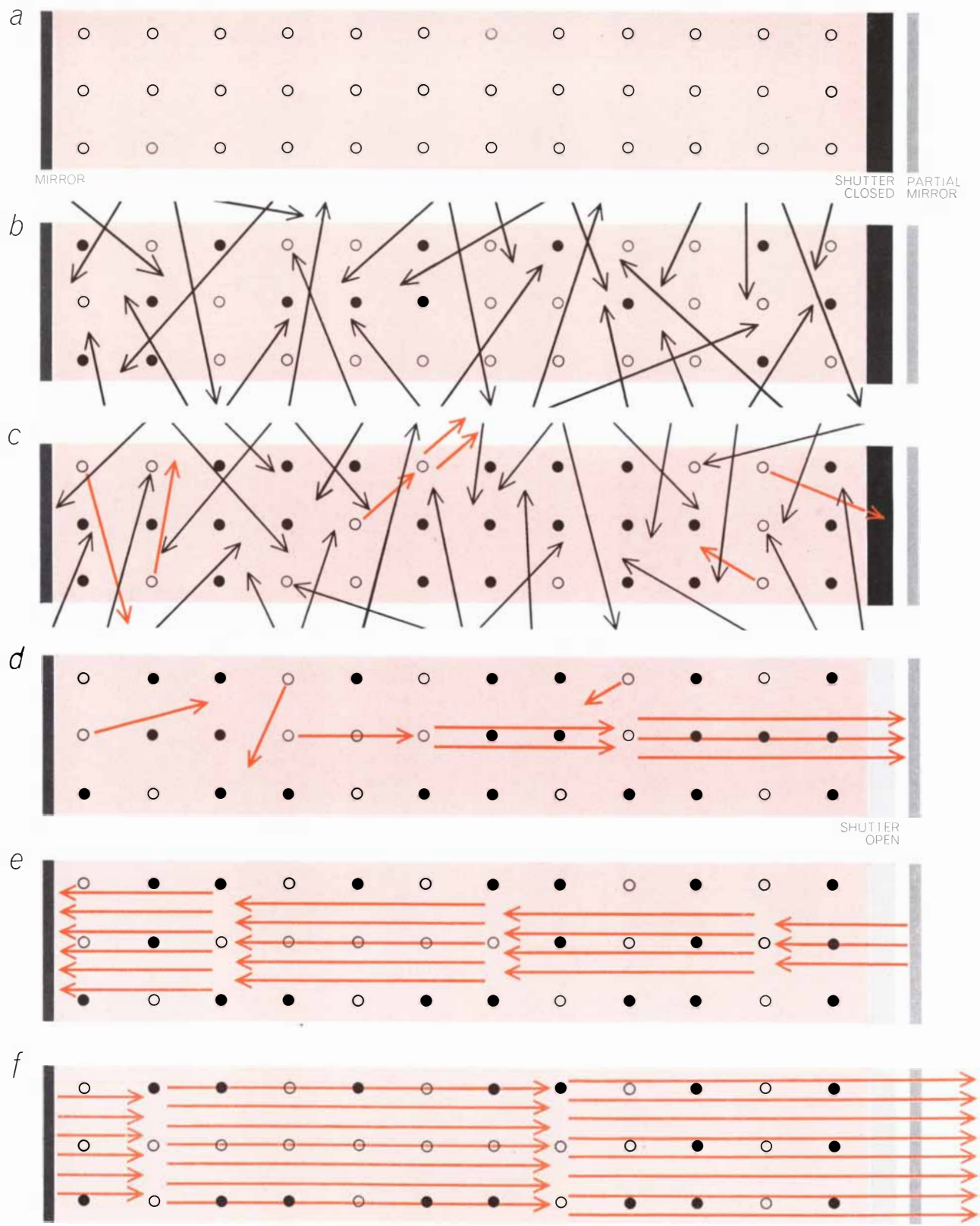
by varying the temperature. Nick Holonyak, Jr., and S. F. Bevacqua of General Electric have shown that still further change in wavelength can be achieved by using three-element alloy mixtures such as gallium arsenide phosphide. Depending on the ratio of arsenic to phosphorus, such a diode will operate between 6,100 and 8,400 angstroms. A three-element mixture of gallium indium arsenide shows promise of operating from 8,400 out to 31,000 angstroms, in the infrared. By adjusting the temperature of operation the output can be brought close to any wavelength desired. This easy tunability makes diode lasers less suitable than others for the generation of an accurately reproducible wavelength. They do, however, have the advantages of compactness, simplicity and efficiency. Also, their output power can be easily and quickly controlled by changing the supply voltage, so that a signal can be impressed on the light beam.

For high output power ruby and certain glasses containing neodymium ions seem to be best. Here the excited ions are provided by a brilliant flash of light, usually from a xenon discharge lamp. As larger rods have become available, larger output energies have been obtained. Total flash energies as high as several hundred joules are delivered in one or two milliseconds. (A joule is one watt for one second.) For this brief period the energy released is equivalent to the output of several thousand 100-watt lamps. Such a flash can be focused to penetrate a steel plate an eighth of an inch thick. This is a considerable advance over the early lasers, which could penetrate one or two razor blades; their output was rated in "gillettes." There is nonetheless a great gulf between existing laser beams and the sort of heat ray, envisioned by some people, that would be able to destroy a ballistic missile. Even a thousand joules will not boil a single gram of water. But when the laser beam is properly focused it can weld, melt or vaporize a small amount of any substance.

Enormously high peak powers and very short pulses have been made possible by the giant-pulse technique first proposed by R. W. Hellwarth of the Hughes Aircraft Corporation. In this method, sometimes known as "Q-spoiling," a fast-acting shutter is interposed between one end of a laser rod and the mirror normally found there. The shutter is closed during most of the pumping-light flash so that light from the end of the rod cannot reach the mirror and be returned to the rod. Since the light path is blocked, laser oscillations cannot start even though a large number of atoms are put into the upper state of the laser transition. Once the rod has been excited into this highly amplifying state, the shutter is quickly opened. As soon as the shutter is open and light can reach the mirror, laser oscillation builds up almost instantly. Under these conditions most of the excitation energy stored in the rod is delivered in one huge burst of light. This giant pulse can deliver up to 50 megawatts lasting for about 10 nanoseconds (billionths of a second). Moreover, the beam from a giant-pulse laser is highly directional. The divergence of the beam can be less than three minutes of arc.

Laser beams of still higher intensity can be obtained by amplifying the output of the giant-pulse laser. The amplifier consists of another rod without mirrors; in fact, to keep the amplifier from oscillating spontaneously the ends of the amplifying rod must be treated to prevent reflection. The amplifier is pumped by its own flash lamp, therefore it is ready to amplify by stimulated emission the instant the giant pulse is delivered.

The intense wave of the giant pulse stimulates all available atoms in the amplifying rod to emit almost as soon as the light pulse begins to pass through them; that is, the leading edge of the pulse is amplified and uses up all the excited atoms. There are then no excited atoms left to reinforce the remainder of the



GIANT-PULSED RUBY LASER employs a shutter to delay laser action until a large population of atoms has been raised to an excited state. Before the pumping light is turned on (*a*), the atoms are in the ground state (*open circles*). The light (*black arrows in "b," "c"*) raises atoms to the excited state (*black dots*). If an emitted photon (*colored arrow*) strikes another excited atom, it stimulates further emission. This stimulation is limited until the shutter is opened (*d*). Then photons traveling precisely parallel to the long axis of the laser are reflected back and forth between the two mirrored surfaces, stimulating a cascade of photons. The cascade culminates in a coherent beam of light, which flashes through the partially silvered mirror with an intensity of millions of watts.

light pulse. As a result amplification makes the giant pulse not only more intense but also briefer.

So far the peak power reported is approximately 500 million watts in a beam whose cross section is less than one square centimeter. Assuming that the beam intensity is about a billion watts per square centimeter, the intensity of the corresponding electric field is nearly a million volts per centimeter in the unfocused beam. A good lens with a focal length of one centimeter could focus the beam to a spot a thousandth of a centimeter in diameter. The beam intensity in this focal spot would be a million billion (10^{15}) watts per square centimeter, and the optical-frequency electric field would be about a billion volts per centimeter. This is more than the electric fields binding the outer electrons in most atoms and would cause severe disruption even in transparent substances. Usually one thinks of the radiation pressure of light as being negligibly small, but in such a focused beam it would be over 15 million pounds per square inch.

Even at ordinary laser intensities transparent materials, which are usually nonconductors, react in an unusual manner. By means of laser experiments it has been shown that the dielectric constant (a measure of insulating ability) depends not only on the material and the light frequency but also on the instantaneous magnitude of the electric field. In other words, the response to high electric fields is nonlinear. When a wave of any pure single frequency passes through such a nonlinear medium, the wave shape is distorted. It can be shown by Fourier analysis that such a distorted wave is equivalent to the original wave with the addition of one or more harmonic waves. These harmonics have two, three or more times the frequency of the original.

The generation of laser harmonics was first observed by Peter A. Franken, A. E. Hill, C. W. Peters and G. Weinreich of the University of Michigan. They focused the 6,943-angstrom light from a ruby maser onto a block of quartz and observed harmonic radiation at twice the frequency, that is, at a wavelength of 3,472 angstroms. In these early experiments the intensity of the harmonic was very low—less than one part per million of the fundamental. Subsequent improvements, principally by J. A. Giordmaine of Bell Laboratories and by P. D. Maker, R. W. Terhune, M. Nisenoff and C. M. Savage of the Scientific Laboratory of the Ford Motor Company, have led to harmonic-generation efficiencies as high as 20 per cent.

Other nonlinear phenomena have been produced by the high intensity of laser beams. These include mixing of light waves to obtain "sum" and "difference" frequencies. It is thereby possible to get intense coherent light at many new wavelengths by combining the outputs of individual lasers. This sort of mixing has long been familiar in the radio-frequency region, but it is new in optics. N. Bloembergen, Peter S. Pershan and their associates at Harvard University have recast a large part of the theory of optical wave propagation to take into account these nonlinearities. All the laws of optics are modified to some extent at the high intensities produced by pulsed lasers.

A different sort of nonlinear effect was observed almost accidentally by E. J. Woodbury of Hughes Aircraft. He was working with a giant-pulse laser in which the shutter was a Kerr cell containing nitrobenzene. (Such a shutter either passes or blocks light in response to an electric field.) Woodbury found that the output beam contained, in addition to the ruby wavelength of 6,943 angstroms, additional wavelengths a few hundred angstroms to the red side of the ruby wavelength. These additional wavelengths were as coherent and as well collimated as the main beam. Careful investigation showed that the new wavelengths were shifted in frequency from the ruby light by amounts equal to the various vibrational frequencies of the nitrobenzene molecule. Such a shift in light frequency is known as the Raman effect. In this case it resulted when the ruby light frequency mixed with the molecular vibrations. The ordinary Raman effect yields incoherent light of low intensity. The Raman laser lines are coherent and intensities up to half that of the original beam have been observed [*see illustration at bottom right on page 36*]. The discovery of Raman laser action makes available new wavelengths of high-intensity coherent light. It also provides a new way of quickly getting information about the frequencies at which molecules vibrate and perhaps about the frequencies at which they rotate.

With these and other radical advances appearing literally every few days, there has been little chance to do the careful, detailed development work needed to realize practical applications. Some of the proposed applications, particularly military ones, require much higher output energies than those now available. Until the efficiency and the average output power (in contrast to the peak power) are increased, it will not be practical to use lasers for large-scale cutting and welding. There is no apparent reason in principle why this cannot be done. High-efficiency lasers do exist, and they run continuously, but they do not yet deliver high power.

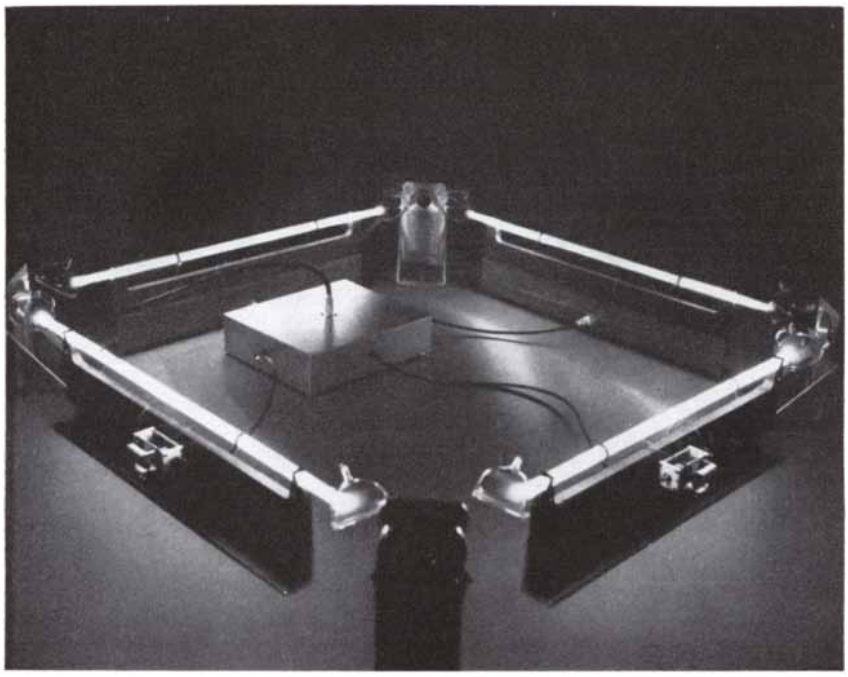
This being so, the first applications will be those in which one of the other properties of lasers, such as high peak power or very monochromatic spectral output, is important. For at least one application a beam of light lasting less than one millisecond and delivering a fraction of a joule is ideal. The application is in medicine: when the retina of the eye is torn or injured, it is possible to "weld" the retina to its support by coagulation with an intense spot of light and thus prevent it from becoming detached. Indeed, following the work of D. G. Meyer-Schwickerath of the University of Bonn, ophthalmologists have used intense light beams from conventional lamps during the past few years for retinal coagulation.

One advantage of the laser for coagulation is that its flash takes less than a thousandth of a second, compared with about half a second for coagulation by ordinary light. In the shorter period there is no opportunity for the eye to move and it does not have to be immobilized, as it does at present. N. S. Kapany and N. A. Peppers of Optics Technology, Inc., and the Palo Alto Medical Research Foundation have designed a compact laser for this purpose that fits into the handle of an ophthalmoscope. Preliminary tests on animals by Harold C. Zweng and Milton Flocks of the Palo Alto Foundation and the Stanford University School of Medicine have shown how to regulate the output of the laser for various eyes. The device is found to be easy to use. If it proves equally successful with human patients, it could encourage ophthalmologists to seek out and repair retinal lesions at an early stage.

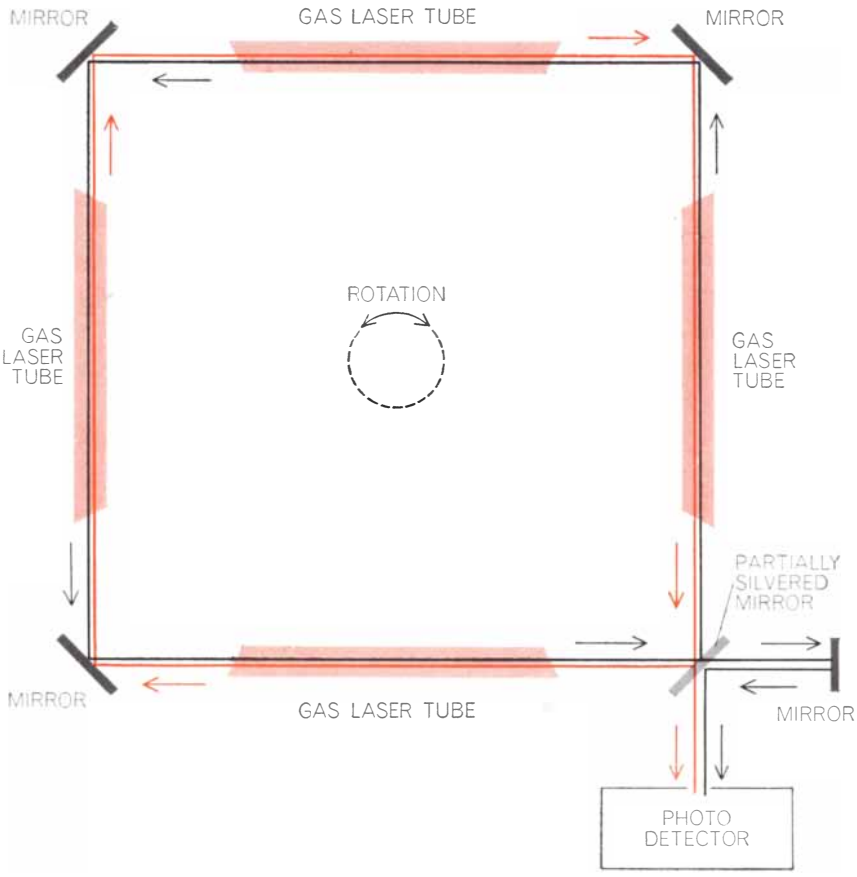
Some other potential applications exploit the extraordinary monochromaticity of the laser beam. For example, at the Massachusetts Institute of Technology, Ali Javan, T. S. Jaseja and C. H. Townes have recently used helium-neon gas-discharge lasers to repeat the classic Michelson-Morley experiment with a new order of accuracy. This experiment, first performed in 1881 by A. A. Michelson and E. W. Morley, showed that the velocity of light is unaffected by the motion of the earth through space. The

	ACTIVE MATERIAL (AND VALENCY STATE)	OUTPUT WAVELENGTHS (MICRONS)	HOST MATERIAL	OPERATING MODE	OPERATING TEMPERATURE (DEGREES CENTIGRADE)
SOLID OR IONIC LASERS	EUROPIUM (3+)	.61	YTTRIUM OXIDE PLASTIC CHELATE IN ALCOHOL	PULSED	20
	CHROMIUM (3+)	.70	ALUMINUM OXIDE	CONTINUOUS	20
	SAMARIUM (2+)	.71	FLUORIDES OF CALCIUM STRONTIUM	PULSED	−196
	YTTERBIUM (3+)	1.02	GLASS	PULSED	−196
	PRASEODYMIUM (3+)	1.05	CALCIUM TUNGSTATE	PULSED	−196
	NEODYMIUM (3+)	1.06	VARIOUS FLUORIDES MOLYBDATES GLASS	CONTINUOUS	20
	THULIUM (2+)	1.12	CALCIUM FLUORIDE	PULSED	−253
	ERBIUM (3+)	1.61	CALCIUM TUNGSTATE	PULSED	−196
	THULIUM (3+)	1.91	CALCIUM TUNGSTATE STRONTIUM FLUORIDE	PULSED	−196
	HOLMIUM (3+)	2.05	CALCIUM FLUORIDE CALCIUM TUNGSTATE GLASS	PULSED	−196
	DYSPROSIUM (2+)	2.36	CALCIUM FLUORIDE	CONTINUOUS	−196
	URANIUM (3+)	2.4–2.6	VARIOUS FLUORIDES	CONTINUOUS	20
GAS-DISCHARGE LASERS	HELIUM	160 WAVELENGTHS BETWEEN 5,940 ANGSTROM UNITS (.594 MICRON) AND 35 MICRONS		CONTINUOUS	
	NEON			CONTINUOUS	
	KRYPTON			CONTINUOUS	
	XENON			CONTINUOUS	
	CARBON MONOXIDE			CONTINUOUS	
	OXYGEN			CONTINUOUS	
	OTHER GASES			CONTINUOUS	
SEMICONDUCTOR INJECTION LASERS	GALLIUM ARSENIDE PHOSPHIDE	.65–.84		PULSED	−175
	GALLIUM ARSENIDE	.84		PULSED CONTINUOUS	20 −196
	INDIUM PHOSPHIDE	.91		PULSED CONTINUOUS	−153 −253
	INDIUM ARSENIDE	3.1		PULSED CONTINUOUS	−196 −269

TABLE OF LASER TYPES shows the output frequency associated with various active materials, mode of operation and maximum operating temperatures. Included among the solid lasers is one liquid laser, an alcohol solution of trivalent europium held in a cagelike compound called a chelate. Not listed is one gas laser, using cesium vapor, that is optically pumped and operates at two wavelengths: 3.2 and 7.2 microns. With this one exception gas lasers are all activated by an electric discharge through the gas.



RING LASER has been built by Warren M. Macek and his associates at Sperry Gyroscope Company. Two laser beams circulate around the apparatus in opposite directions (*see diagram below*). If the apparatus is rotated, one beam rises in frequency, the other falls.



OPERATION OF RING LASER exploits the stable frequency produced by four gas-discharge tubes linked to act as a single laser. The frequency of the two circulating beams is compared by the photodetector at lower right in the diagram. If the ring laser is rotating to the right, for example, the clockwise beam must travel farther to make a complete circuit and its frequency falls. The counterclockwise beam correspondingly rises in frequency.

experiment laid to rest the idea that light waves are propagated through an all-pervading "ether" (in which case the velocity would not have been constant) and set the stage for Einstein's theory of relativity.

To repeat the experiment the M.I.T. group has installed its lasers in a wine cellar on Cape Cod, far removed from automobile traffic. On a day when the weather is calm and the earth is quiet, the frequency of the laser beam will remain constant within a few thousand cycles out of 10^{14} cycles. The relative drift between two lasers is sometimes as small as one part in 10^{13} per second. To achieve such stability the laser structure must be extremely rigid. A change in frequency of one part in 10^{13} would be produced by a change in length of one part in 10^{13}. Since the mirrors at the ends of the laser are separated by about one meter, this means a change in length of 10^{-13} meters, or a thousandth the diameter of an atom.

Javan and his colleagues have repeated the Michelson-Morley experiment by turning their lasers in different directions with respect to the earth's motion. Any change in the velocity of light would change the time required for the laser beam to travel between the two end mirrors and would show up as a change in frequency of the output beam. The apparatus is sensitive enough to detect a change in the velocity of light as small as three millimeters per second. Preliminary results show that the change, if any, is less than this value. Ultimately the apparatus may be sensitive enough to detect a change as small as .03 millimeter per second. The limit of accuracy attained by Michelson was about 150 millimeters per second and, using his methods, his successors were able to improve the accuracy by a factor of about 10.

Another classic experiment of Michelson's has also been repeated in a new way with the aid of optical masers. This is an experiment, first proposed by Michelson in 1904, to detect the absolute rotation of the earth. By means of mirrors light is made to circulate in both directions around the four sides of a square. The time taken for a complete circuit is the same in either direction as long as the square is at rest. But if the square is rotated about an axis perpendicular to its plane, a ray traveling in the direction of rotation will take longer to complete the trip than one traveling against the rotation. The reason is that the mirrors are retreating from the first ray and approaching the second.

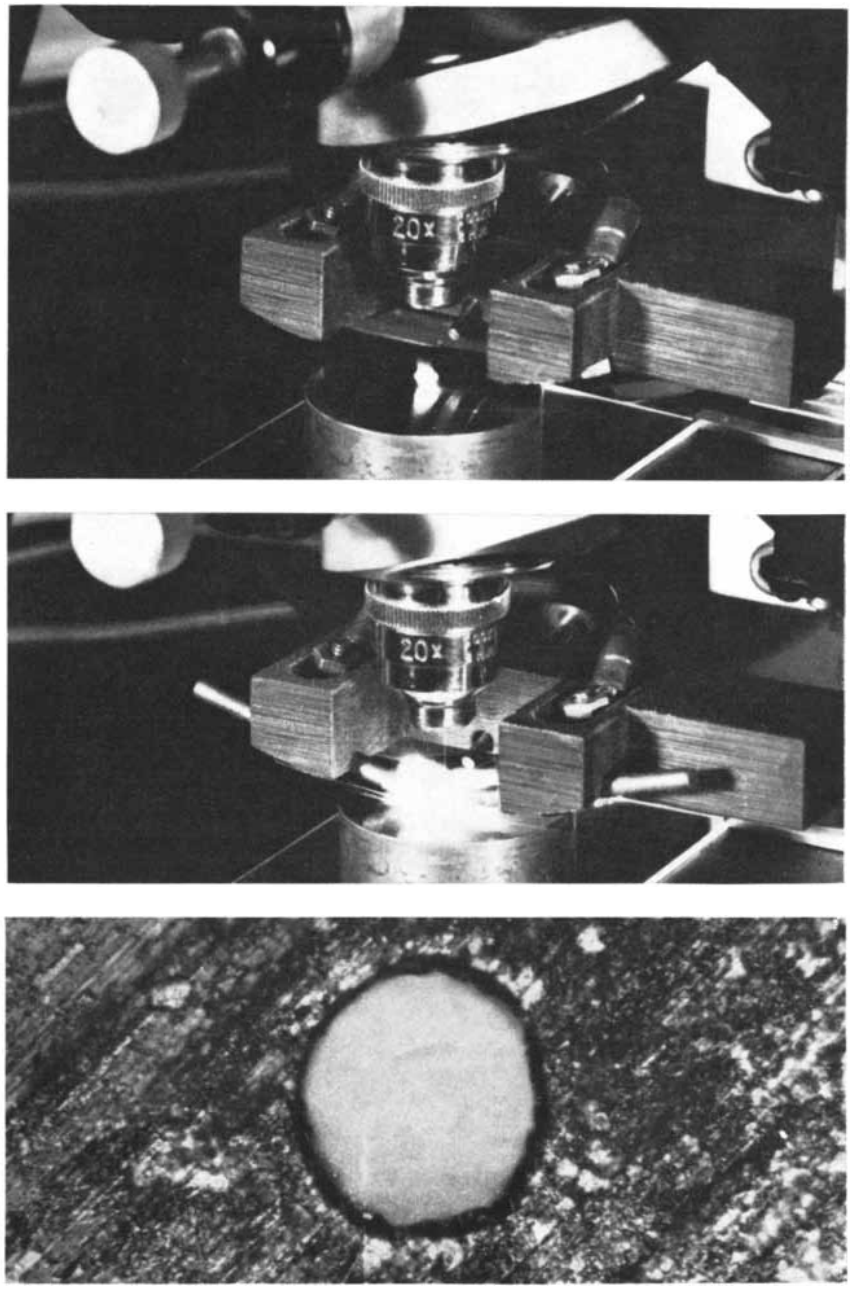
The effect produced by the earth's rotation is, of course, tiny because light travels so much faster than the mirrors move. At a latitude of 40 degrees the rotation of the earth produces a shift of a hundred-thousandth of a wavelength in a horizontal square three meters on each side. Michelson felt that the effect would be too small to be measured. In 1914, however, G. Sagnac of France was able to detect the effect with the four mirrors mounted on a rotating platform. Then in 1925 Michelson and H. G. Gale did the experiment on a heroic scale with evacuated pipes forming a square 450 meters on a side and showed that the earth's rotation caused a shift of a quarter of a wavelength.

With the advent of optical masers it was realized by the late Adolph H. Rosenthal of the Kollsman Instrument Corporation and Warren M. Macek of the Sperry Gyroscope Company that the experiment could be done in a new and more sensitive way. The method uses four helium-neon gas-discharge laser tubes, one mounted on each side of a square [*see illustrations on opposite page*]. Mirrors are placed at the four corners of the square so that light leaving one end of a gas-discharge tube goes around the circuit and returns to its starting point. The entire perimeter of the square in effect constitutes a single laser, which means that light travels around the square in both directions. The time taken for one circuit controls the laser oscillation frequency. When the square is rotated about its axis, the laser produces two slightly different light frequencies corresponding to the two directions in which light travels around the square.

These two oscillations can be combined on a photodetector and the difference between their frequencies measured. For example, a square one meter on a side, operating at a wavelength of 1.1 microns, was shown recently by Macek and Daniel T. M. Davis, Jr., of Sperry to give a beat frequency of 500 cycles per second when the square was rotated at a rate of two degrees per minute. At the latitude of New York the earth's rotation produces a laser rotation rate of about a sixth of a degree per minute, which should show up as a beat frequency of 40 cycles per second. This should be readily detectable. Since this "ring laser" can perform the same function as a gyroscope, it may eventually be useful for navigational purposes.

It will be noted that the few scientific and technical applications I have mentioned are as yet only in the stage of being probable. Most other proposed applications are not even that far advanced. Embarrassed by riches, scientists and engineers have had trouble deciding the laser applications on which to concentrate.

In the end, radically new sources of electromagnetic radiation will have many uses. It has by now been shown that lasers can produce beams of visible or infrared light of almost any wavelength, that they can produce enormous peak powers, that they can be stable and monochromatic and that they can be quite efficient. But no single device combines all these attributes. The engineering task is to select the proper combination of properties for any proposed application and to design the particular optical maser to fit it. One can also be sure that there will continue to be surprising innovations and advances.



NOVEL SPECTROSCOPE employs a pulsed ruby laser to vaporize a microscopic amount of any material for spectrographic analysis. The photograph at top shows a specimen being vaporized by the laser beam. For successful analysis the vaporized material must be superheated. This is achieved by allowing the vapor to produce a short circuit between two electrodes (*middle photograph*). The micrograph shows the 50-micron crater produced by the laser. The instrument was developed by Jarrell-Ash Company, Newtonville, Mass.

The ACTH Molecule

A major product of the pituitary gland, the adrenocorticotropic hormone has an important role in health and disease. The study of its molecule shows how its function is related to structure

by Choh Hao Li

Of all the glands that produce hormones, the anterior pituitary stands first in importance. Often called the master gland of the body, it forms the front half of an ovoid structure, about the size of a pea in man, suspended just below the center of the brain. Its location suggests that it is under direct control of the brain, but how this control is exercised is only partially understood. What has been established is that hormones produced by the anterior pituitary control growth, sexual development, reproduction, thyroid activity and, to an important degree, the body's general response to stress and disease. In most cases this control is a two-stage process: hormones from the anterior pituitary regulate the hormone output of such target endocrine glands as the thyroid, testes, ovaries and adrenals [*see illustration on opposite page*].

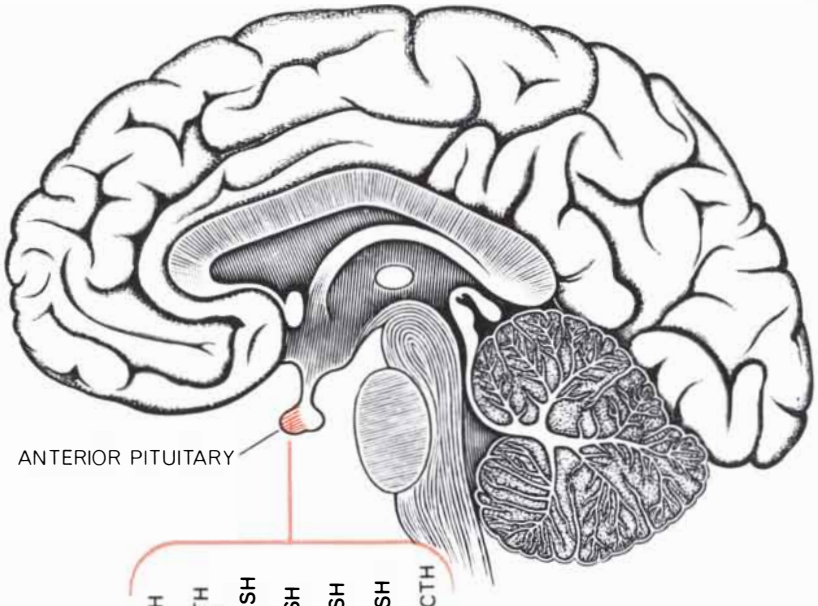
Of the seven anterior pituitary, or adenohypophyseal, hormones, the most important are undoubtedly GH, the growth hormone (also known as somatotropin), and ACTH, the adrenocorticotropic hormone (also known as corticotropin). This article will be concerned primarily with ACTH and the work of my group at the Hormone Research Laboratory at the University of California at Berkeley. Our investigation, which began more than 20 years ago, has led to knowledge of the complete molecular structure of ACTH and to chemical synthesis of various active portions of the molecule. Throughout this period my associates and I have benefited from many important contributions made in other laboratories, especially in the area of chemical procedures.

As a result of this co-operative effort a number of concepts have emerged, some of them quite new to endocrinology. It is now clear, for example, that the standard definition of a tropic hormone, meaning a hormone with a particular target, is no longer adequate. A tropic hormone can exhibit activity in the absence of its defined target organ. It has also been shown that hormones having the same biological function but obtained from different animal species are not necessarily identical. Moreover, the hormone derived from one species may elicit a different pattern of response in another species. Two hormones that originate from different cells of a gland, such as the anterior pituitary, can have certain structural features in common and as a result exert similar biological activity. One finding of particular significance, both from the standpoint of theory and from the standpoint of medical therapy, is that hormonal activities do not depend on the integrity of the whole molecule. Chemically modified molecules or chemically synthesized portions of molecules will show ratios of activity that differ from those produced by the natural molecule.

It has been known since the 1920's that a secretion of the anterior pituitary acts selectively on the cortex of the adrenal glands. This secretion, eventually identified and called ACTH, induces the adrenal cortex to produce half a dozen different hormones, all incorporating a particular molecular configuration known as the steroid structure. In man the adrenocortical hormones include cortisol (formerly known as hydrocortisone), corticosterone and aldosterone, plus lesser amounts of the sex hormones. Apart from the sex hormones, the adrenocortical hormones serve two broad functions: to regulate carbohydrate metabolism and the balance of electrolytes, such as sodium, in the body fluids. The principal steroids serving these functions are respectively cortisol and aldosterone. Malfunction of the adrenal cortex leads to Addison's disease, characterized by a drop in plasma sodium and loss of water from the blood. When administered therapeutically to patients with a functioning adrenal cortex, ACTH more or less mimics the biological behavior of cortisol. Because the ACTH-stimulated glands produce steroids other than cortisol, some of them still unidentified, ACTH is more beneficial than cortisol in certain clinical cases. For example, ACTH is sometimes more effective as an antiallergic agent than cortisol is, and it is usually more

ACTH	ADRENOCORTICOTROPIC HORMONE
FSH	FOLLICLE-STIMULATING HORMONE
GH	GROWTH HORMONE
ICSH	INTERSTITIAL-CELL-STIMULATING HORMONE
LTH	LACTOGENIC HORMONE
MSH	MELANOCYTE-STIMULATING HORMONE
TSH	THYROID-STIMULATING HORMONE

ANTERIOR PITUITARY hormones control a remarkable range of biological functions. The two most important of the seven hormones are the growth hormone (GH) and the adrenocorticotropic hormone (ACTH). GH and the melanocyte-stimulating hormone (MSH), which controls skin-darkening, act directly on cells in various parts of the body. The other five hormones, including ACTH, stimulate specific target organs. ACTH also has important effects that do not depend on its target, the adrenal cortex.



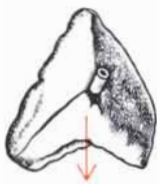
GH LTH ICSH FSH TSH MSH ACTH

BODILY GROWTH AND OTHER METABOLIC PROCESSES

GH

ADRENAL CORTEX

ACTH



CORTISOL, ALDOSTERONE

MAMMARY GLAND

GH

LTH

MELANOCYTE

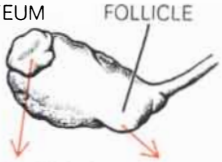
ACTH

MSH

OVARY

CORPUS LUTEUM

FOLLICLE



LTH

ICSH

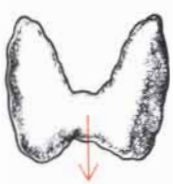
FSH

PROGESTERONE

ESTRADIOL AND OVA

THYROID

TSH

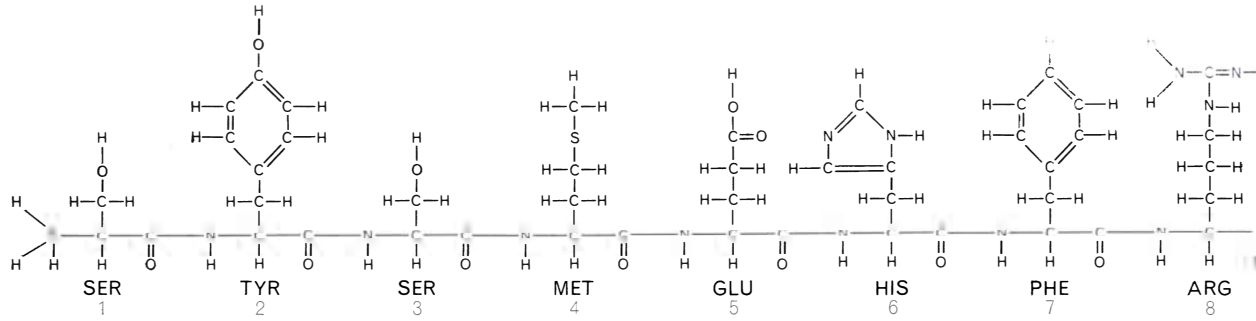


THYROXIN

ICSH FSH

TESTES

TESTOSTERONE AND SPERM



MOLECULE WITH ACTH ACTIVITY, synthesized by the author and his co-workers, contains the first 17 subunits found in the natural molecule of ACTH. Such a molecule is called a polypeptide because the subunits are amino acids held together by

SKIN-DARKENING HORMONE, MSH, has an alpha and beta form containing 13 and 18 amino acid subunits respectively. The alpha form was synthesized in 1958 by Roger Boissonnas and his associates at Sandoz, Ltd., in Switzerland. Except for two small chemical details, alpha-MSH is identical with the first 13 subunits in natural ACTH (*top*). Of the 18 subunits in beta-MSH, half coincide with those in the first 12 subunits of ACTH. Not surprisingly, the 17-subunit molecule with ACTH activity, shown at the top of these two pages, is found in animal tests to have about 10 times the skin-darkening effect of natural ACTH.

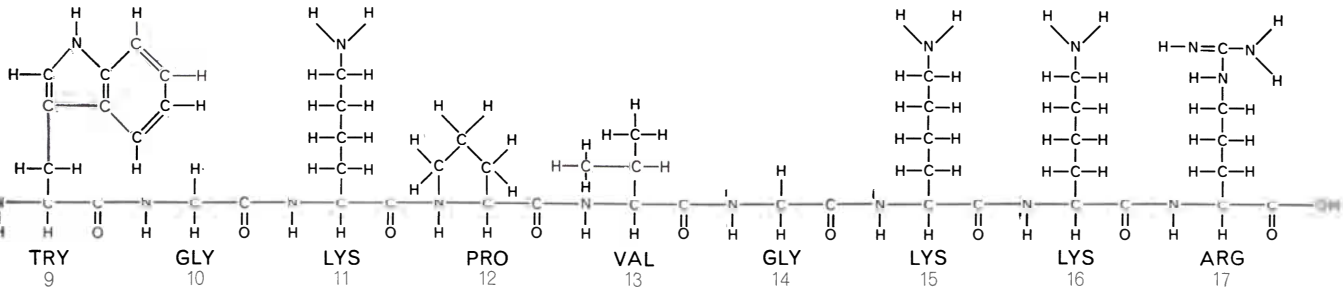
effective in the treatment of patients who have been severely burned.

In man and experimental animals ACTH, in the presence of the adrenals, has the following specific effects. It increases the weight of the adrenal glands and promotes repair of the adrenals in hypophysectomized rats (rats whose pituitaries have been removed). It promotes the production of adrenal cortical hormones, as shown by the level of these hormones in adrenal venous blood. It enhances the production of red blood cells in hypophysectomized rats; furthermore, it elevates the metabolic rate and is responsible for maintenance of muscle glycogen in these animals. It also provokes deposition of glycogen in the liver, as well as an increase of liver fat in fasted animals. It elevates the level of both free fatty acids and degradation products of the fatty acids in the blood serum of fasted rats. ACTH has also been shown to be one of the hormones involved in the production of milk in the mammary glands. Other effects observed after the administration of ACTH include shrinking of the thymus and decrease in the blood cells called eosinophils.

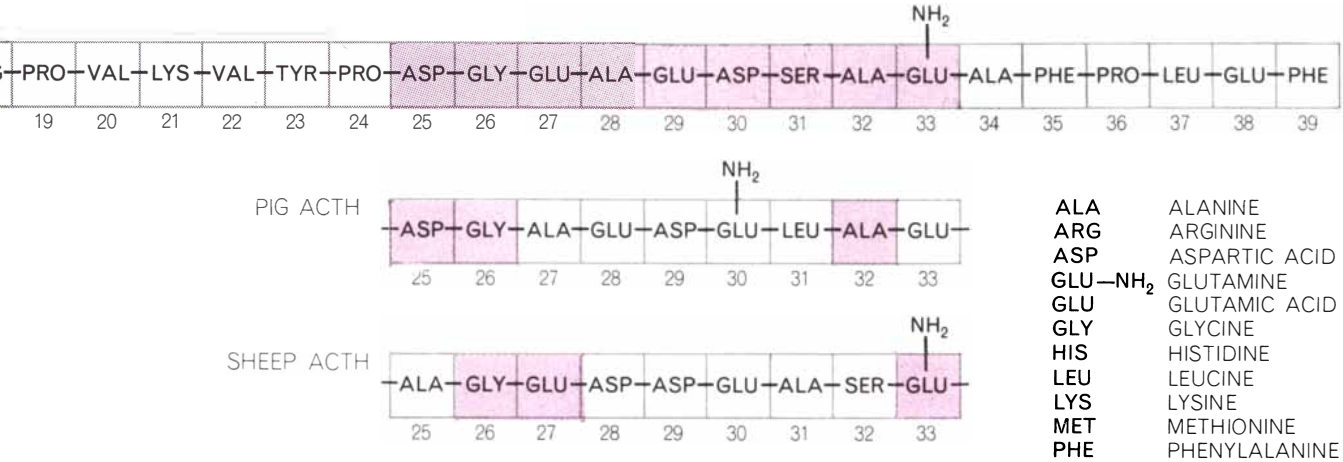
These are the major effects of ACTH in the presence of the adrenal glands. But it is now known that ACTH can also produce physiological effects in the absence of its target organ, the adrenal glands. Some observations on the biological activity of ACTH have been made in human subjects and experimental animals whose adrenals were removed or were not functioning, but the most definitive indications of extra-adrenal effects produced by the hormone have come from tissue-culture studies. For example, in 1958 Frank L. Engel and his co-workers at Duke University found that when ACTH was added to a culture of fatty tissue obtained from rats, it was highly effective in releasing free fatty acids. It has been suggested that this lipolytic response is due to direct activation of a lipolytic enzyme in the tissue.

Another extra-adrenal effect of ACTH occasioned a good deal of controversy when it was first reported. Some workers were skeptical that it was an intrinsic effect of the hormone. Both in living animals and in tissue culture ACTH was found to produce darkening of the skin by stimulating the activity of cells called melanocytes. It seemed plausible that this effect might be caused by impurities in ACTH because the anterior pituitary also produces a melanocyte-stimulating hormone (MSH). Although MSH is found in man and other animals, its skin-darkening effect is most easily observed in amphibians and reptiles, in which it stimulates expansion of pigment cells called melanophores [see "Hormones and Skin Color," by Aaron B. Lerner; SCIENTIFIC AMERICAN, July, 1961]. The controversy came to an end when the structures of the MSH and ACTH molecules were elucidated and were found to have certain features in common.

The unraveling of the chemical structure of ACTH goes back to the early 1940's. To obtain crude extracts of animal hormones it was common practice to secure glands in large numbers from the meat-packing industry. We elected to work with the anterior pituitary



peptide bonds. The whole ACTH molecule contains 39 amino acid subunits, as shown in the illustration below. In both man and animals the adrenal-stimulating potency of the 17-unit compound is only about 5 per cent as high as that of the natural hormone.



ALA	ALANINE
ARG	ARGININE
ASP	ASPARTIC ACID
GLU—NH_2	GLUTAMINE
GLU	GLUTAMIC ACID
GLY	GLYCINE
HIS	HISTIDINE
LEU	LEUCINE
LYS	LYSINE
MET	METHIONINE
PHE	PHENYLALANINE
PRO	PROLINE
SER	SERINE
TRY	TRYPTOPHAN
TYR	TYROSINE
VAL	VALINE

THREE KNOWN FORMS OF ACTH are those derived from beef, pigs and sheep. The three forms differ only between position 24 and 34. In this section beef and sheep ACTH contain the same subunits in slightly different order. In pig ACTH the sequence is also different and leucine replaces serine found in position 31 of beef ACTH. The structures of sheep and pig ACTH were reported in 1955; the structure of beef ACTH was reported in 1958.

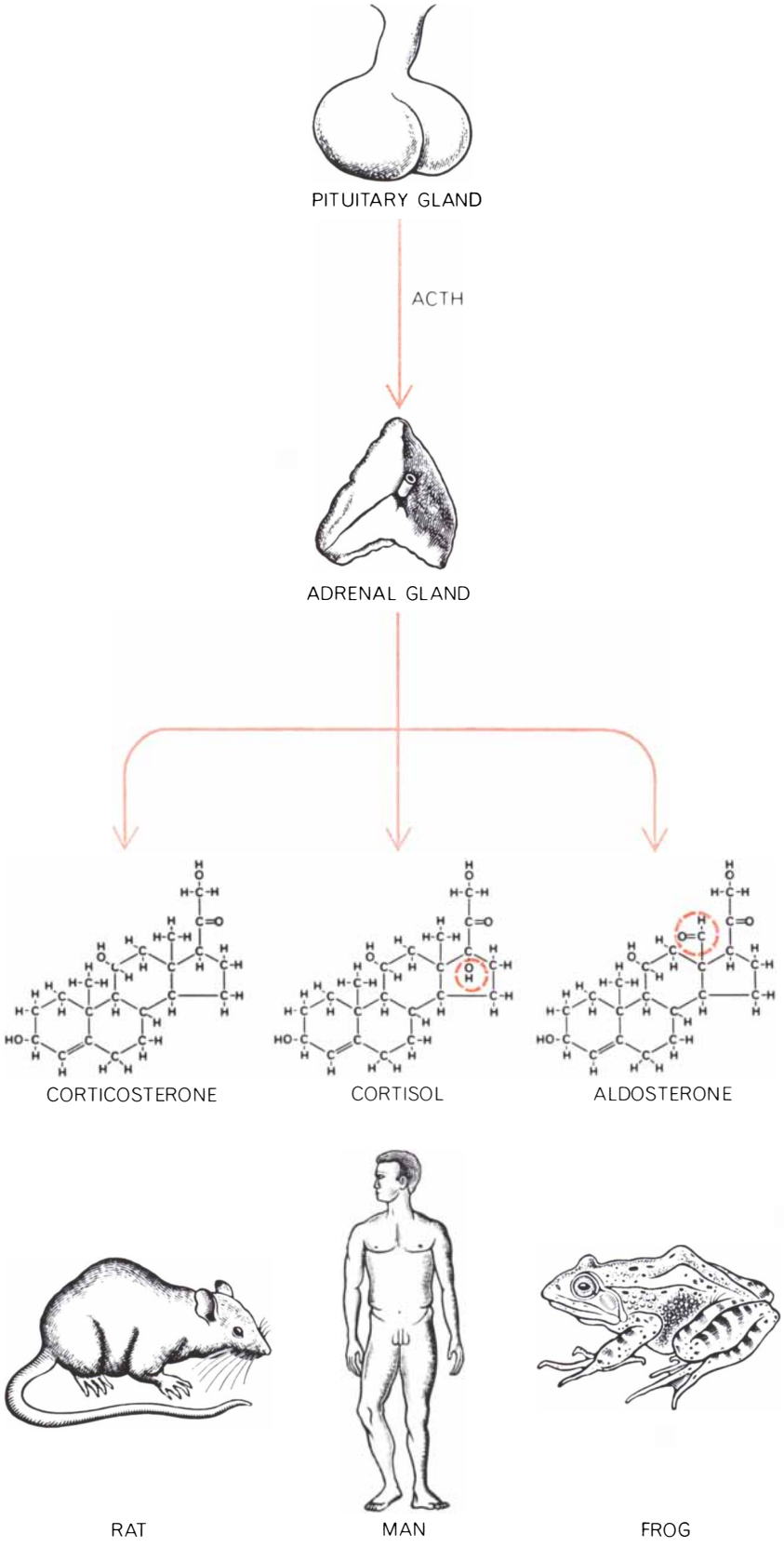
glands of sheep. It became clear rather quickly that ACTH was a protein molecule, but we had no idea whether or not it would be small enough to allow complete chemical identification. We knew that if ACTH turned out to be as large as the insulin molecule, for example, its chemical analysis might take a decade or more.

The distinction between a protein and a smaller molecular structure called a polypeptide is rather arbitrary. Both are built up of amino acids, which combine, with the loss of one water molecule per linkage, to form a peptide chain. Amino acids, in turn, are relatively simple compounds containing carbon, hydrogen, oxygen, nitrogen and, in two cases, sulfur. There are 20 common amino acids; they can be regarded as letters in an alphabet. Depending on which are selected and the order in which they are assembled, different words are produced. If the molecular "word" contains fewer than 100 letters, corresponding to a molecular weight of about 10,000 (that is, about 10,000 times the weight of the hydrogen atom), the molecule is called a polypeptide. If the molecular weight is above 10,000, the molecule is called a protein. The weight of 10,000 is taken as a division point because molecules lighter than that, when in solution, will pass through cellophane.

The peptide chain forms the backbone of a protein and provides its primary structure. In globular proteins (for example, pituitary growth hormone and lactogenic hormone) the polypeptide chains are not straight but are twisted into a spiral, or helix. This helical configuration is called the secondary structure. When the structure of the insulin molecule was finally elucidated in 1954 by Frederick Sanger and his associates at the University of Cambridge, it was found to consist of two chains linked by sulfur bridges. Insulin has a molecular weight of nearly 6,000 and has 51 amino acid subunits. This memorable achievement, the first determination of a large polypeptide structure, took 10 years of intensive effort [see "The Insulin Molecule," by E. O. P. Thompson; SCIENTIFIC AMERICAN, May, 1955]. Proteins can also have a tertiary structure, characterized by further coiling or folding of helices.

In the early 1940's techniques for separating protein fractions from a crude glandular extract were clumsy and tedious. To guide the separation process hormone fractions were assayed by injecting them into rats whose pituitary glands had been removed. If a particular fraction stimulated the adrenal cortex, it was deemed to contain an adrenocorticotropic factor. Even after a fraction of demonstrable potency had been isolated, no single procedure could be relied on to establish its purity with certainty. Not only is a single criterion of purity lacking; the mere fact of agreement among many criteria does no more than increase the probability that the substance is pure.

Finally, in 1942, we obtained from sheep pituitaries an apparently homogeneous protein that possessed ACTH activity. Its molecular weight was 20,000, indicating that it had about 200 amino acid subunits. In the following year George Sayers, Abraham White and Cyril N. H. Long of Yale University



PRINCIPAL CORTICAL HORMONES, produced by the adrenal cortex in response to ACTH, differ from one species to another. The adrenal cortex makes a number of hormones with the same four-ring steroid structure. The ratios of the different steroids vary in different species. Thus the human adrenal cortex makes more cortisol than it does corticosterone or aldosterone. Rats and frogs respectively make more corticosterone and aldosterone.

reported the isolation from pig pituitaries of a highly purified protein with the same molecular weight. Investigation of the two hormone preparations was largely suspended for the remainder of World War II.

There were exciting rumors, however, that German military pilots were being given an extract of the adrenal cortex to enable them to resist fatigue and to increase their tolerance for lack of oxygen at high altitudes. With Government backing a number of universities and pharmaceutical firms set out to synthesize adrenal steroids. The first chosen for synthesis was one that had been named Compound A by its discoverer, Edward C. Kendall of the Mayo Foundation. Enough of the substance for testing was finally produced in 1945, but it proved totally ineffective. Kendall was not discouraged. He urged Merck & Company to work on Compound E, a steroid much more difficult to synthesize. In 1948 Lewis H. Sarett of Merck produced enough Compound E for clinical testing. In one of the first trials at the Mayo Clinic, Philip S. Hench, a colleague of Kendall's, found that Compound E, later to become famous as cortisone, was useful in treating rheumatoid arthritis. Almost simultaneously Hench and others observed that ACTH, by stimulating the adrenal cortex to produce cortisone-like steroids, was at least as useful as cortisone for treating arthritis, acute rheumatic fever and a number of allied ailments.

The reader may recall the nationwide—indeed worldwide—effort that was mounted to increase the supplies of cortisone and ACTH. Many biochemical laboratories undertook to isolate the pure ACTH peptide from pituitaries of various species and to establish its chemical structure. It was generally hoped that once the structure was known the hormone might be synthesized in whatever quantities were desired.

Fortunately in the late 1940's and early 1950's major advances were made in methods for isolating polypeptides and other large molecules. These methods included electrophoresis, chromatography and countercurrent partitioning. The workers chiefly responsible for these advances were Arne W. K. Tiselius of Sweden, A. J. P. Martin and R. L. M. Synge of England and Lyman C. Craig of the Rockefeller Institute. In 1954, largely by means of these new procedures, my associates and I were able to show that sheep pituitary extracts contain a straight-chain peptide with 39 amino acid subunits and a molecular

weight of about 4,500 that is even higher in ACTH activity than the substance of 20,000 molecular weight isolated in 1942. Within a few months Paul H. Bell, Robert G. Shepherd and their co-workers at the American Cyanamid Company announced the purification and the partial determination of the structure of ACTH obtained from pigs. By 1955 the complete sequence of amino acid subunits in sheep and pig ACTH was reported by the American Cyanamid workers and by our laboratory at Berkeley. In 1958 we worked out the complete structure of beef ACTH.

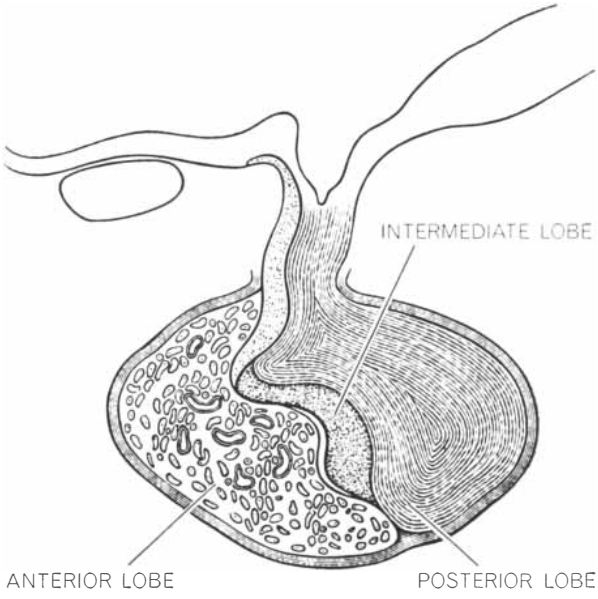
What do these three forms of ACTH have in common and how do they differ? All three varieties contain 39 amino acid subunits. In all three, moreover, the first 24 subunits in the chain and the last six subunits are identical [*see lower illustration on page 49*]. The differences lie in the nine subunits between positions 24 and 34. In this section sheep and beef ACTH have the same subunits but in slightly different sequence. In pig ACTH not only is the sequence different but also a subunit of leucine replaces a subunit of serine, which occupies position 31 in beef ACTH.

During the period from 1954 to 1960 some investigators still had doubts that the chemical make-up of ACTH was known, even though complete structures had been proposed for three major varieties. (The complete structure of human ACTH is still unknown because of the difficulty of obtaining adequate samples.) The usual way to establish the validity of a proposed molecular structure for a natural substance is to show that a completely synthetic compound of that structure has the appropriate biological activity.

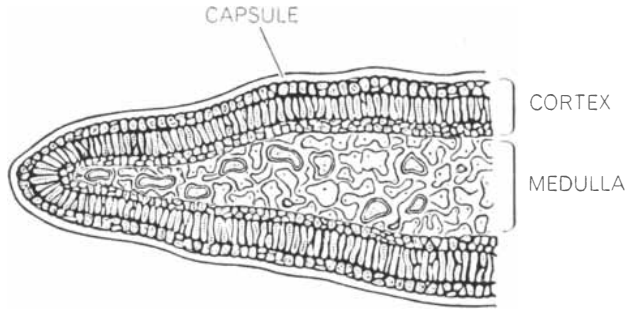
As early as 1947 I had observed that when the ACTH protein was broken into a few large pieces by the enzymatic action of pepsin, the activity of the hormone was not measurably impaired. This observation led, in the first instance, to isolation of the 39-unit peptide. Subsequently both we and workers at American Cyanamid found that removal of the last 11 amino acids from the 39-unit molecule did not impair its activity. This held out the hope that if large quantities of ACTH were needed for medical use, it might be possible to meet the need with a synthetic compound easier to synthesize than the whole molecule.

This possibility was finally confirmed late in 1960 when our laboratory synthesized a peptide composed of the first 19 amino acids of natural ACTH and demonstrated that it possesses all the biological properties of the natural hormone. This synthesis also dispelled any lingering doubts about the proposed structure of ACTH. In subsequent months Klaus H. Hofmann and his coworkers at the University of Pittsburgh School of Medicine and R. Schwyzer and his associates at the Ciba Company in Switzerland also announced synthetic polypeptides, 19 to 24 subunits in length, having ACTH activity.

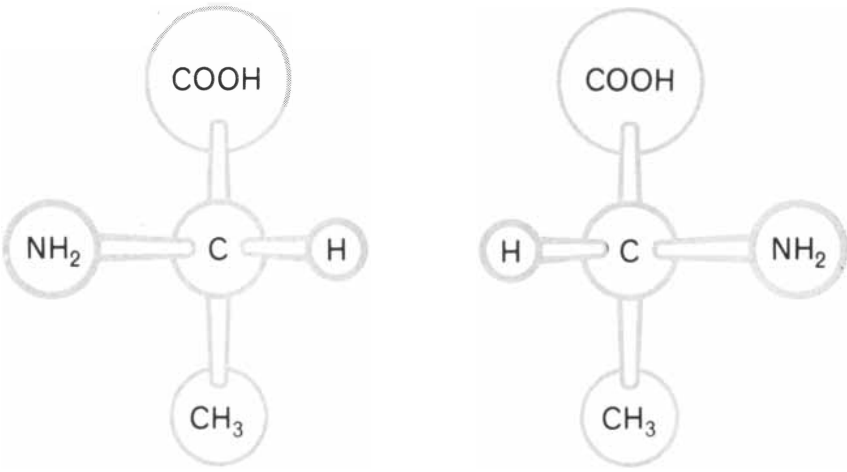
Because natural ACTH does more than just stimulate the adrenal cortex it has been of great interest to measure the extra-adrenal effects of the synthetic polypeptides. From such studies one can discover the relation between structure and activity by noting the varying proportions in which the different activities occur in peptides of various lengths. Eventually one may be able to assign different activities to specific portions of the molecule. The 19-unit polypeptide exhibits about half of the adrenal-stimulating activity of native ACTH in experimental animals, as judged by increase of adrenal weight. This figure is confirmed by measuring the steroid output of isolated adrenal glands, maintained in glassware. In man the synthetic polypeptide is about 80 per cent as potent as the natural hormone; this was demonstrated by Peter H. Forsham and his colleagues at the University of California Medical Center in San Francisco. In cultures of fatty tissue from rats the synthetic product has about 40 per cent of the lipolytic activity of the natural



PITUITARY GLAND is also known as the hypophysis, from the Greek term for "lying under," which describes the gland's position under the brain. The human pituitary is about one centimeter long and 1.5 centimeters wide. The seven hormones produced by the anterior pituitary are identified on page 46. The posterior lobe produces two: vasopressin, which raises blood pressure, and oxytocin, which contracts the uterus and stimulates lactation.



ADRENAL GLAND is about 10 times larger than the pituitary gland and also produces two classes of hormones. The medulla, or inner part, makes epinephrine (adrenaline) and norepinephrine (noradrenaline), which prepare the body to meet emergencies. The cortex, or outer part, produces a variety of steroid hormones, three of which are illustrated on the opposite page. An adrenal gland is located above each of the body's two kidneys.



RACEMIC FORMS OF ALANINE, one of the 20 amino acids that form proteins and polypeptides, are mirror images. When in solution, one configuration called the L-form (*left*) rotates plane-polarized light to the left. The D-form (*right*) rotates polarized light to the right. Natural proteins all contain L-type amino acids. In synthesis of polypeptides L-type amino acids often turn into a mixture of L- and D-types. This is called racemization.

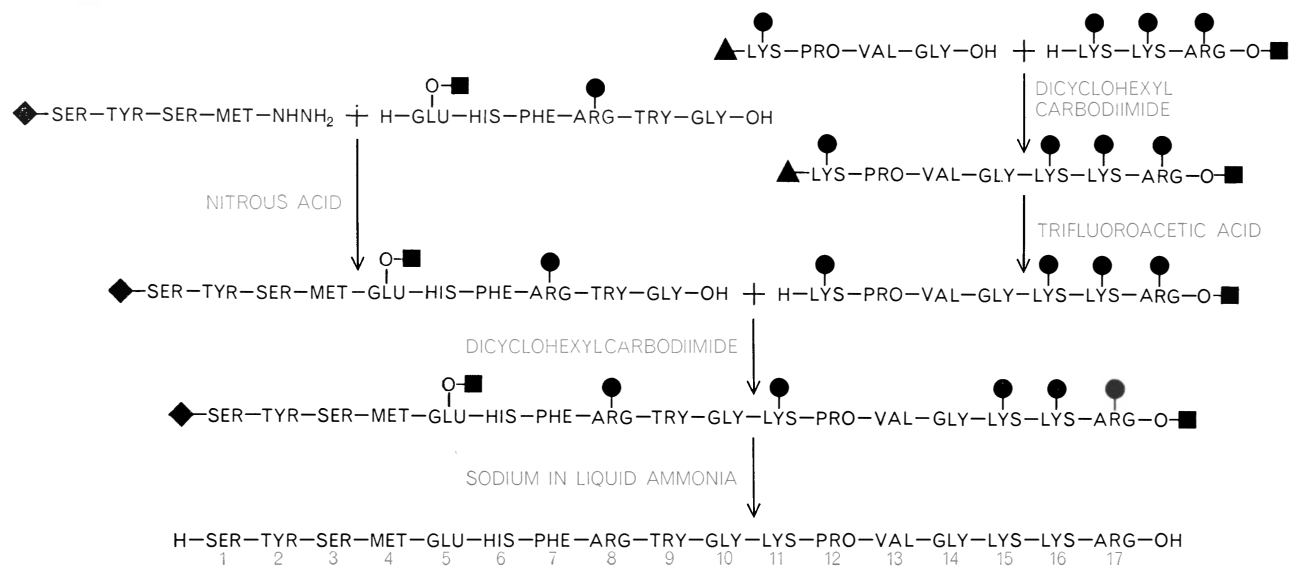
hormone, as determined by release of free fatty acids. Compared with natural ACTH, the synthetic is also 40 per cent as effective in depleting ascorbic acid in the adrenals of rats when injected intravenously, and up to 70 per cent as effective when injected subcutaneously.

In at least one respect the 19-unit polypeptide shows even higher activity than natural ACTH does. The synthetic product causes a greater darkening of the skin when injected into live frogs whose pituitaries have been removed. This has led to the first important correlation between chemical structure and hormonal activity. The complete structures of two skin-darkening anterior pituitary hormones, alpha-MSH and beta-MSH, were established soon after the structure of ACTH was determined. In 1958 Roger Boissonnas and his colleagues at Sandoz, Ltd., in Switzerland synthesized the alpha form of the hormone. Except for two small chemical details the sequence of amino acid subunits in alpha-MSH is identical with the first 13 subunits in ACTH.

This has led to the speculation that the tail end of the peptide chain of ACTH in the natural molecule functions as an inhibitor of MSH activity. To investigate this possibility we synthesized a still shorter polypeptide containing only the first 17 amino acids of natural ACTH. This synthesis was reported just over a year ago. Compared with the natural hormone, the new synthetic was found to be about 10 times more potent in darkening the skin of frogs and also about 10 times more potent in its lipolytic effect, as measured in tissue culture. In both man and animals the adrenal-stimulating potency of the 17-unit polypeptide is only about 5 per cent as high as that of natural ACTH. The new synthetic substance may prove to be about the smallest molecule capable of stimulating the adrenal cortex to any significant degree.

The synthesis of biologically active polypeptide chains has presented chemistry with one of its most fascinating and challenging problems. In our work we have been able to draw on the accumulated experience of scores of brilliant workers, beginning with the pioneer investigations of the German chemist Emil Fischer more than 50 years ago. Fischer was the first to demonstrate how a polypeptide could be built up by lengthening a chain stepwise, one amino acid at a time, or by the joining of small peptide fragments.

One of the chief problems in peptide



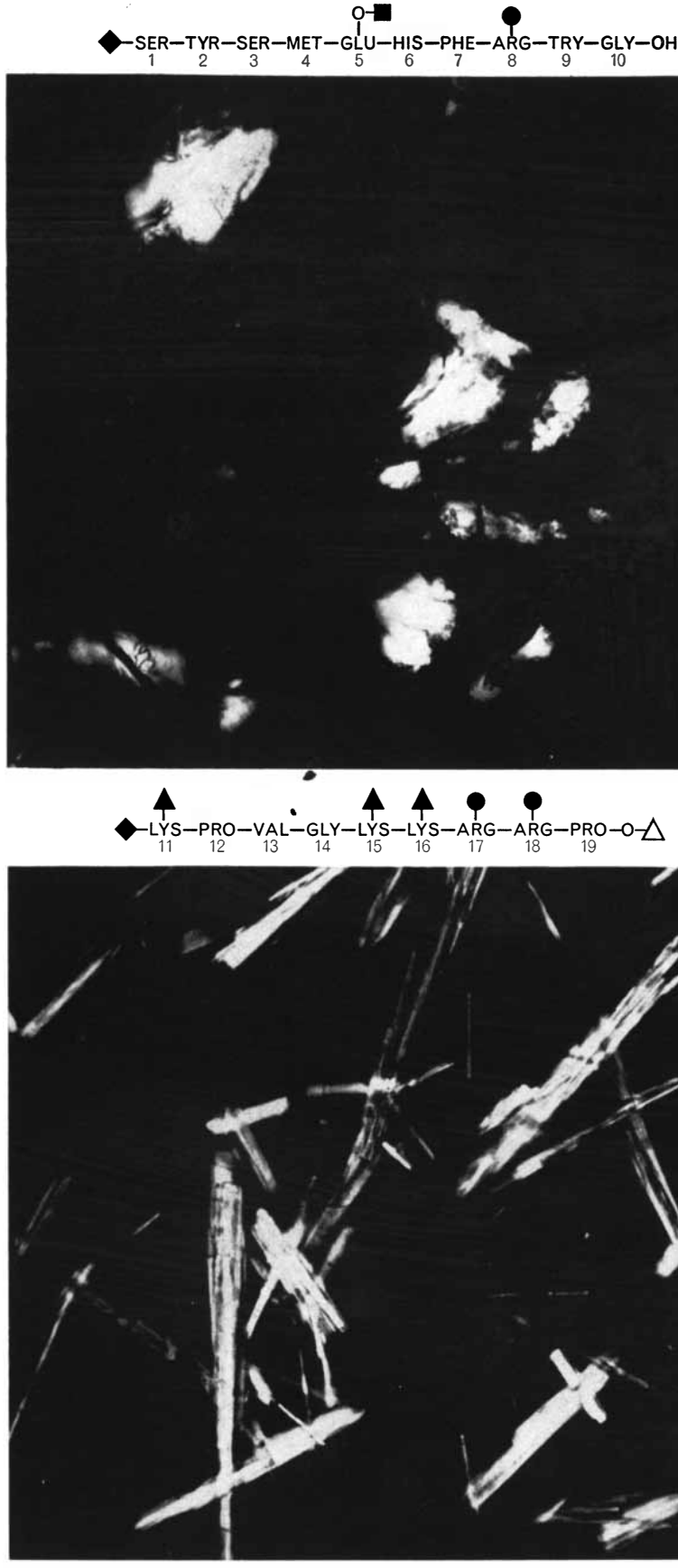
SYNTHESIS OF ACTH FRACTION containing 17 amino acid subunits is accomplished by linking together four polypeptide chains containing three to six subunits. To prevent unwanted reactions from taking place, the reacting molecules must be "protected" by adding various compounds at critical points. These protective groups are identified in the key.

synthesis is to control the spatial geometry of the peptide linkages so that they follow those found in nature. Because their molecules are asymmetric many organic compounds have the ability to rotate the plane of polarization of polarized light to the right or left. The natural amino acids (except for the simplest, glycine) are all optically active and have the same kind of configuration in space, called the L-configuration [*see top illustration on opposite page*]. A common difficulty in organic synthesis is that L-compounds change into a mixture of equal amounts of the L-configuration and its mirror image, known as the D-configuration. (Although "L" and "D" stand for "levo" and "dextro," this does not necessarily mean that they rotate the plane of polarization respectively to the left and right.) This conversion of L-compounds to L and D forms is called racemization.

In peptide synthesis many stratagems must be used to prevent racemization. The final product must be carefully examined, not only with respect to its composition but also with respect to its stereochemical purity. One useful test of stereochemical purity is to expose a compound to certain enzymes that are known to attack only those peptide bonds that are between L-amino acids. Another test is to decompose the peptide into its amino acid constituents and to feed them to microorganisms that can live only on the L-form.

An outline of our method for linking the first 17 amino acids of ACTH into a polypeptide is illustrated at the bottom of the opposite page. Prior to the steps shown, four short peptide chains containing from three to six amino acid subunits must be synthesized. These four chains are then united to form the 17-unit polypeptide.

There is no reason in principle why the whole 39-unit molecule of natural ACTH could not be assembled in the same way. Eventually it will be done, if not by us, then by someone else. Along the way we may learn how the terminal 22 units of the molecule inhibit the skin-darkening and lipolytic activities of the first 17 units. We may learn why the pituitary produces a 39-unit molecule when it is certain that the final 11 units can be removed without any loss of adrenal-stimulating potency. We would also like to know if it is possible to obtain a synthetic product that exhibits one and only one biological effect of ACTH. These are just a few of the important problems to be studied in future investigations of a fascinating molecule.



PROTECTED POLYPEPTIDES, prepared in the author's laboratory, are difficult to obtain in the crystalline form shown. When the two compounds are linked and the protective groups are removed, the resulting compound duplicates the first 19 subunits of natural ACTH.

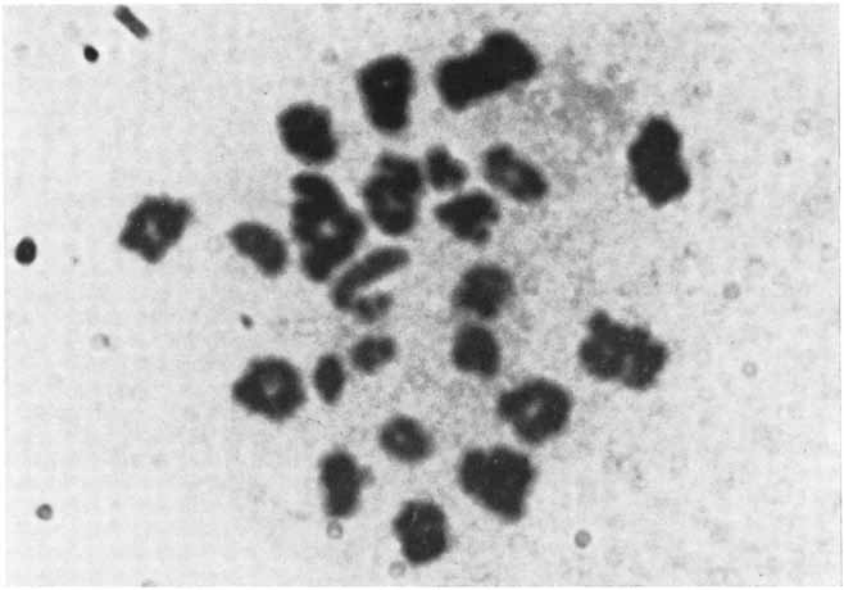
Sex Differences in Cells

The chromosomes differ in males and females. So do certain other structures in cell nuclei. These distinctions are clues to the processes that determine the divergence of the sexes

by Ursula Mittwoch

"Male and female created He them." Until the turn of the century this statement had to stand as a full description of what was known about the mechanism that brings about the divergence of the sexes. With the development of the discipline of cell genetics it has become clear that the chromosomes, the cellular structures that encode the hereditary plan, differ in male and female animals. Sex is determined at conception by the chromosome complement with which the fertilized egg is endowed by the union of the parental sex cells. In recent years other sex differences in cells have been discovered; it is now possible to tell whether a piece of skin or a drop of blood has come from a man or a woman by examining the nuclei of cells of these tissues under a microscope. More important, the recognition of these sex indicators in the nuclei of body cells has opened the way to study of the still largely unknown processes by which the parental chromosomes commit the fertilized egg to development as a male or a female of its species.

The first step in the understanding of the determination of sex came with the discovery in insects that the male sex cells—the spermatozoa—do not all carry the same complement of chromosomes. Half of them were found to contain a chromosome that stands out from the rest because of its characteristic form; it was named the X chromosome. In many species the spermatozoa that lack an X chromosome were found to contain another, usually smaller chromosome; this was labeled the Y chromosome. The chromosome complements of insect eggs, on the other hand, turned out to be uniformly the same; each contains an X chromosome and never a Y.



SEX CHROMOSOMES are clearly identifiable in a male gonadal cell dividing to form spermatozoa. In this photomicrograph from the author's laboratory the homologous chromosomes are paired. All pairs but one are composed of equal chromosomes and are roughly symmetrical. The one hook-shaped pair is composed of X and Y sex chromosomes.

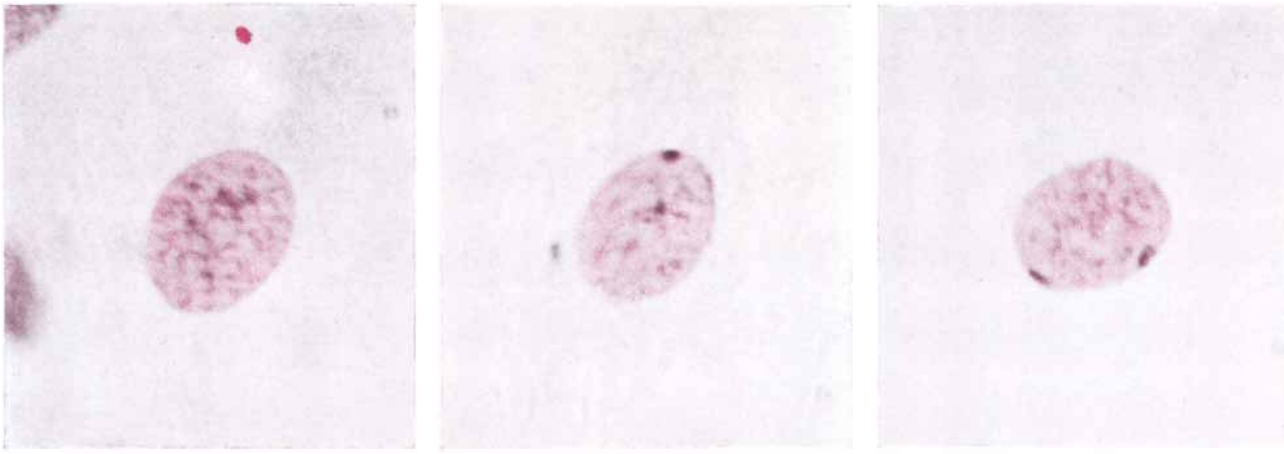
The body cells of animals, as distinguished from their sex cells, have pairs of homologous, or similar, chromosomes, one member of each pair being contributed by the parental sex cells at conception. When investigators first examined the body cells of insects in the early years of this century, they found that the cells of females contain two X chromosomes. In the body cells of male insects they found instead one X and one Y. They concluded that the union of an egg with an X-bearing spermatozoon would give rise to a female offspring with two X chromosomes; correspondingly, a sperm bearing a Y chromosome would give rise to an individual with an X and a Y chromosome, or a male [*see top illustration on page 56*]. So it became established that sex is determined at the moment of conception, that it is determined by the sex-chromosome content of the germ cells and that in most species the differentiating chromosome is carried by the spermatozoon.

The early period of cell genetics can be said to have closed with the appearance in 1925 of Edmund B. Wilson's book *The Cell in Development and Heredity,* which set out the fundamental principles of sex determination by chromosomes. A second period of fruitful investigation of cellular genetics in its bearing on the determination of sex, particularly in human beings, began about 1950 and has gained momentum steadily. Two lines of research—chromosome studies and the work that led to the discovery of the nuclear sex indicators—have joined to bring about an unexpect-

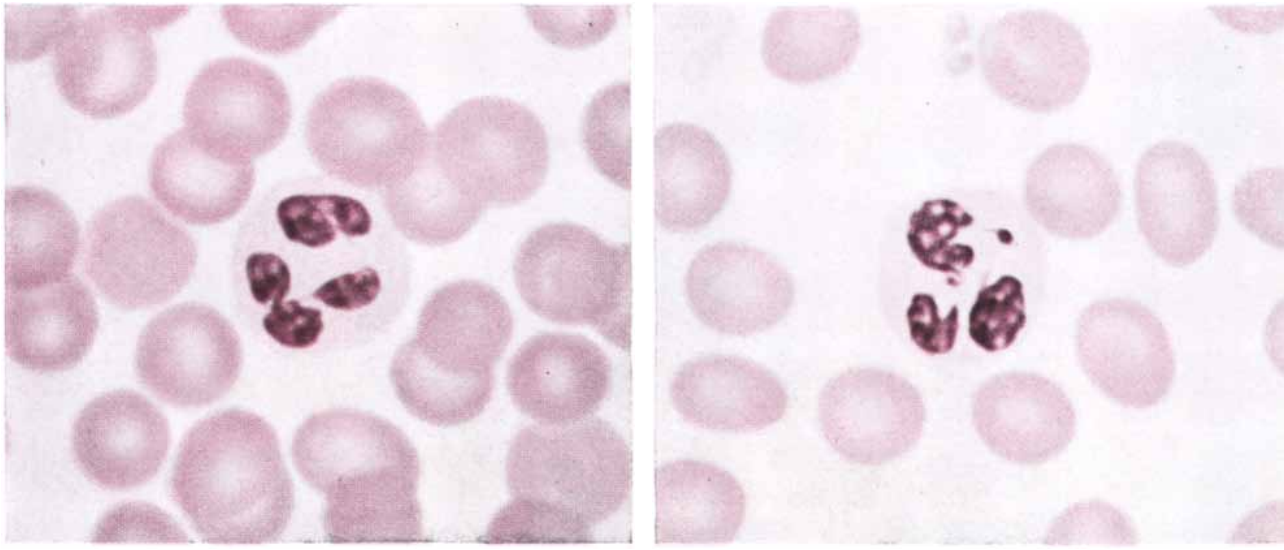
edly rapid advance in the understanding of sexual development in the embryo.

In spite of man's great interest in matters regarding his own species, geneticists for many years knew far less about human chromosomes than about those of many animals and plants. The number of chromosomes in a human cell is large and they tend, under ordinary circumstances, to cluster together in the nucleus; it is practically impossible to count them accurately, let alone study their individual shapes. In the past decade workers in many countries have developed important new techniques for overcoming these difficulties [see "Chromosomes and Disease," by A. G. Bearn and James L. German III; SCIENTIFIC AMERICAN, November, 1961]. The turning point came in 1956, when J. H. Tjio and Albert Levan of the University of Lund in Sweden announced that they had counted 46 chromosomes in cells grown from aborted human embryos—not 48, as had been supposed. The correctness of the new number was soon confirmed by Charles E. Ford and John L. Hamerton of the Radiobiological Research Unit at Harwell in England. Once the number of chromosomes in the normal human cell was determined, the stage was set for more detailed investigations.

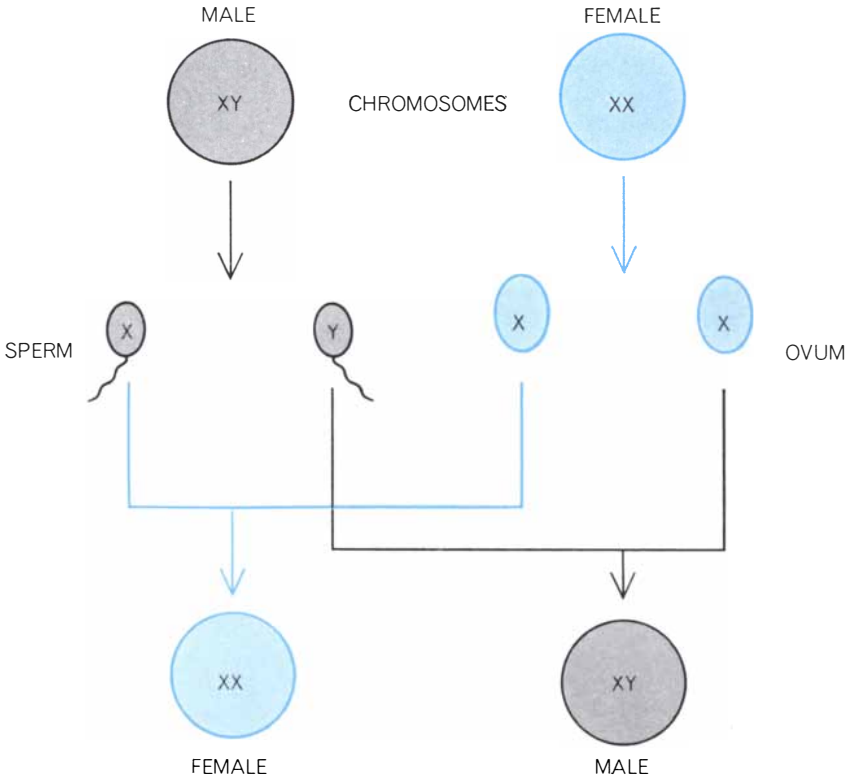
Chromosomes can be seen only in cells that are dividing. They can be seen in gonadal cells, which divide by the special process called meiosis to give rise to sex cells, as well as in cells that divide by the more common process of mitosis, whereby single-celled organisms and the body cells of higher organisms reproduce themselves. The gonadal cells offer certain advantages for study. In mitosis all the chromosomes in the cell replicate before cell division and each of the daughter cells is furnished with a full complement of chromosomes. In meiosis, on the other hand, the homologous chromosomes separate, one member of each pair going to each of the sex cells; the resulting sperm or egg cell is thus endowed with a half-complement of chromosomes, representing a mixture of the



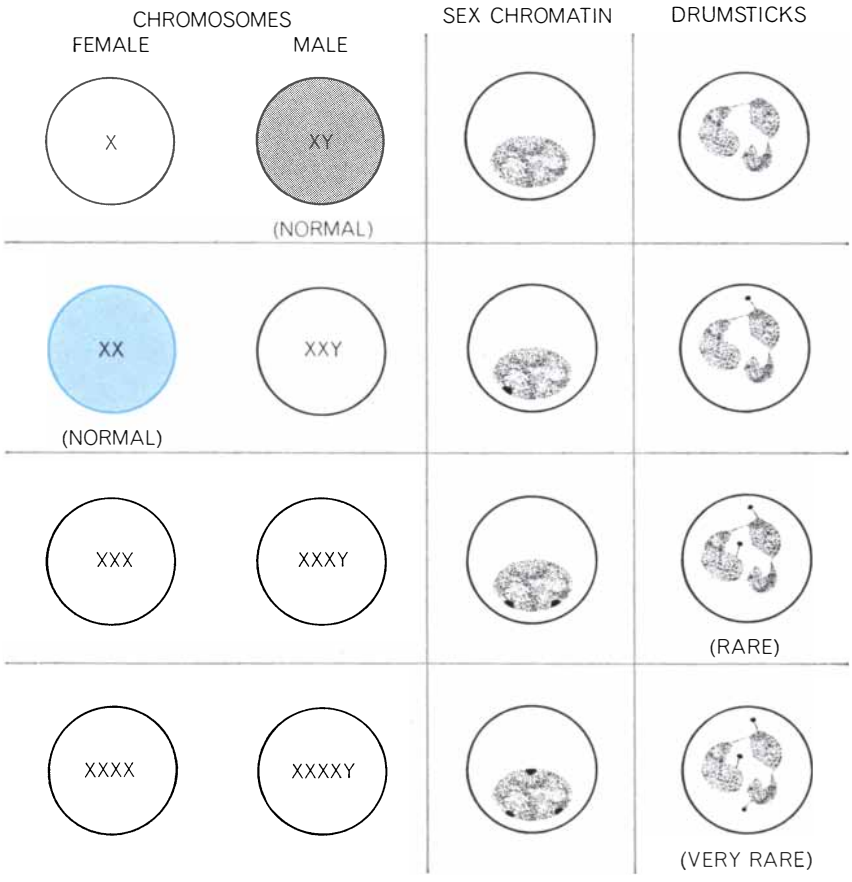
SEX CHROMATIN, or Barr body, is one cellular indicator of sex. It is a darkly staining body that is seen in the nuclei of certain female cells but not in male cells. The photomicrograph at left shows the nucleus of a cell with no sex chromatin. The next photomicrograph shows a similar cell from a normal woman, with one Barr body at the periphery of the nucleus. The cell at right, taken from a woman with three X chromosomes instead of the normal two, has two Barr bodies. The magnification is 2,100 diameters.



"DRUMSTICKS," another sex difference found in cells, appear only in females, in white blood cells called polymorphonuclear leucocytes. The multilobed nucleus of the cell shown at left has no drumstick present. The nucleus at right, in a cell from the blood of a normal woman, has one: the small round body, which is attached to the nucleus by a faint filament. The magnification is 2,200 diameters. The photomicrographs on this page were made by Anthony Bligh of the University College Hospital Medical School.



SEX IS DETERMINED by the sex chromosomes of the fertilized egg. Male cells have an X and a Y chromosome; female cells, two X chromosomes. Half of the sperm therefore carry X chromosomes and half Y; all ova, or eggs, have X chromosomes. Fertilization by an X-carrying sperm produces a female; fertilization by a sperm with a Y produces a male.



SEX DIFFERENCES in cells are related as shown here. The maximum number of sex-chromatin bodies and of drumsticks is one less than the number of X chromosomes in the cell.

chromosomes with which the gonadal cell was endowed by the parents of the organism. Just before they part company the homologous chromosomes of the gonadal cell are intimately associated with each other; in the cells of the human gonad the 46 chromosomes appear as 23 pairs.

A photomicrograph of such a cell from the male gonad [*see illustration on page 54*] shows that all but one of the pairs are symmetrical since they are composed of two similar chromosomes—the autosomes, or nonsex chromosomes. The asymmetric pair is made up of the X and Y chromosomes. The X is considerably larger than the Y; the two are associated end to end. The trouble is that male gonadal cells are rarely available for study; the stage of chromosome division in the female when the ova, or egg cells, are formed has never been seen.

In human beings chromosomes are most commonly studied in body cells taken from the bone marrow, skin or blood. Cells in bone marrow are normally in a state of active division, since it is their function to replace blood cells as they become worn out. Dividing cells can be seen, therefore, in bone marrow samples immediately after the material has been taken from the body. Cells from the lower layer of skin also divide, although slowly, to replace those in the upper layer that are sloughed off; these cells must be cultured for at least two weeks before chromosome studies can be undertaken.

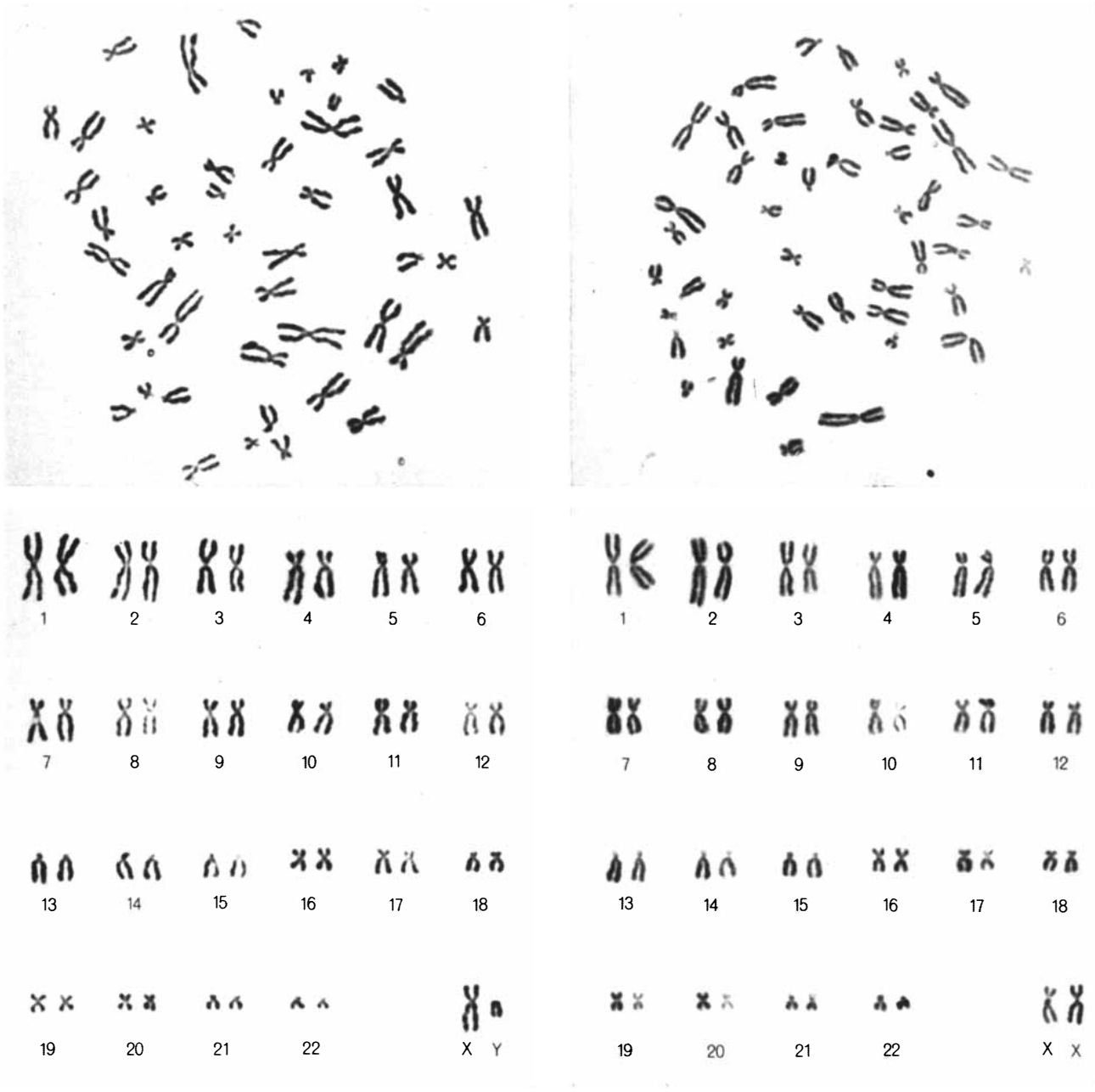
The white cells of the blood are, of course, more conveniently sampled, from both the subject's and the investigator's point of view. Although they do not normally divide once they have been liberated from the bone marrow, it was shown by Edwin E. Osgood and John Brooke of the University of Oregon Medical School that a reagent extracted from beans, called phytohemagglutinin, can be used to induce them to divide in a culture medium. Addition of the plant alkaloid colchicine to the medium inhibits cell division at the stage known as metaphase, when the chromosomes are most clearly seen. Then the cells are bathed in a solution of sodium citrate at a concentration lower than that of the salts inside the cells. Osmotic pressure causes water to enter the cell, swell the nucleus and disperse the chromosomes. Finally the cells are killed, placed on a slide and usually stained.

Human chromosomes obtained from blood cells by this procedure are discrete structures of different sizes, symmetrical along a longitudinal axis and

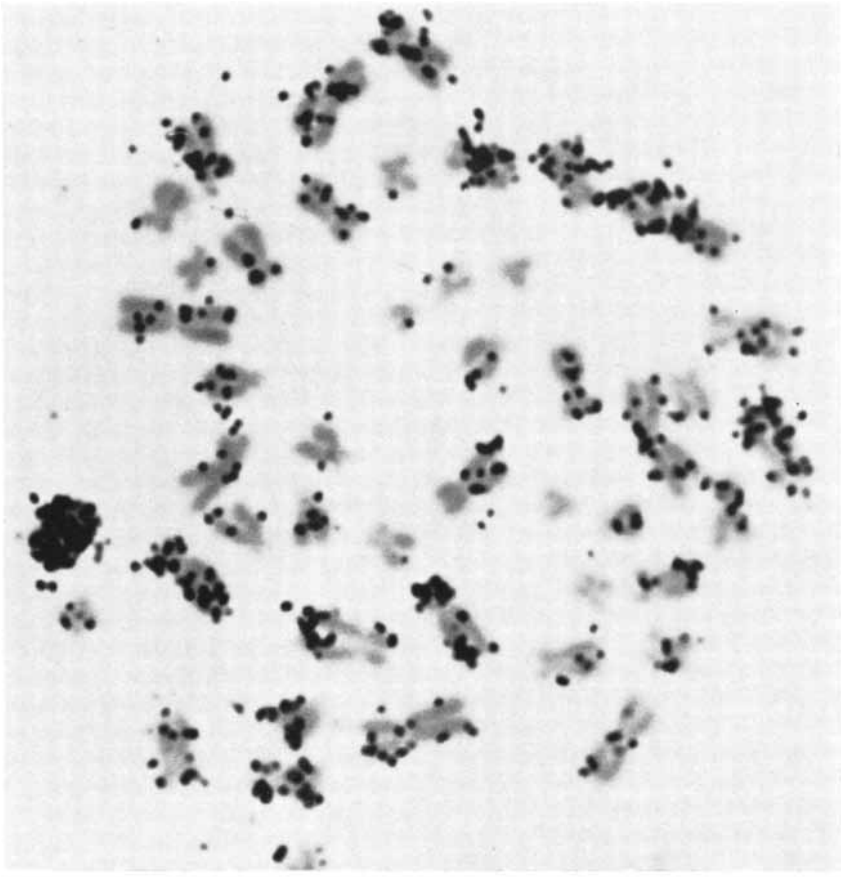
roughly cross-shaped or V-shaped. Their symmetry results from the fact that they have already replicated; each has formed a copy of itself, to which it is joined at a constriction called the centromere. (In the normal course of cell division the centromere would have divided and the two halves of the doubled chromosome would have moved off in opposite directions to two daughter cells.) Both the over-all size and the position of the centromere are characteristic for each chromosome. In this type of cell, unlike a germ cell, the chromosomes are not naturally paired with their homologues. But a trained person can cut the individual chromosomes from a photograph and arrange them in pairs according to their size and the position of their centromeres.

If the cell comes from a man, one of the pairs will be composed of unequal partners; these are the X and Y chromosomes. The X chromosome is of medium size and is cross-shaped, whereas the Y is very small and is V-shaped. The other chromosomes—the autosomes—are numbered from one to 22 in order of decreasing size. If the chromosomes of a similar cell from a woman are arranged in the same manner, all the pairs will be composed of equal partners because a woman has two X chromosomes [*see illustration below*].

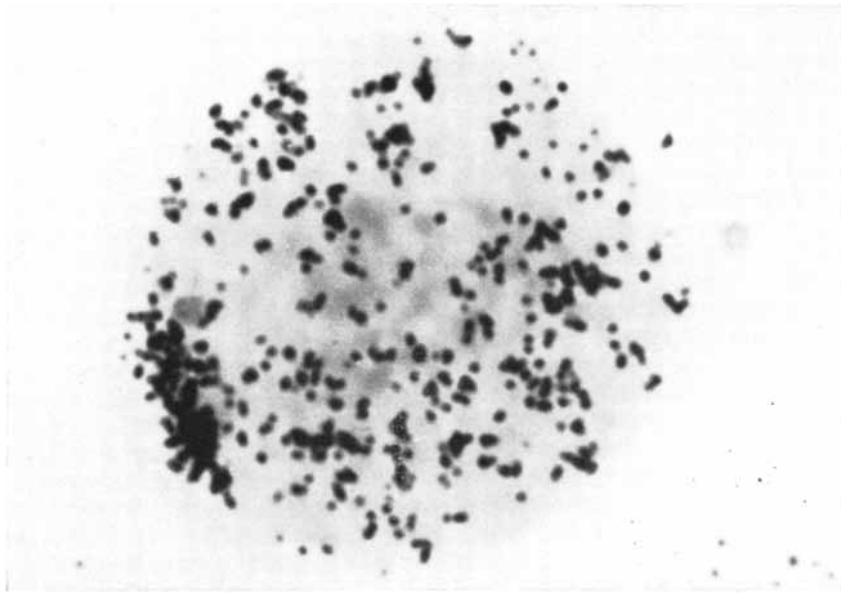
By comparing cells from males and females it was possible to learn to identify the X chromosome fairly reliably as one of medium size with its centromere near the middle. But there are a number of other chromosomes (those labeled six to 12) that look rather similar, so at present no one can be sure that the one la-



HUMAN CHROMOSOMES from blood cells, prepared as described in the text, are enlarged 1,400 diameters in the two upper photomicrographs. The cell at left is from a man, the one at right from a woman. In the lower part of the illustration the chromosomes have been arranged in pairs. There are 22 pairs of autosomes in each cell and one pair of sex chromosomes: XY in the male and XX in the female. The cells were prepared by Ruth Marshall in the author's laboratory; the photomicrographs were made by Bligh.



AUTORADIOGRAPHY reveals a late-replicating X chromosome in this photomicrograph made by James L. German III of the Rockefeller Institute. Radioactive thymidine was added to a culture of female blood cells when this cell had almost completed DNA synthesis, and was taken up only by late-replicating chromosomal regions. Now, at metaphase, the late X is identified by the concentration of dark spots (*left*) on a radiosensitive emulsion.

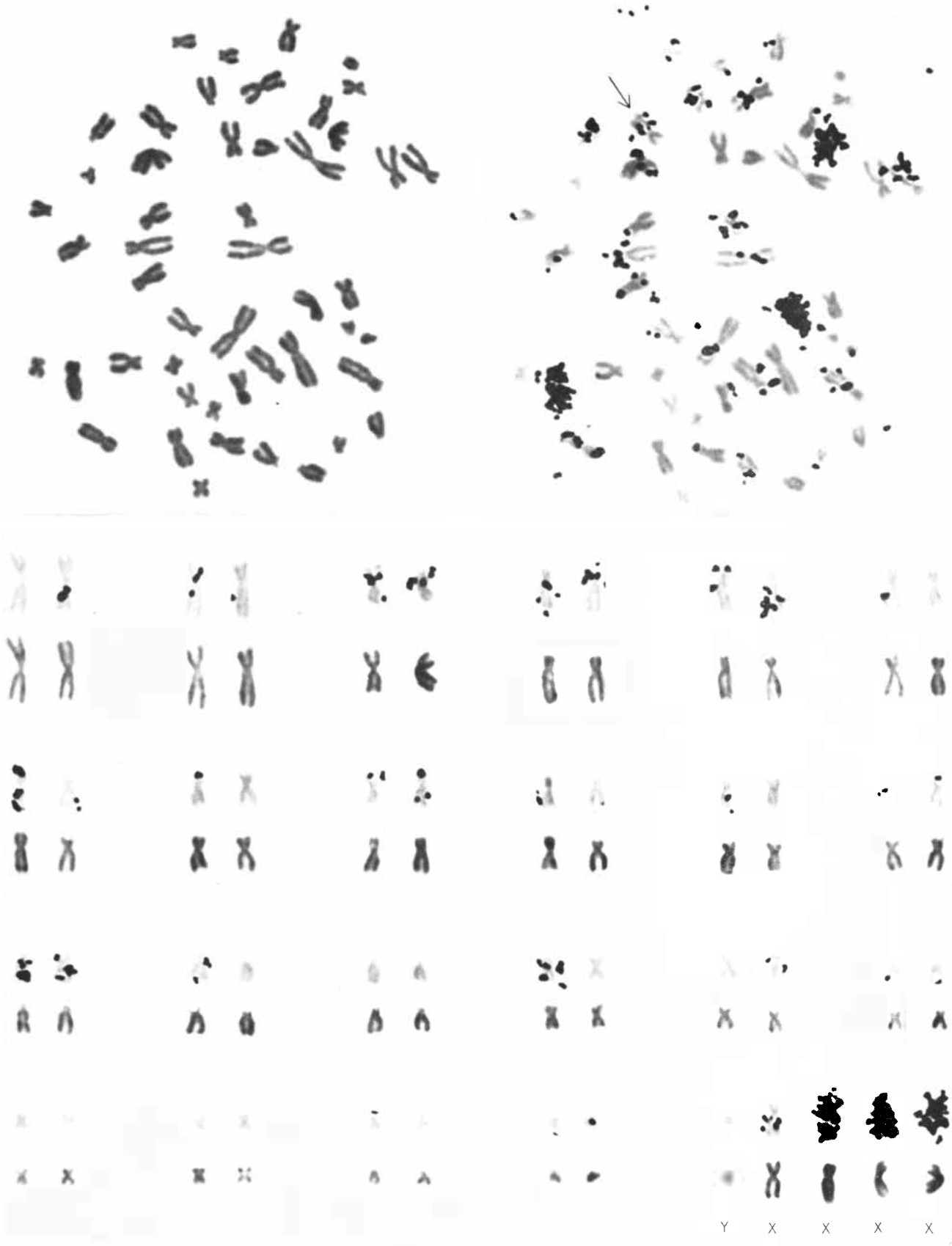


LATE-REPLICATING MATERIAL is seen at another stage of the cell-division cycle in this photomicrograph, also made by German. This cell, a neighbor on the microscope slide of the one at the top of the page, was also far advanced in DNA synthesis when exposed to radioactive thymidine; unlike the other cell, it has not yet reached metaphase. The chromosomal material that took up the largest quantity of radioactive thymidine, and which would at metaphase presumably be seen as a late-replicating X like the one at the top of the page, is visible (*left*) at the edge of the nucleus, the area in which Barr bodies are usually found.

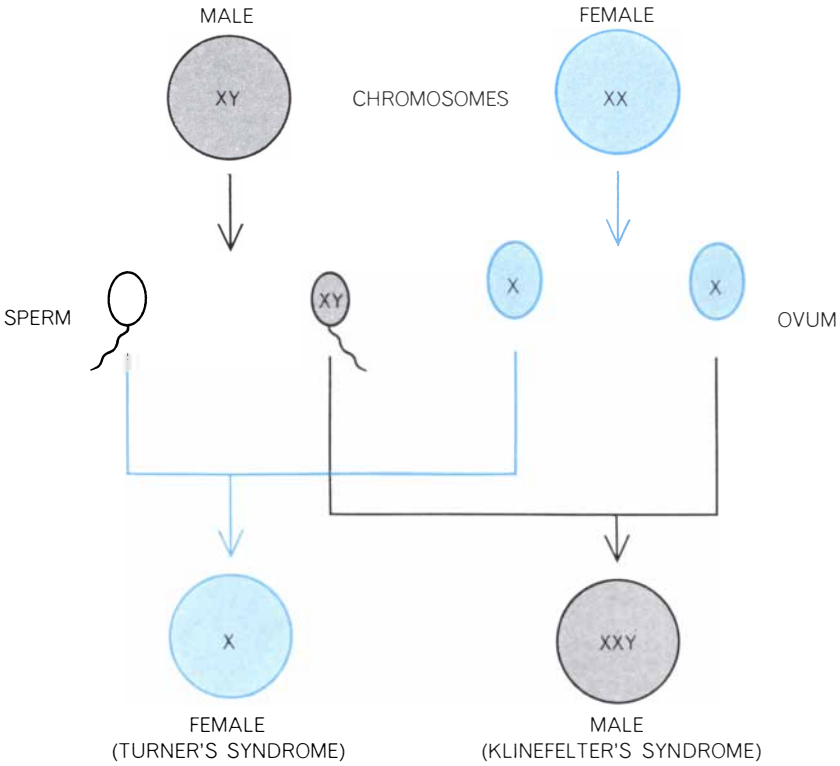
beled X in any specific instance is in fact the X chromosome. The Y chromosome is easier to identify; although it looks quite like chromosomes No. 21 and No. 22, it can usually be distinguished from them because it is a bit larger and its two arms lie closer together.

The second line of research on the cellular basis of sex stems from a fortuitous discovery in 1949 by Murray L. Barr and E. G. Bertram of the Medical School of the University of Western Ontario. While studying the nerve cells of a cat they noted a body in the nucleus of each cell that stained deeply with certain dyes. When they looked for this body in the nerve cells of a number of cats, they could see it in the cells of some animals but not in those of others. On investigation they found that it was the sex of the cats that made the difference: the nuclei of female cells contained a special body that was missing in male cells. The same sex difference turned up in other cat cells and then in other animals and in humans. The differentiating structure is called sex chromatin, or, after its discoverer, a Barr body. It is found in a variety of tissues, but the simplest way to demonstrate it is in cells scraped off the buccal mucosa: the inside surface of the cheek. The cells are placed on a slide, fixed in alcohol and stained. If the cells come from a woman, many will contain a darkly stained Barr body at the periphery of the nucleus [*see upper illustration on page 55*].

A few years after Barr and Bertram announced their findings William M. Davidson and David Robertson Smith of King's College Hospital in London decided to conduct a systematic search for sex differences in blood cells. They found one in the cells called polymorphonuclear leucocytes, white cells in which the nuclei, as the name implies, assume many different shapes. In the nuclei of some of these cells from females Davidson and Smith observed a unique appendage: a round body attached to one of the lobes of the nucleus by a thin stalk. They called it a "drumstick" and showed that although it is present in a small percentage of the polymorphonuclear leucocytes of a woman, it is entirely absent in normal males and therefore provides an additional indicator of sex. To demonstrate drumsticks one needs only to spread a drop of blood on a slide, fix and stain it and examine it under the microscope [*see lower illustration on page 55*]. In view of the great number of such blood films studied over the years in medical practice and research, it seems strange that until 1954 no one



ABNORMAL CELL with four X chromosomes and a Y shows three late-replicating X chromosomes. The chromosomes were photographed before (*top left*) and after (*top right*) the application of a radiosensitive emulsion. Pairing the chromosomes of the unlabeled photomicrograph according to the usual standards (*bottom rows in lower part of illustration*) identified the X chromosomes. When the labeled chromosomes were similarly paired (*top rows*), the heavily radioactive late replicators were shown to be X's. The arrow (*top right*) indicates the "first" X chromosome. These photomicrographs are from a study by B. B. Mukherjee, O. J. Miller and Saul Bader of the Columbia University College of Physicians and Surgeons and W. Roy Breg of the Southbury Training School.



NONDISJUNCTION, the failure of homologous chromosomes to separate during cell division, can cause sexual abnormalities. This diagram shows the possible effects of nondisjunction in the father during sperm formation. The fertilized egg will have two X chromosomes and a Y or only one X. Both chromosome constitutions lead to known intersex syndromes.

had noticed that female cells can be distinguished from those of males so easily. But in science nothing seems more obvious than what has just been discovered; the problem is to know what to look for.

Both Barr bodies and drumsticks occur in cells that are not dividing, whereas chromosomes are visible only in dividing cells. There can be no doubt, however, that sex chromatin and drumsticks are somehow related to the X chromosome. Some of the first indications that this is so emerged from studies of certain abnormalities in sexual development.

Although the great majority of people are clearly either male or female, with the normal characteristics of their sex, a few individuals suffer from various types of errors in sexual differentiation: their apparent sex is not the same as the "actual" sex of their cells. One such condition in men is Klinefelter's syndrome, named after Harry F. Klinefelter, an American physician who first described it in 1942. It is characterized by underdevelopment of the male sex glands, enlargement of the breasts and sometimes mental retardation. When the new techniques of "nuclear sexing" became available, it developed that in most of these men there are Barr bodies in cells from the buccal mucosa and drumsticks in the polymorphonuclear leucocytes. In other words, the nuclear sex of these individuals is female. A little later Patricia A. Jacobs and J. A. Strong of the Western General Hospital in Edinburgh counted 47 chromosomes in the cells of Klinefelter's-syndrome men instead of 46; the additional chromosome appeared to be an X. The existence of an XXY chromosome constitution in this condition has since been confirmed by many workers.

An abnormality in women had been described in 1938 by Henry H. Turner of the University of Oklahoma School of Medicine. Individuals with Turner's syndrome are usually abnormally short, have tiny ovaries and lack many sexual characteristics that normally develop at puberty. In 1954 the British investigators Paul E. Polani, W. F. Hunter and Bernard Lennox and the U.S. workers Lawson Wilkins, Melvin M. Grumbach and Judson J. Van Wyk reported that most of these women are "chromatin-negative": there are no Barr bodies in their buccal mucosa cells and no drumsticks in their blood cells. A few years later the chromosome count of these women was found to be only 45: one X chromosome and, of course, no Y. More recently Jacobs and her colleagues discovered that certain women have three X chromosomes—a total count of 47. The triple-X condition does not seem to be associated with a distinct clinical abnormality, although many of these women are mentally retarded. Their cells show not one but two Barr bodies. So do the cells of the few men who have three X chromosomes and a Y, along with the characteristics of Klinefelter's syndrome. More rarely still, investigators have found individuals with four X chromosomes—males (XXXXY) as well as females (XXXX). Whether from male or female, cells with four X chromosomes have a maximum of three Barr bodies.

All this made it evident that the formation of sex chromatin bears a direct relation to the number of X chromosomes present in a cell. Here was a clue to the behavior of the chromosomes from one cell generation to the next and to their function in shaping the destiny of the cell. During cell division, when the chromosomes are visible, they split to form two daughter nuclei. But the molecular agent of heredity in the chromosomes—deoxyribonucleic acid (DNA)—performs its genetic work, including its own replication, during interphase: between cell divisions. It is then, when the chromosomes as such are invisible, that Barr bodies and drumsticks are seen.

The technique of autoradiography has provided some clues to what goes on during interphase and has thereby thrown some light on the relation of Barr bodies to the X chromosome. Cells are supplied with a radioactive component of DNA, usually thymidine labeled with radioactive hydrogen (tritium). The radioactive thymidine, incorporated into the replicated chromosomes as DNA is synthesized, reveals itself by producing dark spots on a photographic emulsion placed in contact with the cell. When J. Herbert Taylor of Columbia University applied this technique to hamster cells, he learned that the various chromosomes of a cell synthesize DNA at different times in the course of interphase [see "The Duplication of Chromosomes," by J. Herbert Taylor; SCIENTIFIC AMERICAN, June, 1958]. In the past few years a number of investigators in the U.S. and England have autoradiographed human cells. Their results show that if a cell is exposed to tritiated thymidine late in interphase, most of the chromosomes will already have completed their DNA synthesis. But in female cells one of the chromosomes, which in shape and size resembles an X, replicates late and therefore incorporates a great deal of the radio-

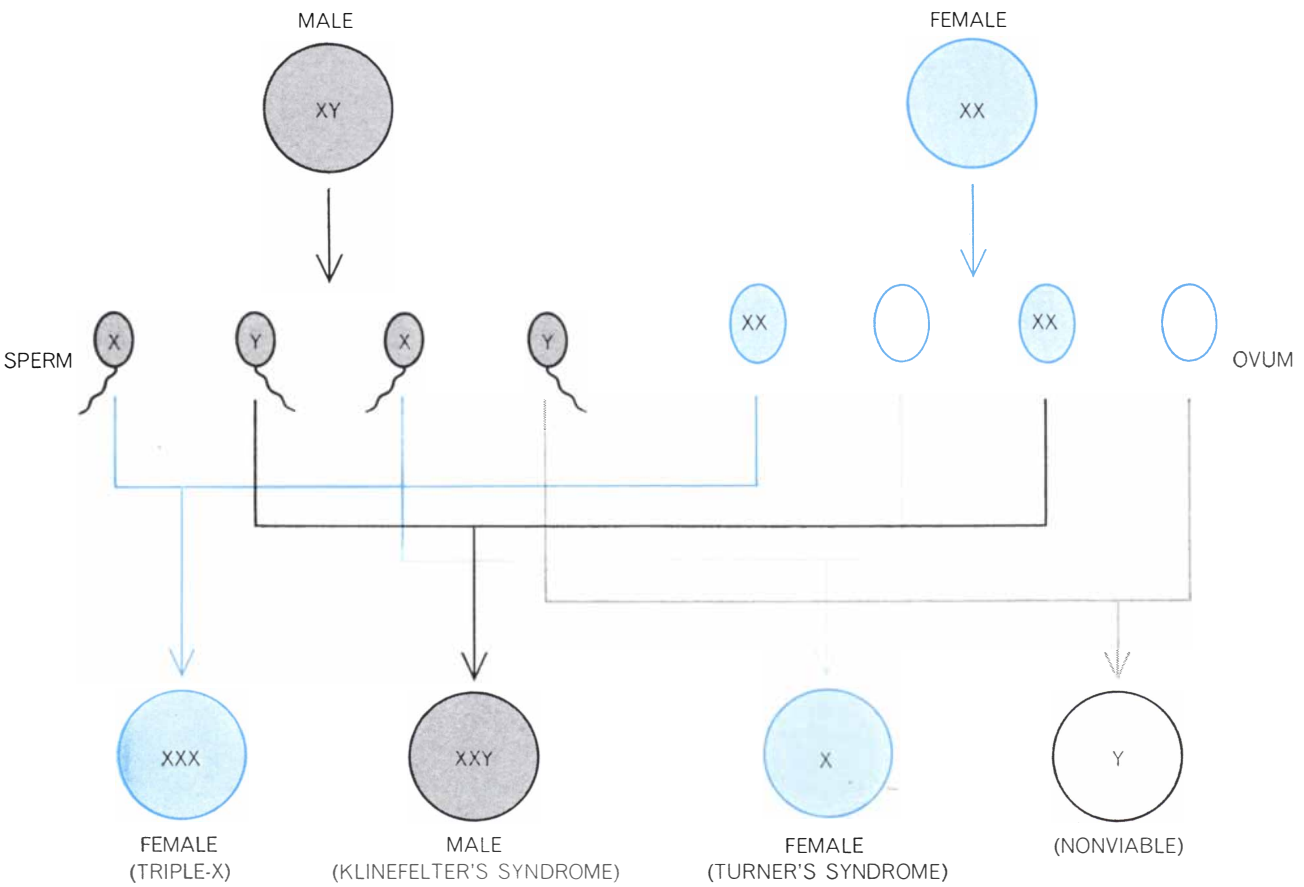
active thymidine, and stands out from the others because it is so heavily labeled [*see top illustration on page 58*]. No such late-replicating X chromosome is found in normal male cells. In individuals with more than two X chromosomes, the number that replicate late is regularly one less than the total number of X chromosomes [*see illustration on page 59*]. The incidence of late-replicating X chromosomes is strikingly parallel to that of Barr bodies. This suggests that any X chromosome in excess of one behaves differently from the rest of the chromosomes and is responsible for the presence of sex chromatin.

There are a number of other observations, some of them quite tentative, that support this conclusion. For one thing, when the chromosomes first become visible as delicate threads in the stage of cell division called prophase, one thread may be more highly condensed than the rest in female body cells. Susumu Ohno of the City of Hope Medical Center in Duarte, Calif., suggested in 1959 that this thread is the chromosome responsible for the formation of the Barr body. Moreover, some investigators have reported that the late X chromosomes tend to be situated toward the periphery of the nucleus—as are Barr bodies.

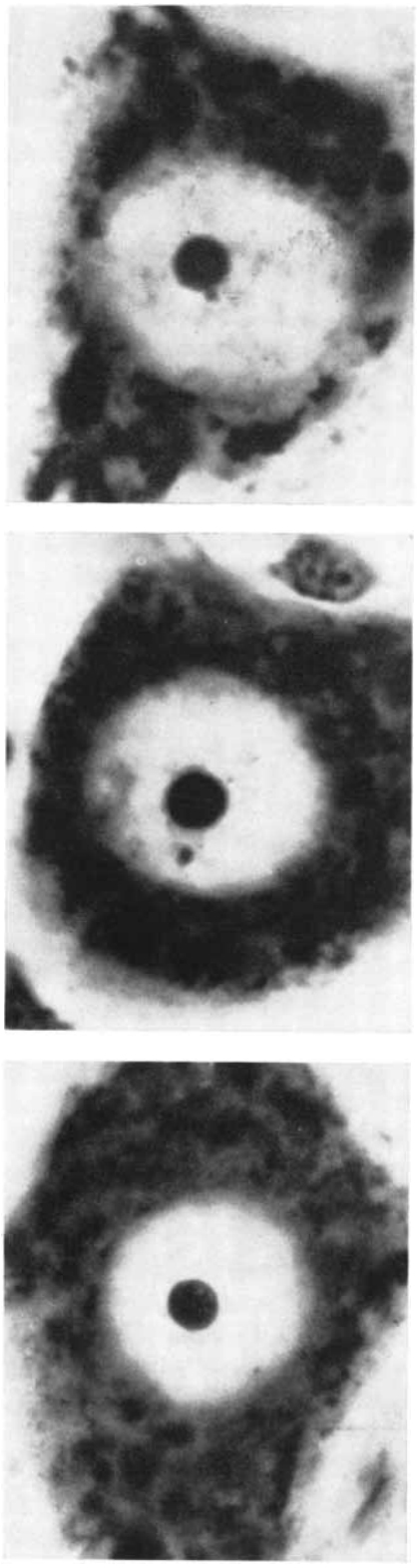
If Barr bodies are clearly related to the X chromosome, the same must be true of drumsticks, since there is such good agreement between the presence of Barr bodies and of drumsticks in normal people and in people with abnormalities of the X chromosome. The formation of drumsticks, however, is dependent on the rather peculiar maturation process of the polymorphonuclear leucocytes, during which their nuclei divide into a number of lobes. In some chromosomal anomalies lobe formation is not quite normal, and drumsticks may for this reason be reduced in number or even entirely absent. The interpretation of drumsticks is therefore sometimes less straightforward than that of Barr bodies; although the maximum number of drumsticks is one less than the number of X chromosomes, this maximum may rarely be reached. But there is no longer any doubt that both structures are the expressions of any X chromosomes present in excess of one.

The numerical relation between X chromosomes and Barr bodies is not only of theoretical interest; it has already proved to be of great value in studies of various intersex conditions. Since the techniques of nuclear sexing are much simpler and less time-consuming than an analysis of chromosomes, one can investigate the presence or absence of Barr bodies in a large number of people. The results allow one to forecast the number of X's in any patient before undertaking a chromosome study. The determination of the nuclear sex is also an indispensable adjunct to correct chromosome analysis because, as I have indicated, the X chromosome cannot yet be distinguished with certainty.

It nows appears that, regardless of the number of X chromosomes present, an individual who bears a Y chromosome in his cells is a male and one without this chromosome is a female. Although normal women are XX and normal men are XY, the addition of one, two or even three X chromosomes to an XY constitution still results in development that is essentially male. The male-determining effect of the little Y chromosome in humans has been recognized only within the past few years, and the discovery came as a surprise. This was because a



NONDISJUNCTION IN MOTHER produces ova with either two X chromosomes or none. Depending on the sperm by which they are fertilized, such ova can give rise to any one of four possible chromosome constitutions. Three are abnormal; one is not viable.



BARR BODY was observed for the first time in the nerve cells of cats, seen in these photomicrographs made by Murray L. Barr and E. G. Bertram of the Medical School of the University of Western Ontario. Their attention was drawn to a small, dense body near the nucleolus of female cells (*top*) that migrated away from the nucleolus (*middle*) after electrical stimulation. No such body appeared in male cells (*bottom*).

great deal of work had been done on the determination of sex in the fruit fly *Drosophila melanogaster*. In flies as in humans males are XY and females are XX but the Y chromosome plays only a small part in development. XXY flies are ordinary females, and flies with one X and no Y are males, although they produce nonmotile spermatozoa and are therefore sterile. In *Drosophila* the X chromosome has a tendency to produce female characteristics; it is the autosomes that tend to produce male characteristics. It is now certain that the details of sex determination in humans are different: the Y chromosome has a strong tendency to switch development in the direction of maleness. The exact function of the X chromosome in humans is less certain. For example, although a single X chromosome will in the absence of a Y give rise to a female, such a female is not normal.

The sex of an embryo is determined at conception, but the structural differentiation of the sexes does not become apparent until the seventh week of embryonic life. It seems likely that in the beginning the sex glands have the potentialities of both sexes. At some critical stage the presence or absence of a normal Y chromosome is probably all-important. If a Y chromosome is present, the sex glands develop into testes; if there is no Y chromosome, ovaries form. Once testes are present in an embryo they produce hormones under the influence of which further male characteristics develop. Alfred Jost of the University of Paris has been able to demonstrate that male development occurs in rabbit embryos only if testes are present. But ovaries are not necessary for female development; this can occur even in the absence of sex glands.

It would seem that the function of the sex chromosomes in man is to switch the embryo into one or the other channel of sexual development. Thereafter the hormones take over the work of further differentiation. If the switch mechanism is faulty, the production of hormones will become abnormal and give rise to an aberrant sexual condition.

The discovery that errors in sexual development may be associated with abnormalities of the chromosomes has provided new leads to understanding of the process of sex determination. Many of these errors result from accidents affecting the production of the ovum or the spermatozoon that goes into the making of the organism. Normally the two partners of a pair of sex chromosomes separate before a germ cell is formed. In the great majority of cases this "disjunction" comes about without a hitch. Sometimes, however, the chromosomes fail to disjoin. Klinefelter's syndrome and Turner's syndrome can arise from nondisjunction in the germ cells of either the father or the mother. Nondisjunction in the mother can also produce a triple-X female. It might even produce a fertilized ovum with only a Y chromosome and no X, but such individuals have never been found. It is reasonable to assume that cells need at least one X chromosome in order to function and that embryos with none at all fail to develop. An ovum or spermatozoon lacking a sex chromosome might also be formed if during cell division an X or a Y moved too slowly and failed to become included in one of the daughter cells. Such a loss of a chromosome may be an additional cause of Turner's syndrome.

Errors can occur in the development of the embryo as well as in the formation of germ cells. In young embryos the cells are engaged in active division, with each daughter cell ordinarily receiving one longitudinal half of each replicated chromosome. Very rarely, however, a cell may receive both halves or neither—and such a cell may then produce a whole line of cells with one chromosome too many or one too few. The organism to which such an embryo gives rise may have more than one type of chromosome constitution. Such "mosaic" individuals have, in fact, been encountered among patients with sexual abnormalities. A few patients with Klinefelter's syndrome have some XX cells as well as XXY; others have XY and XXY. Similarly, some women with Turner's syndrome have both XX and X cells, whereas others are mosaics of XXX and X cells. The number of possible combinations is large and new ones are continually being found.

The study of the cellular basis of sex in man is in a state of rapid progress. The knowledge recently gained has already yielded its first fruits in medicine by ascribing physical causes to a number of hitherto unexplained conditions; further studies may well uncover even more subtle forms of abnormality in human beings. The next step, the prevention or cure of these afflictions, is undoubtedly still some way ahead, but it will surely follow. There is a special fascination in these new insights into the relation between the structures of cells as seen under the microscope and the characteristics of the two sexes—unless, of course, one agrees with Hamlet that "man delights not me; no, nor woman neither."

Kodak advertises:

hot new color films without favors . . . ionizable, water-soluble NMR standard . . . a white polyester fiber, a really white one

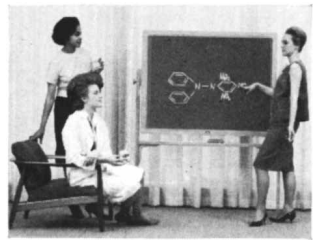
X marks three hot new color films for still cameras. They have hit the film counters in recent months. They involve no favors from the factory, no special code numbers, no burdensome minimum quantities, all have the same daylight speed: 64.

KODACHROME-X Film is not only faster than KODACHROME II Film, but its higher contrast gives the impression of more sharpness. Blues are richer and reds a little darker. With a CC10R color-correcting filter and 2⅔ stops of extra exposure allowance, it gives proper color rendition at as long as 1000 seconds of exposure time.*

KODAK EKTACHROME-X Film is twice as fast as the EKTACHROME it replaces and slightly sharper in rendition of edges. Can deliver saturated reds and clean yellows; available in 120, 126, 127, 135, 620, and 828 sizes; offers practical possibility for user-processing.

In 135 and 126 KODACOLOR-X Film, which is processed to color negatives for as many prints as you want, the X likewise indicates a doubling of speed along with improved sharpness and latitude for overexposure, so that only good can come of the change.

The song of the protons



Bright chemists who were six years old in 1946 regard magnetic resonance spectra as just another accretion to the culture, like decimal points or hot pyridine. In that year physicists announced that protons in a magnetic field absorb energy from radiation of the same frequency as the precession rate, which is proportional to the field strength.

Actually it is hard to mount a single proton on the end of a pin. In the real world, the protons in a target are subjected to different field strengths, however uniform the applied field. For one thing, electrons in the vicinity of a proton act as little magnets themselves and affect the proton's magnetic environment. But on the average, a proton on the third carbon from the end in a certain molecule finds itself in the same magnetic situation as the proton on the third carbon from the end in another molecule of the same substance in the same liquid sample. Furthermore, their common situation differs significantly from that of a proton linked to an electron-greedy oxygen atom that keeps pulling the orbital covers off.

Chemists got the point very quickly, thanked the physicists, and took over. Today a central chemical research laboratory without a nuclear magnetic resonance outfit simply doesn't belong to the club. Ours belongs to the club.

Nuclear magnetic resonance service with a smile is available to anybody working in our central lab who is pretty sure of the molecular structure of the contents of a little bottle he carries into Room 258 but would prefer to be a little surer. He comes away with a roll of paper bearing a plot of energy absorbed at 60mc *vs.* magnetic field. One very sharp, high peak at the end of the spectrum is a reference line from tetramethylsilane, $(CH_3)_4Si$, which one mixes in with the sample because it's loaded with protons that are uniformly and heavily shielded by electrons. It has become customary to refer to resonances by how far down they come from the TMS line.

It is too bad that TMS is virtually insoluble in water. Recently the inventor of the TMS gambit fixed this by replacing one of the methyls with a propanesulfonyl.

Inevitably, thank goodness, there arrived a letter which attempted to persuade us that this ionizable, water-soluble version "might be of greater interest to NMR spectroscopists around the country if it were more readily available." Within the week, we replied that production of the requested compound was under way, closing: "Thank you very much for bringing this product to our attention, as we sincerely appreciate knowing what new chemicals are required for today's research."

This was the proper sentiment to express, rather than to admit we had to make it anyway for Room 258. Now it is proper simply to announce that a gram of the compound as 3-(Trimethylsilyl)-1-propanesulfonic Acid Sodium Salt (EASTMAN 8773) *is obtainable for $2.85 from Distillation Products Industries, Rochester 3, N. Y. (Division of Eastman Kodak Company), which happily supplies without charge its List No. 43 of some 4100 other* EASTMAN *Organic Chemicals.*

Price subject to change without notice.

Fluorence! Fluorence!

One of us is advertising manager for fibers and faces the problem of explaining to people who make clothes and people who wear clothes what's new and different about KODEL IV Polyester Fiber. One of us has won a bit of recognition for 30 years of research on the psychophysics that underlies color photography and now faces the problem of showing what pertinence the concept of "fluorence," which he discovered and named, bears to life and labor. The two problems solve each other.

Still another of us, who works in England to make photographic paper stay white, focuses his thoughts on chemical mechanisms for soaking up a little energy from the near ultraviolet (near enough to penetrate glass) and re-emitting it just over the line in the visible violet, where all organic fibers tend to drop off a mite in reflectivity. (Your great-grandmother to the contrary notwithstanding, her hankies were never as white as yours; the lost violet wasn't being replaced. When many launderings have removed more of the modern brighteners than the brightener-loaded modern detergents can redeposit, modern spirits sag and dry-goods cash registers tinkle.)

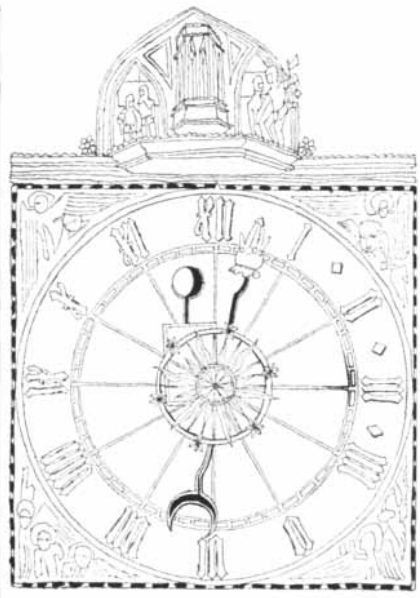
Some of the Englishman's thoughts, passing through Tennessee minds, have now led to a way of permanently building this mechanism into the very structure of the polyester fiber itself. *That's* what's different about KODEL IV Polyester. Its brightness is locked in, which means that for the cash registers to peal out again, the lady must tire of the design, but that can be arranged.

For the current season, white has been decreed from Paris—a good omen, but only now are KODEL IV-bearing fabrics issuing from the mills, and the channels of the garment trade are long and tortuous. We may not catch the white wave, but men's white shirts and women in white for a livelihood will still be around. Women out of uniform will enjoy the fluorence of KODEL IV after white reverts to social acceptability for the well-dressed woman only at oriental funerals. Furthermore, a woman is permitted to combine delicious feminine submission to fickle fashion with intellectual curiosity.

A fluorent color appears to glow of itself. It has no grey in it. This sounds like giddy chatter but isn't. It deals objectively with subjective phenomena. Fluorence is the appearance of fluorescence. Fluorence is psychophysical; fluorescence is physical. We have shown to our own surprise (*J. of the Optical Society of America, 49*, 1049 (1959)) that there can be fluorence without fluorescence and fluorescence without fluorence. Fluorence can be demonstrated and measured at all dominant wavelengths and purities. Fluorence can be either enhanced or suppressed through the dyer's art. Raw KODEL IV Polyester is both fluorent and fluorescent. There is nothing like it on the market.

Ladies (or gentlemen) desiring reprints of the above-cited paper should write to Eastman Kodak Company, Color Technology Division, Rochester 4, N. Y. Eastman Chemical Products, Inc., Kingsport, Tenn., just sells the fiber and talks to the trade.

*What's the proper color of an object so dim that it takes 16 minutes of exposure? Or is the diaphragm stuck so that it cannot be opened wider than a pinhole?



The Pesticide Report

A report by the President's Science Advisory Committee has called for wide reforms in the control and use of chemical pesticides. In the committee's view insecticides, herbicides and other toxic agents are indispensable to the maintenance of our food supply and the control of such insect-borne diseases as malaria. Because pesticides are toxic agents, however, their widespread application presents threats to both man and nature. No chemical pesticide can be wholly safe, and the risk is particularly great with long-lived toxic chemicals that may accumulate in man and his environment; these should be replaced as soon as possible with shorter-lived, more selective compounds.

The report, which was prepared by a panel headed by Colin M. MacLeod of the New York University School of Medicine, termed present Federal machinery for controlling pesticides "inadequate." Under current Federal law, tolerances for pesticide residues remaining on foods are set by the Food and Drug Administration. Other aspects of pesticide control are the responsibility of the Department of Agriculture, with which all pesticides must be registered and which must evaluate their efficacy and safety. "Decisions on safety," the panel found, "are not so well based as those on efficacy." Moreover, the powers of the Department of Agriculture are severely limited. Registration cannot be withheld even from pesticides considered unacceptable; action can be taken against a pesticide only after it has been registered for sale. The product meanwhile is not required to carry a warning to the purchaser that its registration has been issued under protest.

The U.S. currently uses about 350,000,000 pounds of pesticides a year. The application of this large quantity of chemicals has inevitably led to an increase in the detectable levels of certain toxic compounds in the environment. Pesticides have on many occasions caused widespread destruction of wildlife, particularly when they are sprayed or dusted from aircraft. Moreover, acute insecticide poisoning is responsible for about 150 deaths a year, half of them among children. As many as 1,100 cases of occupational insecticide poisoning have occurred among agricultural workers in a single year in the state of California.

The report, which pays tribute to Rachel Carson's best-selling book *Silent Spring* for alerting the public to the hazards of pesticides, concludes with a long list of specific recommendations. A key one is that the Government transfer responsibility for all health aspects of pesticides from the Department of Agriculture to the Department of Health, Education and Welfare. Another is for the development of a data-gathering system to monitor pesticide levels in the environment, as exposure to radioactive materials is now monitored. A third recommendation, that Federal agencies halt area spraying with long-lived insecticides "except for necessary control of disease vectors," has already been put into effect. A week after the report was published, the Department of Agriculture announced it was switching from DDT to a new short-lived insecticide for a forest-spraying program in the State of Washington to avoid contamination of oysters, which are highly sensitive to DDT, in nearby coastal waters.

One Trillion Electron Volts

A special panel of physicists has advised the Government that continued progress in particle physics will require particle accelerators between six and 30 times more powerful than any now in existence. Convened by the President's Science Advisory Committee and the General Advisory Committee of the Atomic Energy Commission, the

panel urged the construction before 1980 of a proton accelerator with a power of 1,000 billion electron volts (Bev), costing an estimated $1 billion, and another capable of 200 Bev, costing $240 million. Shortly after the panel made its report, Glenn T. Seaborg, chairman of the AEC, announced that under a new exchange agreement the U.S. and the U.S.S.R. will discuss the prospects of building a 1,000-Bev machine jointly. Among the problems to be considered are choice of site and allocation of costs. Seaborg also warned that the U.S. faces some difficult decisions on priorities in large-scale scientific investigation: the cost of the proposed accelerator program might run to $600 million a year by 1981, compared with $175 million a year now.

In addition to the two huge accelerators the panel, headed by Norman F. Ramsey of Harvard University, suggested the construction of a 12.5-Bev proton accelerator at Madison, Wis., and a 10-Bev electron synchrotron at Cornell University. The group also urged that the 33-Bev alternating-gradient synchrotron at the Brookhaven National Laboratory, the largest machine now operating, be modified to increase its energy by producing "clashing," or opposed, beams of protons.

Closing Window

An important radio window on the universe is being closed in the interests of commercial television. Last year Congress decided that all new television sets would have to be equipped to receive the 68 ultrahigh-frequency channels, and applications for station allocations have been pouring in to the Federal Communications Commission. The UHF bands can accommodate 2,000 stations across the country, 19 of them on Channel 37. Unfortunately the channel coincides with the portion of the spectrum between 608 and 614 megacycles, which was set aside in 1959 by the International Telecommunications Union for the exclusive use of radio astronomy. Decisions of this international body are not binding, and so far the U.S. has assured protection only to the band from 1,400 to 1,427 megacycles, which contains the vitally important 21-centimeter line emitted by un-ionized hydrogen in

space. In the study of a cosmic radio source, however, it is customary to measure emissions an octave apart (differing in frequency by a factor of two); the region from 608 to 614 megacyles is an octave below the 21-centimeter line.

So far the FCC has managed to avoid assigning stations to Channel 37, but at Paterson, N.J., a few miles from New York City and its seven VHF television stations, that will be the only UHF channel available. Over strenuous objections from the American Astronomical Society, which wants to keep Channel 37 completely clear, the FCC is proposing to approve an application for the channel at Paterson, although prohibiting the station from broadcasting between midnight and 7:00 A.M. until 1968. Radio telescopes within a range of 600 miles, including the instruments at the National Radio Astronomy Observatory in Green Bank, W.Va., will not be able to operate in that region of the spectrum while the station is on the air. This handicap to observation is much worse for radio astronomy than it would be for optical astronomy: radio telescopes can be used 24 hours a day. After 1968, when a sky survey now being conducted by the University of Illinois radio observatory at Danville, Ill., would presumably be finished, the FCC will lift all restrictions on Channel 37 broadcasts and Channel 37 stations.

Ergosomes at Work

Recent experiments have added important details to the concept that protein synthesis is an assembly-line process in which a coded tape of instructions is carried past a reading head, where the protein molecular chain is forged link by link. The coded tape is messenger RNA, which transcribes the instructions for assembling proteins from the genetic material DNA. The reading head is provided by the cellular particle called the ribosome. Electron micrographs published early this year showed that several ribosomes are often attached to a single strand of messenger RNA. Now Hans Noll, Theophil Staehelin and F. O. Wettstein of the University of Pittsburgh School of Medicine have reported in *Nature* a detailed study of the relation between the size of the ribosomal aggregates—which they call ergosomes—and the rate of protein synthesis. For this study they have used a preparation of rat liver cells to which were supplied the raw materials for protein synthesis: 20 kinds of amino acids, various enzymes and energy-supplying compounds.

The Pittsburgh workers find that the rate of protein synthesis, as measured by the incorporation of an amino acid labeled with radioactive atoms, goes up steadily as the number of ribosomes in the ergosome increases from two to eight. Above 10 ribosomes there is no further increase in synthesis rate. Single ribosomes are completely inactive. As the synthesis time is extended, however, the number of single ribosomes in the reaction mixture rises and so does the level of radioactivity in the pool of single ribosomes.

From this and related experiments the Pittsburgh group presents the following picture of protein synthesis. The ribosomes are strung together by one continuous strand of messenger RNA. Each particle contains a groove, or reading head, through which the strand must move to deliver its message. Amino acids are carried to the reading head by "transfer" RNA. With the help of at least two enzymes, and with energy supplied by guanosine triphosphate, the appropriate amino acid is added to the growing protein chain. A complete protein is synthesized at the site of each ribosome. When the protein molecule has been completed, the ribosome drops from the strand of messenger RNA, carrying with it the freshly synthesized protein.

The Dangerous Polygraph

A warning against the increasing and largely unrestricted application of lie-detector techniques in business and industry has been issued by a psychiatrist and a psychologist at the University of Virginia School of Medicine. The lie detector, or polygraph, records such variables as a subject's pulse and respiration rates, blood pressure and skin resistance as he answers questions. Emotional reactions are mirrored by these responses of the involuntary nervous system.

Writing in *The American Journal of Psychiatry*, H. B. Dearman and B. M. Smith explain that their interest in the issues attending the commercial use of polygraphs was stimulated by a case involving the young vice-president of a bank who was subjected to a "routine" polygraph examination by the bank's detective agency. He showed a "violent" reaction to the question: "Have you ever stolen any money from the bank or its customers?" On questions designed to pinpoint the amount of money involved, he showed peak reactions at $800 and $1,000. Thoroughly confused and convinced of the machine's infallibility, he confessed to having stolen $1,000

and told how he must have done it. When an audit uncovered no such shortage or manipulation, the young man was referred for psychiatric examination. This revealed that he had ambivalent feelings toward his mother and wife, both of whom were customers of the bank. He felt somewhat guilty about personal financial affairs involving him and them to the extent of $800 and $1,100. Careful analysis of a polygraph retest proved that he consistently showed emotional reactivity only to questions in which the word "customer" appeared: the wife-mother-"customers" association was responsible for what had been considered "positive evidence of lying."

This bizarre case, Dearman and Smith point out, illustrates the fact that the polygraph merely measures involuntary responses. It cannot determine whether the response was stimulated by conscious deception or by a factor such as surprise, pain or shame, any of which might be unconsciously motivated. Yet an examiner usually seeks to impress the subject with the idea that the machine "can't be beat" and so to encourage confessions; he "uses deception in his effort to detect deception." The authors conclude that lie-detector tests should not be conducted by private concerns and that the use of polygraphs by public agencies "should be carefully and continually scrutinized, lest we find that George Orwell's *1984* is upon us."

Hypernova?

Two Yale University astronomers have found that the celestial object known as 3C-273, only recently identified as the brightest and one of the most distant of all known galaxies, has been fluctuating widely in intensity over a period of years. The object was first reported as a "radio star" of very small angular diameter; spectral analysis subsequently indicated that it was not a star but a galaxy some 100 times more luminous than our own, situated about two billion light-years away and receding at a sixth the speed of light [see "Science and the Citizen," SCIENTIFIC AMERICAN, May].

In an effort to learn something about this unusual object Harlan J. Smith and Dorrit Hoffleit traced its photographic history through hundreds of plates in the files of the Harvard Observatory. They estimated its apparent magnitude on each plate by comparing its luminosity with that of three adjacent stars of known magnitude. From the five to 50 measurements available for almost every year from 1887 to 1963 they calculated

and plotted a mean annual magnitude; they found that these points showed a cyclical fluctuation between magnitudes of about 12.9 and 12.3. Even more surprising, they discovered a number of brief and intense "flashes" in which the magnitude shot as high as 11.5. The major group of flashes was recorded between 1927 and 1929 and was followed by a precipitous drop in average brightness. In an article in *Nature* the authors discuss the implications of these large and sudden variations in intensity. It is impossible for an entire galaxy to become everywhere brighter in a few months or even a few years; any disturbance that might trigger off such an increase in brightness would require thousands of years, traveling at the speed of light, simply to traverse the galaxy. The flashes therefore imply that 3C-273 must contain small substructures—conceivably unusual stars—capable of attaining absolute magnitudes about 10,000 times greater than the most brilliant known supernova.

Jobless Suicides

An analysis of suicide rates for the past 40 years suggests that unemployment is a major factor in suicide among American males. Among white American men over the age of 45—a segment of the population particularly subject to unemployment—the suicide rate reached a peak of more than 60 per 100,000 per year during the depression year of 1933, dropped to a low for the past 40 years (less than 30 per 100,000 per year in the 45–54 age group) during the full employment of World War II, rose again at the end of the war, fell once more during mobilization for the Korean War and since then has risen and fallen with fluctuations in unemployment.

The study was carried out by Brian MacMahon and Thomas F. Pugh of the Harvard School of Public Health and Samuel Johnson of the University of Colorado School of Medicine. Writing in *Public Health Reports*, MacMahon and his associates point out that the pioneer French sociologist Émile Durkheim suggested nearly 70 years ago that suicide was related to social conditions but that Durkheim's thesis had received little documentation with statistical data from the U.S.

As in most other countries, in the U.S. suicide is more frequent among men than among women. In contrast to many other nations, however, the age-specific suicide rates for white U.S. women fall off after age 54, whereas the rate for white American males continues to increase.

Suicide rates for Negro males are much lower than those for white males in the South; in the North, on the other hand, the rates for Negro and white males are more nearly comparable. Since both groups—older white males and urbanized Northern Negroes—are among the first to feel the pinch of joblessness, this suggests unemployment as a factor in suicide. The close parallel between unemployment levels and suicide rates for older white males tends to bear out the hypothesis.

The DNA Zipper

After 10 years of conjecture evidence is accumulating that the two-strand helical molecule of DNA, which bears the genetic code, behaves somewhat like a simple zipper when it replicates itself. It has been known for some time that the two strands give rise to perfect copies. There have been two main hypotheses as to how this happens. The original pair of strands might open from one end, like a zipper, and be copied in parallel as they unzip. The other possibility, which had received considerable support from certain experiments, is that the paired strands might unzip from both ends, thereby enabling the copying to take place in an antiparallel direction.

Experiments supporting the first, or parallel, hypothesis have now been reported from Australia, Princeton University and Columbia University. The Columbia experiments, performed by Toshio Nagata (now at Harvard University), are particularly clear-cut.

Nagata followed the DNA replication mechanism by using cultures of colon bacteria containing viral particles known as prophages. In the prophage state the viruses are benign; they occupy specific positions on the DNA molecule and are passively replicated when the DNA replicates. Nagata synchronized the reproduction of all the cells in a culture, thereby obtaining synchronized DNA replication. He could then remove samples at various intervals and determine when DNA replication reached the site of the prophage. At this point in time the concentration of prophage in the culture doubled sharply. Measurement of the prophage concentration depended on the fact that ultraviolet radiation can turn the prophage into an active virus, which multiplies rapidly and kills the cell. The increase in prophage coincides with what one would expect if DNA were to unzip from one end and if its two strands were to replicate in parallel.

The Voyage of Mariner II

Late in 1962 this 447-pound spacecraft flew by Venus in the deepest successful penetration of the solar system. A great technological feat, it produced much scientific information

by J. N. James

On December 14, 1962, the U.S. spacecraft *Mariner II* completed the first successful interplanetary voyage when it passed within 22,000 miles of the planet Venus. If an observer had been riding in the craft, he would have seen Venus as a brilliant disk 900 times the area of the full moon as viewed from the earth. At its historic rendezvous *Mariner II* was 36 million miles from the earth, having traversed 180.2 million miles of space in 109 days. During that time and for 20 days thereafter the 447-pound vehicle maintained constant communication with the earth, obeying commands and sending back a huge volume of information about itself, interplanetary space and Venus.

The voyage of *Mariner II* was a technological feat of the first magnitude. The craft had in effect been launched three times: first from the surface of the earth, then from a "parking" orbit of the earth and finally from an orbit of the sun, nine days and 1.5 million miles from the earth, where it was put through a maneuver to place it in a new solar orbit. Throughout most of the flight it maintained a rigid orientation in space with respect to the sun and also with respect to the earth. It even recovered its proper orientation after being struck by an object in space. *Mariner II* proved that a spacecraft can be tracked with impressive accuracy on a microwave channel using only three watts of power and can be guided from the earth across tens of millions of miles.

Scientific instruments accounted for less than 10 per cent of the total weight of the craft. All across the void between the two planets, however, they produced unprecedented quantities of data about the magnetic fields of the solar system, cosmic rays and the solar wind—the streams of protons and electrons that issue from the sun. At the rendezvous with Venus the instruments observed the planet with a resolution impossible at this time from the earth. Venus, it can now be said, is covered by cold, dense clouds but has a surface temperature of approximately 800 degrees Fahrenheit on both its dark and its sunlit side. The planet seems to have little or no magnetic field and hence no belts of trapped radiation analogous to the Van Allen belts of the earth, and to be rotating very slowly or not at all. From the tracking of the spacecraft it will also be possible to calculate the astronomical unit (mean distance from the earth to the sun) with greater accuracy than ever before, to figure the mass of Venus and the moon with far more precision than that previously attained and even to locate certain points on the surface of the earth more accurately.

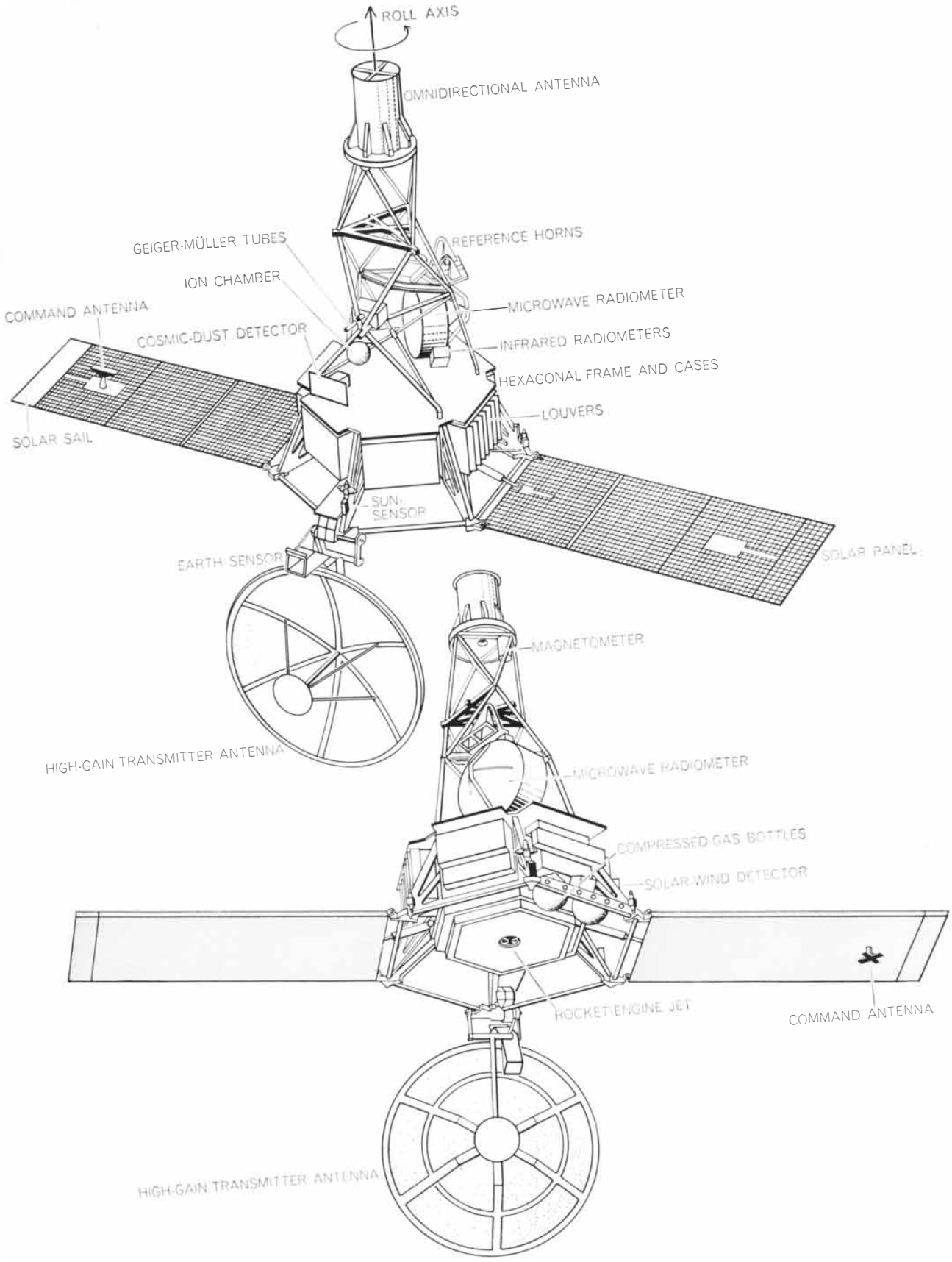
Rendezvous with Venus

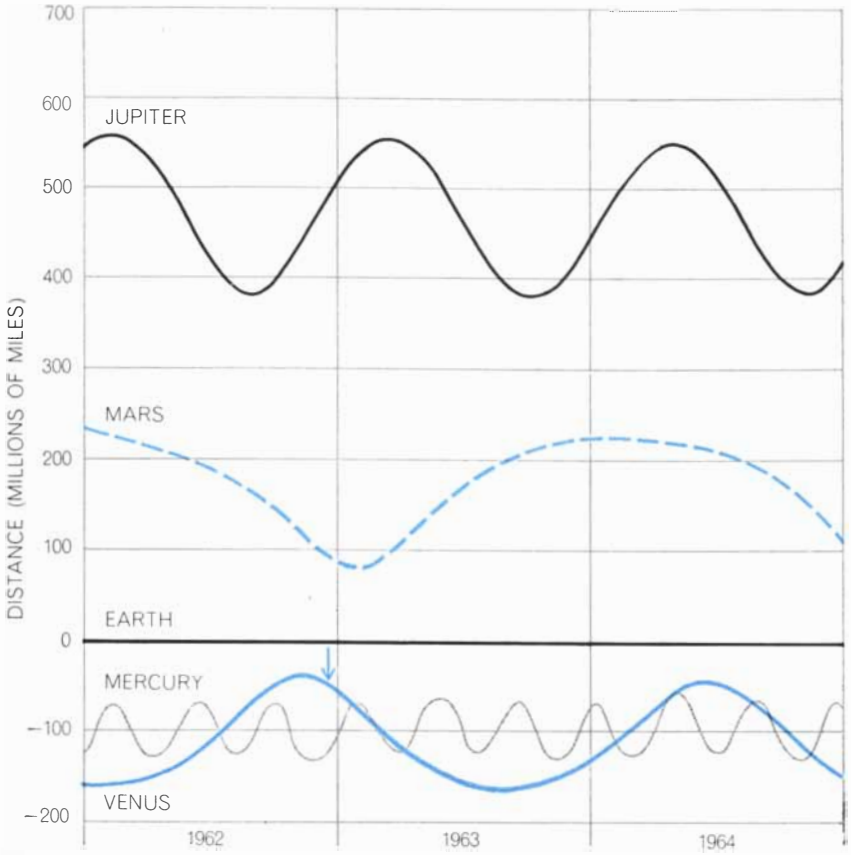
The story of *Mariner II* begins in July, 1960, when the National Aeronautics and Space Administration (NASA) approved the proposal of the Jet Propulsion Laboratory of the California Institute of Technology to send a spacecraft to Venus in the summer of 1962. The choice of Venus as the destination for the first NASA venture in "deep" space was a conservative one: the other planets are even more difficult to reach. Every 19 months Venus and the earth come within 26 million miles of each other; Mars on its closest approaches is between 35 million and 63 million miles away, and these approaches occur at the longer interval of 25 months [*see top illustration on page 72*]. To effect an interplanetary journey with a minimum expenditure of energy the spacecraft must be launched, some months before the planet's closest approach to earth, on a trajectory that will bring it into encounter with the planet sometime after the planet's closest approach to earth. A voyage to Venus would take three to four months; a voyage to Mars would normally require seven or eight months. Radio transmission from Venus would require less power and there would be more solar energy available in its vicinity: at a distance of about 67 million miles from the sun the solar-power cells of a spacecraft would receive a great deal more sunlight to convert into electricity than they would at the distance of Mars, some 142 million miles from the sun. A Mars flight would thus have called for a heavier and more expensive spacecraft and a more powerful rocket for launching.

Altogether a rendezvous with Venus presented a much more feasible objective. In the summer of 1960 it was not possible to schedule a flight for the next launching opportunity in January and February, 1961. The choice of the opportunity after that—in July and August, 1962—gave us two years to get ready.

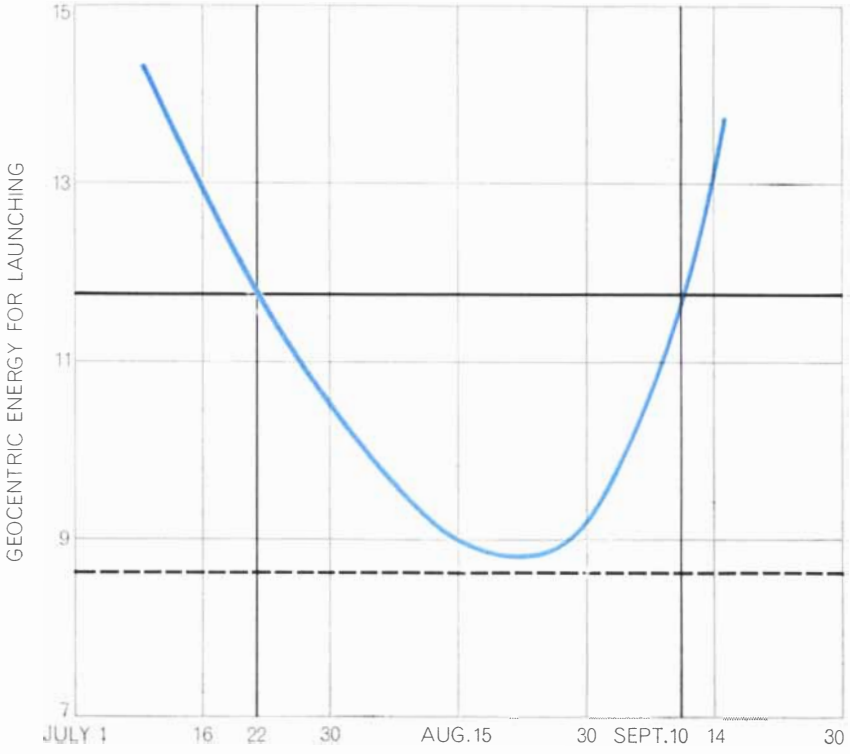
As of July, 1960, it appeared that the Atlas-Centaur would be developed in time to serve as our launching vehicle. This new combination, with a Centaur second-stage rocket fueled by hydrogen and oxygen, made it possible for us to think in terms of a half-ton spacecraft. With this mass available we were able to commit ourselves to the building of an "attitude-stabilized" spacecraft, like the lunar *Ranger*, rather than a "spin-stabilized" craft, like the *Explorers* and *Pioneers*. Because the former could hold

***MARINER II* is diagramed in two positions to show its major parts. Craft was built around a hexagonal frame. While microwave radiometer scanned Venus, reference horns on it provided calibration by scanning space. Solar cells are seen in top drawing.**





DISTANCE OF A PLANET from the earth changes over time. Interplanetary mission is launched when another planet is nearing its closest approach to the earth. *Mariner II*, launched on August 27, 1962, passed Venus on December 14, 1962 (*arrow*).



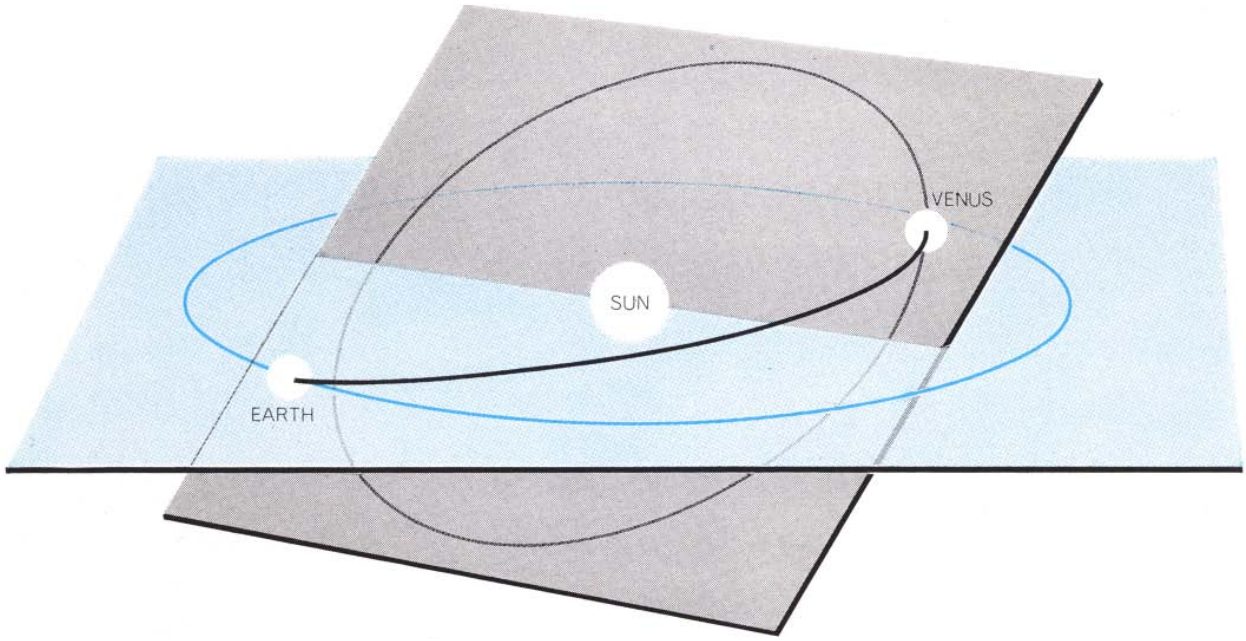
THEORETICAL LAUNCHING PERIOD of 51 days was available in summer of 1962 for sending craft to Venus. Launching-energy figures come from complex calculations. Before Agena was made 110 pounds lighter rockets could produce only 8.7 units of energy to launch 447-pound vehicle (*broken black line*); afterward figure was 11.8 units (*solid line*).

a rigid orientation in all three dimensions, it could simultaneously point solar cells at the sun, directional antennas at the earth for greater range of communications, and directional instruments at the target planet. Finally, it could be pointed in any direction for maneuvers in space. Spin stabilization, achieved by spinning the whole craft about one of its axes, did not offer all these advantages. By the fall of 1960 we were busy designing an 1,100-pound spacecraft. Our program called for the fabrication of three identical craft and for the detailed planning and engineering of two launchings in the summer of 1962. The extreme technological challenges made it unlikely that we would succeed on both tries. Assuming that the delicate instruments and complex spacecraft mechanisms survived the accelerations, vibrations and changing atmospheric pressure of the ascent into space, they would have to spend three or four months, unattended except for a few remote commands by radio, in a hostile environment both of extreme vacuum and cold and of heat and high-energy radiation from the sun and cosmic sources. Not all the hazards could be anticipated, and those that could be anticipated could not all be simulated in the laboratory in time to meet the schedule of design and operational deadlines.

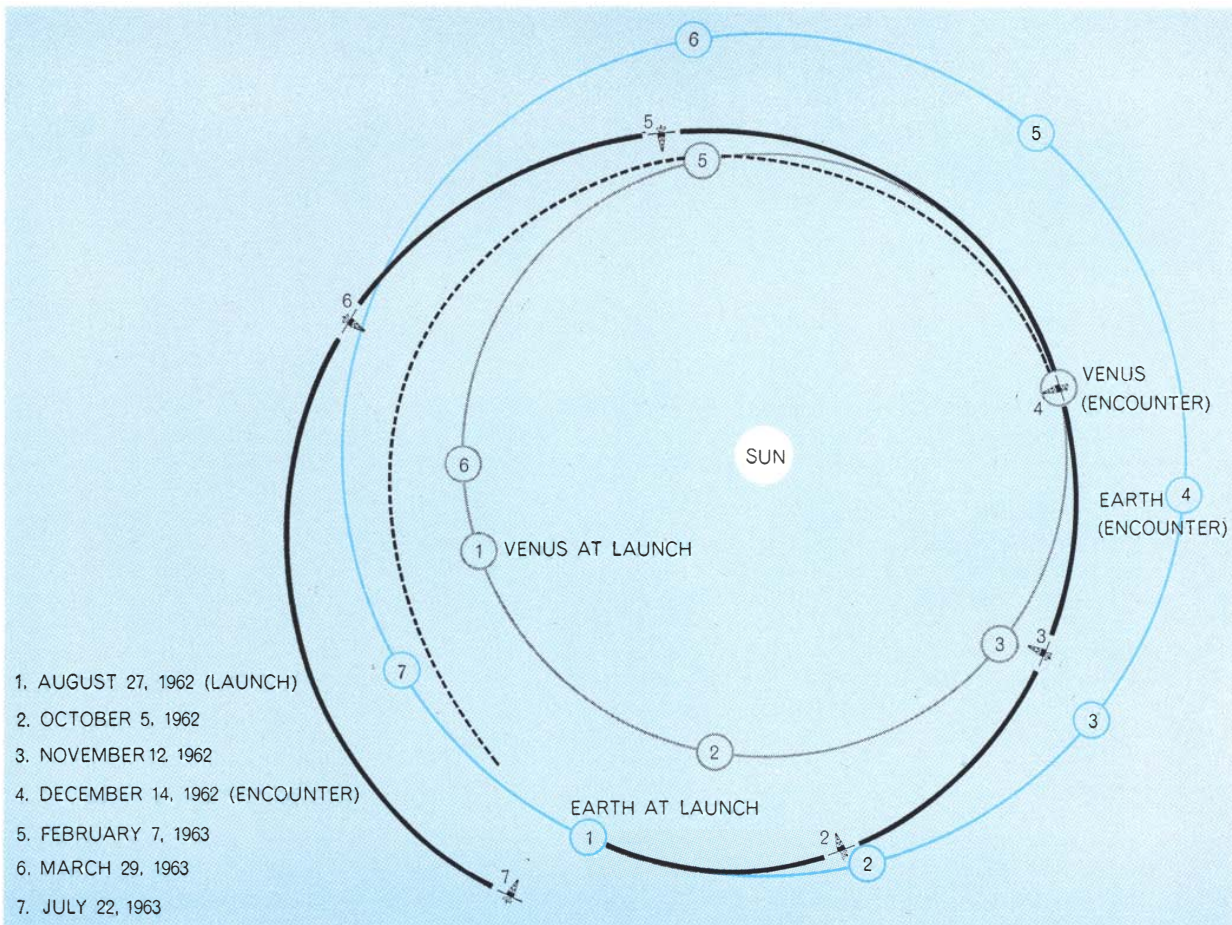
In February, 1961, the U.S.S.R. launched a spacecraft toward a rendezvous with Venus at the conjunction in May. The fact that the craft went silent after 12 days gave us the possibility of reaching Venus first and added the interest of competition to the basic challenge of space exploration.

A 447-pound Spacecraft

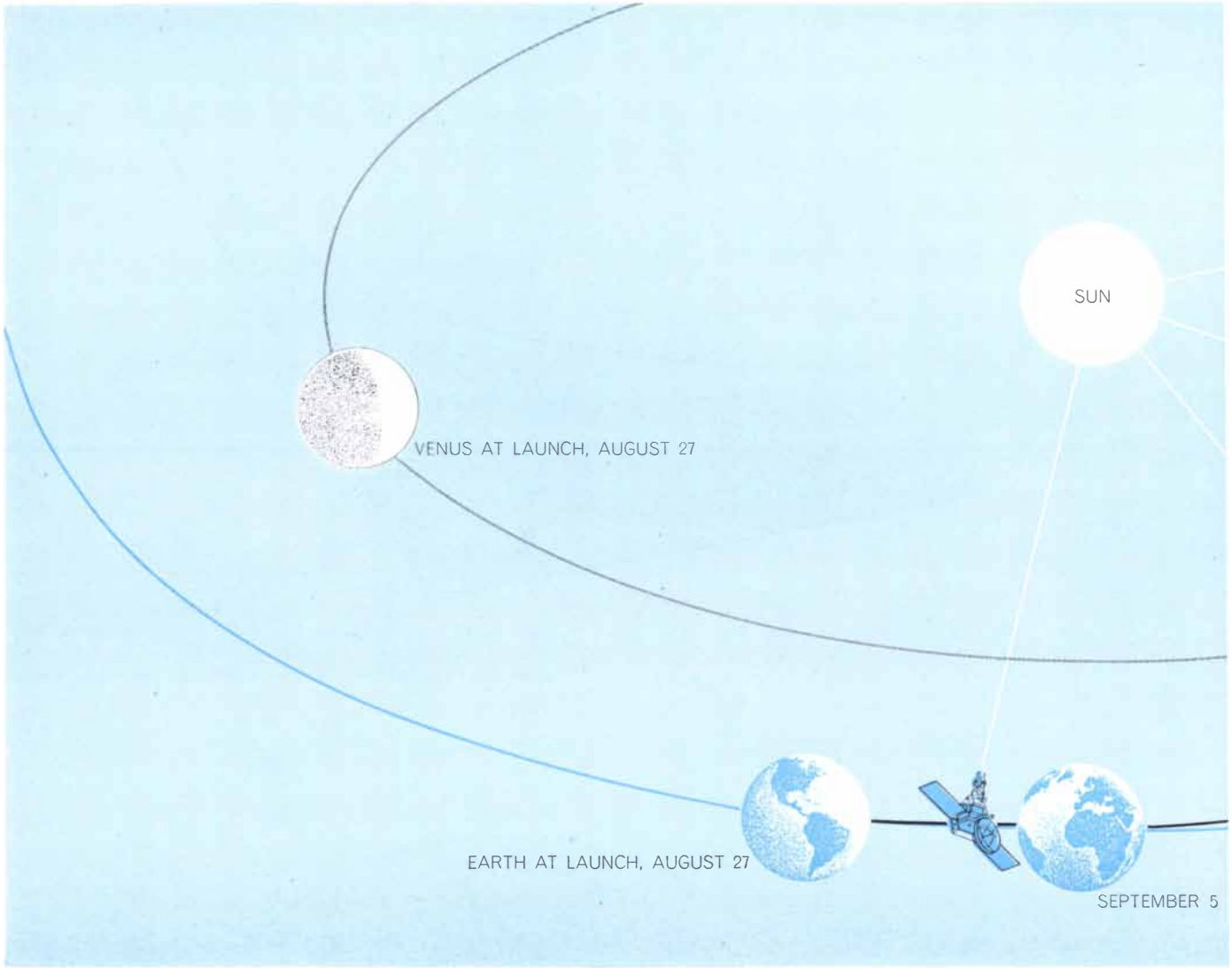
As our work on *Mariner* went forward into the spring of 1961, the parallel development of the Centaur began to falter. In August it became certain that this second-stage rocket would not be ready in time. The Jet Propulsion Laboratory now had to shelve its designs for an 1,100-pound spacecraft and decide if the instrumental payload of a much smaller spacecraft that might be launched by the Atlas in combination with an Agena second-stage rocket would yield enough scientific and technical information to justify the considerable investment in its building and launching. In this effort we had the encouragement of the designers and fabricators of the Atlas-Agena, who believed they could strip 110 pounds (other than fuel) from the total weight of the



PROBLEM OF REACHING VENUS is complicated by the fact that plane of orbit of Venus (*gray*) tilts with respect to plane of earth's orbit (*color*). Tilt is 3.4 degrees but is exaggerated here 10 times. Earth is shown at launching date, Venus at encounter date. The trajectory for a spacecraft (*black curve*) is in a third plane that cuts across the planes of the orbits of the two planets.



ORBITS AND POSITIONS of earth (*color*), Venus (*gray*) and *Mariner II* (*black*) are seen from directly above plane of earth's orbit. Broken black line marks path *Mariner* would have taken had it not been affected by gravity of Venus. The relative positions of the two planets and the spacecraft are shown at various dates. *Mariner* now makes one trip around the sun every 345.9 earth days.

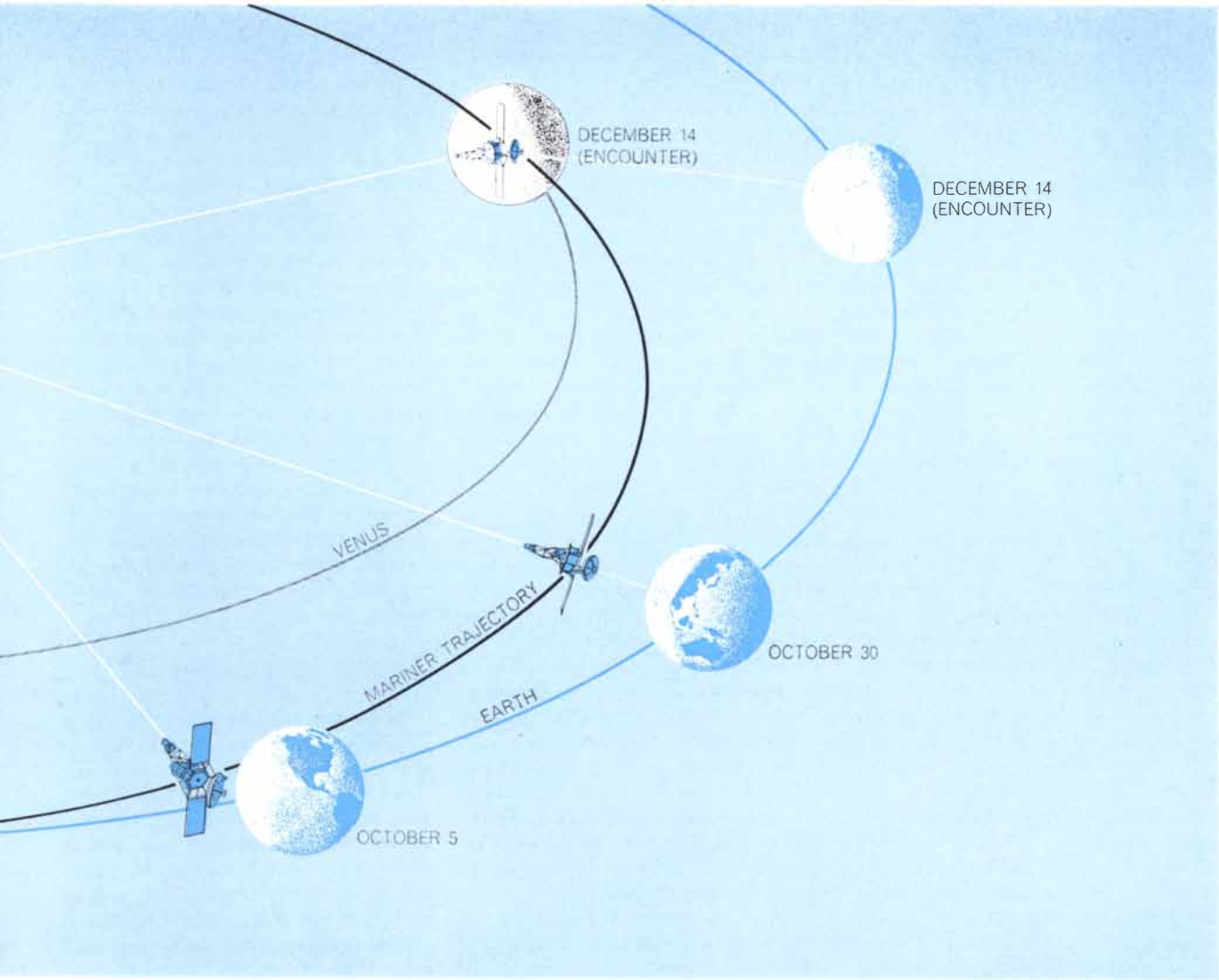


ORIENTATION OF *MARINER II* and its transmitting antenna in relation to the earth and the sun on various dates is seen in this oblique view of the orbits. The size of *Mariner* and of the planets is greatly exaggerated. *Mariner* is seen on September 5 just be-

Agena. In the three weeks from August 8 to September 1, 1961, using designs from the *Ranger* spacecraft (which was launched that month) and the 1,100-pound *Mariner,* we projected a *Mariner* that would weigh 447 pounds. Within a few days NASA agreed that this *Mariner* was equal to its mission. We now had nine months left to design, build and deliver the spacecraft and its launching vehicle to Pad 12 at Cape Canaveral in June, 1962, and have all in readiness for a launching in July or August.

These deadlines were dictated, of course, by the date of the next nearest approach of Venus on November 12, 1962. The Atlas-Agena combination did not, however, offer much power in excess of that required for the minimum-energy trajectory to allow any wide latitude in scheduling the launching [see "Interplanetary Navigation," by Aubrey B. Mickelwait, Edwin H. Tompkins, Jr., and Robert A. Park; SCIENTIFIC AMERICAN, March, 1960]. Taking into consideration the weight, thrust and staging of the rockets and the weight of *Mariner,* as well as the motion of Venus, we found that theoretically we had 51 days, from July 22 through September 10, during which we could effect the launching [*see bottom illustration on page 72*]. Happily this gave us time to plan for two attempts; Pad 12 was the only installation that could handle the Atlas-Agena, but it could not be readied for a second launching in less than 24 days after the first. The extra 27 days within the 51-day launching period was barely enough time in which to cope with the delays that could arise. Fully fueled on the launching pad, the Atlas-Agena and the *Mariner* spacecraft would weigh more than a quarter of a million pounds and would stand 10 stories high; yet an additional three pounds on *Mariner* or the Agena (other than fuel) would take away one day of the precious launching period.

As history has now recorded, the several governmental, industrial and university agencies participating in the preparations for the venture, together with their numerous collaborators and subcontractors, all managed to make their diverse contributions on schedule within the nine-month lead time. Since the Jet Propulsion Laboratory was to "fly" as well as design and fabricate the spacecraft, its staff proceeded to compute trajectories and prepare operation plans to conform to the range of launching dates. The transmitting and receiving systems of the three Deep Space Instrumentation Fa-



fore its mid-course maneuver and on October 30 at time it passed the earth. Geographic features on the earth indicate time of day.

Jets of compressed gas and devices to sense earth and sun held *Mariner* in its rigid orientation with respect to earth and sun.

cilities operated for NASA by the Jet Propulsion Laboratory—at Johannesburg in South Africa, Woomera in Australia and Goldstone in California—also had to be modified to be compatible with the specifications and limitations of the 447-pound *Mariner*.

A True Spacecraft

Three complete *Mariners* were built, two for launching and one for testing and to serve as a spare; all came within three pounds of the design weight. With its hinged parts folded compactly for stowage in the protective nose cone during the ascent through the atmosphere, *Mariner* measured five feet in diameter at its base and 10 feet in height. Unfolded for flight in the vacuum of space, the spacecraft gained two feet in height (or length) and an ungainly "wingspread" of 16.5 feet, the "wings" being the two solar-cell panels bearing a total of 9,800 cells.

The term "spacecraft" is no misnomer as applied to *Mariner*. To accomplish its mission something more than a package of scientific instruments was required. *Mariner* itself played an active part in delivering the instruments to their destination and in carrying out the program of observation for which they were designed. In fact, the gear necessary for navigation on command from earth, for transmission of data to earth, for precise stabilization of its attitude in flight and for propulsion during the mid-course maneuver took up a full 406 pounds of the total weight of the craft. The "spaceframe" of *Mariner* was a hexagonal structure that held six cases of electronic and electromechanical apparatus. Two of the cases were occupied by the self-contained electrical power system, consisting of a 33.3-pound rechargeable silver-zinc storage battery and the switchgear to regulate and distribute the power from the solar cells or the battery. A combined radio receiver and three-watt transmitter and the control system for the scientific instruments filled two other segments of the hexagon. The fifth segment contained gear for translating the output of the scientific instruments and the inboard sensing devices into digital code for transmission to earth. The sixth segment of the hexagon bore the three gyroscopes that sensed and controlled the orientation of *Mariner* in space; it also held the heart —more properly, the brain—of the spacecraft: the "central computer and sequencer" that integrated the workings of the entire system around the ticking of a highly accurate electronic clock locked

into the timekeeping system of the control stations on earth. In addition this segment contained the memory unit for storing the program of instructions for the expedition and for retaining commands received from earth in the course of the flight.

Mounted in the center of the hexagon and pointing aft along the roll, or long, axis of the spacecraft was the rocket motor that supplied the propulsion for the mid-course maneuver. It had been designed to give enough thrust to correct the predicted inaccuracies in the launching trajectory. Mounted on the outside of the hexagon was the power plant for attitude control: two bottles made of titanium, each holding 4.3 pounds of nitrogen under a pressure of 3,500 pounds per square inch, connected by small pipes and valves to 10 small jet nozzles located about the structure. These "motors" were controlled by the gyroscopes and the earth- and sun-sensors. On command they would jet tiny puffs of gas through orifices aimed along one or another of the three axes of the spacecraft.

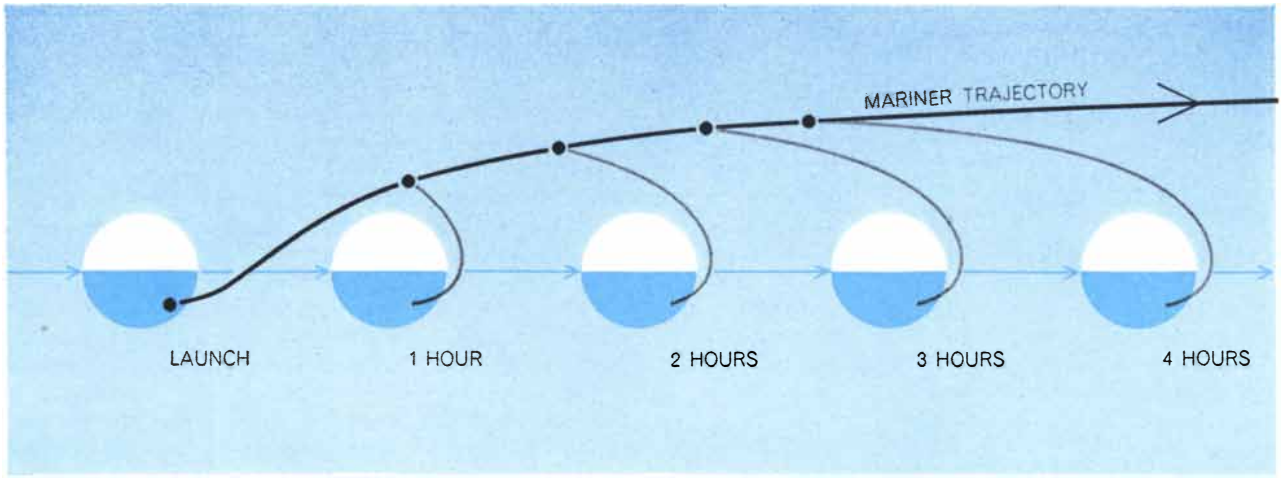
Surmounting the open-frame superstructure that rose from the hexagon was an omnidirectional antenna. From this the spacecraft radiated its three-watt signal during periods when it was rolling or tumbling out of its designed orientation in flight. At such times the ground stations on earth had to listen sharply for the much attenuated signal. On the underside of the hexagon—at the bottom, or stern, of the spacecraft—was a four-foot parabolic "high gain" transmitting antenna. During periods of normal flight, when the spacecraft was locked in its proper orientation, this antenna focused the signal toward the earth. An earth-sensor—a photomultiplier tube mounted on the antenna—caused it to swing on its hinge and point steadily earthward as the spacecraft proceeded on its orbit. Signals from the earth, radiated at high power and focused by the great parabolic antenna at each of the three ground stations, were picked up by small antennas carried on the solar panels.

The payload of instrumentation was variously arrayed on the spaceframe. A detector for counting protons in the solar wind and a crystal microphone for registering impact by particles of interplanetary dust were mounted directly on the hexagon. Other instruments, including three Geiger-Müller tubes, an ion chamber and a magnetometer, had to be mounted on the superstructure away from the magnetic fields set up by the electrical and electronic gear. There they were also exposed to a minimum of the secondary radiation generated by the impact of cosmic rays on the metal of the spacecraft. The most elaborate piece of instrumentation was a parabolic antenna 20 inches in diameter and three inches deep, which was to scan the surface of Venus at two microwave frequencies and which, in addition, carried two optical sensors to take parallel readings of the infrared radiation from the planet. This assembly was mounted on the superstructure above the hexagon.

One of the thorniest problems to be anticipated in the design of *Mariner* was temperature control. Some measure of passive control was sought by giving the various surfaces different degrees of reflectivity and insulation against the full power of raw sunlight to which they were to be exposed. Movable louvers on the outside of the case containing the central computer and sequencer provided some active control at this critical point. In the extremes of environmental and mechanical stress to which we subjected a thermal-control model of *Mariner*, we tested particularly for the effects of heating and ways to minimize them. Unfortunately there was no test chamber in the U.S. at the time that could simulate solar radiation adequately. Such a chamber, completed after the launching, yielded some answers immediately, but too late to protect *Mariner II* from what proved to be the most serious jeopardy to its performance at the very moment of encounter. Nor were we able to launch a prototype *Mariner* on a test flight, a routine procedure in the development of launching rockets and some spacecraft and instrument packages. We had no choice but to commit the first U.S. interplanetary vehicle to its full journey into space.

The Launching

In the first week of June, 1962, three *Mariners*, two Atlases and two Agenas were shipped to Cape Canaveral. The Atlas-Agena-*Mariner* was set up by mid-July. Banking on optimum performance by the rockets and with the aim of stretching the theoretical launching period, we decided to attempt a launching on July 19, three days early. Countdown delays postponed the launching until 4:21 A.M. on July 21. The launching failed, however, owing to a defective signal from the Atlas and the omission some years earlier of a single symbol from the program equations of the computer



LAUNCHING OF *MARINER II* was in direction opposite to the orbital path of the earth. Position of earth is shown at launching and at hourly intervals thereafter for four hours. Path of *Mariner* leaving earth is gray line; *Mariner*'s orbit around sun is black line; earth's orbit is colored line. *Mariner* was hurled "backward" from earth in order to slow it, bring it closer to sun.

guiding the flight. The Atlas-Agena began to turn wildly and it was necessary to blow up the rockets. *Mariner I* had been sending signals and continued to do so until it hit the Atlantic Ocean 357 seconds after lift-off.

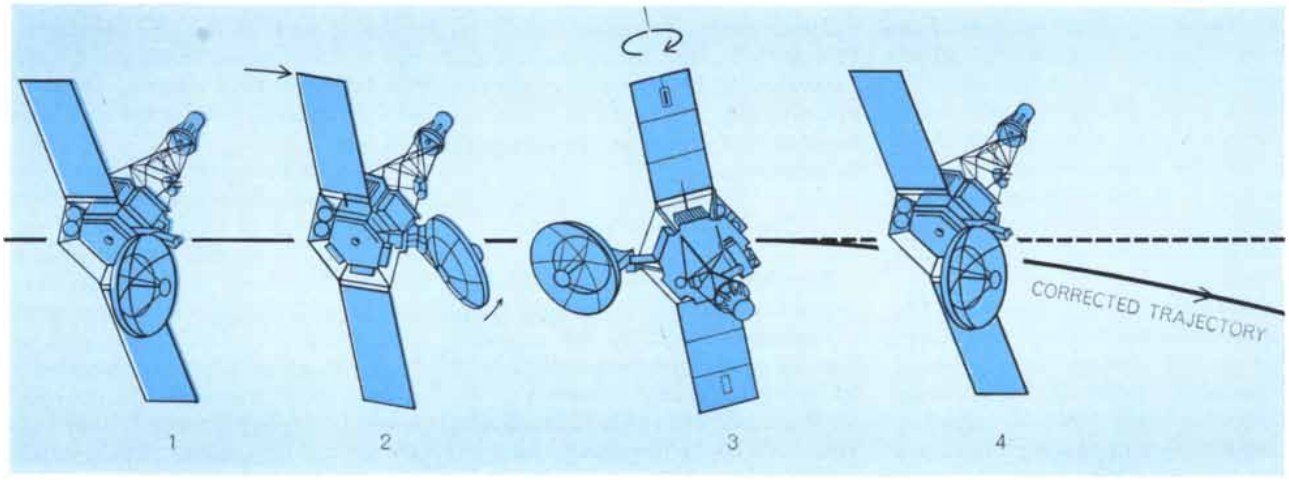
The schedule now called for launching *Mariner II* 24 days later, on August 14. Problems plaguing the second Atlas caused several postponements and we were not able to bring off the launching until August 27. The huge Atlas fired at 1:53 A.M. and soared to an altitude of 100 miles. The nose cone protecting *Mariner II* was popped off and the Atlas separated from the Agena. The Agena-*Mariner* pitched over almost to the horizontal, pointing in a southeasterly direction. Then the Agena fired for the first time, burning for 147 seconds, just long enough to go into a "parking" orbit at an altitude of 115 miles. There it coasted until 24 minutes after launching, when it reached a latitude of 14.8 degrees south of the Equator and a longitude of 2.1 degrees west—over the middle of the South Atlantic, the optimum location for taking off for Venus on this particular day at this particular time.

The Agena now fired again for 95 seconds, achieving the velocity necessary to escape the earth's gravitational field and accelerate itself and *Mariner II* into an orbit of the sun that would deliver the latter to the vicinity of Venus in mid-December. Explosive charges and springs separated the Agena from *Mariner*. Small nozzles expelled residual gases to turn the spent Agena aside and slow it down, separating it from *Mariner* so that the rocket carcass would not interfere with the optical sensors and placing it on an orbit that would carry it safely wide of Venus. *Mariner II* was now slowly tumbling and was drawing on its battery to send numerous signals, which were arriving at the earth stations right on schedule.

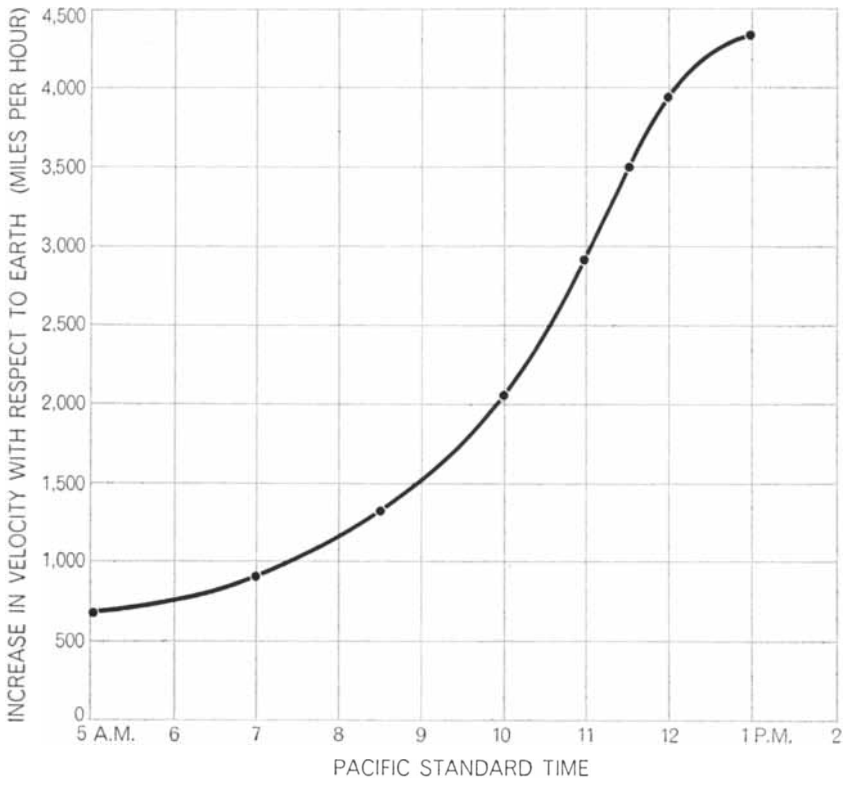
Within an hour after lift-off the central computer and sequencer on board *Mariner II* caused the solar panels to open out; it then instructed the gyros and sun-sensors to activate the nitrogen jets and point the long axis of the spacecraft toward the sun. The stabilization system still allowed the spacecraft to roll slowly about its long axis, but the solar cells were now facing into the glare of the sunlight. Some 195 watts of electricity converted from solar energy promptly relieved the drain on the battery, supplying nearly all the power necessary to operate the spacecraft. The average demand during most of the journey was 151 watts. On closer approach to the sun the output of the solar cells would rise gradually to about 275 watts and the excess energy would continually recharge the battery, which by itself could meet all needs for 9.5 hours.

As *Mariner II* was fired into its parking orbit and then into its interplanetary trajectory by successive thrusts of the Agena, it was moving around the earth more rapidly than the earth turns on its axis. Because the spacecraft was also increasing its distance from the earth, however, it appeared to reverse its direction about 80 minutes after launching. The point on the earth's surface above which it was at zenith had traveled southeastward, had turned northeastward and now swung around to speed westward as the earth rotated. With respect to the earth's revolution about the sun the spacecraft presented a quite different motion. The launching from the night side of the earth at 1:53 A.M. in a southeasterly direction had added a component of the earth's rotational speed to the velocity imparted by the rockets and had hurled the spacecraft out ahead of and around the earth as the latter proceeded on its orbit. By this maneuver the spacecraft had been headed into space in a direction opposite to the motion of the earth about the sun and inward toward the sun [*see illustration on opposite page*]. As *Mariner II* fell behind the earth, 8,000 miles per hour had been subtracted from the 66,500-mile-per-hour orbital speed around the sun that it had possessed, along with the earth, at the instant of its launching. The slower speed of revolution would let the gravitational field of the sun pull the spacecraft inward, ultimately to cross the orbit of Venus. Since the plane of the orbit of Venus is tilted at three degrees to the plane of the earth's orbit, the earthbound navigators of *Mariner II* had also canted the orbit of the spacecraft in a direction calculated to intersect the plane of the orbit of Venus at the point of the rendezvous 109 days later.

As soon as *Mariner II* had escaped the earth's gravitational field a computer at the Jet Propulsion Laboratory was calculating its exact course. The angle at which the parabolic antennas on the ground picked up the spacecraft's signal most strongly located its direction from the earth against the background of the stars. Measurement of the Doppler shift (change in frequency) of the signal from the frequency at which it was transmitted yielded a correspondingly pre-



MID-COURSE MANEUVER started with *Mariner II* "locked" on earth and sun (*1*). Then large antenna folded up out of range of rocket jet and the craft rolled nine degrees (*2*). It pitched, or turned, 140 degrees away from sun and rocket motor fired (*3*). Finally *Mariner* turned back and reoriented itself in relation to earth and sun (*4*). The change in its orbit is exaggerated here.



INCREASE IN VELOCITY OF *MARINER II* due to gravitational pull of Venus started two days before encounter and reached 671 miles per hour by 5:00 A.M. December 14. During the next eight hours, as shown by this curve, velocity increased sharply. Later it decreased.

cise plot of the spacecraft's radial velocity (speed away from the earth). For this purpose signals were sent out from the earth at a frequency held stable to one part in 100 billion, and they were returned immediately by the spacecraft. The signals, doubly shifted toward longer wavelengths in their round trip to and from the receding spacecraft, produced measurements of its velocity accurate to within a tenth of an inch per second—even at the end of its active life, when it was 54 million miles from the earth and moving away at 49,000 miles per hour. Ten hours after the launching the computer had calculated that *Mariner II* would miss Venus by 233,000 miles, crossing its orbit ahead of it. Happily the necessary correction lay within the capacity of the mid-course propulsion system of the spacecraft.

During the first two days of the trip *Mariner II* transmitted only the readings from the 52 devices that registered temperatures, angles of hinged units, voltages, currents, fuel-tank pressures, transmitter power and other information about its own performance. The computer aboard was programed to start transmission from the scientific instruments on the seventh day. Because the engineering data showed that the whole craft was working perfectly, the Johannesburg station on the third day commanded it to begin sending data from all the scientific instruments except the Venus radiometers. To conserve power the rate of transmission was slowed from 33 "bits," or units of information, to 8.3 bits: about one message or measurement per second. From then until a few hours before it passed Venus *Mariner II* sent scientific information for 20.16 seconds and then information about "itself" for 16.8 seconds. The latter was essential for evaluating the operation of this first interplanetary craft, for deciding on commands to give it and for designing its successors.

The Mid-Course Maneuver

A week after launching, when *Mariner II* was 1.2 million miles from the earth, a command stored in its computer memory caused the spacecraft to point its high-gain parabolic antenna at the earth and assume a stable flight attitude. This could not be attempted earlier because the earth had been too bright for the earth-sensor mounted on the antenna. The spacecraft now ceased rolling; its tendency to pitch and yaw was restrained to within one degree around its long axis, which pointed toward the sun in the orbital plane of the craft. All was supposedly in readiness for the mid-course maneuver. It was apparent, however, that something was wrong just as soon as the transmitter switched over from the omnidirectional antenna to the parabolic one. The signal from the earth-sensor was only half as strong as had been expected—as though the device was "seeing" an object only half as bright as the earth. It might have been "locked" on the moon, but the earth at that distance is not two times but 83 times brighter than the moon. We decided to wait a day and see if the angle of the antenna hinge changed 1.5 degrees, which it would do to stay locked on the earth, or seven degrees, which would show that it was locked on the moon. If it was locked on some other object, such as the Agena carcass, or was not working properly at all, the angle of the hinge would show still another change. In case it was not pointed at the earth, we could command it to unlock and start to roll so that the sensor would see and lock onto the earth before it had rolled all the way around and locked onto the mysterious wrong object again.

Fortunately the signal the next day showed a hinge movement of 1.5 degrees. We still did not know why the sensor was giving such a low signal. Since everything else was working, however, we decided to go ahead with the mid-course maneuver.

On September 5, nine days after launching, punched tapes containing the calculated commands were fed into an encoder at Goldstone. These were transmitted to *Mariner II* for storage in its computer. They told the craft to unlock from earth and sun and roll slightly in order to position the cold-gas jets for the next movement, which was to point the omnidirectional antenna, or "bow," of the spacecraft 140 degrees away from the sun.

Then the hydrazine rocket motor was to fire. The motor was designed to burn for any length of time between .2 second and 57 seconds, and thereby to change the velocity of the spacecraft by as little as .7 foot per second or as much as 200 feet per second (136 miles per hour). Our instructions commanded it to burn for 27.8 seconds. The net effect would be to push *Mariner II* away from the sun and thus make it remain outside the orbit of Venus just long enough to allow Venus to pass by before *Mariner II* crossed its orbit. This maneuver added 45 miles per hour to its previous orbital

speed of 60,250 miles per hour with respect to the sun and was chosen from among the several that might have accomplished the course correction for two secondary reasons. First, it would point the omnidirectional antenna toward the earth, ensuring an uninterrupted communication during the anxious moments of the maneuver. Second, and more important, it would fix the time for the encounter with Venus at an hour when the planet would be above the horizon at Goldstone, thereby assuring that the spacecraft could be kept under the surveillance of Goldstone's special equipment.

At 2:49 P.M. Pacific Standard Time, with the spacecraft 1,492,500 miles away, we gave the command for execution of the maneuver. This remote-control "launching in space," as delicate and nerve-racking as any on the earth, required three and three-quarter hours. While it was taking place *Mariner II* drew power from its battery instead of the solar cells and transmitted over the omnidirectional antenna. Afterward it reoriented itself, locking on the sun and then on the earth with the help of the gyroscopes, sun-sensors, earth-sensor and the cold-gas jets.

Within the next few days tracking established that the maneuver was a success. *Mariner II* was traveling, it was true, two miles per hour faster than had been planned. Instead of passing Venus at the hoped-for distance of 10,000 miles it would pass the planet at a distance of 21,648 miles. This was still well within the 40,000-mile target zone [*see illustration at right*].

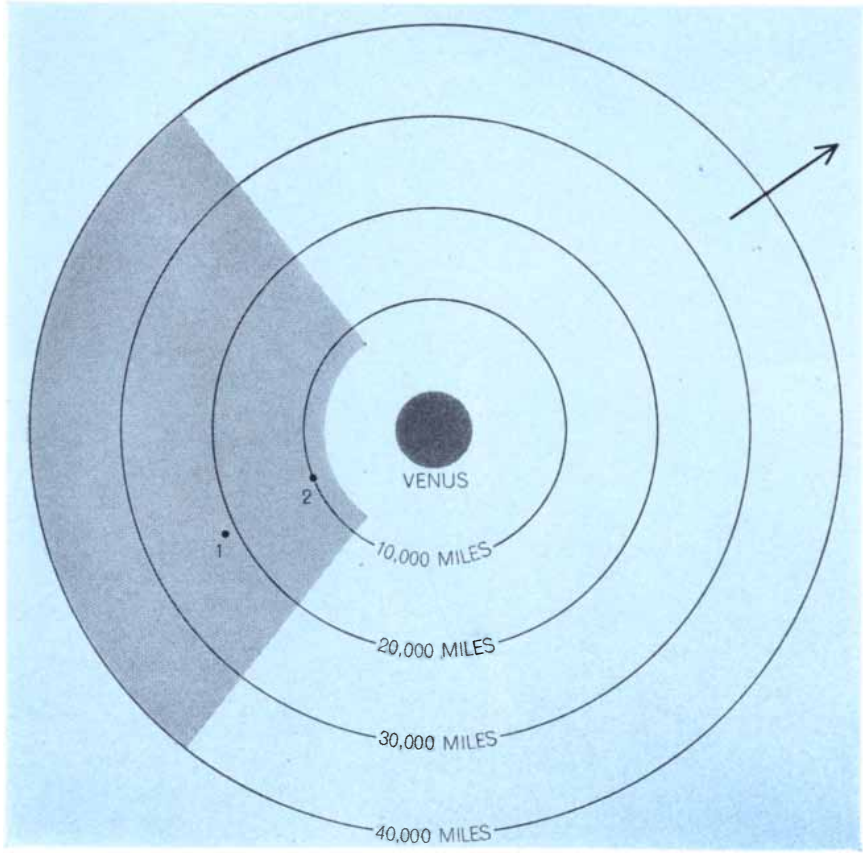
Adventures in Space

On the 12th day of the flight *Mariner II* lost its lock on the earth and the sun; it recovered, however, within three minutes. Apparently it had collided with a substantial bit of interplanetary rubble. On the 33rd day the spacecraft momentarily lost its earth and sun lock. When the craft recovered, the earth-sensor was operating at the proper strength! The sensor, incidentally, produced a fascinating record throughout the flight, reporting clear variations in the brightness of the earth as the land masses, clouds and oceans alternated in its field of view.

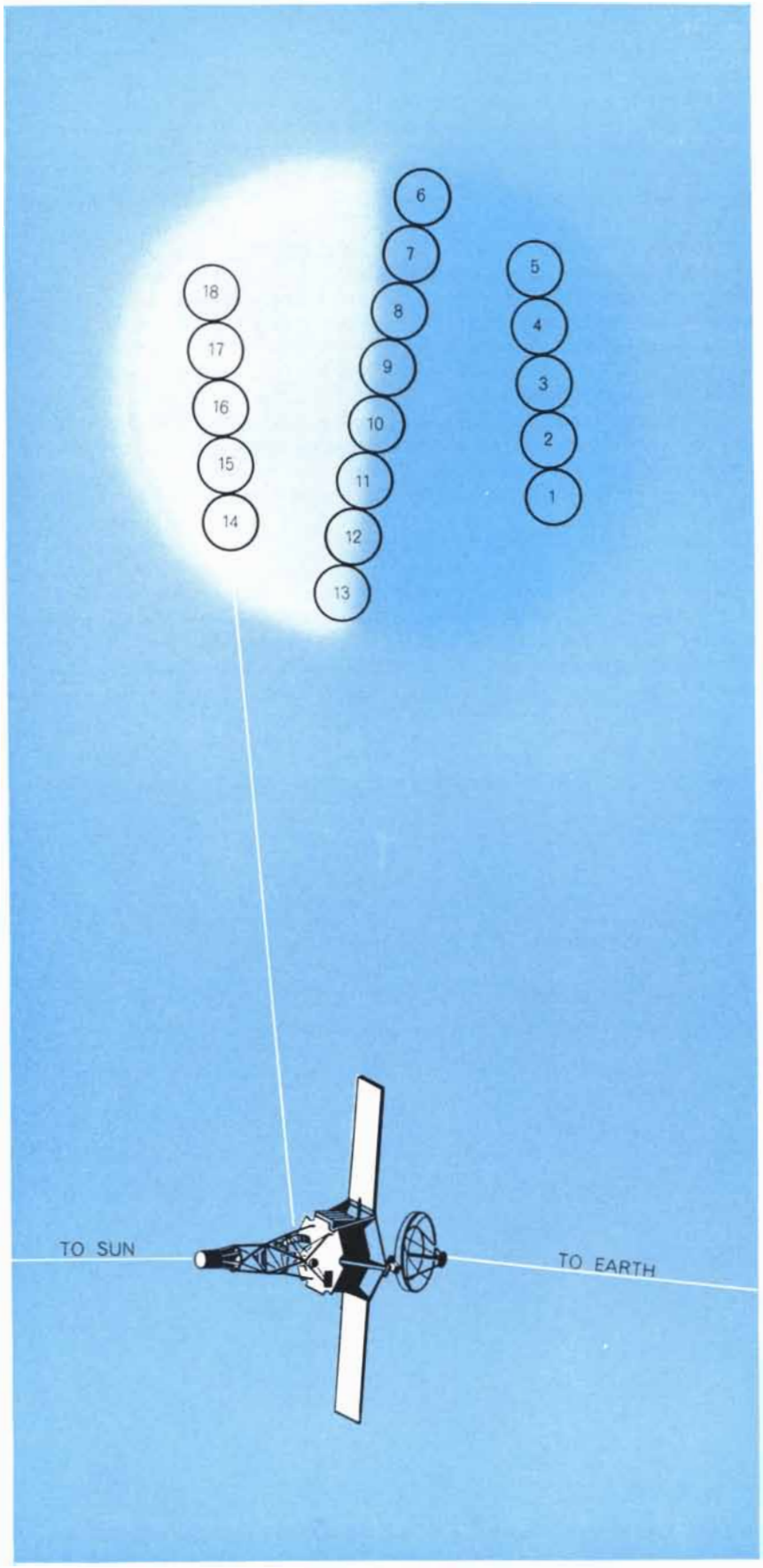
Meanwhile, as the spacecraft fell toward the sun, it was picking up orbital speed. On the 64th day after launching it overtook and passed the earth. The next day a short circuit occurred in one of the solar-cell panels. Fortunately the craft was now close enough to the sun for the other panel to supply more than enough power by itself. That panel had more solar cells than the other; we had found in May that the rockets could handle additional weight and we had used the weight to increase the spacecraft's power safety margin. To balance the craft against pressure exerted on it by sunlight, we added a "sail" without power cells to the other panel. It was the panel with the sail that shorted out. The short circuit cured itself and recurred a few days later with no ill effects. We turned off the scientific experiments for eight days, until we were sure the craft had enough power to handle them.

On the 91st day, at 22.5 million miles from the earth, *Mariner II* set a new distance record for communications. It was to exceed this record continuously for the rest of the trip.

By the 100th day of the flight, with Venus nine days away, the temperatures of *Mariner II* had risen alarmingly, averaging 40 degrees Fahrenheit more than expected. Most of the apparatus could function well between 14 and 149 degrees F. The battery, however, had reached the upper limit, the earth-sensor had passed it and other units were approaching it. Moreover, the situation could only grow more taxing as the voyage continued. The solar radiation impinging on *Mariner II*, which amounted to 130 watts per square foot near the earth, would exceed 250 watts at Venus. All this was painful to observe because one week of flight data after launching had told us enough for us to have kept the spacecraft at a safe temperature range throughout the flight by simple adjustment of paint patterns. Now we could only wait and hope. On the 104th day four of the 52 engineering sensory devices failed, undoubtedly because one blew a fuse common to all four. On the 107th day the central computer failed to deliver a calibration signal that normally came every 16.6 hours. We had to assume that heat was to blame and that we could no longer rely on the computer to initiate the operations programed for the meeting with Venus two days later. As a hedge against this untoward possibility, we had designed the system to accept a "back-



***MARINER II*'S CLOSEST APPROACH TO VENUS** (*1*) **was 21,648 miles from the surface. Aiming point at mid-course maneuver** (*2*) **was 10,000 miles out. Target zone is shaded. Without maneuver *Mariner* would have passed 233,000 miles away** (*arrow*), **about 9.5 inches beyond 40,000-mile ring. In this schematic diagram, *Mariner* would be heading into the page.**



SCANS OF VENUS by the microwave and infrared radiometers covered first the dark side, then terminator, or line between dark and light sides, and finally the sunlit side. The process took 35 minutes. The points from which the craft reported readings are numbered in order.

up" command from earth that would set the scanning program in motion. But there was now some anxiety about our chances for a successful encounter.

Observations in Space

We found what comfort we could in the assurance that the flight had already been remarkably successful. The magnetometer, consisting of three magnetic cores each aligned along a different axis, had given a fine picture of magnetic-field strengths and fluctuations in the region of the solar system it had traversed. This instrument was sensitive to half a gamma, a field strength about .00001 that of the earth. (In the laboratory it could detect a nail in the shoe of anyone within 10 feet of it.) At times when the sun was quiet it had found field strengths of two to five gammas, compared with the earth's 30,000 gammas at the Equator and 50,000 gammas at the poles. During magnetic storms it had reported readings as high as 25 gammas. Changes in the flow of the solar wind were associated with such fluctuations, and it also appeared that the solar wind pushes the magnetic fields in interplanetary space around, just as it does the magnetic field of the earth.

The solar-wind detector recorded 40,000 spectra of particle energies throughout the flight and found that the solar plasma—a gas of dissociated charged particles composed in this case chiefly of electrons and protons—constantly pervades inner interplanetary space, a fact not known before. This apparatus was a particle counter ingeniously designed to discriminate and count protons over the energy range from 240 to 8,400 electron volts; it was mounted in the long axis of the spacecraft and hence pointed constantly "upwind." The density of particles, according to its reports, ranges from 10 to 20 per cubic inch and their velocity varies between 200 and 500 miles per second as they stream outward from the sun. Disturbances on the face of the sun caused the solar-wind detector to register increases of 20 to 100 per cent in the velocity of the particles on 20 different occasions during the flight. When these "gusts" in the solar wind subsequently arrived at the earth, they stirred up storms in the terrestrial magnetic field.

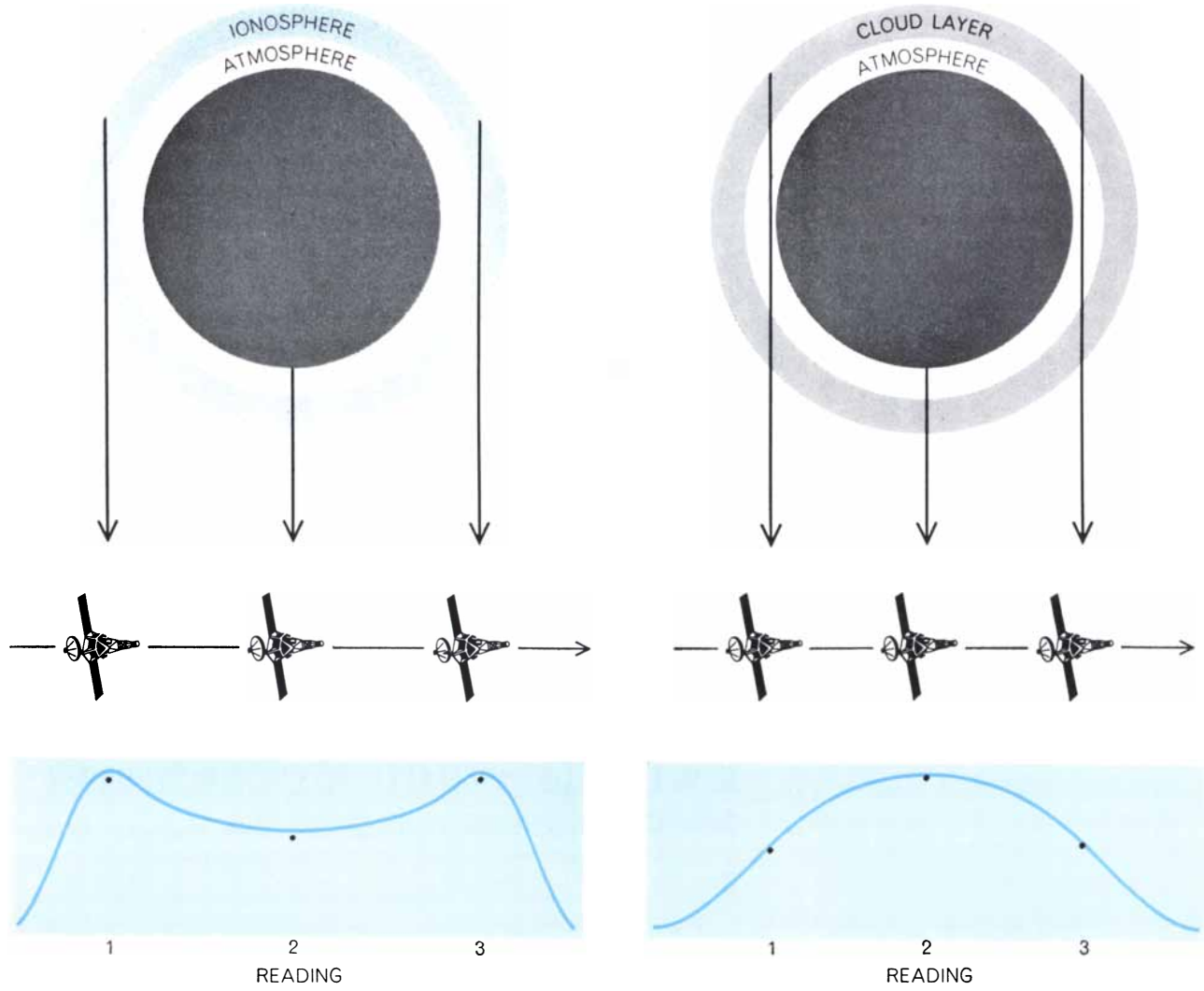
The three Geiger-Müller tubes and the ionization chamber carried by *Mariner II* found that the density and energy spectrum of the much-higher-energy cosmic ray particles in interplanetary space remains constant regardless of distance

from the sun. This is a clear indication that these instruments were counting true cosmic rays originating outside the solar system. Only one solar disturbance, on October 23 and 24, sent out protons of sufficient energy to penetrate the counters. The total dosage of radiation throughout the flight as measured by the ionization chamber amounted to about three roentgens, approximately what a person on earth receives in 30 years from cosmic and other natural sources. It would seem that, from the standpoint of radiation, interplanetary space travel in 1962 would not have been dangerous for an astronaut.

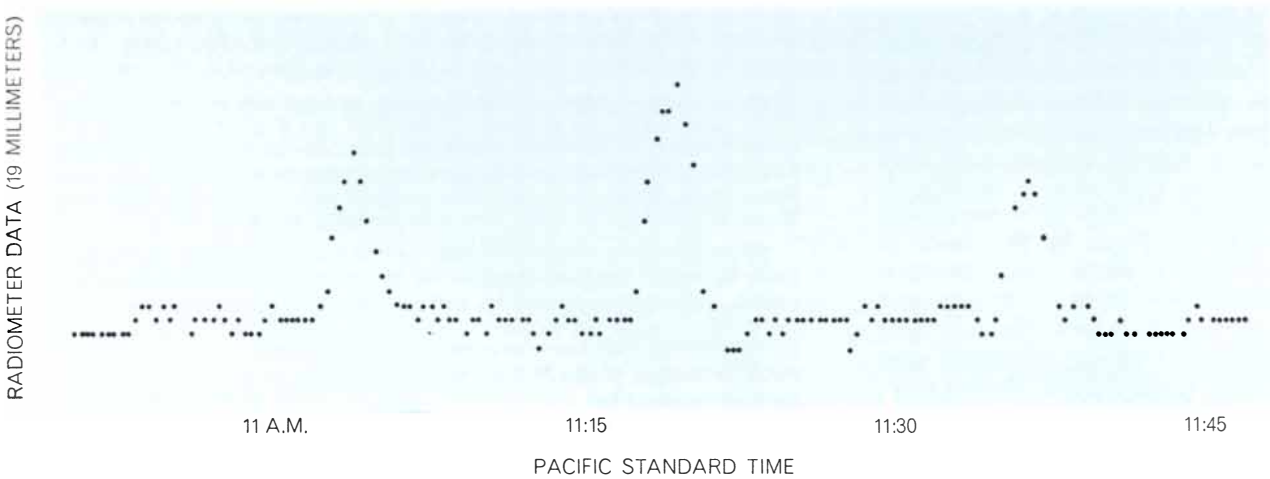
As for the more macroscopic particles of interplanetary dust, the crystal microphone mounted in the center of a sounding plate counted only two impacts in the course of the flight. This instrument was designed to respond to particles as small as .0000000013 gram. Near the earth the flux of such particles is 10,000 times greater.

Rendezvous with Venus

All these instruments were to continue in operation throughout the encounter with Venus and to report their readings along with the measurements made by the radiometers. Early in the morning of December 14, the 109th day of the flight, it became apparent that the central computer and sequencer aboard *Mariner II* had failed to start the operations scheduled for the encounter to come a few hours later. We gave the back-up command to start these operations, therefore, shortly after Venus and the approaching spacecraft rose above the horizon at Goldstone. With *Mariner II* 36 million miles away it took 6.5 minutes for the signal, traveling at the speed of light, to reach the craft and make the return trip to the earth, telling us that the small parabolic antenna and all its attachments had gone into operation for the microwave and infrared scans of Venus. Until it reached the scan zone the antenna would move at one degree per second, warming up the stabilization system for the encounter. To compensate for the motion of the antenna, which would otherwise have set the entire spacecraft into equal and opposite motion, the sun- and earth-sensors and the gyroscopes actuated the nitrogen-gas jets so as to maintain a steady platform. *Mariner II* was now so hot that seven of the 18 measurements of temperature had gone off their scales, and the earth-sensor and the communication system were nearing uncertain states. The scientific instruments



TWO THEORIES to explain high temperature of Venus as recorded by radiometers on earth are ionosphere model (*left*) and "greenhouse model" (*right*). A highly active ionosphere, with many charged particles and electrical discharges, would have given high readings (*dots*) at limbs, or edges (readings *1* and *3*), and low in center, where ionosphere as seen by spacecraft is thinner. This is limb-brightening. Greenhouse model, with heat trapped near surface by clouds, would have shown limb-darkening—low readings at edges, high in center. Colored curves would have resulted from continuous scans across mid-line of the disk of Venus.



ACTUAL OUTPUT of *Mariner II* from 19-millimeter scan shows close resemblance to theoretical prediction for a greenhouse model. Study was reported by Alan H. Barrett of Massachusetts Institute of Technology and A. Edward Lilley of Harvard College Observatory.

and the essential working parts of the spacecraft were nevertheless operating properly at 5:30 A.M. Pacific Standard Time, with the encounter with Venus less than six hours away.

The transmitter was accordingly instructed to stop sending engineering data and to switch over to full-time reporting of the readings from the instruments. One of the space-flight operation teams, on the way to breakfast a few minutes later, saw Venus to the southeast shining in the clear California sky in all its brilliance as the morning star. The men were awed to realize that their spacecraft, which had just responded to their signal, was almost within that disk of light, closer to the planet than the moon is to the earth. *Mariner II* was then moving at a speed of 13,000 miles per hour toward Venus, 86,000 miles per hour in its orbit around the sun and 39,000 miles per hour away from the earth.

The Close-up of Venus

At 10:54 A.M. the spacecraft reached the scan zone. As the radiometer antenna made its first scan of the planet at 11:03 A.M., it slowed its motion to a tenth of a degree per second. In accordance with instructions, it proceeded to scan the disk of the planet, which was 16 degrees in diameter at this close range. When the radiometer indicated that the antenna had scanned past the limb, or edge, of the planet and was looking into space, the antenna drive reversed its direction and started the next scan. Altogether it made three passes across the disk "up and down," while the orbit of the craft provided the lateral motion. The radiometer sent 18 readings, five from the night side of Venus, eight from the terminator (the shadow line between the dark and light sides) and five from the day side [*see illustration on page 80*].

Although the antenna was small, its resolution so close to Venus could have been equaled on the earth only by a parabolic antenna thousands of feet in diameter. The two wavelengths on which it operated—13.5 and 19 millimeters—were chosen to settle some long-standing questions and controversies. In the first place, the difference in the readings between the two frequencies would show if there was any water in the planet's atmosphere and how much of it there was, because any water present would strongly absorb and so reduce radiation of the 13.5-millimeter wavelength. In the second place, the 19-millimeter wavelength would provide the surest measurement of the surface temperature of the planet; radiation of this wavelength would come up unhindered from the surface even through the thick cloud cover that gives the planet its high albedo and hence its brightness in the sky.

Radio observations of Venus from the earth had indicated surprisingly high temperatures—in the range of 600 degrees F. Such readings are of course taken from the whole disk of the planet. One school of investigators was therefore able to argue that the radio emissions indicating a high temperature were really coming from an ionosphere, and that these readings did not necessarily mean that Venus had a hot surface. Another group argued for the "greenhouse model," asserting that the radiation does come from a hot planet and that the heat of solar radiation is trapped under the planet's thick clouds.

The radiometer aboard *Mariner II* could settle this question because it could make readings at discrete points across the disk of the planet. If it found "limb-brightening," or high readings near the limb, where the instrument would be measuring the temperature of the planet's upper atmosphere, and relatively lower readings at the center of the disk where the atmosphere would be thinner, then the proponents of a hot ionosphere would have the better of the argument. On the other hand, "limb-darkening," or readings lower near the limb than at the center, would support the greenhouse model.

Mariner II found an unquestionable limb-darkening and found furthermore that there is little difference in temperature on the dark side compared with the sunlit side of the planet. On the basis of the still incomplete analysis of the radiometer scans, the surface of Venus, where the 19-millimeter radiation originates, appears to have a temperature of about 800 degrees F. Thus the surface, which is hot enough to melt lead, could not sustain any form of life that is known on earth. Apparently there is also very little water vapor in the atmosphere—less than a thousandth that of the earth's atmosphere.

The infrared radiometer attached to the microwave antenna essentially confirmed the findings made at the longer wavelengths. It was hoped that this instrument would detect any breaks in the cloud cover and yield a measurement of the carbon dioxide content of the planet's atmosphere. The infrared radiometer was designed to make comparative measurements of the radiation from the atmosphere of Venus at two wavelengths, 8.4 and 10.4 microns respectively. Radiation from the ground and the lower atmosphere would presumably come through breaks in the cloud cover on the 8.4-micron wavelength, whereas a high concentration of carbon dioxide in the atmosphere would absorb and reduce radiation at the 10.4-micron wavelength. The comparative measurements on the two wavelengths by the radiometer gave substantially the same results. Accordingly we can conclude that there were no breaks in the cloud cover over the regions scanned and that there is no significant amount of CO_2 in the upper clouds; the amount of carbon dioxide below the clouds remains unresolved.

The readings on the two wavelengths did, however, indicate the same temperature (about −30 degrees F.) for the top of the clouds on both the day and the night side of the planet. These measurements support the greenhouse concept of a thick cloud cover that keeps the heat from radiating away from the surface. One anomaly, a spot 20 degrees cooler than any other point seen at the same angle by the infrared radiometer, showed up in the lower half of the pass along the terminator. It could conceivably have been caused by a surface feature such as a very high mountain.

A Featureless Planet

Meanwhile the other instruments aboard *Mariner II* showed the external atmosphere of Venus to be equally featureless. The magnetometer found no increase in magnetic-field readings near the planet compared with the measurements taken farther out in space, and it recorded fewer fluctuations as it approached. If Venus had a magnetic field similar to that of the earth, the magnetometer would have reported 100 to 200 gammas at the point of closest approach instead of a steady reading of a fraction of this strength. The Geiger-Müller counters detected no increase in the density of particles and found a slight increase rather than a decrease in the velocity of the solar wind. In both cases the earth's magnetic field brings about opposite effects near the earth. The low-energy radiation, as measured by the more sensitive Geiger-Müller counter, would have jumped 10,000-fold if Venus had a magnetic field like that of the earth. The magnetic field of the planet, if any, must have a strength less than 10 per cent of the earth's. The

conclusion is that Venus rotates very slowly or not at all, confirming studies made from terrestrial observatories. It is the rotation of the earth and the motion of its fluid interior that are believed to generate this planet's magnetism.

The dust detector was not struck by a single particle in the vicinity of Venus; it would have been bombarded by such particles near the earth. The significance of this observation is not fully understood as yet.

The engineering data that shared such important radio time with the observations of the scientific instruments aboard *Mariner II* also produced important findings. So accurate was the tracking and orbital determination that we know to within 10 miles that the craft was 21,648 miles from the surface of Venus, even though at the time it was 36 million miles from the earth. Astronomers have been watching Venus for decades in an effort to calculate its mass, and they have found it to be .8148 times that of the earth to within .05 per cent accuracy. Two weeks of tracking *Mariner II* within the gravitational field of Venus show that the planet deflected the spacecraft 24.5 degrees from its approach path and changed its velocity appreciably; these observations have given Venus a mass of .81485 times that of the earth to within .005 per cent. Computer calculations employing the tracking data have also enabled us to arrive at a more accurate measurement of the mass of the moon than we have ever had before and to interlock the cartographic grids of the earth's continents with greater precision.

Most important, the 22,000 Doppler readings from *Mariner II* along with simultaneous tracking of Venus by the Goldstone station will enable us to measure the astronomical unit—the mean orbital distance of the earth from the sun—to several more significant figures. The relative distances of the sun, Venus, the moon and other bodies in the solar system are known from Kepler's laws and centuries of astronomical observation. With the absolute distance to Venus established, it becomes possible to give absolute values to all these other distances, including the astronomical unit itself.

After making its nearest approach to Venus at 32 seconds before noon Pacific Standard Time on December 14, *Mariner II* continued in its now eternal orbit around the sun. The "year" of this new solar satellite has a duration of 345.9 terrestrial days. It made its closest approach to the sun, at 65.5 million miles, on December 27, and on the 129th day, January 2, 1963, ceased to transmit information to the earth. It gave no clue as to why it stopped sending. At that time it was 54 million miles from the earth, 5.7 million miles from Venus and had traveled 223.7 million miles through the solar system in 129 days. Scientists and engineers will spend years studying the 11 million measurements it sent back, all now recorded on magnetic tapes and stored in vaults.

EXPERIMENT	MEASUREMENT RANGES	FINDINGS	EXPERIMENTERS
Microwave radiometer	Wavelengths of 13.5 and 19 millimeters	Venus surface temperature of about 800 degrees F. on both dark and light sides	A. H. Barrett, Massachusetts Institute of Technology; D. E. Jones, Jet Propulsion Laboratory; J. Copeland, Army Ordnance Missile Command; A. E. Lilley, Harvard College Observatory
Infrared radiometer	Wavelengths of 8.4 and 10.4 microns	Top of Venus' clouds at —30 degrees F. No breaks detected in clouds. Cold spot found, indicating possible high surface feature.	L. D. Kaplan, J.P.L. and University of Nevada; G. Neugebauer, J.P.L.; C. Sagan, University of California at Berkeley
Magnetometer	Up to 64 gammas in interplanetary space, up to 320 gammas near Venus	Venus has little or no magnetic field, is rotating slowly or not at all. Weak, fluctuating solar magnetic fields found in interplanetary space.	P. J. Coleman, Jr., National Aeronautics and Space Administration; L. Davis, California Institute of Technology; E. J. Smith, J.P.L.; C. P. Sonett, NASA
Ion chamber and Geiger-Müller tubes	Protons above 10 million electron volts (Mev) energy, electrons above .5 Mev, alpha particles above 40 Mev. Directional tube counted protons above .5 Mev, electrons above .04 Mev.	Total radiation dosage for whole trip: three roentgens. Cosmic ray flux fairly constant throughout trip, not changing near Venus.	H. R. Anderson, J.P.L.; H. V. Neher, C.I.T.; J. A. Van Allen, State University of Iowa
Crystal microphone	Dust particles as small as .0000000013 gram	Detected only two particles throughout voyage, none near Venus.	W. M. Alexander, NASA Goddard Space Flight Center
Solar-plasma spectrometer	Protons from 240 to 8,400 electron volts	Solar wind "blows" constantly, varies in intensity and temperature with events on sun.	M. M. Neugebauer and C. W. Snyder, J.P.L.
Radio (tracking)	Employed three-watt transmitter, high-gain antenna on *Mariner* at frequency of 960 megacycles per second.	More precise measurement of astronomical unit, mass of moon and Venus, and location of tracking station on earth	T. W. Hamilton, J. F. Koukol, N. A. Renzetti, D. W. Trask and J. D. Anderson, J.P.L.

SCIENTIFIC RESULTS of voyage of *Mariner II* are summarized. Radio tracking, while not an experiment, is included because it produced valuable scientific data. Microwave and infrared radiometers scanned Venus only; other instruments studied space also.

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Here are some of the ways new Polacolor film has been put to use.

1 This is a photomicrograph of a section of a heart muscle, magnified 175 times. Dyes have been injected into the tissue which have turned the muscle tissue red and a blood vessel blue. With Polacolor film the pathologist knows in less than a minute if he has a perfect photomicrograph. There is no waiting while the film is sent out to be processed. If the picture isn't perfect, he knows it immediately and can take another one right away. He doesn't run the risk of having to repeat a difficult and time-consuming procedure at some later date. And he can proceed with his analysis that much faster.

2 Who is the girl? Employee identification is of vital importance to many Government and industrial organizations. Full color portraits on ID badges and record cards give far more information than black and white pictures, but have been too costly and time-consuming up to now. Polacolor film solves these problems. In this case, the film was used in a special camera that makes four identical images at once on one print. Costly darkrooms aren't necessary. Pictures are finished and can be checked in 50 seconds. (Polacolor prints don't even require coating.) Records can be completed on the spot and the new employee gets on the job faster.

3 This is a picture of a plastic model of a metal part. Stress analysis of the model shows how the part will react to strains it will experience in use. By putting it under pressure and viewing it in polarized light, the lines of strain are readily apparent. These lines and concentrations vary in color as the pressure varies. Polacolor film gives the engineer an accurate picture in 50 seconds that he can study, analyze and file for future reference.

4 Here's how many people will use Polacolor film. Images like this can now be created in one simple step in 50 seconds, rather than the 22 processing steps for conventional color pictures and the 93 minutes development and printing time. The picture is sharp and virtually grainless, the colors strong yet subtle, the skin tones accurate. An 8-layer negative less than half the thickness of a human hair now accomplishes the same function as a technician in an elaborately equipped darkroom and in 1/100 of the time.

This is just a sample of what Polacolor film will mean. More uses are being discovered all the time for full-color pictures which are made in 50 seconds. And many of them will have significant value to you, whether it is in science, industry, business or your own back yard.

If you want more information about how Polacolor film is being put to use, write Polaroid Corporation, Dept. S, Cambridge 39, Mass. Photography by: 1. Leo Goodman Mallory Institute of Pathology; 2. Fran Wing, Jr., Itek Corporation; 3. Professor William Murray and Jerome Catz, Cambridge Mass.; 4. Holly Perry, New London, Conn

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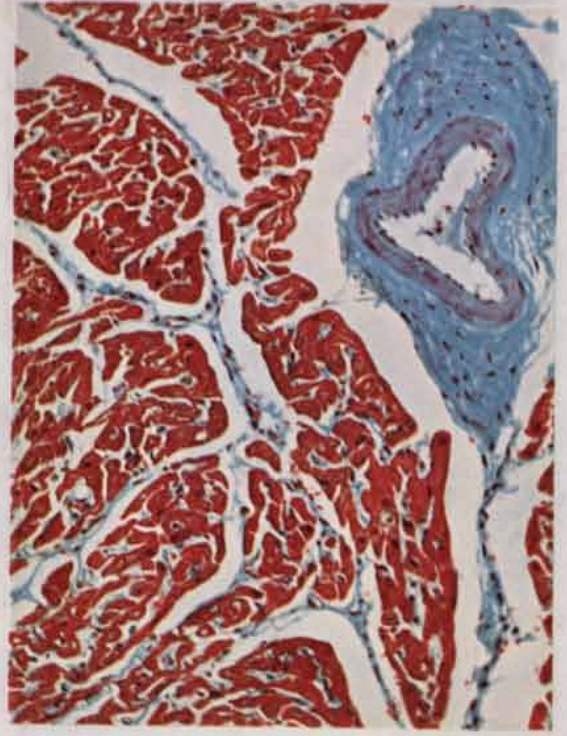

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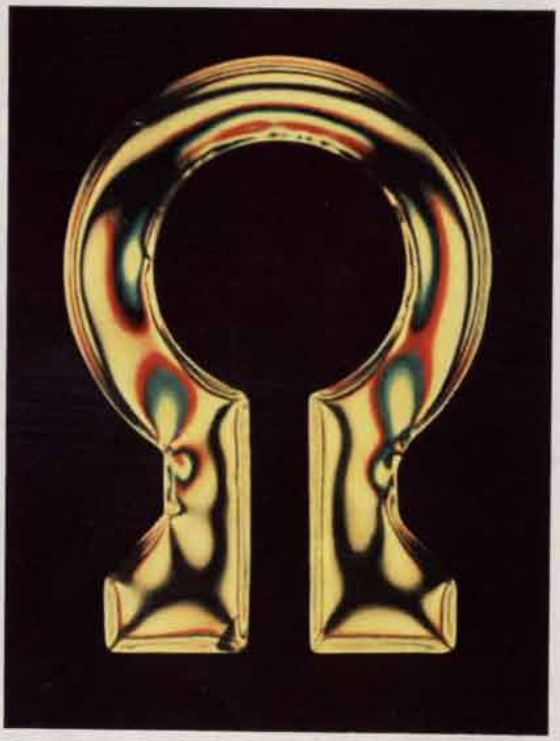

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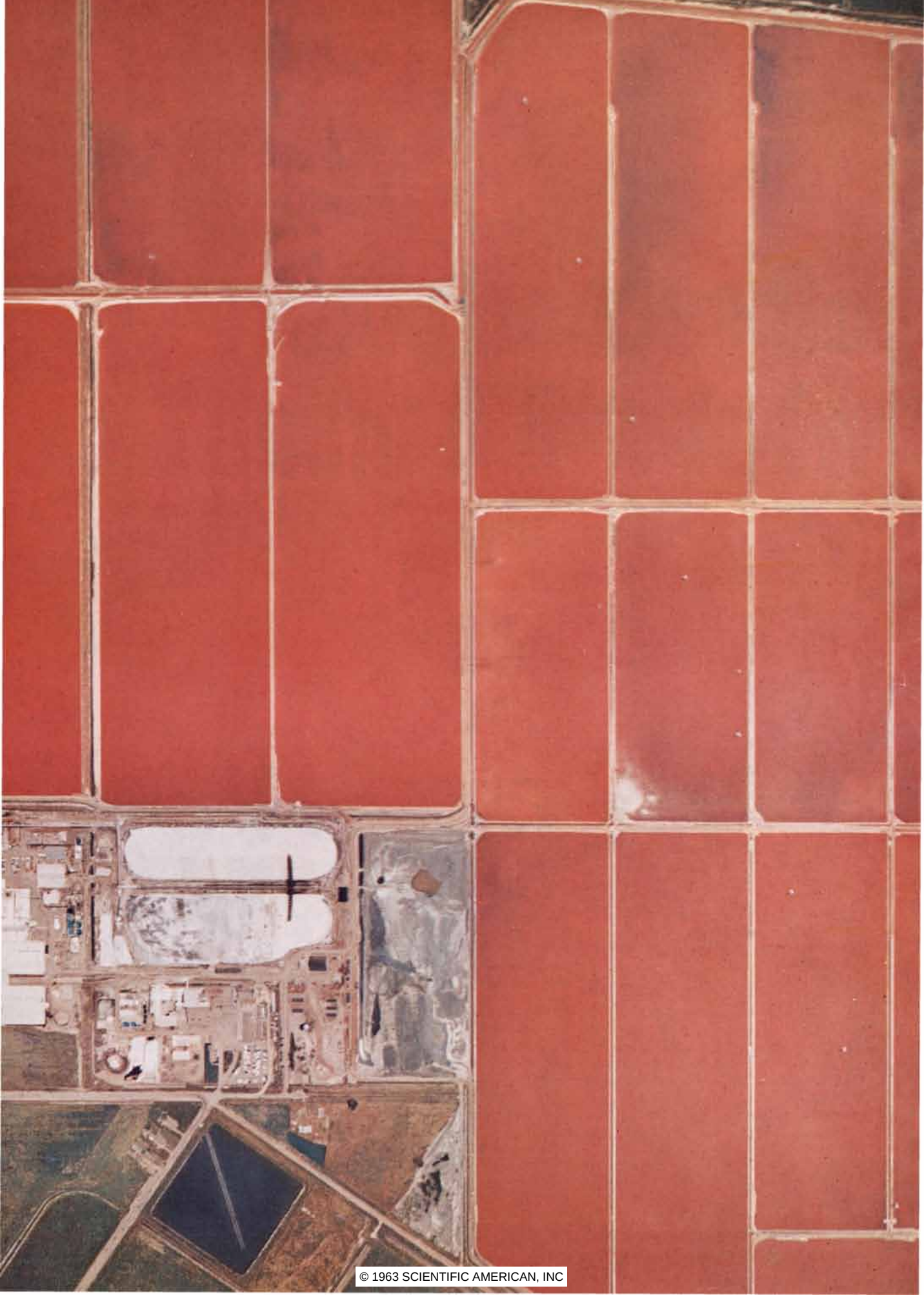


THE SOCIAL INFLUENCE OF SALT

Salt is a necessity of human life, and many people are addicted to using more of it than they need. Its sources are surprisingly limited, a fact that has shaped history in many curious respects

by M. R. Bloch

The Bible assigns a high value to salt ("Ye are the salt of the earth"). The great importance of salt to man was noted by a number of ancient writers (Plutarch, for example); indeed, "salt hunger" has a folklore all of its own. Typical is a pathetic story recounted in 1708 by a French cleric named J. Bion:

"In France... there are some poor peasants and their whole families who, for want of salt, eat no soup sometimes in a whole week; though it be their common nourishment. A man in that case, grieved to see his wife and children in a starving, languishing condition, ventures to go abroad, to buy salt in the Provinces where it is three parts in four cheaper. If discovered, he is certainly sent to the galleys. It is a very melancholy sight to see a wife and children lament their father, whom they see laden with chains and irrevocably lost; and that for no other crime but endeavoring to procure subsistence for those to whom he gave birth."

For want of salt men have risked their lives and endured the most disagreeable circumstances. Over large areas of Africa, lacking other sources, people used to drink the urine of animals for its salt. We are not likely to think of salt as one of the major necessities of life, but in fact it is as essential as water, and for precisely the same reason.

The chemical requirements of the human body demand that the salt concentration in the blood be kept constant. If the body does not get enough salt, a hormonal mechanism compensates by reducing the excretion of salt in the urine and sweat. But it cannot reduce this output to zero. On a completely saltless diet the body steadily loses small amounts of salt via the kidneys and sweat glands. It then attempts to adjust to this by accelerating its secretion of water, so that the blood's salt concentration can be maintained at the vital level. The result is a gradual desiccation of the body and finally death. The organism literally dies of thirst.

In the case of lack of water to drink, the crucial factor—the salt concentration in the blood—is the same but the hormonal mechanism works in the opposite direction. It operates to reduce the secretion of water and increase the salt secretion, in order to maintain the correct salt level; nonetheless, the inevitable, irreducible water losses lead to death. In short, the body's normal craving for salt and for water are both aspects of the same vital need: a saline internal fluid.

In regions of the world where the population lives mainly on meat or fish the year round salt is no great problem—the meat or fish provide enough. (Curiously, however, salt is habit-forming: people who live on a high salt intake become addicted to it. Obviously they must also secrete it at a higher rate.) Salt deprivation is a predicament of the vast areas where meat is scarce and men depend primarily on a vegetarian diet. On such a diet a human being needs a minimum of two to five grams of additional salt per day in mineral form. In many regions no mineral source is available. This was the case in parts of precolonial Africa. Its people survived only by drinking the blood and urine of cattle and wild animals, which roamed over wide areas collecting and concentrating the salt in their systems by feeding on plants. As a result inner Africa was able to support only a thin human population.

Aside from serving as a staple of the diet, salt is a necessity in civilized communities for storing meat and fish. It performs its function as a preservative by extracting water from the animal tissues; the dehydrated meat is then immune from attack by bacteria. There are, of course, other methods of preserving meat, but salt is still the most important one around the world.

It was the availability of mineral salt that enabled dense populations to arise and flourish in the valleys of the Jordan, the Nile, the Tigris-Euphrates, the Yellow River of China and the Salt River of Arizona. The same is almost certainly true of the valleys of Mexico and Peru, and of many in the far-flung Roman Empire.

Today the world population of three billion consumes an estimated 80 million tons of salt a year. But the per capita consumption varies widely. Some populations live on the edge of necessity, averaging two grams per day. Other countries enjoy the luxury of using salt for the production of such chemicals as sodium bicarbonate and polyvinyl chloride. In the U.S. the per capita use of salt is 280 grams a day, four times the world average. A salt shortage in the U.S. would result in some pinch of living standards; in Bengal, where the average daily consumption is five grams, it would mean famine and wholesale death.

In view of all this, it is interesting to investigate the history of the salt econ-

MODERN SALT PANS of the Leslie Salt Company in California get their color from reddish microorganisms in the brine with which the pans are filled. When solar evaporation concentrates the brine, the salt is deposited in layers, which can then be harvested. The buildings of the salt-processing plant appear at lower left. The two white oblong areas are mounds of harvested salt. The approximate scale of distance in this aerial photograph is one inch to 1,800 feet.

omy and its influence on civilization. In a very literal sense, as we shall see, salt has represented tides in the affairs of mankind. The investigation must depend largely on indirect evidence, because written history, oddly enough, does not furnish much information on the subject. There is much eloquent evidence, however, in the archaeological record.

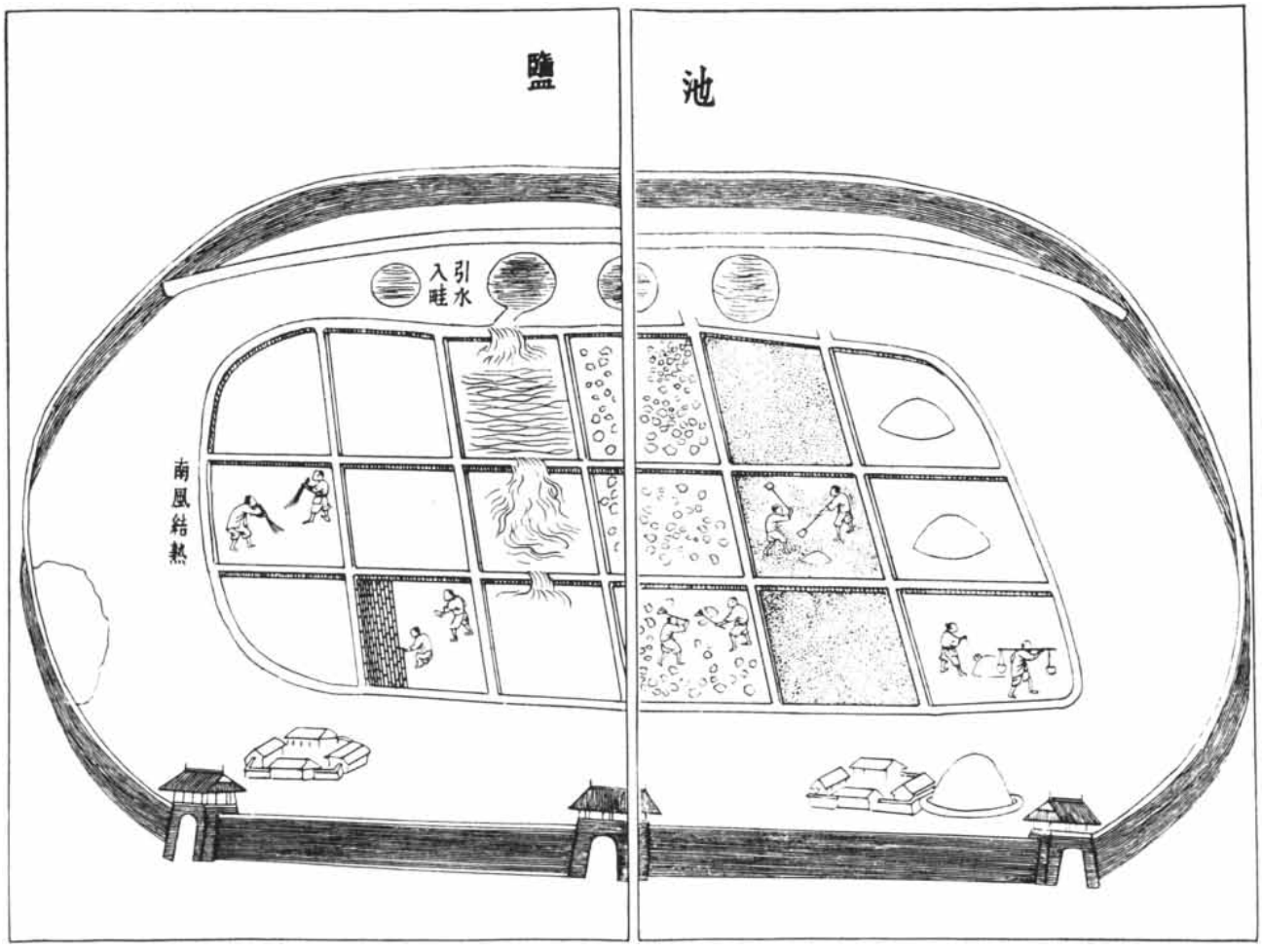
In such an inquiry we cannot do better than to begin by hunting for the sources of possible supply. Where and how did man find salt-rich sites for his early civilizations?

We think at once, of course, of the Dead Sea, the world's saltiest body of water. Near the shores of the sea is a hill of salt known as Jebel Usdum (Mount Sodom). There salt has been quarried since early times, going back before the Bronze Age, and it is no coincidence that some of the earliest known agricultural settlements arose in this area, at Jericho and near the mouth of the Jordan at the north end of the Dead Sea. There were other places in the ancient world where salt could be had merely by digging it out of the ground. Herodotus mentioned salt quarries in North Africa; it is known that the Phoenicians quarried salt in Spain; and prehistoric salt quarries containing stone axes have been found in Asia Minor (Armenia), South America and at pre-Columbian sites in Arizona.

Quarrying led to attempts to mine salt in deeper levels. Remains of such mines have been found at Hallstatt in the Austrian Alps and in several other places [*see map on pages 92 and 93*]. The tools were primitive and the yields low. Nevertheless, salt mining made Hallstatt an important center of ancient middle Europe. A salt mine at Camp Verde in Arizona made possible the Salt River valley civilization of pre-Columbian times.

Easier than quarrying and mining was the production of salt from concentrated brines. All one had to do was to wall the natural brine in a shallow enclosure, let the sun evaporate the water and then harvest the deposited layers of salt. At the edges of the Dead Sea there are remains of rectangular "solar pans" that were diked in by ancient salt-makers. In China, in a salt-water swamp at the great bend of the Yellow River, ancient solar pans are still in operation [*see illustration below*]. They were described in 1882 by the German geologist and explorer Baron Ferdinand von Richthofen as follows:

"The floor of the valley is drained by 150 corporations; each corporation has a strip 600 feet wide running across the length of the valley down to the lake.... Every winter holes are made in the soil, 20 feet deep and 50 feet wide.... There the concentrated brine collects. Around these holes, flat fields with low dividing



CHINESE SALT PAN described in the text has been used from earliest times to the present. It is located in a salt-water swamp at the great bend of the Yellow River in China. Circles at top represent large holes in which brine collects. The drawings on these two pages first appeared in 1637 in the book *Tien Kung Khai Wu* ("The Exploitation of the Worlds of Nature") by Sung Ying-Hsing.

walls are constructed. The summer's task is to lift the brine from the holes into these fields. This is done with a swinging bucket."

There were salt swamps in Persia, the deserts of Egypt and the Sahara. Early man came to recognize the oases of the mineral by their red color. The redness is due to the fact that in briny, shallow ponds reddish microorganisms multiply. Usually the redder the brine, the higher its salt content. The similarity of the red brine to blood, in taste as well as color, must have made a profound impression on primitive folk.

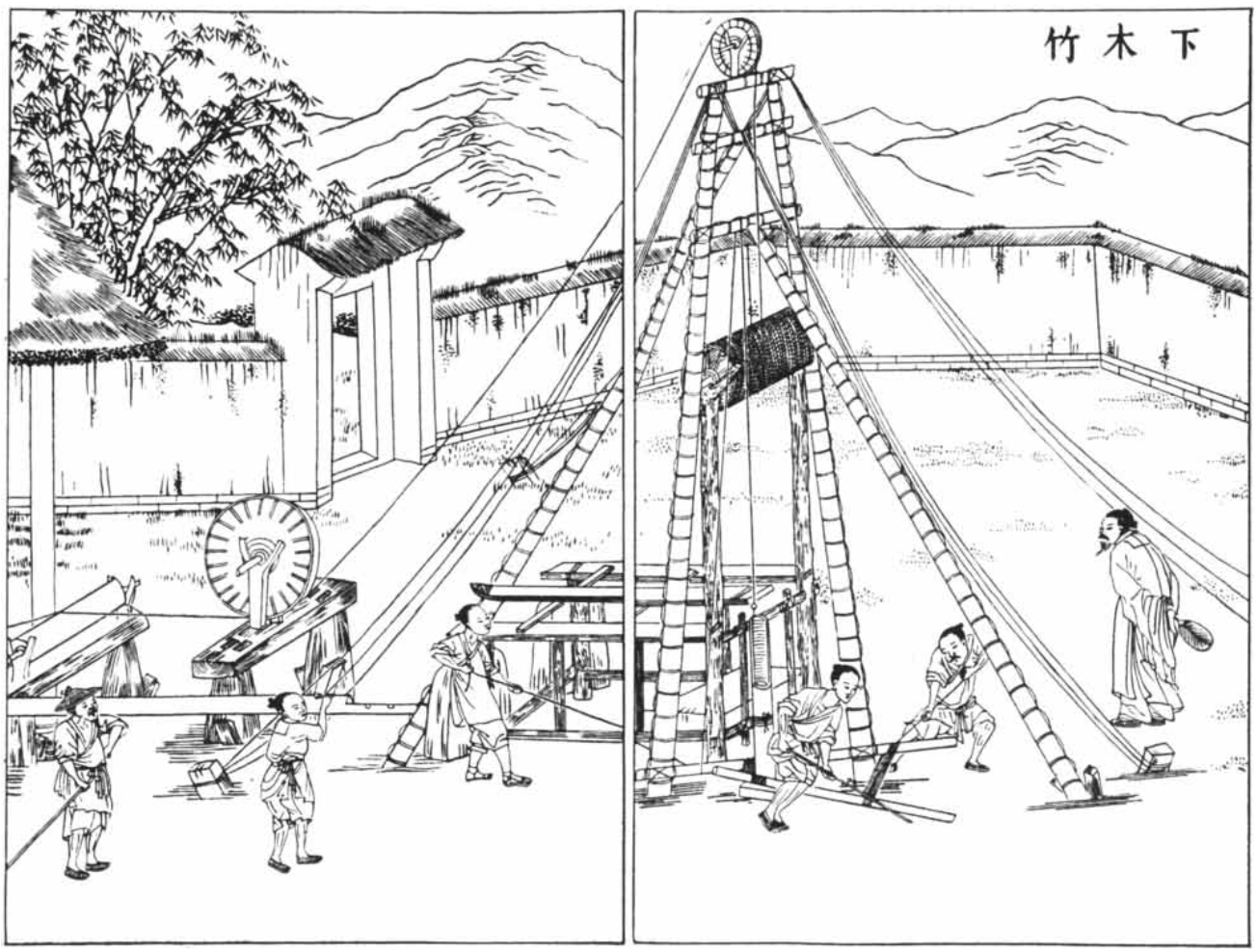
Indeed, the Bible indicates this, as we read in the Second Book of Kings: "And they rose up early in the morning, and the sun shone upon the water, and the Moabites saw the water on the other side as red as blood. And they said, This is blood...." The passage probably refers to salt pans at Sodom. The name Sodom itself very likely came from the Hebrew words *sade* ("field") and *adom* ("red"). In a cave near the Dead Sea archaeologists have found a piece of reddish salt, made by careful crystallization around a wooden stick, along with remains that are dated from the time of the Bar-Kochba Jewish uprising against Rome about A.D. 130.

In contrast to the salt from solar pans, salt quarried from the ground is gray; it usually contains gypsum and has less savor because it does not dissolve completely. A map made around A.D. 450 shows two ships sailing on the Dead Sea, one loaded with reddish salt from the solar ponds and the other with gray salt from a quarry at Mount Sodom.

Rare are the places in the world where salt can be obtained so easily. Inland peoples in most regions of the earth had to search for salt and work hard to extract it. In China some ingenious engineer about A.D. 400 conceived the idea of drilling deep into mountains to salt deposits and bringing up the brine via pipes made of bamboo; some of these salt holes are as deep as 3,000 feet. The brine was then evaporated over fires fueled by coal, wood or natural gas.

Elsewhere early settlements grew up around salty springs, which hunting tribes located by following animals to them. It was difficult to concentrate salt from these dilute sources, but the hunters kept wood fires going and boiled away the water. These salt-boiling civilizations go back to Neolithic times. Among the centers were the Tirol region of the Alps, the Moselle and Franche-Comté areas in France, the Saale and Lüneburg areas in Germany and Droitwich in England. Whole forests were burned up in this industry, and the salt-makers had to haul their wood from farther and farther away, often on river rafts from distant places.

The most abundant and ubiquitous



CHINESE SALT DRILLS were first used about A.D. 400 to reach salt deposits as much as 3,000 feet below the surface. The brines were pumped to the surface through bamboo pipes. These drawings of the pan and drill were photographed from a reprinted edition of *Tien Kung Khai Wu*. The reprinted edition, published in 1930, is in the collection of the East Asian Library of Columbia University.

source of salt on our planet is of course the ocean. Its content of salts is low—only about 3 per cent, compared with close to 30 per cent in the Dead Sea. The ocean nonetheless was and still is the main source that has sustained the earth's human populations. Of the 80 million tons of salt produced today, some 30 million are extracted from ocean water by means of solar energy according to a system that apparently goes back at least to Mycenaean times some 3,500 years ago and possibly to the early Minoan civilization about 5,000 years ago.

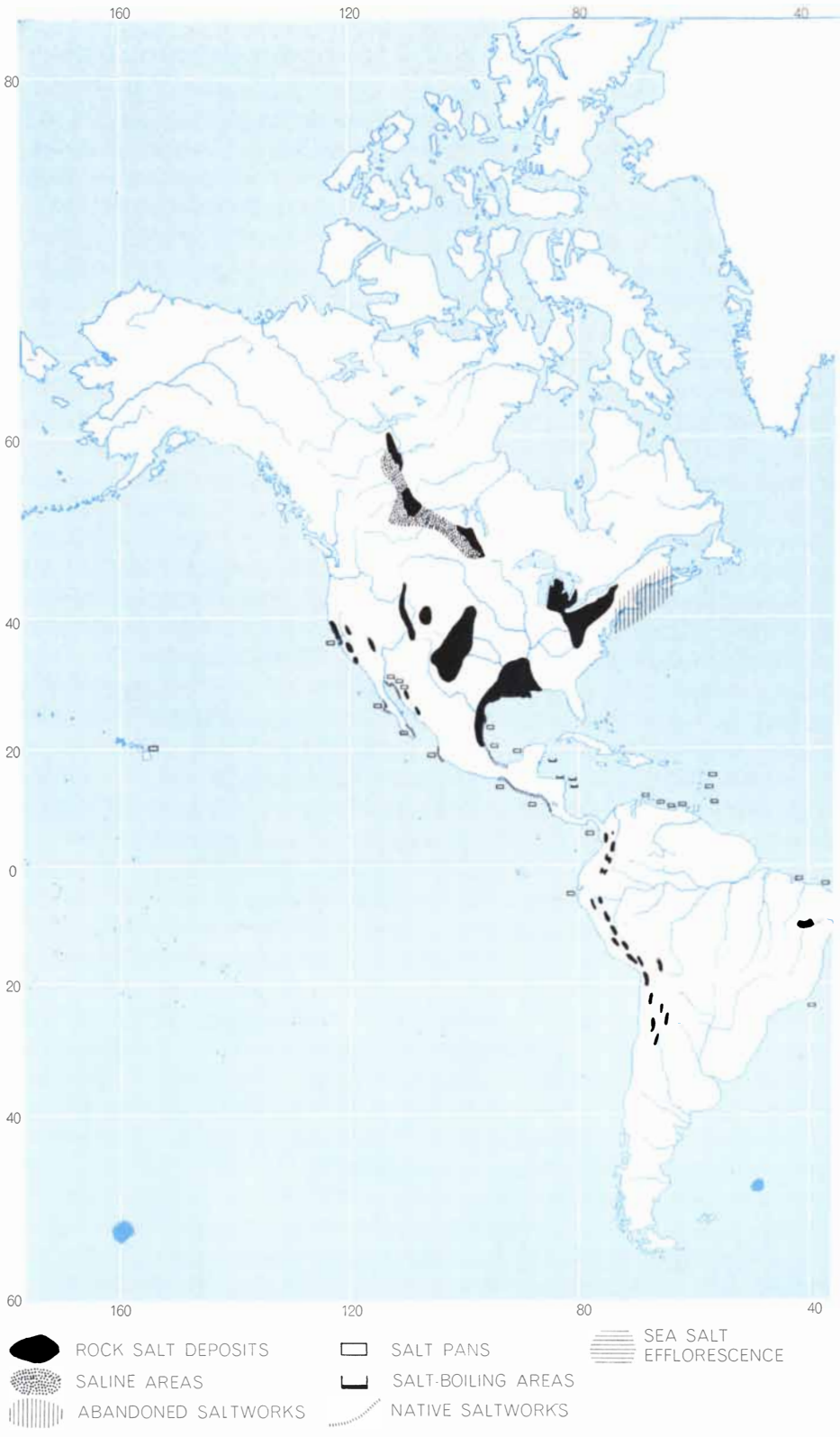
This system is useful only in regions of abundant sunshine. The peoples of rainy northern Europe—Britain, the Netherlands, Scandinavia—were blessed, however, with stored solar energy in the form of peat. Along the coastal areas of the North Sea they dug out immense quantities of peat that had been soaked with sea water at low tide. This they dried and burned; then they extracted the salt from the ashes with sea water, filtered the extract and evaporated the water in caldrons—using peat for the fires. The remaining concentrate (more than 90 per cent salt) was dried beside the fire in small clay vessels. The final salt loaves represented money in prehistoric times, and they still do in parts of Africa. This use of salt as money is embedded in language; the word "salary" is one example.

In the span of northern European history from Neolithic times until the peat began to give out about 400 years ago, millions of tons of peat were harvested for salt. It was a cheap, convenient method and it made the civilization of northern Europe possible.

Sunshine, however, is cheaper, and it is inexhaustible. It is gratifying to note in this day of talk of harnessing solar energy that solar energy is already harnessed on a considerable scale to provide man with one of the chief necessities of life. Huge areas of the earth's sunny zones are devoted to solar saltmaking. Ocean water is pumped into flat, low-lying, diked compounds connected by canals; there the water evaporates under the sun and leaves a harvest of salt. It takes 50,000 cubic yards of sea water, spread over 100,000 square yards of flatland, to produce 1,000 tons of salt per year. This is enough to support the salt needs of a population of 100,000 comfortably.

Until a few years ago the techniques employed for producing and harvesting the salt were exactly the same as those invented thousands of years ago. New methods of treating the brine and more efficient pumping and harvesting are now improving the yields. Saltmaking, which includes fractional harvesting of the various salts of different solubility, is a high art.

Of all the basic necessities of life, salt is unique in that it is confined to certain limited locations. Men can make a living by hunting, fishing, raising animals and cultivating land over vast areas of the earth, but salt can come only from the comparatively few places where it is



readily obtainable from salt lakes, mines, springs, or the ocean shores and means are at hand for extracting it. This fact, from the very beginning of civilization, has operated to make transport one of the cardinal necessities of civilized life.

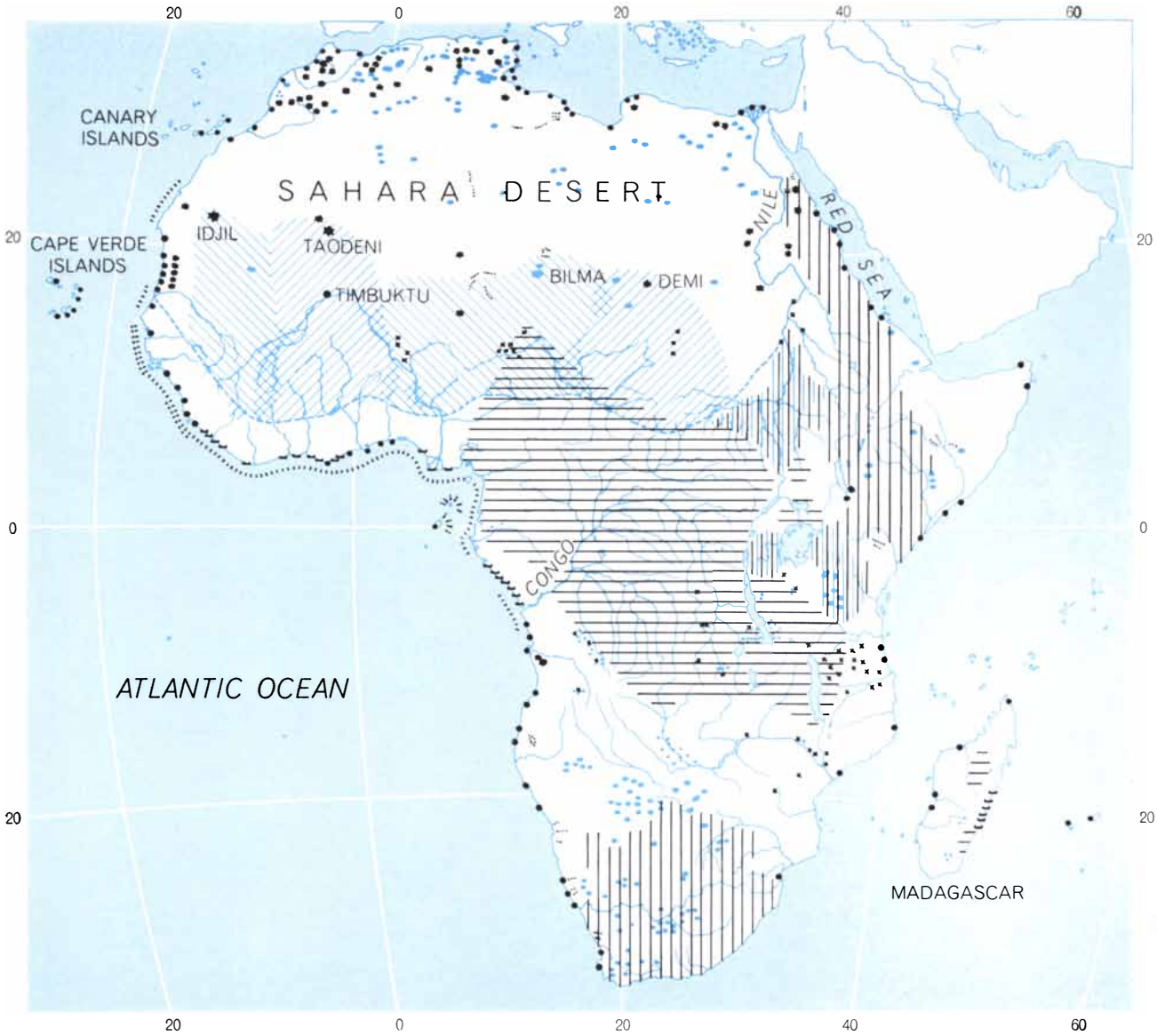
To perceive this we need only look at the maps of the ancient civilizations. In Palestine agriculture spread up the Jordan River from the Dead Sea, and places such as Magdala on the Sea of Galilee became fishing and salting centers. In Egypt early farming depended on boats bringing salt up the Nile from the salt swamps at the river mouth and on caravans bringing it in from the salt lakes in the deserts. In France the hinterland was nourished by salt carried up the Rhone from pans near Marseilles. The same pattern is visible in Mesopotamia,

SALT IN ANCIENT TIMES was usually obtained from the types of source (*keyed at left*) indicated in the map on these two pages. Rock salt was generally dug directly out of the ground. "Saline areas" provided salt through soil compounds and salt springs. In "Salt-boiling areas" sea water or brine was boiled to produce salt. "Sea salt efflorescence" resulted from the freezing of sea water.

Persia, India, China and pre-Columbian Mexico.

River transportation was obviously the easiest. For so precious a commodity, however, every possible means was pressed into service. Caravans of camels, horses, donkeys and llamas carried salt across deserts and over mountains to salt-hungry populations. (A camel can carry some 300 pounds.) Up to a few years ago a great caravan brought salt twice a year to Timbuktu in Mali from the Taodeni salt swamp in the Sahara Desert. To maintain Timbuktu, with its celebrated market, a caravan of 2,000 camels left the town semiannually on a 450-mile journey to the swamp for the single purpose of bringing back 300 tons of salt.

Salt was also an important item of ocean-going commerce. Hundreds of ships plied the Atlantic and northern European waters to bring salt to the Netherlands, Britain, Scandinavia and Russia. Spain and Portugal traded salt to Africa, India and the Americas, and Britain later joined in this trade, shipping salt from Cheshire, where it was produced with the help of coal. In the time of the Hanseatic League, France sent salt by



ROCK SALT DEPOSITS
SALIFEROUS SOILS
SALT EFFLORESCENCE
SALT LAKES
SALT SPRINGS
SALT-BOILING OPERATIONS
NATURAL FORMATIONS OF SEA SALT OR SALIFEROUS BEACH DEPOSITS
SOUTHERN LIMIT OF THE SALT TRADE SOUTH FROM THE SAHARA
PLANT ASHES
SALT FROM CONSUMPTION OF ANIMAL BLOOD
SALT FROM CONSUMPTION OF CATTLE URINE
SALT IMPORTS FROM EUROPE BEFORE 1800
SALT IMPORTS FROM EUROPE AFTER 1800

SALT IN PRECOLONIAL AFRICA was sufficiently scarce to require the importation of salt as well as the exploitation of various native sources. The imports and different sources are keyed at left. The ashes of burned plants were used as condiments and as a substitute for normal salt. The hatched areas associated with Idjil, Taodeni, Bilma and Demi represent the areas in which salt from each of these sources was distributed.

the thousands of tons to the Baltic countries (the Baltic waters being relatively low in salt content). A single ship could carry more than 150 tons—as much as a caravan of 1,000 camels.

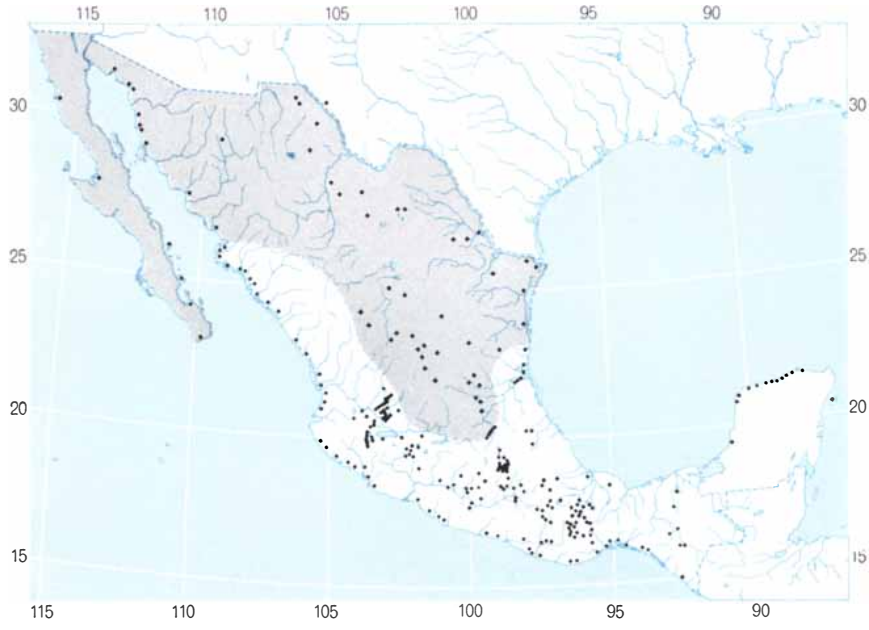
The salt trade, particularly the overland traffic, inevitably had military, social and political consequences. The caravans and ships, and the depots to which they delivered their salt, had to be protected against bandits and marauders. It became necessary to provide them with convoys and to fortify way stations, shipping ports and trading posts. In short, the system of "protection" came into existence. As the most valuable single commodity in commerce, salt required the services of powerful protectors.

A certain political pattern seems to emerge: where salt was plentiful, the society tended to be free, independent and democratic; where it was scarce, he who controlled the salt controlled the people.

In the very early settlement of Jericho the farmers pursued an independent existence and needed no fortifications to defend their abundant source of salt. (The town's famous walls were built later.) Along the shores of the Mediterranean and the North Sea, farmers and fishermen also nourished free societies. We know that the economy of the Athenians depended in considerable part on the salting of meat and hides, for which they sacrificed hundreds of cattle daily on the Acropolis. Salted fish was a staple of the diet throughout the Hellenistic world, thanks to the salty Mediterranean. Later the empire of the Caesars, utilizing the seacoasts and ocean coasts along its borders, was able to produce about a million tons of salt a year for the population of the empire, which is estimated to have totaled some 100 million.

In northern Europe the abundance of fish, peat and tidally shallow, salty seacoast allowed the Dutch, the English and the French to be more than self-sufficient. They were able to maintain small, independent communities that not only supported themselves but also sold their salted fish to markets as far away as the Mediterranean. In the Middle Ages the Dutch shipped salted herring to half of Europe. When peat and wood gave out, the English turned to coal as a fuel for saltmaking, and this use of coal made Britain the world's foremost salt producer during the 18th and 19th centuries.

In contrast, areas of the world that had to import most of their salt or obtain it from small, isolated sources show a more autocratic pattern—a history of frequent conflict, monopoly and all-powerful rulers. In the ancient river-valley civilizations of the Nile, Babylon, India, China, Mexico and Peru the kings and priests maintained their rule and obtained their income through their monopoly of salt, on which the population was helplessly dependent. By their control of the military forces that guarded the stores of salt these rulers exercised a power of life and death over their people.



SALT IN PRE-COLUMBIAN MEXICO influenced the distribution of agricultural populations. This map shows available salt sources before (*dots*) and after the Spanish Conquest in 1519 (*crosses*). Most of the indigenous populations occupied southern Mexico (*unshaded*).

In middle Europe during Roman times salt was a focus of instability. Unlike the salt-rich Dutch, English and French, the German tribes fought wars over their meager salt sources, so Tacitus tells us, and small dukedoms consolidated around the centers of production located at Halle, Hallstatt, Seille and Lüneburg.

In Africa the scarcity of salt made it more precious than human freedom; it was, in fact, a most powerful factor in the slave trade. Families in the African interior sold children into slavery for a handful of salt. As recently as 1882 a traveler in British East Africa reported that he was offered a young girl for four loaves of salt.

Students of recent history will also recall that the salt monopoly and salt tax (*gabelle*) in France was one of the main causes of the French Revolution, and that Mahatma Gandhi climaxed his crusade for emancipation of the Indian people by leading them in the famous salt march.

What is most startling in the whole salt story is that geological history has played a crucial but unappreciated role in the world's salt supply. Bear in mind that a large share of the salt (more than a third) is obtained from low-lying flat lands at the ocean's edge; that is, from natural or diked pans of sea water, which can be evaporated by the sun or by the use of fuel. What happens when the ocean rises because of melting of the glaciers?

We know that within the history of human civilization the sea level has risen and fallen periodically in what is called eustatic ebb and flow. From tracing old shore lines, from carbon-14 dating of plant and animal remains and from historical records, we can make a rough chart of these oscillations [*see illustration on page 98*]. It appears that after the last continental glaciation the average sea level rose some 20 feet and then settled down to a cycle of minor rises and falls.

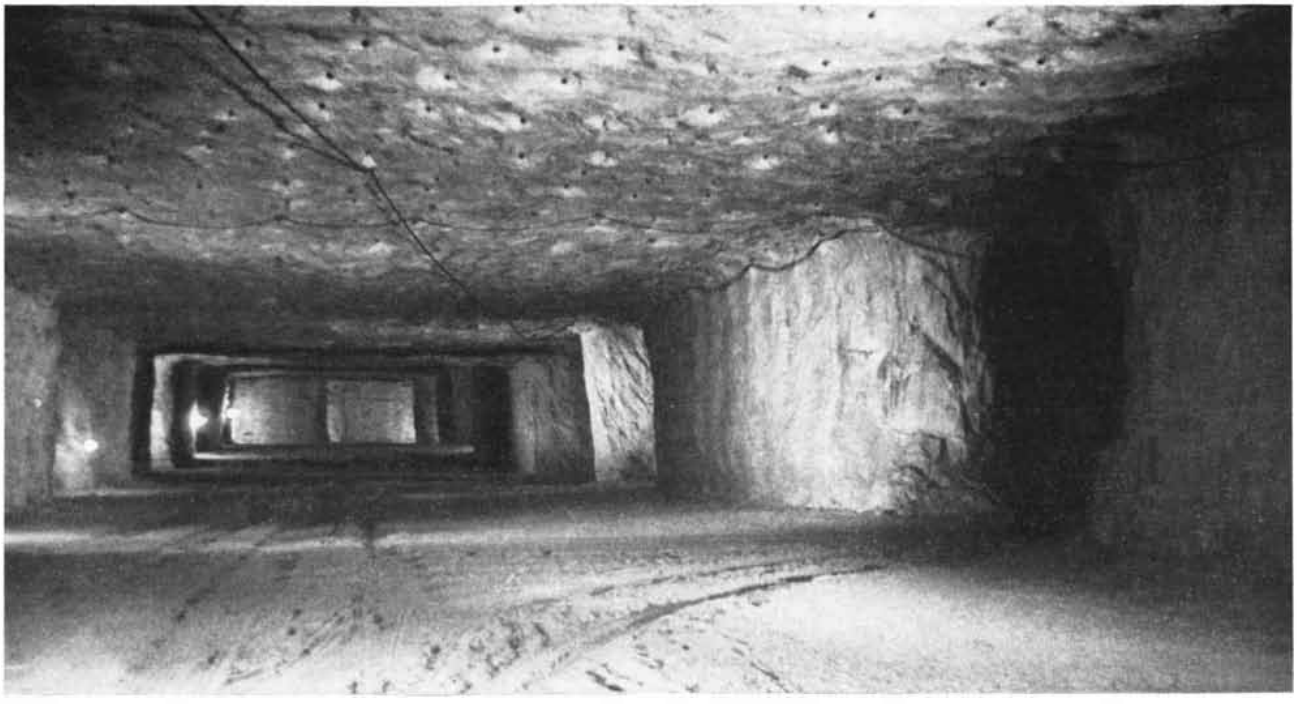
At the height of the ancient Greek and Phoenician civilizations the sea level was more than three feet lower than it is today. For 1,000 years or so saltmaking in solar pans and in peat marshes flourished in the Mediterranean, the Atlantic and the North Sea. But the sea was rising. By A.D. 500 it had risen more than six feet (about three feet higher than it is now). This may seem a rather minor change. It was enough, however, to

inundate most of the sea salt ponds all over the world!

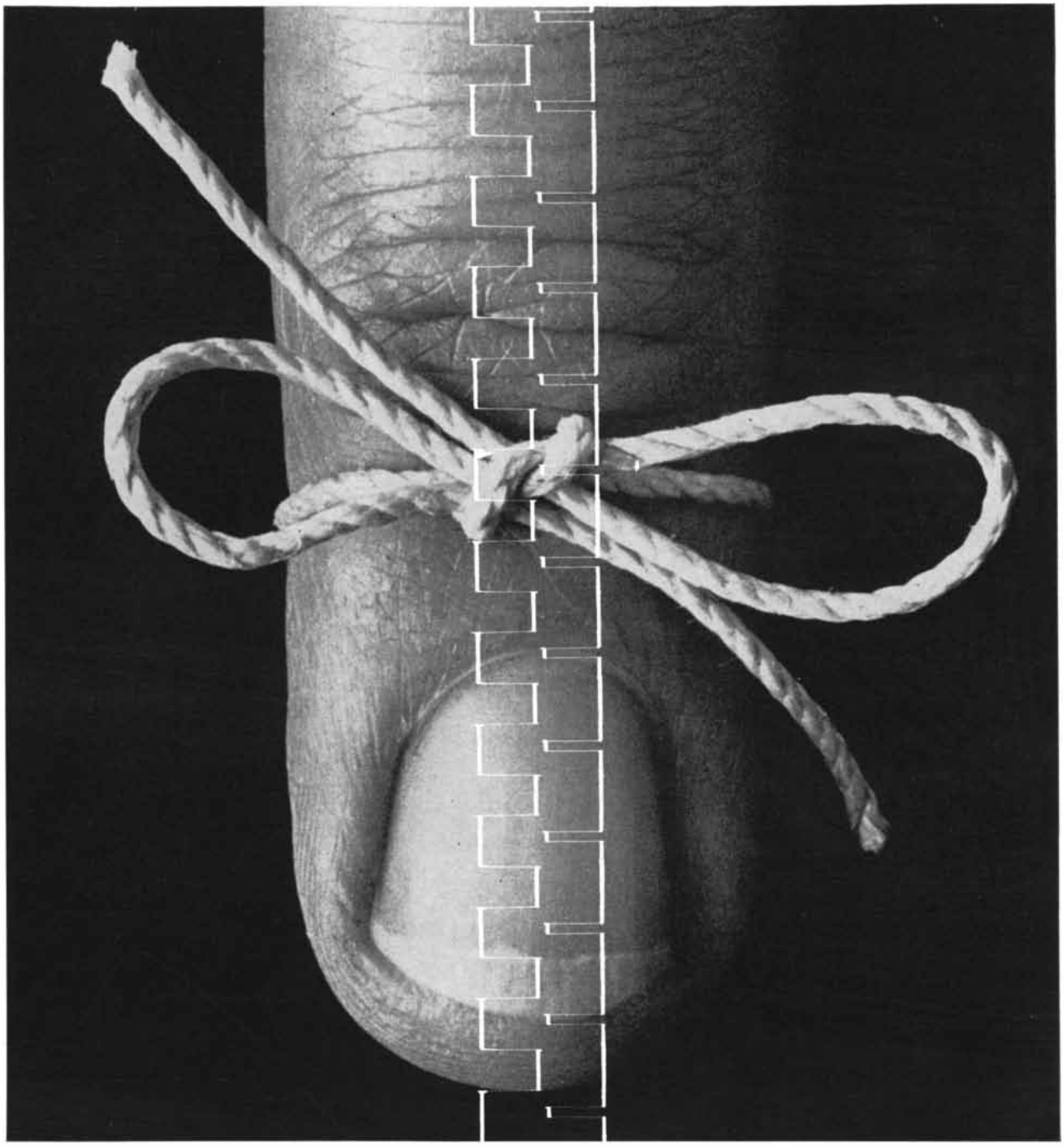
The solar pans of Athlit in Palestine sank below sea level. So did those at Marseilles and Narbonne in France and at other places around the Mediterranean; only at the mouth of the Po River and a few other places did the salt pans survive. In northern Europe the marshes were similarly flooded and salt-making all but stopped. Only a few North Sea islands and Duurstede in the Netherlands provided any salt.

The effects on Europe were nearly catastrophic. The Belgian historian Henri Pirenne observes that Europe fell into an economic dark age. The salt traffic virtually disappeared; the coasts of Britain and France were deserted; the northern part of the continent became an "underdeveloped" area, and people began to

HICKLING "BROAD" is among the numerous shallow "lakes" and inlets on the east coast of England that were created by the removal of immense quantities of peat. The peat, soaked in sea water, was dried and burned for salt. This practice was prevalent from about the ninth until the 16th century, when the rising sea level flooded the areas and rendered them useless as sources of salt.



HUGE ROCK SALT DEPOSIT at the Fairport Harbor Mine of the Morton Salt Company near Cleveland is mined at a level 2,000 feet below the surface. "Room and pillar" mining has left pillars of rock salt to support the ceiling, which is about 18 feet high.



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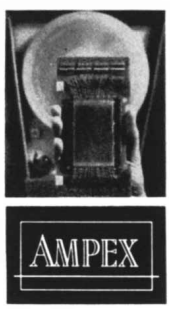


migrate to the more arid areas of the Mediterranean in quest of lifesaving salt.

The salt mines, the desert salt lakes and the Dead Sea became the saving sources for European civilization. This explains the otherwise senseless determination of the Roman emperors Vespasian and Titus to conquer the deserts around the Dead Sea. In the sixth century A.D. the ports and other towns of Palestine became great trade centers and grew to cities of 100,000 or more. For the salt and salted food they provided to the collapsing West they received gold, marble and other luxuries.

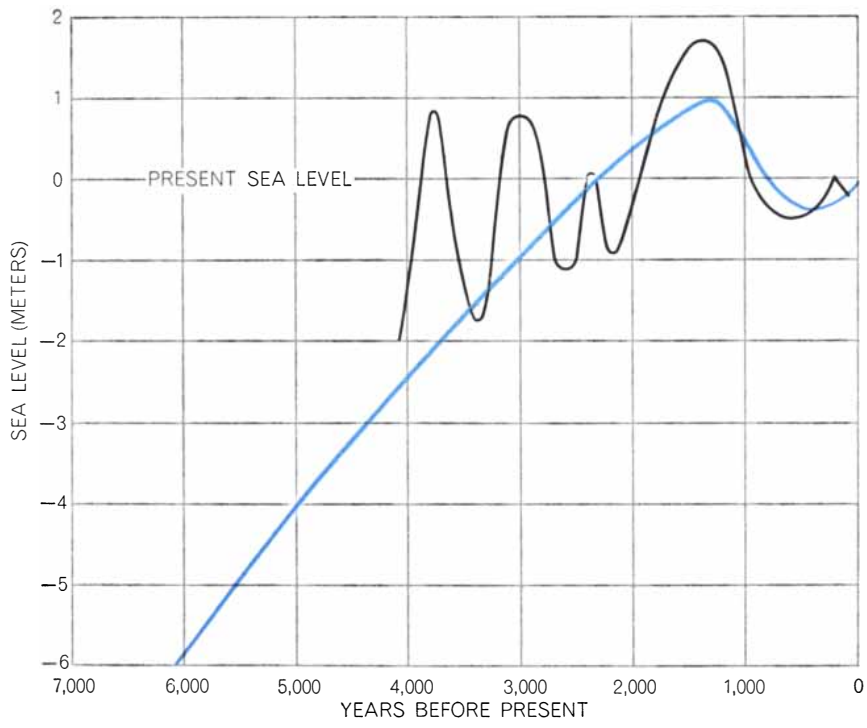
The sea receded, and Europe came back. By the 10th century the English, French and Dutch were again making salt in their peat bogs. Essex, according to the *Domesday Book* of the time of William the Conqueror, was operating hundreds of salt pans; the island of Yarmouth had revived as the center of Britain's fish-salting industry; and salt production was in full swing in Normandy, on the west coast of France, at the mouth of the Rhone, in Sicily and the Crimea.

The revival of European saltmaking brought invaders; Europe's population vacuum began to fill up violently. From the north the Norsemen took over the British and French salt centers; from the east the Arabs invaded France and clashed with the Norman conquerors in Provence.

In the 16th century the oscillating sea level again flooded saltmaking centers along the European coasts and made lakes of the peat excavations—now known as the "broads" of eastern England, the "meers" of the Netherlands and the "claires" of France. The rising tides covered part of the "red hills" in Essex and elsewhere on the shores of the North Sea; these hills were formed by the piling up of hundreds of thousands of tons of broken clay forms in which peat salt was cast over the centuries from Neolithic times on.

Recent rises in sea level have not gone as catastrophically high as during Europe's dark age. Industrialization has largely removed the danger of salt famine from the Western world. In the U.S., for example, large quantities of salt are produced from natural salt lakes, from rock salt and by drilling into deep underground salt deposits where water is pumped in and the brine pumped out —as well as from solar pans on the California coast.

Yet some 30 per cent of the world's salt is still obtained from seacoast solar ponds, which are vulnerable to a rise in sea level. Thus the small eustatic fluctuations of the ocean level may produce profound effects on human civilization in the future as they have in the past.

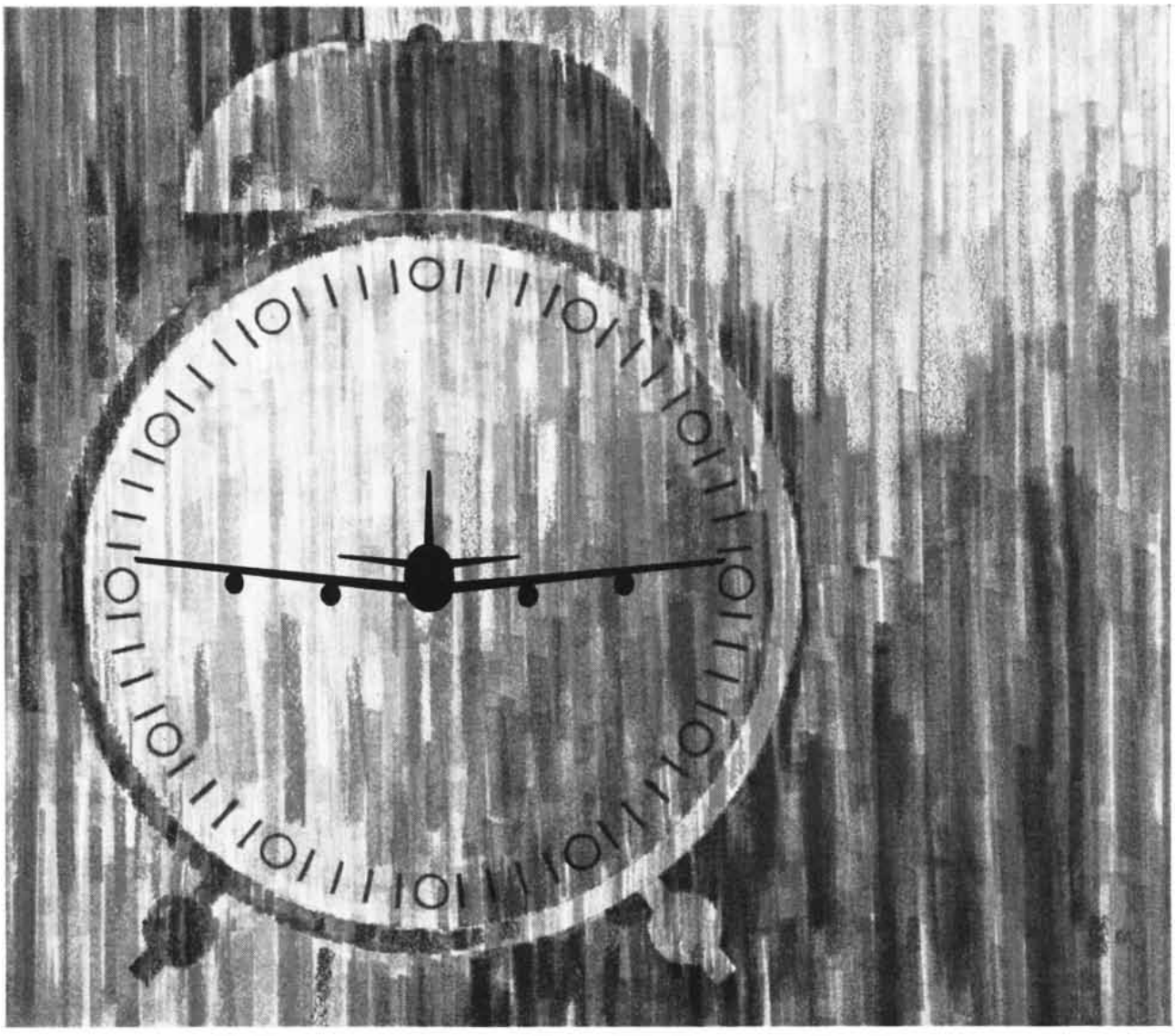


EUSTATIC CHANGES OF SEA LEVEL over the past 6,000 years have greatly affected the production of salt, as discussed in the text. In the past 4,000 years there have been small but important oscillations (*black curve*) in the over-all rise of sea level (*colored curve*).

Freight-to-passenger ratio for airlines gives strong evidence of following railroad patterns. Fifty years showed freight increasing from 20% to 88% of total railroad business. Cargo by air has grown from 3% to 9% in the past fifteen years. Freight-by-air is a sleeping giant which could awaken with a roar as a result of important shipping economies being made possible by the new Douglas jet freighters now entering service. □ And Douglas is helping awaken the giant on several other fronts. These include coordinating a study of freight movement statistics in conjunction with several major airlines; designing improved terminals and cargo handling systems; analysis of terminal-to-terminal control; and, of course, continuing production of jets with lowest possible operating costs.

SLEEPING GIANT

...AND WHAT DOUGLAS IS DOING ABOUT IT



Douglas research programs involve 23 technological areas relating to aerospace and defense systems. Major Douglas divisions are located in Santa Monica and Long Beach, California; Tulsa, Oklahoma; and Charlotte, North Carolina.

DOUGLAS

THE ARCHER FISH

This remarkable animal of southeast Asia downs its insect prey with a powerful spout of water. A discussion of the anatomical and behavioral adaptations that account for its unique ability

by K. H. Lüling

In 1764 John Albert Schlosser, a Fellow of the Royal Society of London, described to his colleagues an extraordinary animal: the East Indian "jaculator, or shooting fish." Schlosser reported that "this cunning fish," sighting a fly on a plant above the water, "ejects out of its tubular mouth a single drop of water, which never fails striking the fly into the sea, where it soon becomes its prey." Although Schlosser's story was inaccurate in some of its details, it was essentially correct. Scholars nonetheless discounted it and many similar reports. Only at the beginning of this century did the Russian ichthyologist N. Zolotnisky take the trouble to observe some archer fish that had been imported and placed in an aquarium. He confirmed Schlosser's account of their shooting prowess and noted several other aspects of their behavior. The archer fish became a popular aquarium specimen, but it was not until the 1930's that a U.S. ichthyologist could describe the anatomical structures that enable it to function as a living water pistol. Ten years ago I undertook to investigate the remarkably specialized behavior of the archer fish—behavior that so far as I know has no parallel in the animal kingdom.

The habitat of the genus *Toxotes* (from the Greek word for "archer") ranges from India to the northeastern tip of Australia. *Toxotes* is adapted to various environments at the edge of the sea: coastal salt water, the brackish waters of mangrove swamps, bays and estuaries; it even moves some distance upstream in rivers. Of the five species that have been distinguished, *T. jaculatrix* (Schlosser's "jaculator") is the best known and the one with which I have usually worked. It is a small fish, attaining a maximum length of about seven inches, and is silvery in color with dark patches and bars on its flanks. As one might expect, the eyes of this sharpshooter are quite distinctive: large, rather protruding and mobile. Most observers have been struck by their brightness and even an appearance of keenness not usually associated with the eyes of fishes.

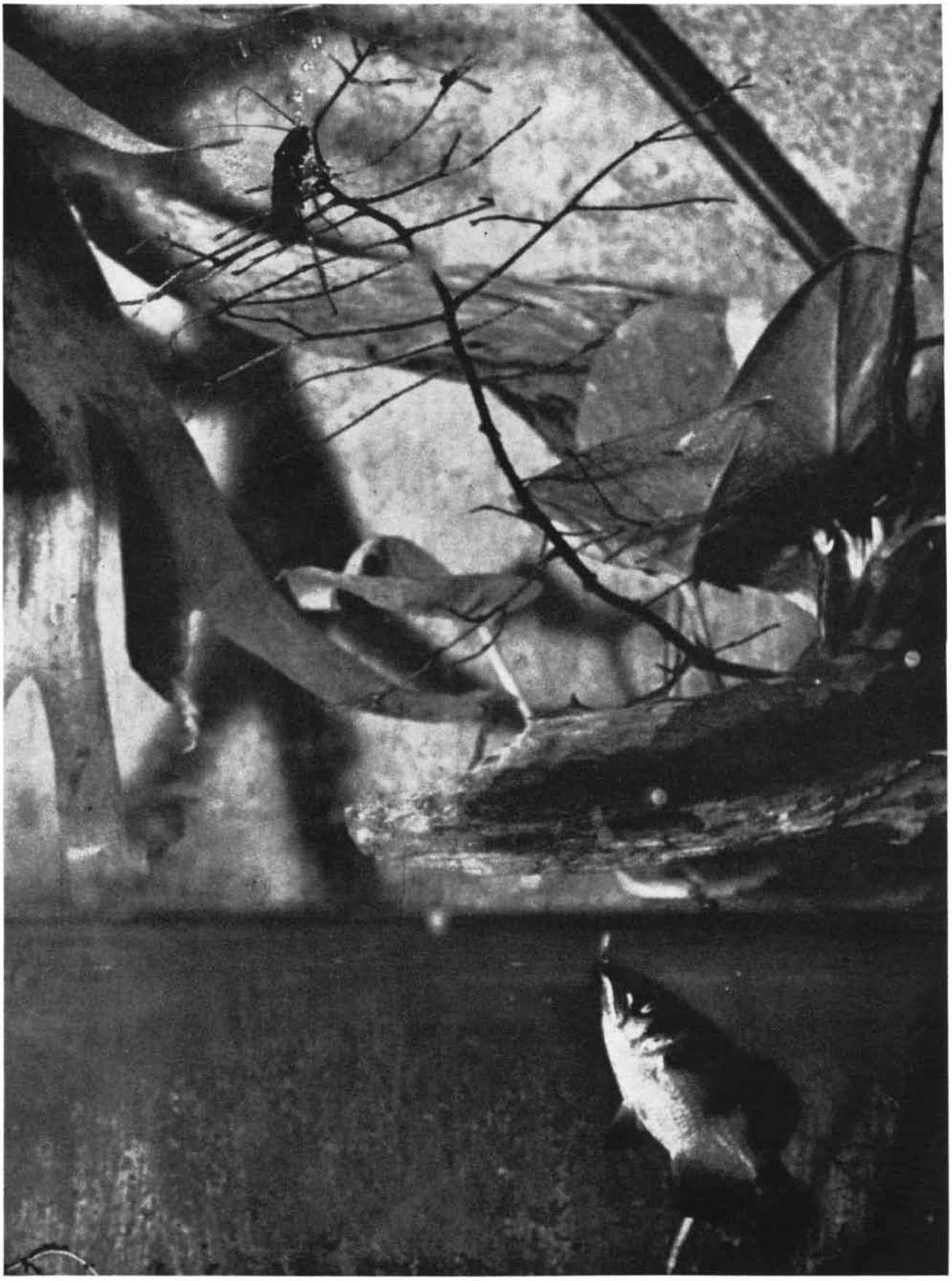
One other anatomical detail should be mentioned because of its apparent adaptive significance. The bodies of juvenile archer fish shine with luminous spots that at times are so bright they resemble tiny greenish fluorescent lamps. The light, however, is not produced by the fish itself; it apparently results from the enhanced reflectivity of the tissue between the dark dorsal patches, which is particularly soft in the young fish. Juvenile archer fish are gregarious, and it seems likely that their luminosity helps them to keep contact with one another in the dark and muddy waters they so often frequent.

In its native habitat the archer fish swims at the surface or just beneath it, the great eyes peering upward in what appears to be a purposeful search for prey. When it spots a likely insect on a water plant or a mangrove root, it takes up a characteristic position with its snout just breaking the surface and lets fly a jet of water. Its aim is remarkably good: the first shot is usually successful at distances up to two or three feet. The insect, its wings doused with water, falls to the surface, whereupon the fish quickly eats it. In captivity *T. jaculatrix* retains its spouting behavior. Once it has become acclimated to the aquarium it will readily shoot at a meal worm held above the surface with a pair of tweezers or at a cockroach running about on the glass cover of the tank. It may even shoot the aquariist in the eye as he peers into the tank, the movement of his eyelids having stimulated the act of spouting.

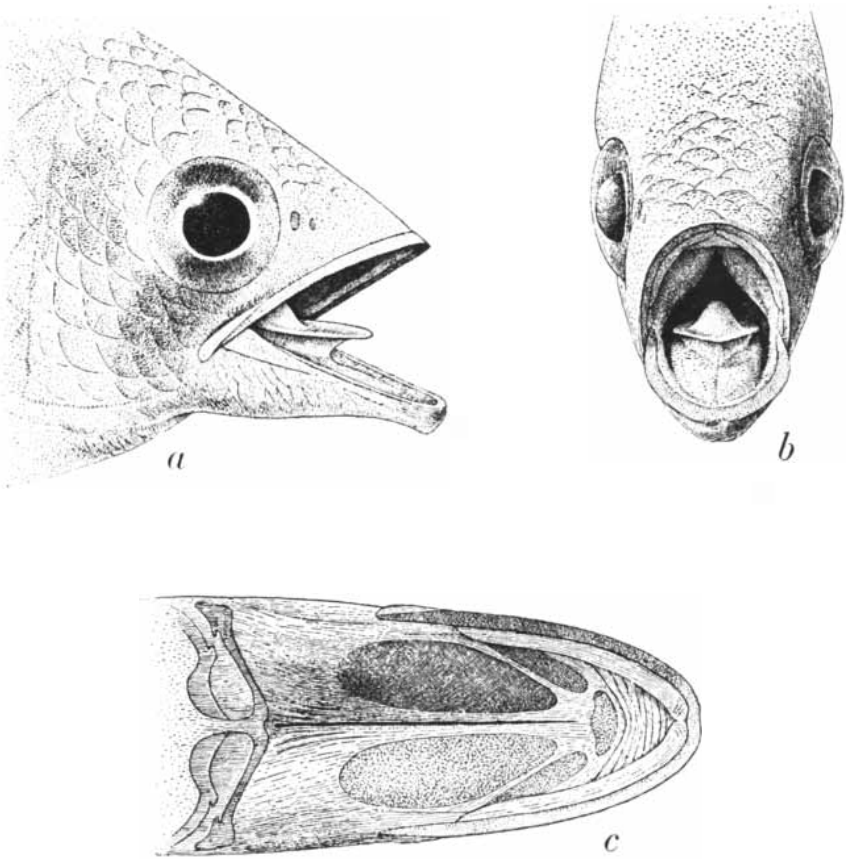
One of the most interesting things about *T. jaculatrix* is that its highly specialized water-shooting is not its primary means of food-gathering; a number of restrictions are placed on this behavior by external factors and by the nature of the fish itself. First of all, the spouting is only possible where the surface is calm and there is vegetation; it is obviously impossible in open coastal waters where the fish spend some of their time. Moreover, the aerial targets must be within a reasonable distance of the surface. Very young fish can manage a jet only two or three inches long; in fact, they shoot down hardly any of their food. Adults are rarely successful beyond three or four feet. Another restriction is that the fish tend to fire with more vigor than is necessary; a powerful squirt may drive a nearby insect out of reach. Perhaps most important, the fish are not squirting machines but living things; they get tired. Even if insects are still available, a fish may weary of squirting and shift to another form of food-gathering if it is still hungry.

For all these reasons *Toxotes* depends largely on food it finds on or below the surface. It prefers insects that have fallen to the surface, but it will also take food that has sunk a few inches into the water. This raises an interesting question for evolutionary theory: Spouting, if it is so unimportant, can hardly have been a significant factor in the survival of the species or in selection and differentiation within the species.

Leaving this question aside, it is true that the archer fish does spout and knock down insects. The main reason for the long refusal of scholars to accept this fact was the lack of any obvious water-propelling mechanism in



ARCHER FISH is a native of coastal waters and rivers from India to northeastern Australia. This photograph shows *Toxotes jaculatrix*, the most common species, scoring a direct hit on an insect on a twig above the water. The fish spouts a stream of water, which breaks up into drops that strike the prey. The photograph was made by Heine Hediger and H. Heusser of the University of Zurich.



ARCHER FISH'S MOUTH, while superficially similar to that of many other fishes, has structures that explain its ability to spout. The bony tongue is thin in front but swells into a ridge toward the rear (*a*). When the mouth closes, the tongue almost fits into a V-shaped depression in the roof of the mouth (*b*) but leaves a small channel through which water is forced by compression of the gill covers. The roof of the mouth is seen from below at *c*.

the archer fish. As the British ichthyologist Francis Day wrote in 1889, "the action is one which the mouths of these fishes appear incapable of effecting." This objection was finally disposed of by the U.S. ichthyologists Hugh M. Smith and George S. Myers. Smith found that the propulsive force came from a sudden compression of the fish's gill covers; in fact, he was able to simulate the natural shooting act by holding a fish in his hand at the water surface and forcefully squeezing the gill covers. Myers then searched for some structural peculiarity of the mouth parts that would explain the formation of a jet of water. He discovered a narrow groove running along the roof of the mouth. When the fish closes its mouth, its tough tongue is pressed up against this groove, creating a tube like the bore of a gun. Pressure from the gill covers forces water through the tube and out of the slightly open mouth; the stream may be regulated in part by the thin tip of the tongue [*see illustration above*].

The work of Smith and Myers left unexplained one important question: How does a fish, with its eyes below the surface, discern small targets above the water and sight them accurately enough to score hits? A fish's-eye view of objects above the surface is notoriously poor. Moreover, the refraction of light rays as they enter the water makes an object above the surface appear to be where it is not. These difficulties prompted some people to insist that the archer fish must raise its eyes above the water surface at the moment of spouting. When this turned out not to be true, one ichthyologist suggested that the fish must have "a truly remarkable trigonometric range finder in its brain."

Neither this visual problem nor other details of the unique behavior of the fish could be satisfactorily investigated by casual observation in aquariums or in the field. I decided in 1952 to make a careful study of the spouting act with motion picture photography and to supplement this analysis with an anatomical study of the archer fish's eye structure. I obtained seven specimens of *T. jaculatrix* ranging from two to four inches in length. Four of these I dissected for the anatomical investigation. I put the others in a tank, in which I stood a pane of frosted glass that projected 20 inches above the surface. When my fish squirted at cockroaches or ants placed on the glass, the location and shape of each broadside was recorded by a drenched area on the glass. With a soft pencil I traced these areas for later analysis. I used a similar setup for the filming operation, placing the lens of my camera level with the water surface. In this case I offered live targets on a pane of glass and also various dummies either fastened to wires or placed in flat-bottomed glass tubes fixed to the pane. In order to measure the angles at which the fish spouted I wanted to catch a fairly long stream of water on each frame, so I shot the film at 24 frames per second rather than at a very high speed.

My observations confirmed reports from the field that the archer generally keeps to the upper few inches of the water, often swimming with its head in contact with the surface. In the turbid water it often frequents this is a necessity if it is to catch sight of its prey. A fish that is in a squirting mood (which is to say a fish that is hungry and has not spouted for a while) keeps looking upward and, when it sees a target, heads for it in a manner so characteristic that I could take it as a signal to start my camera. The fish gives the impression of stealth and determination as it closes in on the prey slowly and deliberately. The archer has binocular vision and its great eyes can be seen to range horizontally as they focus on the target. If the fish is high in the water, it moves toward its prey directly beneath the surface; if the fish is deeper, the approach path is diagonally upward [*see illustration on opposite page*].

In either case the fish swims until it is almost directly below its prey. The reason is immediately apparent, and it is important: The refraction of a ray of light decreases as the angle of incidence increases; light striking the water surface at right angles is not bent at all. When the archer fish is directly below its prey or nearly so, there is no refraction, or extremely little, of the light rays reflected from the quarry and reaching the archer's eyes. The eyes, in any case, are so close to the surface of the water that refraction can hardly be much of a problem.

Once it has arrived below the target, the archer fish makes a peculiar move-

ment that occurs so quickly it can hardly be perceived except in a series of photographs. The fish shifts from a diagonal position, with the top of its head touching the surface, to a more vertical position. This characteristic movement was repeated in every spouting performance I recorded. Once it has reached its near-vertical firing position, the fish may move slightly forward or even backward, apparently adjusting its aim and making its final distance calculations. There is a noticeable increase in tension, visible as an extension of the pelvic and dorsal fins, and then the fish lets go its jet of water.

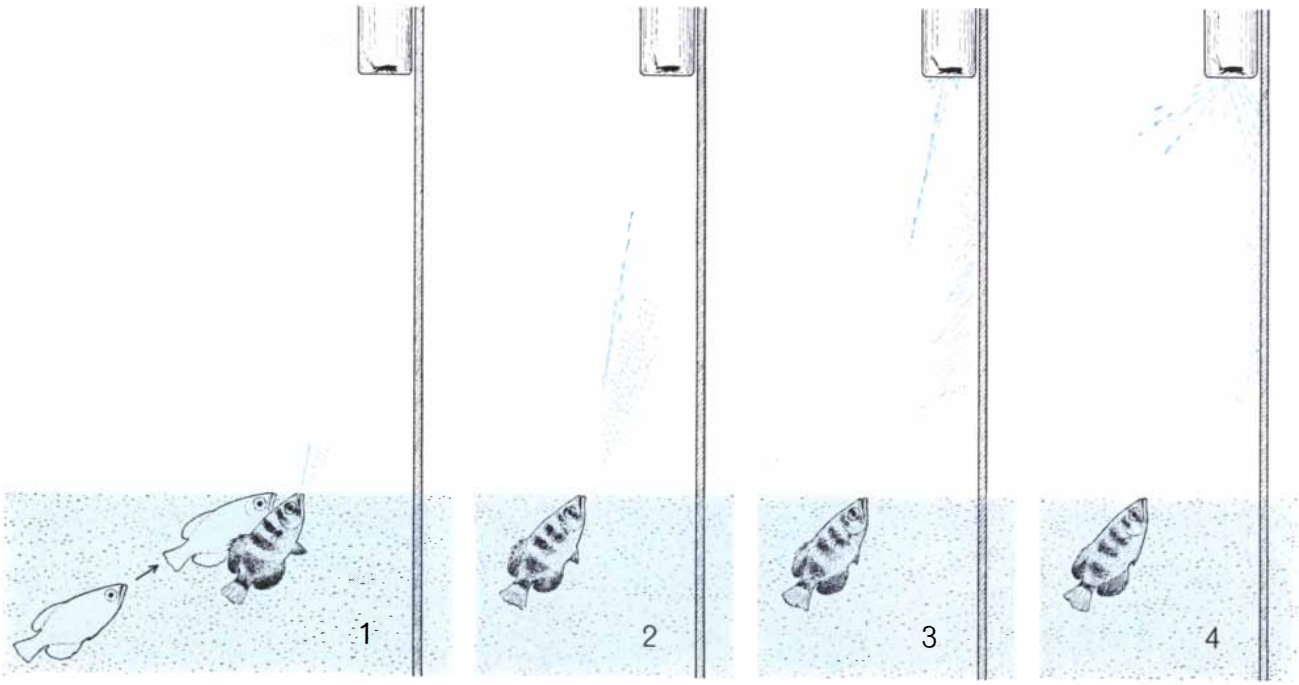
There would seem to be two reasons for the pivoting movement of a fish that is about to fire. One is that the shape of the archer fish's snout sets limits to the angle between the axis of its body and the line of fire. As will be seen, however, this angle is subject to quite some variation. A more important reason, I think, is that the near-vertical position minimizes parallax—the angle between the eyes-to-target line of sight and the mouth-to-target line of fire—and thereby eliminates what could be a serious obstacle to accurate aim [*see illustration on page 106*]. Parallax would still exist for short-range shooting, but as a matter of fact prey very near the surface are almost always seized by jumping rather than shooting. Accurate jumping is made possible by the archer's binocular vision, and particularly by its ability to direct its eyes forward to see prey close to its snout.

One of the details I sought to pin down was the precise angle between the longitudinal axis of the fish's body and the line of fire. I found that the archer fish is able to score hits when this angle is anywhere from 140 to 170 degrees [*see illustration on page 106*]. In other words, the fish can adjust its direction of spouting within these limits. Actually this is rather surprising. One would have thought that the anatomy of the animal would prescribe a constant angle, in which case the archer fish, like a fighter plane with a fixed machine gun, could aim only by pointing its entire body in the proper direction.

One of the most difficult things to determine was the exact nature of the spouted stream of water. Earlier observers had spoken of single drops of water or a succession of drops. Even my film did not yield clear evidence whether there is in fact a single jet of water or a spray. It often appeared to me that there was a spray made up of a large number of individual drops discharged in rapid succession. It remained for some later investigators to clear up this question. Two years ago Heine Hediger and H. Heusser of the University of Zurich made a careful study of the archer's spouting behavior with the aid of very high-speed motion picture photography. They found that the fish actually ejects a single jet of water that travels between two and four inches and then breaks up into a fine spray and a few large drops. It is these drops, which quickly pass the spray, that strike the insect prey.

I noticed that the area of frosted glass wetted by the stream of water was substantial and was usually larger in the vertical dimension than the horizontal. This is partly because of the fringe of spray that falls somewhat short of the target and partly, as Hediger and Heusser observed, because the fish is not absolutely still in the water as it shoots. It begins to spout while it is still "rocking" toward a vertical position, so that the beginning of the jet leaves its mouth at a smaller angle to the water than the end does.

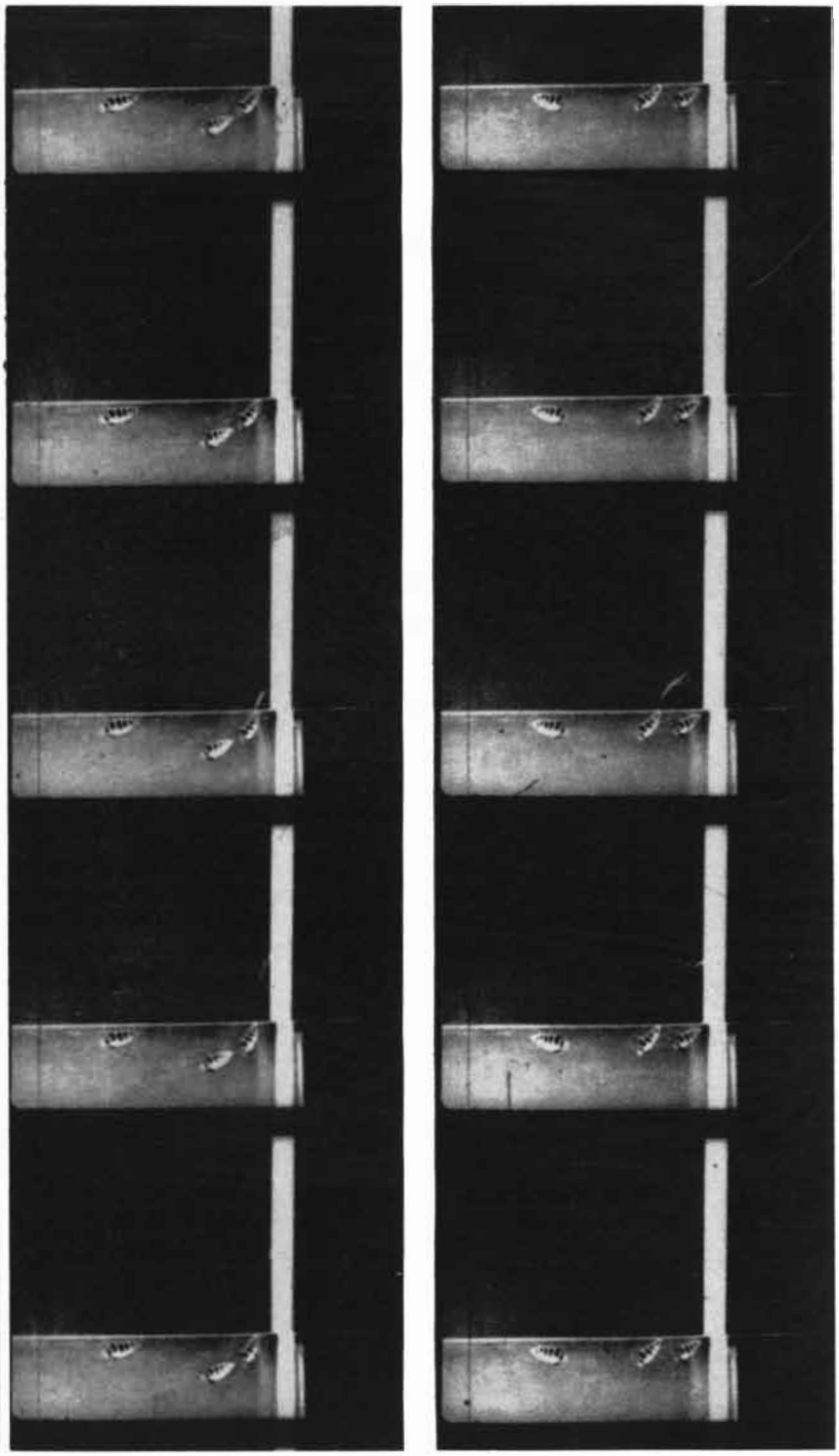
A final reason for the large size of the area wetted by a stream is the force with which it is ejected, which is always the same regardless of the target's distance. This constancy in the expenditure of energy is a conspicuous example of rigidity in instinctual behavior. The amount of energy in a jet becomes apparent if the stream misses its target: Myers noted that some drops spouted by a three-inch archer at an insect three feet away missed and traveled more



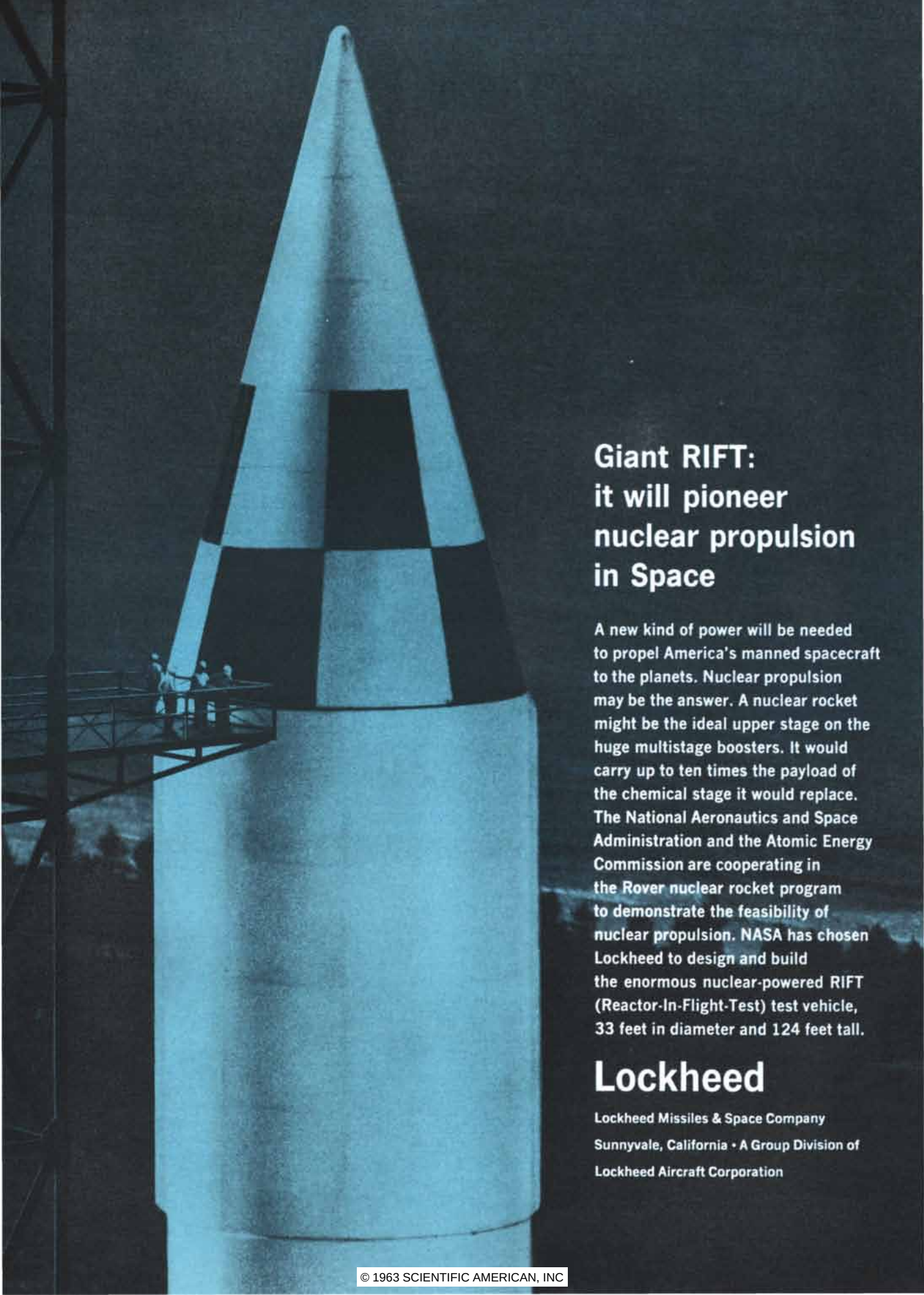
ACT OF SPOUTING is diagramed in these drawings based on a film made by the author. A characteristic approach is shown by the two fish drawn in outline (*left*). Once in position the fish pivots to a more vertical attitude, tenses its fins and ejects a stream of water (*1*). The stream breaks up (*2*) and strikes the target (*3*) as the fish relaxes its fins (*4*) and waits for the prey to fall.

than 15 feet! I observed that the jets carried at least 20 or 22 inches on a straight trajectory. An archer fish that fails to hit its prey with its first volley will immediately try again, once or several times, if it is not too tired.

Sheer force, however, is not always enough to knock the archer fish's prey from its perch. If the insect is on a vertical surface (my pane of glass or, in natural conditions, a twig or a branch), a jet of water striking its back would often "fasten" it more firmly instead of dislodging it. In this case, I was fas-



MOTION PICTURE SEQUENCES show two spouting acts. In each case an archer fish is seen (*top to bottom*) shifting to the near-vertical shooting position and then squirting at a target. The strip at right shows a fish spouting weakly because it has insufficient energy. These are frames from two segments of the author's film, shot at 24 frames per second.



Giant RIFT: it will pioneer nuclear propulsion in Space

A new kind of power will be needed to propel America's manned spacecraft to the planets. Nuclear propulsion may be the answer. A nuclear rocket might be the ideal upper stage on the huge multistage boosters. It would carry up to ten times the payload of the chemical stage it would replace. The National Aeronautics and Space Administration and the Atomic Energy Commission are cooperating in the Rover nuclear rocket program to demonstrate the feasibility of nuclear propulsion. NASA has chosen Lockheed to design and build the enormous nuclear-powered RIFT (Reactor-In-Flight-Test) test vehicle, 33 feet in diameter and 124 feet tall.

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cinated to observe, the fish apparently aims not directly at its prey but at a point just below it. The water ricochets from the vertical surface and catches the insect in the abdomen, lifting it neatly from its perch.

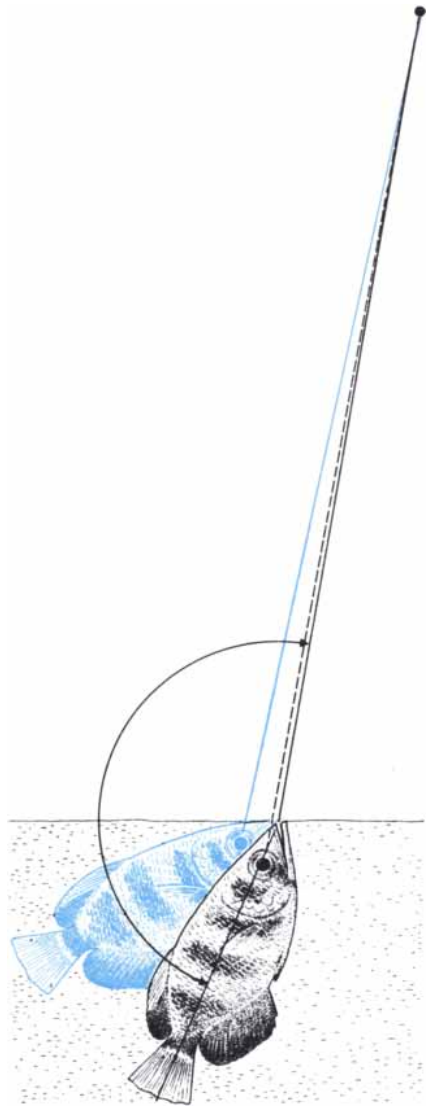
The archer fish's aim is not matched by selectivity in choice of target. When it is ready to spout, the fish will let fly at almost anything; in my experiments the fish spouted eagerly at drops of water on the frosted glass, paper cutouts in the shape of insects, a large paper rectangle and a real wasp that was much too big for the fish to swallow. When the target—any target—falls to the water, the fish seizes it. Only then does the fish decide whether or not the fallen object is edible. When I dropped a pin on the surface immediately after a fish had spouted, the fish rushed to seize it and then, of course, released it at once. This impetuous retrieving behavior immediately after shooting is probably dictated by the fact that other archer fish nearby will snatch the marksman's prey if they can.

A fish that has a lot of what I call "reaction-specific energy" stored up will spout even when it sees food that does not call for spouting at all. For example, I have placed a mealworm on the surface of the water near a hungry fish; the fish darts forward, stops short a fraction of an inch from the worm and squirts water into the air. A droller version of this behavior may rarely take place at the bottom of a tank. A fish rushes toward some food lying on the sandy bottom and then suddenly stops. As it does so the food zooms off a few inches along the bottom, struck by an underwater jet from the fish. One is reminded of the circus clown who keeps stooping to pick up a ball but can never quite get it because he kicks it along the ground just as he reaches down.

Successful spouting seems to occur only when a fish is hungry and has enough energy available. The drive to spout is strongest in fish that are hungry and have not spouted for some time. If an archer fish is hungry but in a state of reduced energy because it has been spouting a lot, its efforts to hit a new target are unsuccessful. The stream of water simply falls short [*see bottom illustration on page 108*]. The fish may continue to squirt desultorily for a while; eventually it ceases even to try.

A little should be said about the relation between the archer fish's spouting behavior and its eyes and eyesight. The importance of binocular vision is indicated by the ineptitude of an archer fish that has only one good eye as a result of an injury or a parasitic infestation. It is unable to judge either distance or direction correctly. One of my specimens, which was blind in the left eye, regularly aimed its jet too far to the right and was also unsuccessful in jumping at a target.

The archer fish's eyes are not only large and capable of binocular vision but also structurally more highly developed than the eyes of most other fishes. The



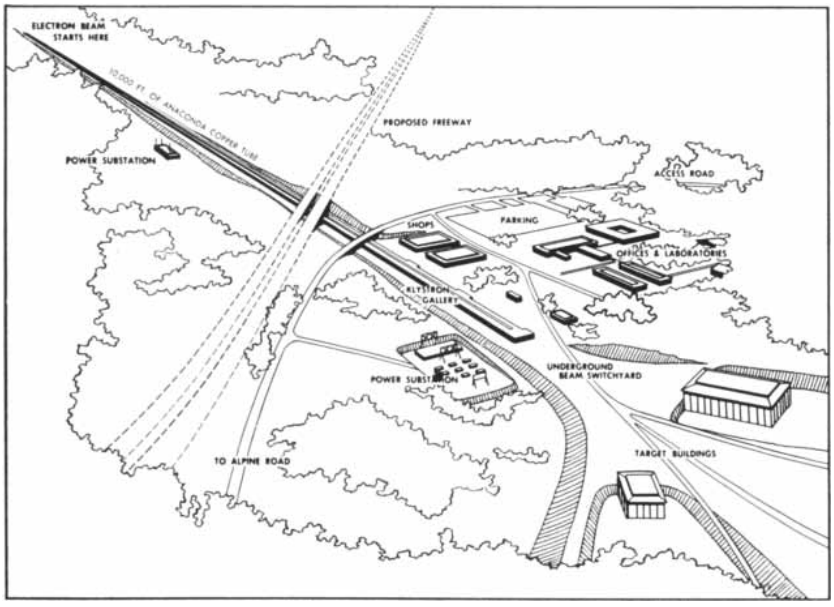
PIVOTING MOVEMENT before spouting begins brings the fish from a nearly horizontal (*color*) to a nearly vertical (*black*) position. This has the effect of reducing the parallax between the direction of sighting (*colored and broken black lines*) and the mouth-to-target direction of spouting (*solid black line*). The angle (*arrow*) between the spouting direction and the long axis of the body is between 140 and 170 degrees.

ANACONDA COMMENTS

new facts about copper—man's oldest metal

NUMBER 10 OF A SERIES

ANACONDA CHOSEN TO SUPPLY TWO MILES OF COPPER TUBE FOR WORLD'S LARGEST ELECTRON ACCELERATOR



Sketch of proposed Stanford two-mile accelerator site shows scope of project. The strip of land is almost three miles long, occupying 480 acres in all. The accelerator tube passageway will be covered over with 25 feet of earth.

Anaconda American Brass Company has just signed a contract to produce copper tube and copper component items for Stanford's two-mile accelerator, the largest research instrument ever to be built. The electron accelerator, being built under contract with the Atomic Energy Commission, will be one of the most important tools available for particle physics research.

Upon its completion, sometime late in 1966, the Stanford accelerator will produce a beam of electrons with an energy of 20 billion electron volts. These electrons will be accelerated to a speed close to 186,000 miles per second by energy from a series of 240 klystrons spaced at intervals along the 10,000-foot-long, four-inch-diameter copper tube—which will be housed 25 feet underground. Each of the klystrons will produce up to 24 million watts in 2.5 millionths-of-a-second bursts.

Anaconda will be fabricating about 936,000 pounds of copper tube and component items—all made of a special high-purity OFHC* (Oxygen-Free High Conductivity) Copper which requires the strictest manufacturing procedures imaginable.

The breakdown is 250,000 pounds for production of the main (4.1″ OD by 3.1″ ID) tube, 360,000 pounds for the rectangular waveguides to feed high-frequency radio waves from the klystrons to the main tube, 168,000 pounds for the thousands of discs spaced along the interior of the main tube, 122,000 pounds for rectangular cooling tube, and 36,000 pounds for round cooling tube. It is expected that Anaconda will also supply OFHC rod, sheet, strip and plate to the klystron producers. Approximately 75 per cent of these copper products needed for the project will be delivered within the next year.

Equipped to meet strict material specifications

Some of the most critical requirements in the Stanford accelerator's specifications involve the material to be used. OFHC Copper is not a new product, but requirements for the quantity to be supplied are different and more rigid than ever before. For example, oxygen content has to be held to a maximum of ten parts per million.

The advanced quality control equipment which will be used for this job had been purchased for metallurgical research in Anaconda's new Research and Technical Center. In its early down-to-earth application, it will help to assure maintenance of high quality levels.

Other material requirements called for a complete mill research program involving production equipment and personnel. These demands were tackled by Anaconda metallurgical engineers, well-practiced in the science of translating customer requirements into mill procedures.

In short, the new Research Center has significantly increased Anaconda's problem-solving capabilities. A fact you might remember—in case a pertinent metallurgical problem should appear on your own horizon.

One other memorable fact: modern copper metals (including brasses and bronzes) offer a broader range of properties than ever before. So when your newest application calls for a material with high performance in many areas . . . Think Copper. And think of Anaconda. As the world's largest supplier of copper metals in all mill forms, we probably can provide the modern metal you need. Anaconda American Brass Company, Waterbury 20, Connecticut. (In Canada: Anaconda American Brass Ltd., New Toronto, Ont.)

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*Trade mark of American Metals Climax, Inc.

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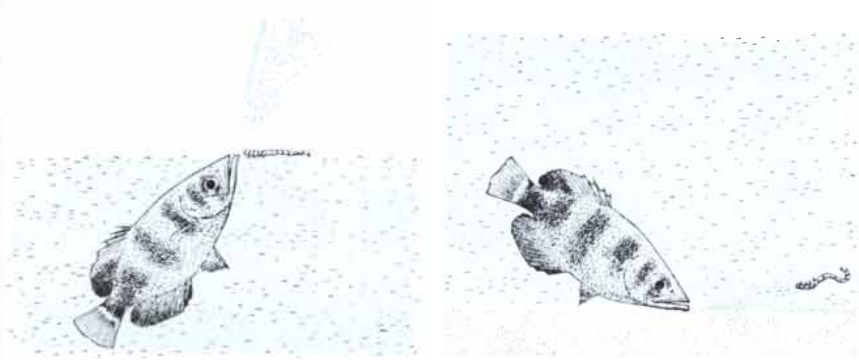
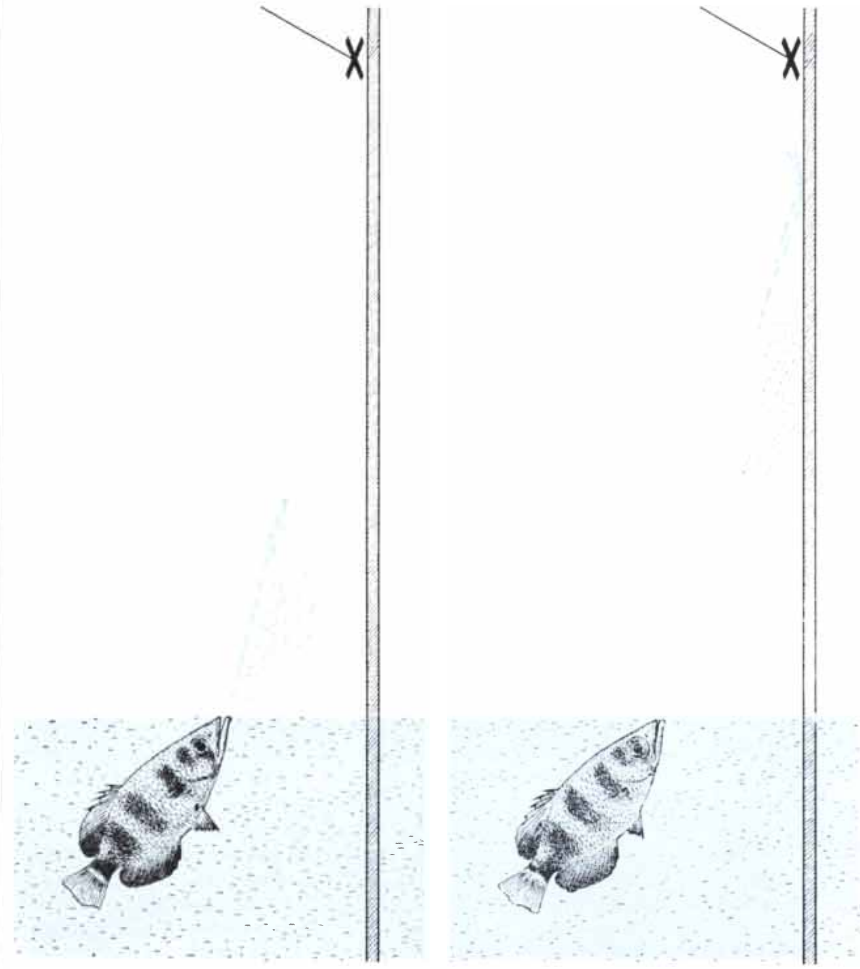
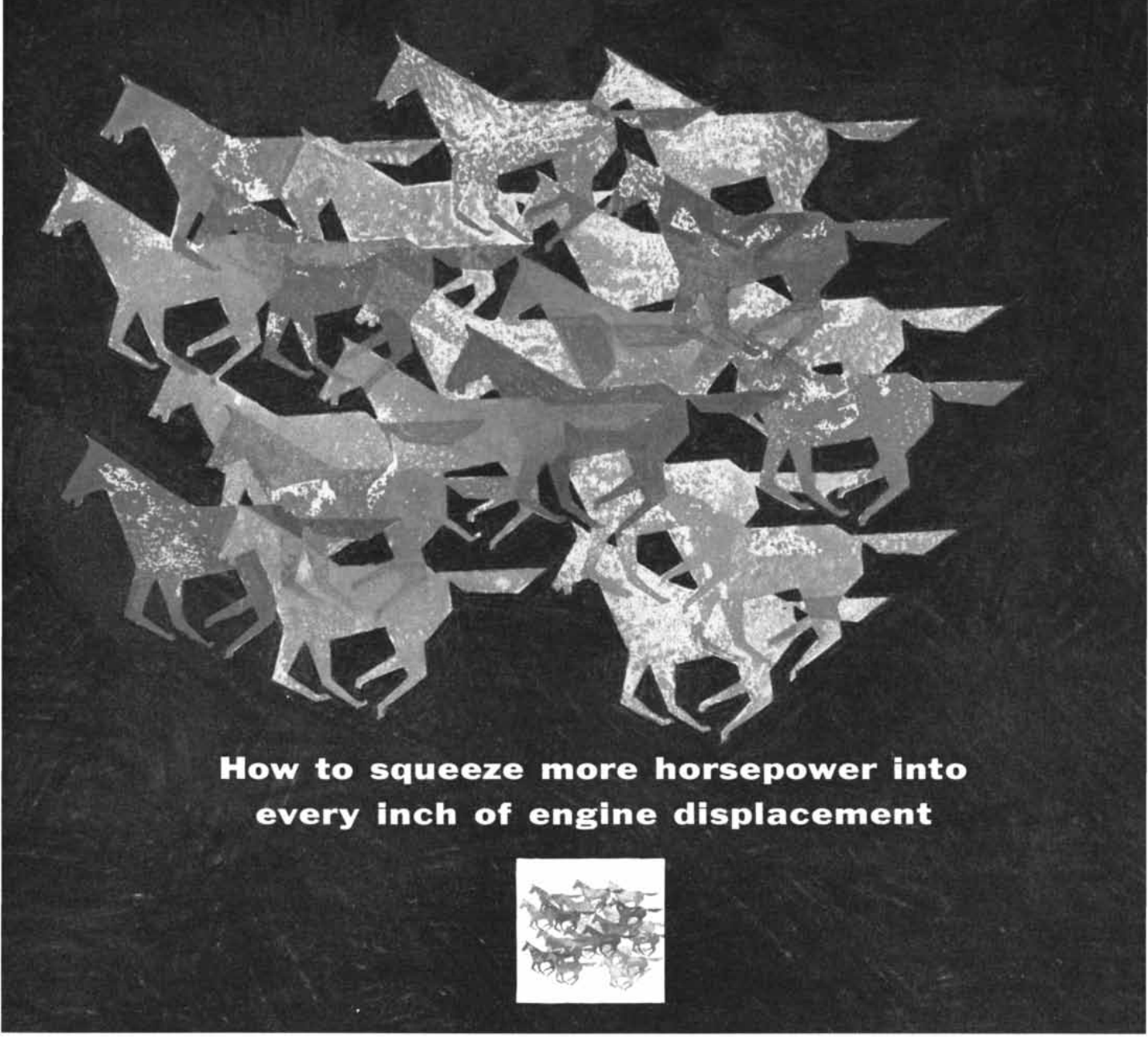


ACCUMULATED ENERGY can make a fish spout without an appropriate target. The reaction can be triggered by the sight of food on the surface (*left*) or on the bottom (*right*).

retina is particularly advanced. It has a very large number of cones and rods: I have counted eight or nine cones (for daylight vision) and 217 rods (for vision in semidarkness or in turbid water) ranged along a line .08 millimeter long. (The eel, by comparison, has in the same distance seven much smaller cones and 143 rods.) This retinal structure gives the archer fish excellent vision in dim light as well as bright. Hugh Smith, who squeezed the gill covers of archer fish to demonstrate how they could fire a jet of water, asserted that they could extinguish cigarettes in total darkness. There is good reason, in fact, to believe that an archer fish can shoot down a luminescent insect at night.



ENERGY IS REDUCED after the fish has spouted repeatedly. If it is still hungry and sees a target (in this drawing a paper cross on a wire), it spouts weakly and falls short.



...another example of Caterpillar capabilities at work

When Caterpillar Research Engineers talk about this project, they call it VHO.

Officially, it's a research project to design a family of four Very High Output engines for the U. S. Army Tank Automotive Command. The family goal: delivery of more working horsepower per inch of displacement than any compression-ignition engine now available. Horsepower-to-weight ratios will be in the gas turbine range.

Current design indicates a realistic initial target of 80 HP from each cylinder at 2800 RPM. This is without revolutionizing engine structure or creating highly sophisticated aspiration methods.

Even in the design stage, family likeness is certain. Of the 194 major parts needed for the entire family, only 30 parts have single usage and 164 are used in at least two models.

Because of this high interchangeability, vehicle designers won't be hampered by a single engine configuration. They will be able to arrange external accessories on these 4.5 x 5.5 bore and stroke engines to suit the vehicle . . . without adding parts to the logistics system.

The VHO research program demonstrates another of Caterpillar's capabilities in the area of military vehicles and engines to power them.

If anyone knows how to squeeze a thundering herd of horsepower into a military compression-ignition engine—or create a highly specialized piece of ground support equipment—Caterpillar does. To find out just how far Caterpillar's abilities range, contact Defense Products Department, Peoria, Illinois.

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The Fermi Surface of Metals

It is not a real surface but a picture of how the electrons in a metal behave. These pictures explain such properties of metals as luster, ductility and the conduction of electricity and heat

by A. R. Mackintosh

Everyone knows what a metal is and can describe many of its characteristics. It is safe to say, however, that few people would define a metal as "a solid with a Fermi surface." This may nevertheless be the most meaningful definition of a metal that one can give today; it represents a profound advance in the understanding of why metals behave as they do. The concept of the Fermi surface, developed by quantum physics, provides a precise explanation of the main physical properties of metals: their conduction of electricity and heat, their hardness and ductility, their lustrous appearance and so on.

What, then, is a Fermi surface? To answer this question we must first make it clear that the Fermi surface is not a surface at all in the physical sense; it has no existence in the real world but is an imaginary concept used to express a mathematical picture. It has to do with the motions and energies of the electrons in a metal. The theory speaks of "velocity space," "wave-number space" and similar abstractions, but all these shorthand expressions provide accurate descriptions of the actual conditions within the metal. A physicist with a trained eye can look at the model of a particular metal's Fermi surface and deduce from it a detailed account of how the metal will behave. More than that, he can predict how a change in its structure (produced, for instance, by alloying it with another metal) will change its properties.

A model of the Fermi surface of a metal is a rather strange affair that, as the British solid-state physicist John M. Ziman has remarked, "might be mistaken for a piece of modern sculpture." The models are based on difficult and precise physical measurements of the behavior of the metal under different experimental conditions. In the last decade such models have been constructed for a number of metals, and with this work has come a great deal of progress in our understanding of their properties.

The story begins with an idea proposed in 1900 by the German physicist Paul Karl Drude. Inspired by J. J. Thomson's discovery of the electron just five years earlier, Drude pictured a metal as being a box containing a "gas" of freely circulating electrons. At first this may seem a highly unrealistic way of thinking about a metal. That electrons could be free to wander about in the crystal lattice of a metal, in spite of the electrostatic repulsion of other electrons and the attraction of the positive ions of the lattice, would appear to be a contradiction of everything that is known about electric forces and the structure of a metal. Nevertheless, the Drude "free electron" model, particularly as developed by the Dutch physicist Hendrik A. Lorentz, proved to be very successful in explaining many properties of metals. It accounted for the conduction of electricity through a metal by means of the movement of electrons. Furthermore, it showed that electrons were also involved in the conduction of heat, and it scored its greatest triumph by explaining the earlier discovery that a metal's conductivity of heat and electricity were related in a certain ratio (the Wiedemann-Franz constant).

The Drude-Lorentz free-electron model turned out to be quite inaccurate, however, in some of its predictions, particularly the prediction regarding the specific heat of the electron gas, that is, the amount of energy required to raise the temperature of the gas by a given amount. Experiment showed that it took much less energy to raise the temperature than the theory had predicted.

To understand this failure of the theory and to see how it was eventually explained, we must first consider the classical picture of a gas. In a classical gas the molecules move about at various speeds; most of them have a velocity around the average, but some are substantially slower and some faster, so that the distribution of velocities of the individual molecules is represented by a statistical curve known as the Maxwell-Boltzmann distribution [*see top illustration on page 112*]. When the gas is heated, the applied heat is absorbed by the entire group of molecules, and the curve of velocities as a whole moves to the right, as the illustration shows. Because the energy input is shared among all the molecules, it takes a considerable quantity of heat to raise the temperature of the gas by a small amount. In other words, the gas has a comparatively large specific heat, or heat capacity. The same situation was implied in the Drude pic-

COPPER VALENCE 1

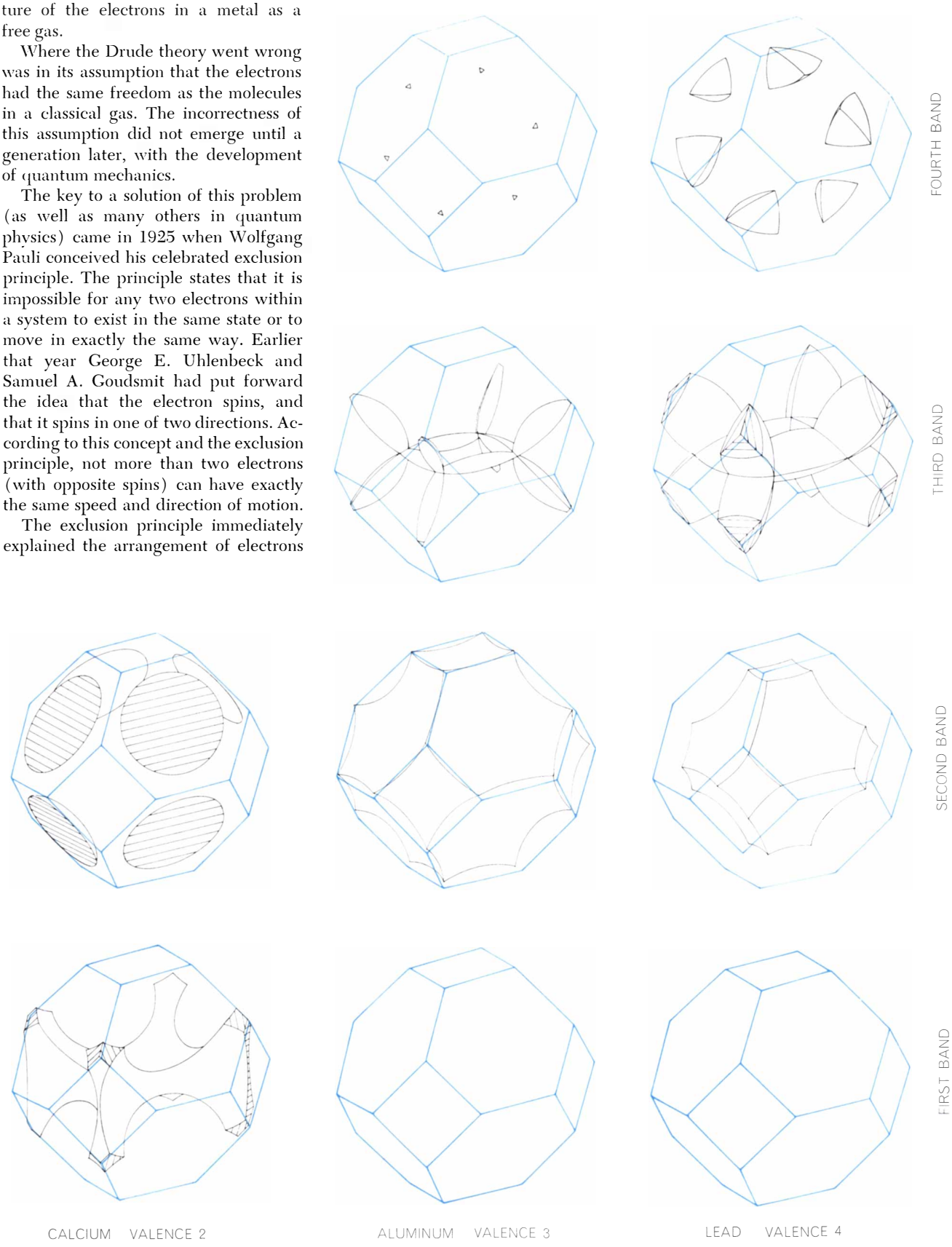
FERMI SURFACES illustrated here are those of four metals with the same crystal structure (face-centered cubic) and thus the same kind of Brillouin zone (*colored polyhedrons*). The Fermi surface of copper

ture of the electrons in a metal as a free gas.

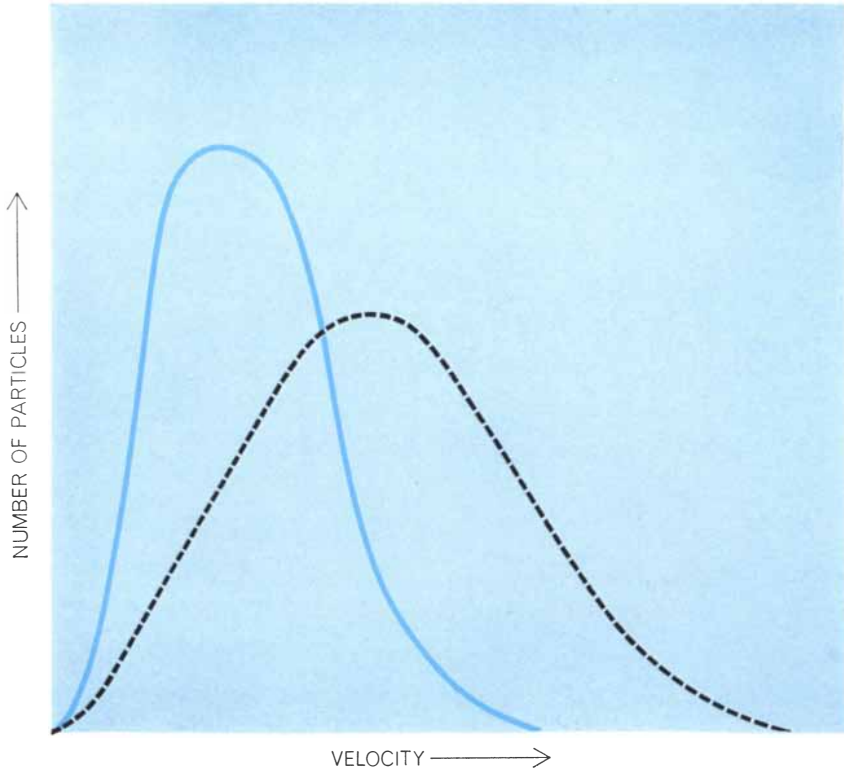
Where the Drude theory went wrong was in its assumption that the electrons had the same freedom as the molecules in a classical gas. The incorrectness of this assumption did not emerge until a generation later, with the development of quantum mechanics.

The key to a solution of this problem (as well as many others in quantum physics) came in 1925 when Wolfgang Pauli conceived his celebrated exclusion principle. The principle states that it is impossible for any two electrons within a system to exist in the same state or to move in exactly the same way. Earlier that year George E. Uhlenbeck and Samuel A. Goudsmit had put forward the idea that the electron spins, and that it spins in one of two directions. According to this concept and the exclusion principle, not more than two electrons (with opposite spins) can have exactly the same speed and direction of motion.

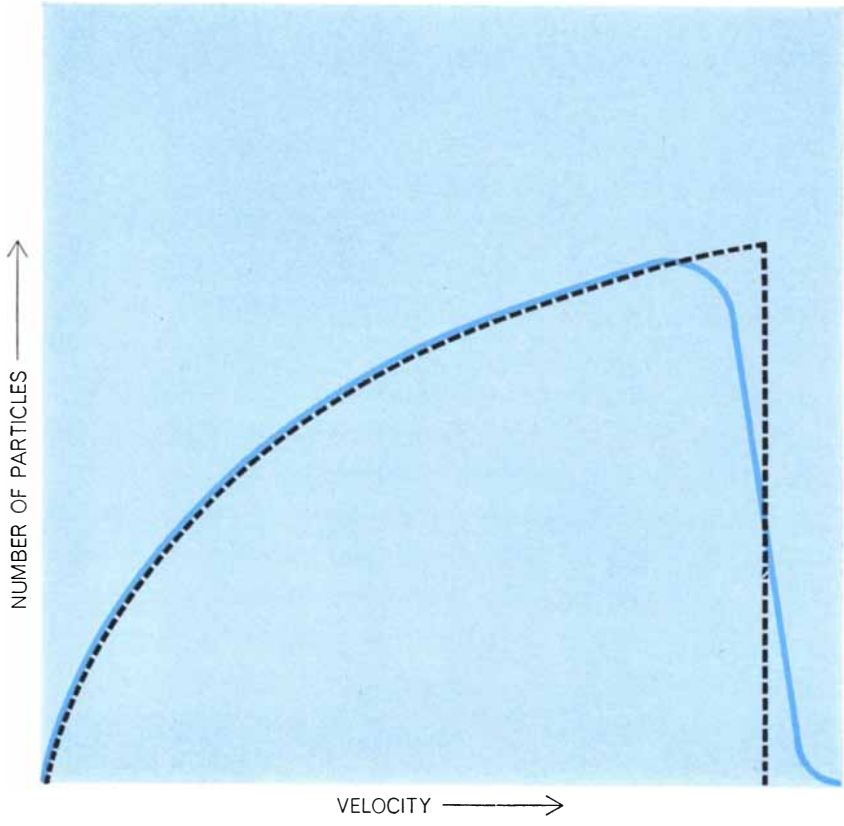
The exclusion principle immediately explained the arrangement of electrons



(first determined by A. B. Pippard of the University of Cambridge) is a sphere with "necks," or bulges, and falls within the first Brillouin zone ("Band 1"). In calcium parts of the surface extend into contiguous zones; thus any calcium Brillouin zone is also a "second" zone ("Band 2") containing pieces of other Fermi surfaces. Reassembled, the pieces from both bands approximate a sphere. In aluminum and lead, which have higher valences (more "free" electrons), the surface falls entirely outside the first zone, into higher zones. Except in the case of copper, the surfaces depicted are only close approximations of the true Fermi surfaces.



MAXWELL-BOLTZMANN DISTRIBUTION of molecular velocities in a classical gas varies with temperature. The velocity distribution is narrower and the average velocity lower at room temperature (*colored curve*) than at some higher temperature (*broken curve*).



FERMI-DIRAC DISTRIBUTION of velocities in an electron gas at absolute zero (*broken curve*) differs little from that at room temperature (*colored curve*). The first ends abruptly at the "Fermi velocity." At ordinary temperatures few electrons have a higher velocity.

in an atom: they are arranged in a series of different shells and subshells because each orbit is limited to a maximum of two electrons. In 1926 Enrico Fermi and P. A. M. Dirac independently applied the same reasoning to an electron gas. No more than two electrons in the gas can possess the same velocity and direction. As each velocity state, starting with the lowest, is filled, other electrons must go into the next higher state, and so the electrons occupy a series of states of higher and higher velocity.

In diagraming the velocities we can think of the electrons as occupying a three-dimensional velocity space, with the radii of successive spheres representing higher velocities [*see top illustration on opposite page*]. As the spheres become larger there is room for more states between neighboring spheres. That is to say, going up the velocity scale we find more and more electrons in the gas at a given velocity. This distribution of the electron velocities is very different from the Maxwell-Boltzmann curve [*bottom illustration at left*].

Fermi calculated that at a certain velocity the curve would end suddenly, as the illustration shows: there would be few or no electrons in the gas with velocities greater than this. At a temperature of absolute zero this "Fermi velocity" is the limit of the "occupied" velocities, and even at ordinary temperatures there are relatively few electrons at higher speeds. This is just a consequence of the fact that at absolute zero any system tends to stabilize itself at the lowest possible energy level; the electrons fill up all the permitted velocity states and do not go higher than they are forced to by the exclusion principle. (It is interesting that at absolute zero the exclusion principle compels many of the electrons to go to high velocities!)

This, then, is the Fermi surface: the sphere that represents the boundary between "occupied" and "unoccupied" velocities for the electrons in a gas. The velocities of all or nearly all the electrons in the electron gas are represented by points in the velocity space bounded by the Fermi surface. To change the metaphor, we can think of the velocity space as a "sea" of states with a spherical surface.

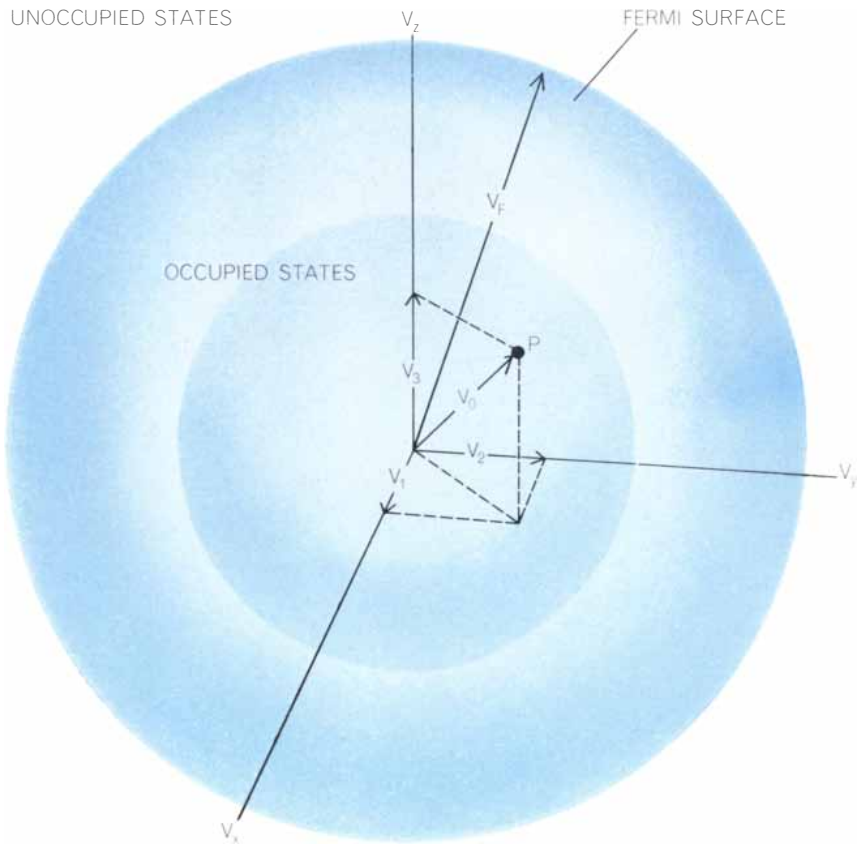
It was the German physicist Arnold Sommerfeld who applied these ideas to the electron gas in a metal and corrected the Drude model so that it successfully explained most of the electronic properties of metals. The exclusion principle solved the mystery of the comparatively small specific heat of the electron gas.

When heat is applied, the electrons in low velocity states cannot increase their velocity because the states above them are filled; consequently only the electrons with speeds near the Fermi surface can be accelerated; these rise to unoccupied velocity states above the Fermi level. That is to say, in contrast to the situation in a classical gas, where an input of energy is absorbed by all the molecules, in an electron gas the applied heat affects only the relatively small number of particles near the Fermi surface; that is why it takes much less heat to raise the temperature of the gas.

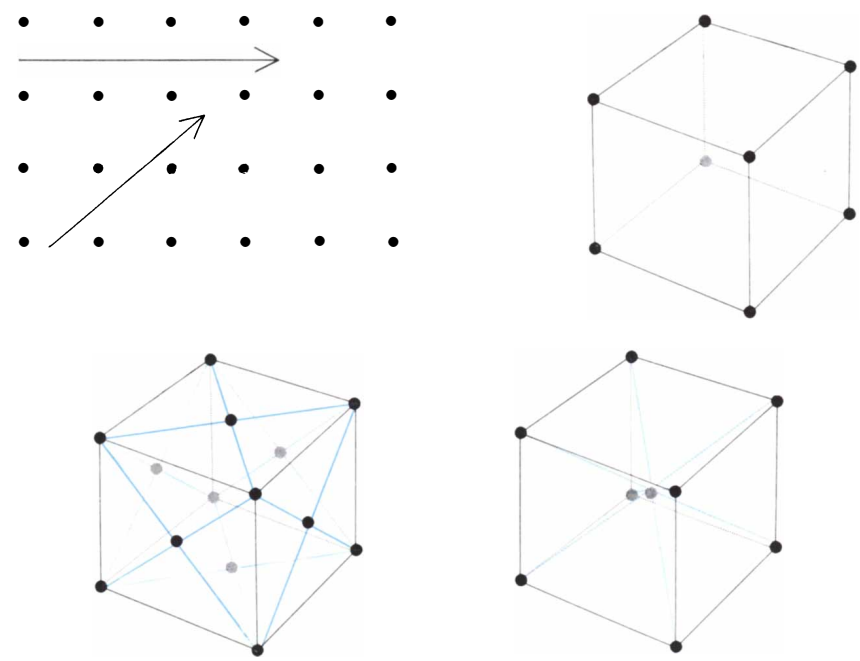
The exclusion principle explained another inaccuracy of the old Drude model. The model had implied that an applied magnetic field should line up the spins of the free electrons in a metal and thus give rise to an induced magnetization ("paramagnetism"). But experiments had failed to show the predicted amount of magnetization. The new quantum picture made the reason clear: the electrons in filled states cannot change their spin (i.e., line up in the same direction) because this would violate the exclusion principle.

To recapitulate, the Sommerfeld model, developed in the late 1920's, offered this picture of a metal. The valence electrons of the atoms (each metallic element has at least one such "loose" outer-shell electron) are free to move through the metal and constitute a kind of gas. Quantum restrictions, however, dictate the allowed velocities of the electrons' motion in the metal. Only two electrons (with opposite spins) can have the same speed and direction. The number of velocity states per unit of volume in the metal can be calculated, and from this one can calculate the distribution of the electron velocities. The distribution has an upper boundary known as the Fermi surface. At absolute zero temperature all the states up to this level are filled and all above it are empty. When the temperature is raised, some electrons move up to higher velocities, and the number of occupied states above the Fermi level is equal to the number of vacated states below it.

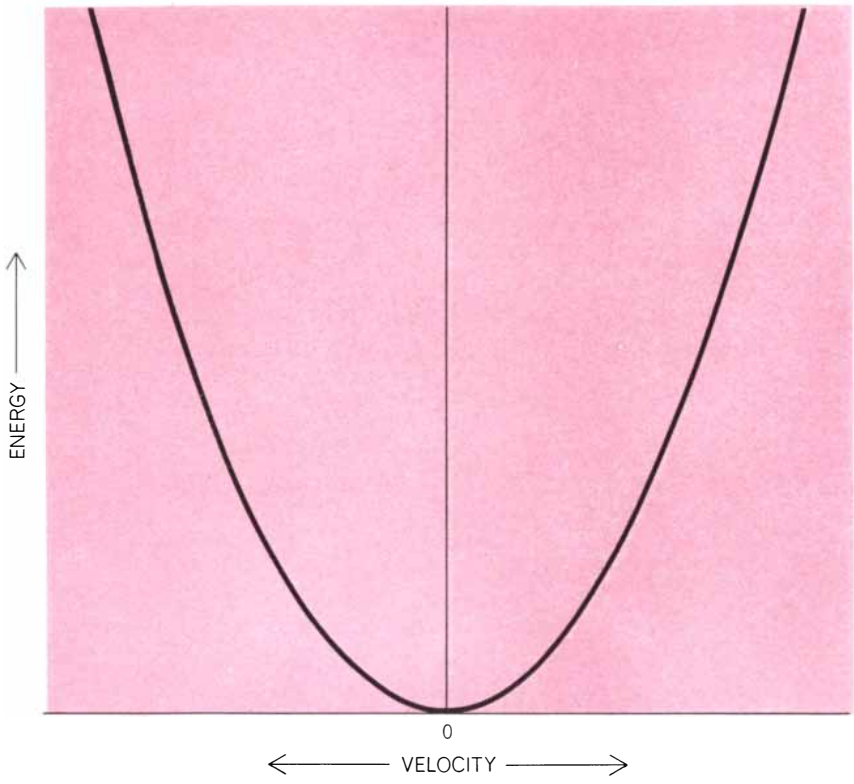
Sommerfeld's theoretical calculations agreed very well with most of the measured properties of metals. But the model failed to explain a number of puzzles, in particular what distinguished a metallic conductor from a semiconductor or an insulator. This incompleteness of the theory is understandable, because it ignored two considerations, namely, the ways in which the movement of the electrons must be affected by (1) the



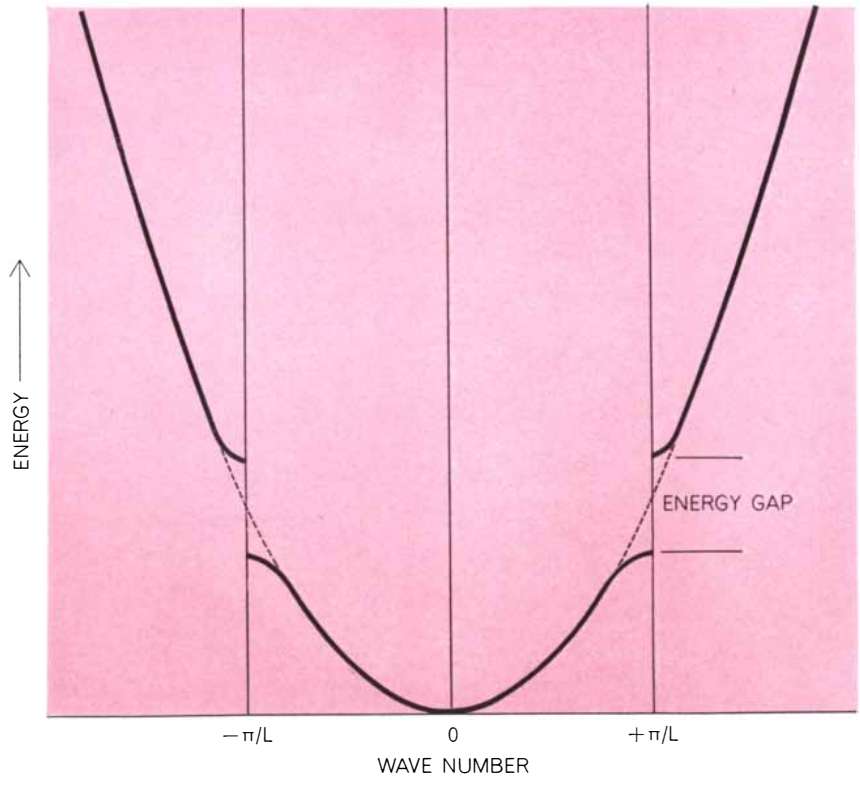
"VELOCITY SPACE" is a three-dimensional co-ordinate system for representing the motion of particles (e.g., electrons) by single points. Point P represents an electron with a total velocity V_0; all electrons with the same speed can be represented by points on a sphere of radius V_0. Electrons with different speeds would be plotted on spheres with different radii. The Fermi surface is the boundary between "occupied" and "unoccupied" velocities in an electron gas; the highest occupied velocity is the Fermi velocity, designated as V_F.



EFFECT OF LATTICE STRUCTURE on electron motion in a metal (and thus on the shape of its Fermi surface) is considerable. In a simple cubic lattice an electron (*horizontal arrow at top left*) moving along a row of positive ions (*dots*) interacts more often with the ions than one moving diagonally does. The effects are more complicated in face-centered cubes (*bottom left*) and body-centered cubes (*bottom right*) than in a simple cube (*top right*).



PLOT OF ENERGY AGAINST VELOCITY for an electron moving at different speeds in a particular direction in a metal is a parabola. "Energy" is kinetic energy of the electron.



PLOT OF ENERGY AGAINST WAVE NUMBER for an electron moving in a particular direction approximates a parabola with "energy gaps." The wave number is the number of waves in a given distance, and it is directly proportional to the electron momentum; L represents the distance between two positive ions in the lattice through which the electron travels.

positively charged ions that make up the lattice structure of a metal and (2) the mutual repulsion of the negatively charged electrons themselves.

The second factor turned out to be comparatively unimportant. At first thought the strong repulsive forces between the electrons might be expected to modify the velocity distribution greatly, so that there should be no sharp Fermi surface. But all the experiments showed that such a surface did indeed exist, and in the 1950's theoretical physicists (notably David Bohm and David Pines) suggested a plausible explanation. Because of the repulsive force between electrons, the free electrons in a metal do not come very close to one another; in effect, each electron is surrounded by a space, or "hole," that other electrons are unlikely to enter. The hole is partly occupied by the positive charge of the lattice, which represents a screen between pairs of electrons. This reduces the electrostatic force between electrons to a small value, and as a result there are few effective collisions among the moving electrons as they travel through the metal.

The effects of the lattice on the electrons, however, are very important. In 1928 Felix Bloch, then at the Federal Institute of Technology in Zurich, took up the investigation of this problem. Consider an electron moving through a crystal lattice in which the atoms are arranged in a simple cube [*see bottom illustration on preceding page*]. When the electron travels in the direction of the rows toward a face of the cube, it "sees" ions at shorter intervals than when it moves diagonally toward a corner. In other words, it has a higher frequency of interaction with the ions. Each such interaction affects the electron's kinetic energy. Therefore its energy will depend on the direction of its travel; it will differ according to whether the electron moves parallel to or diagonally across the rows of ions. The result of this effect on the energies of the moving electrons is to distort the Fermi surface in particular directions: the Fermi surface is no longer a smooth sphere, as in a free gas, but has bulging contours [*see illustration on pages 110 and 111*].

Apart from the electrostatic interference of the ions, the lattice affects the electrons' energies in another important way. The electron has the properties of a wave as well as of a particle, and in the narrow spacing of a crystal lattice its wave aspects become detectable. When an electron's wavelength corresponds to a multiple of the distance between atoms

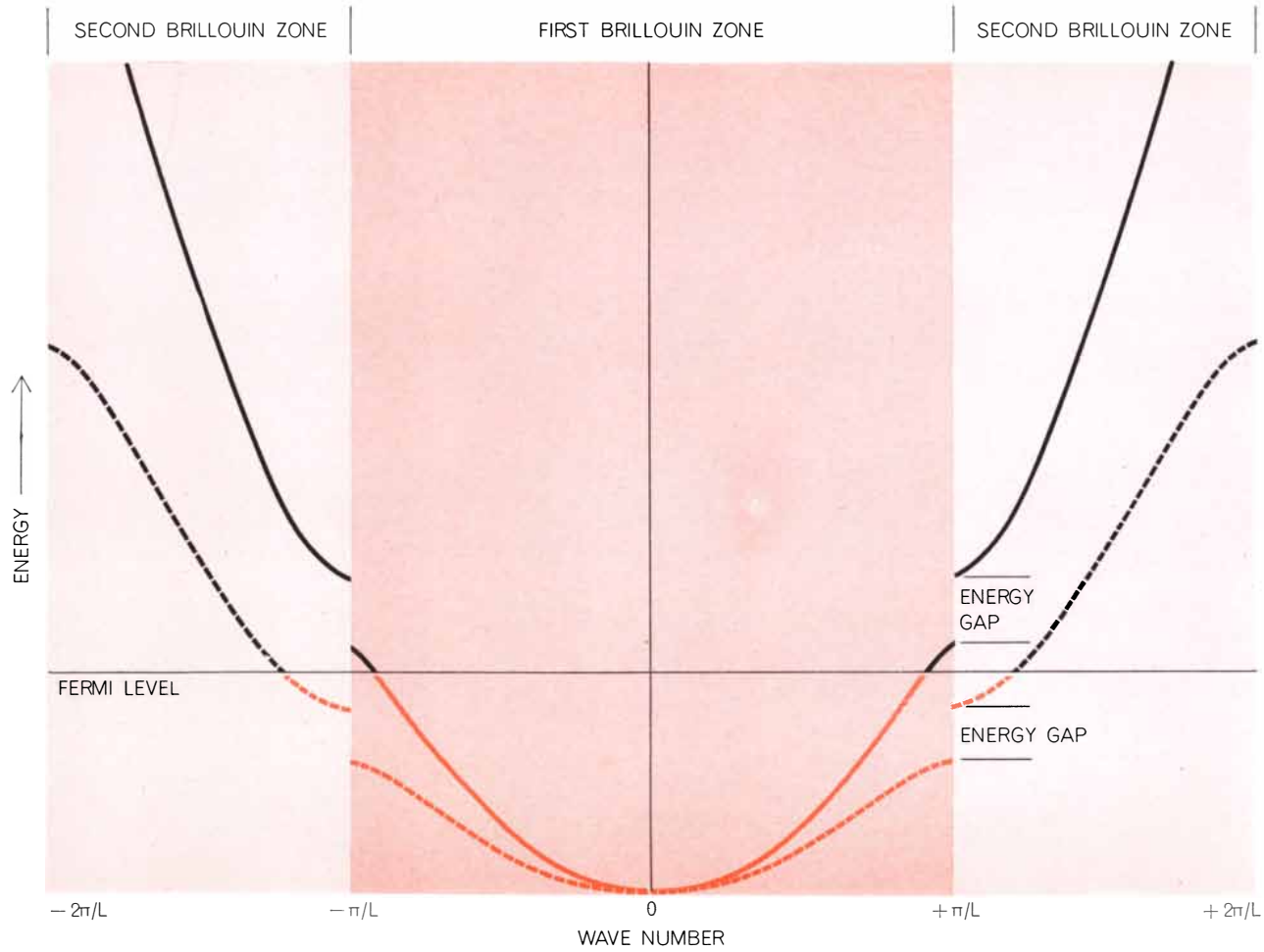
in the lattice (if, for example, the wave is just twice the length of this spacing), the electron will be reflected, or scattered, as X rays are reflected by a crystal in the well-known Bragg effect. The reflected electron waves can form two different standing-wave patterns that, because they interact differently with the lattice, have different energies. The range of energy between the energies of the two standing waves is forbidden to the electrons; that is, there are gaps between regions of allowed energy for the electrons in the crystalline solid.

Bloch arrived at a formula for calculating the lattice effects by the use of Erwin Schrödinger's equation of wave mechanics. An electron's wavelength depends on its momentum. (Momentum equals mass times velocity.) For convenience in calculation, physicists use not the wavelength but the "wave number," the number of waves fitting into a certain distance, which is taken as 2π centimeters in the direction of the wave's motion; the wave number can be expressed as $2\pi/\lambda$. The wave number of a free electron is directly proportional to its velocity. Bloch showed that the motion of an electron could be specified completely by the relation between its wave number and its energy; the plot of energy against wave number is similar to the graph of energy against velocity [*see illustrations on opposite page*]. Therefore we may speak of the Fermi surface in wave-number space instead of in velocity space.

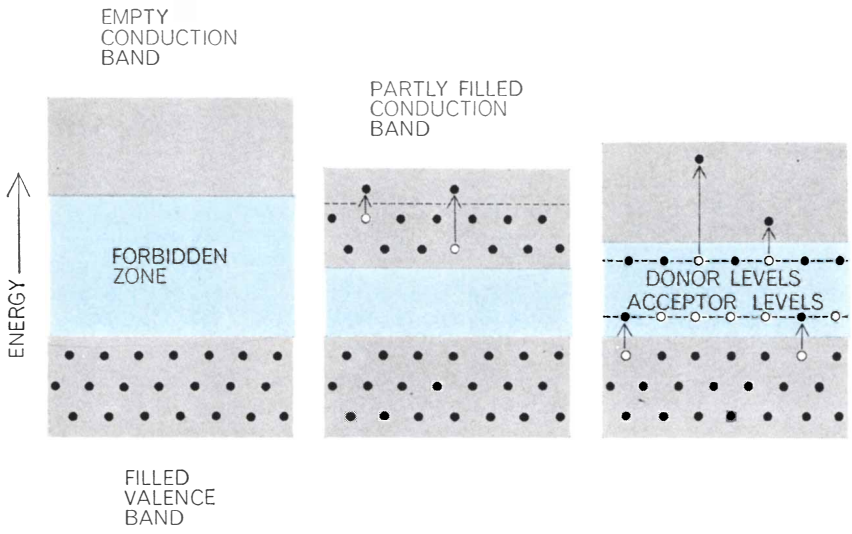
For many of the properties of metals the Bloch model is merely a refinement of the Sommerfeld picture. The distortion of the Fermi surface caused by the lattice alters the density of allowed states near it, and this has some effect on the specific heat and the magnetic properties of the metal: the more electrons there are near the Fermi surface, the larger is the number that can increase their energy when the metal is heated, and also the number whose spins can be lined up by a magnetic field, inducing paramagnetism in the metal.

But the particularly important feature of the new Bloch picture was its disclosure of the existence of the energy gaps. These have a profound effect on the form of the Fermi surface, and they are an important ingredient in much of the modern theory of solids, particularly with respect to the property of electrical conductivity.

A plot of energy against wave number for electrons in a lattice shows the location of these energy gaps. In the early 1930's the French physicist Louis

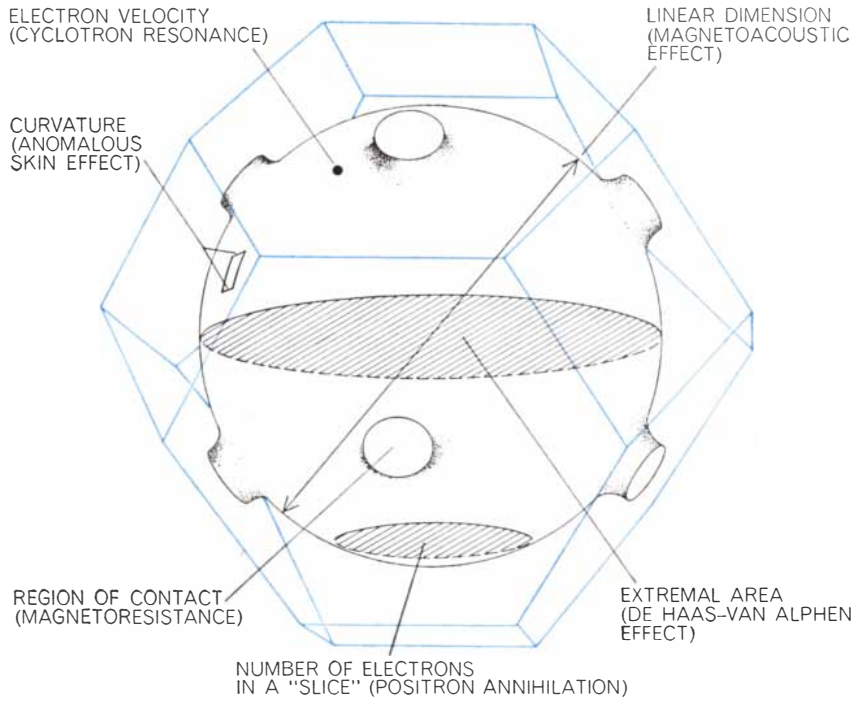


"WAVE-NUMBER SPACE," in which energy is plotted against wave number, is a more convenient co-ordinate system for representing the motion of an electron in a crystal lattice than velocity space is. Here curves of energy against wave number are plotted for electrons moving in two different directions. The "Fermi level" marks the highest energy state occupied by electrons; occupied states (*colored curves*) are below it and empty states above (*black curves*). The wave number at which the curves meet (at the Fermi level) gives the position of the Fermi surface in a particular direction in wave-number space. In this case part of the surface lies in the first and part in the second Brillouin zone. Allowed velocities above Fermi level, if occupied, would extend surface as shown.



BAND THEORY OF SOLIDS describes electronic states in a solid in terms of allowed and forbidden "bands," or groups, of energy levels. Represented here are the band schemes of an insulator (*left*), a metal (*center*) and a mixed semiconductor (*right*). An insulator has the widest forbidden zone. Donor and acceptor levels are energy levels of electrons (*black dots*) of special impurities in the semiconductor; they contribute to electrical conduction by donating electrons to the conduction band or by accepting them from the valence band.

Brillouin studied the location of the energy gaps in wave-number space in great detail, and he described them in terms of what have come to be known as "Brillouin zones." The boundaries of each zone mark the places where energy gaps occur, as the illustration at the bottom of the preceding page shows. We can consider the zone a box, or cell, with energy gaps over all the faces. The location of these gaps varies with the direction of motion of electrons in the lattice; the diagram here illustrates the curves of energy against wave number for electrons moving in two different directions in a metal. All the energy states up to the Fermi level are filled, and all the others are empty. Thus there is one piece of Fermi surface in the first zone and one in the second. In some metals the energy–wave-number curves are so complex that there are sections of Fermi surface in five or six different zones, and this produces some very complex shapes.



SIX TECHNIQUES described in the text provide different data concerning the shape of the Fermi surface of a metal. The "Extremal area" is the largest cross-sectional area determined from measurements of the De Haas–Van Alphen effect. The "Linear dimension" is the diameter of the surface. "Electron velocity" is the velocity of an electron at the Fermi surface. The surface touches the surounding Brillouin zone in the "Region of contact."

Now, the principal significance of the energy gap is that it helps us to explain why some solids conduct electricity and others do not. We note, to begin with, that to transmit a current through a solid, electrons must be accelerated in a particular direction, which means that they must be raised to a higher energy state. If all the states up to an energy gap are filled and the levels above the gap are empty, no electrons can be accelerated to a permitted level by an ordinary electric field, because it does not provide enough energy to make the electrons jump the gap. Therefore no current can flow. This is the situation that characterizes a nonconductor, or insulator. Its filled electronic states are topped by a wide energy gap, and there are no electrons above the gap that can be raised to an unfilled state.

A semiconductor owes its ability to conduct electricity to one of two conditions: either the energy gap is narrow, so that at ordinary temperatures a small number of the electrons cross the gap by thermal motion and can then be accelerated by the electric field, or there are impurities in the lattice that create empty levels into which electrons can be boosted by the field.

Metals, on the other hand, are good conductors because they always contain electrons in unfilled levels above the energy gaps. In other words, they have a free Fermi surface from which electrons can be raised to allowed and unoccupied velocity states. In any conductor the current is carried by comparatively few electrons—those free electrons that the electric field can accelerate into unfilled energy states. The general picture, including the existence of the Fermi surface, is summed up in the "band theory" of solids, which describes the electronic states in a solid in terms of the allowed and forbidden energy bands [*see top illustration on this page*].

One of the properties that most clearly distinguishes a metal from other solids is the fact that its electrical conductivity decreases as the metal is heated. This is owing to the thermal vibrations of the crystal lattice. The vibrations tend to scatter the accelerated electrons and

thereby reduce their speed. By increasing the lattice vibrations, a rise in the temperature of the metal shortens the electrons' mean free path, or the "relaxation time," between collisions with the vibrating lattice. On the other hand, a reduction of the temperature of the metal lengthens the interval between collisions and thus increases the metal's conductivity.

The electrical conductivity of any metal can be calculated from a knowledge of the shape of its Fermi surface and the relaxation time for all the electrons on that surface. The same knowledge also enables one to predict how a metal will conduct heat and sound under various conditions. In addition, the form of the Fermi surface is important in explaining the crystal structure of metals, their absorption and reflection of light, their superconductivity at low temperatures and many of their other physical properties.

It must be abundantly clear by now to readers of this article that the theory of the Fermi surface and the construction of the surface in particular cases are somewhat complicated. Nevertheless, in spite of the difficulties, the theory has been extensively explored by a number of workers, and the Fermi surfaces of several metals have been worked out in detail by a variety of subtle techniques. These include bombardment of the metals with microwaves and positive electrons (positrons) and studies of the effects of large magnetic fields on the properties of the metals under various conditions.

Let us first consider the techniques and what they disclose. Because most of the measurements for determining the geometric form of the Fermi surface require a very long relaxation time for the electrons, the experiments usually have to be done with a very pure crystal of the metal at low temperature (using liquid helium to cool it).

Each technique has a specific name:

Anomalous skin effect. The surface of the metal is irradiated with a beam of microwaves. Measurements of the absorption of these waves on various crystal faces indicate the curvature of the Fermi surface in different directions, and from this information it is possible by laborious calculation to reconstruct the shape of a simple Fermi surface.

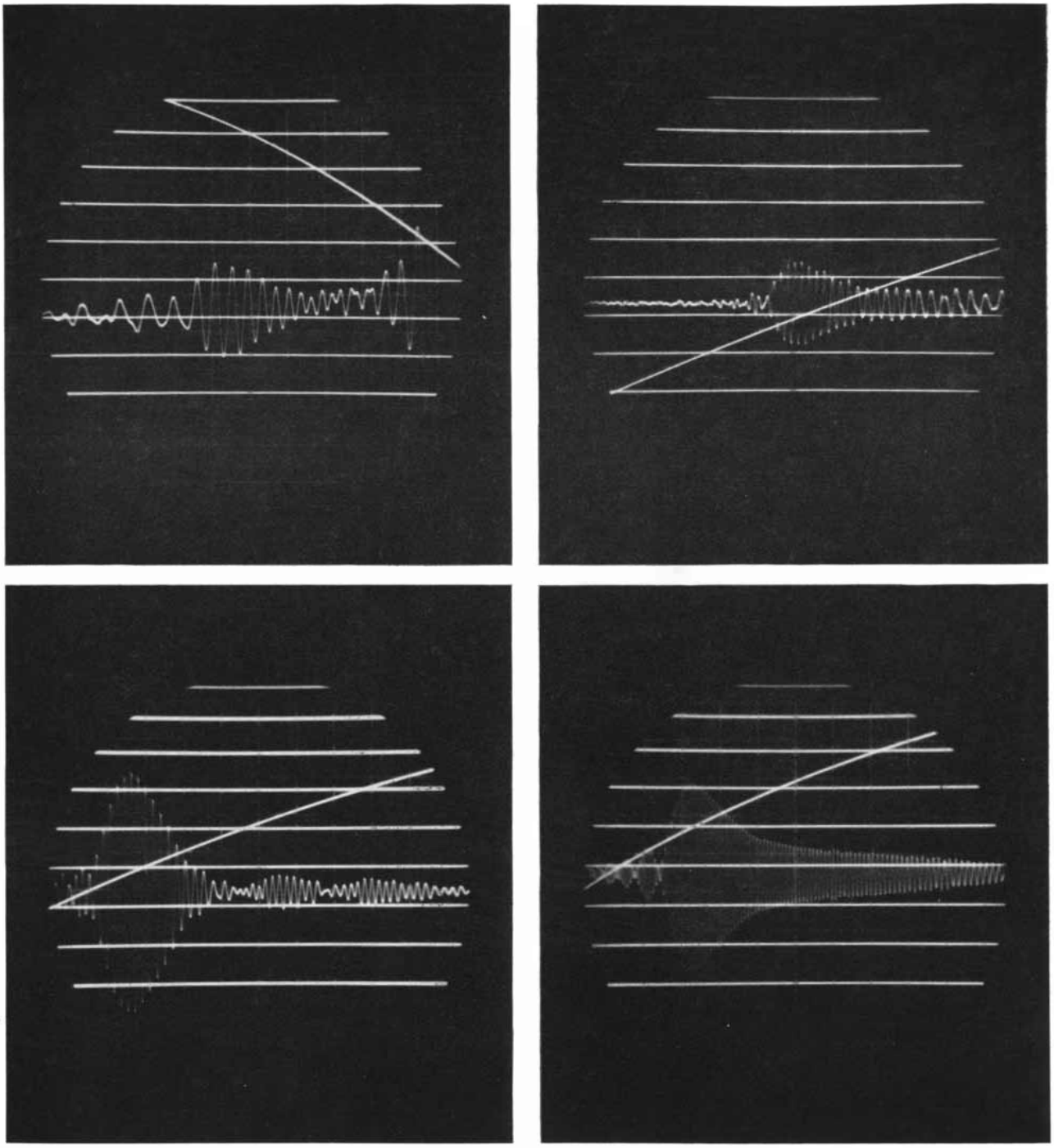
Magnetoacoustic effect. The absorption of sound waves by the metal is measured while magnetic fields of various strengths are applied to it. From the effects of the fields in changing the amount of sound absorption one can calculate

the breadth (or diameter) of the Fermi surface.

De Haas–Van Alphen effect. A strong magnetic field is applied to the metal at low temperature, and the amount of magnetism induced in it by the field is measured. From this it is possible to deduce the area of a cross section through the Fermi surface at right angles to the direction of the magnetic field.

Magnetoresistance. A magnetic field is applied to the metal while it is conducting a current. From the effect of the magnetic field in increasing the metal's resistance to the current one can determine whether or not its Fermi surface touches the boundary of the Brillouin zone, and also the location of such contacts.

Cyclotron resonance. In an applied magnetic field the metal's absorption of microwaves is measured. The field at which the metal shows a resonance absorption reveals the velocity of the elec-



DE HAAS–VAN ALPHEN EFFECT in iron was recorded in these four oscilloscope traces during experiments to determine the shape of the Fermi surface of this metal. The effect appears in the numerous vertical oscillations, which represent magnetic oscillations in the metal. The sloping traces record the applied magnetic field that induced the oscillations. Horizontal lines are calibration traces of the field strength, which changes rapidly with time (*left to right*); the change in field strength from one line to the next is about 20,000 gauss. Experiments were done by Andrew V. Gold and Peter Panousis at Iowa State University of Science and Technology.

trons at the Fermi surface. From this one can calculate the density of electron states near the surface, which in turn determines the electronic specific heat of the metal.

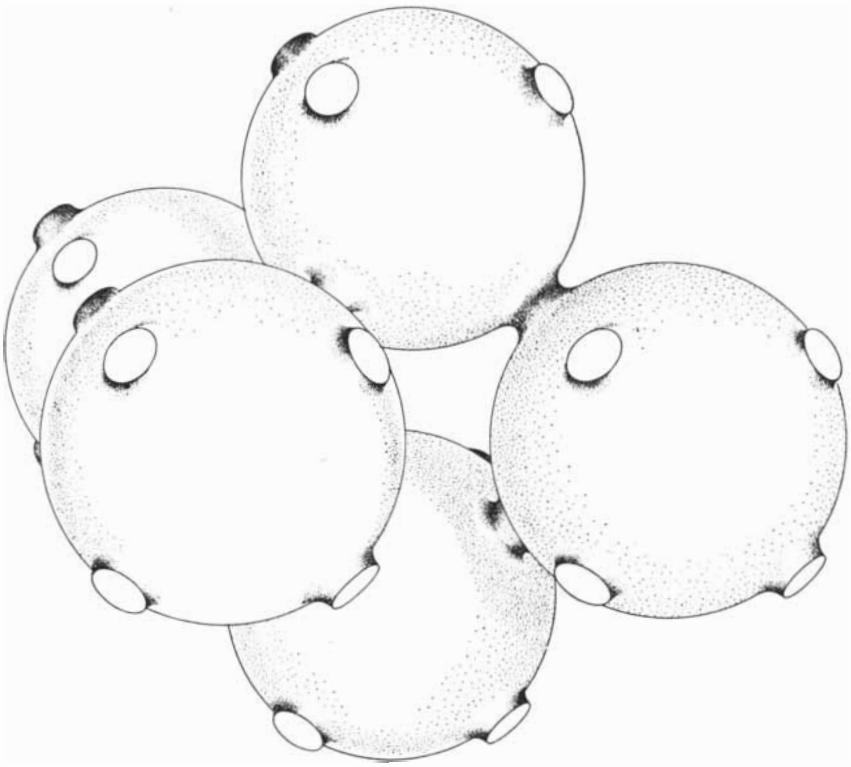
Positron annihilation. The metal is bombarded with positrons. When a positron meets an electron in the metal, they annihilate each other and are transformed into two quanta of electromagnetic energy—photons—that fly out of the metal at a certain angle to each other. This angle indicates the momentum that the annihilated electron had. By studying the angles between pairs of photons produced during the positron bombardment, it is possible to estimate the momentum distribution of all the electrons in the metal. This in turn gives a rough indication of the number of electrons in any cross section ("slice") through the Fermi surface. The technique has the great advantage that it can be used to study metals, including alloys, at ordinary or high temperatures, because it gives measurable results regardless of the relaxation time of the electrons.

The way in which a combination of these six techniques can determine the form of a Fermi surface is shown in the bottom illustration on page 116.

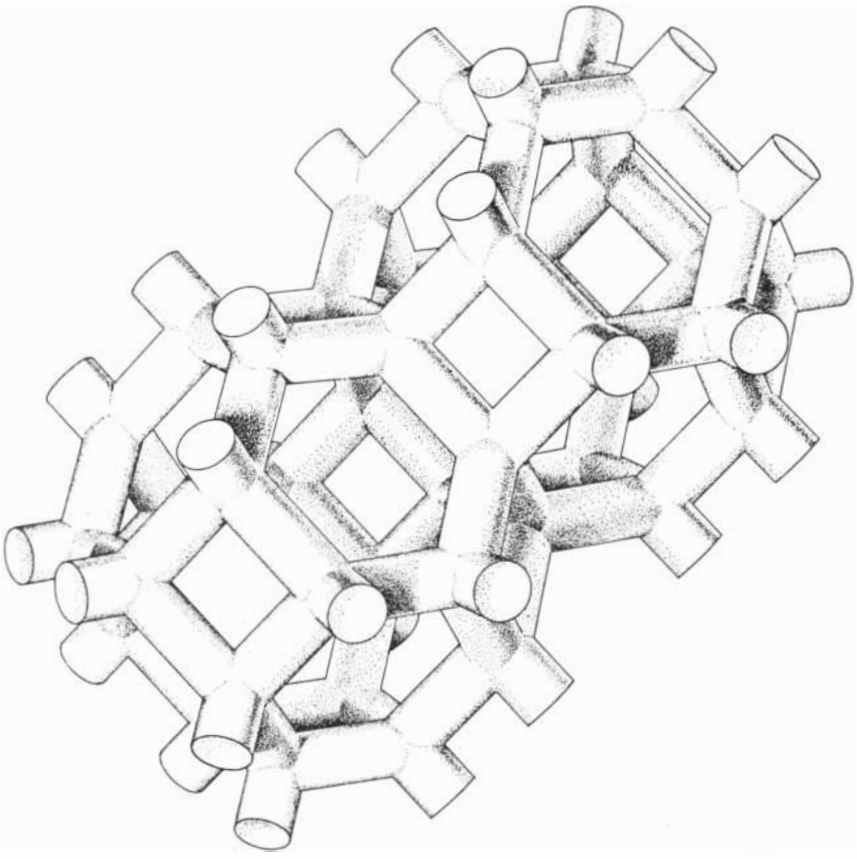
The first investigator to construct a detailed picture of a metal's Fermi surface was A. B. Pippard of the University of Cambridge. In 1957 he determined the shape of the Fermi surface of copper. Using the technique of the anomalous skin effect, he found the curvature and shape of copper's Fermi surface by exploring it with microwaves. This surface is basically a sphere, with "necks" pulled out at the places where it touches the boundary of the first Brillouin zone, which in three dimensions is a truncated octahedron.

Pippard's achievement was an event of great importance in solid-state physics. It was the precursor of an enormous amount of investigation of metals that has had fruitful results. Moreover, his picture of copper has been confirmed as being essentially correct, although it has been modified slightly in some details.

Copper is a monovalent metal (i.e., it has one outer, detachable electron) and it forms a face-centered cubic crystal: a cube with an atom in the center of each face [*see bottom illustration on page 113*]. The metals that have been most successfully explored are those that, like copper, are monovalent—notably silver and gold. David Shoenberg of the University of Cambridge, using



EXTENDED-ZONE SCHEME OF COPPER, based on a model by David Shoenberg of the University of Cambridge, represents the arrangement of Fermi surfaces in repeated copies of the first Brillouin zone. Any two Fermi surfaces are connected at a region of contact.



EXTENDED-ZONE SCHEME OF LEAD depicted here is based on a model originally suggested by Gold. The regions of contact between surfaces are different from those of copper.

the technique of the De Haas–Van Alphen effect, has found that silver and gold have Fermi surfaces very similar to that of copper, the only difference being the extent of the surface's contact with the Brillouin zone boundary. Details of the Fermi surfaces of these three metals have also been established, through other techniques, by Robert W. Morse and his collaborators at Brown University, Yu. P. Gaidukov in the U.S.S.R. and Arthur F. Kip and his students at the University of California at Berkeley.

Although the Fermi surfaces of these noble metals are known with a high degree of precision, the situation with regard to the polyvalent metals is not so good. Metals with many conduction electrons, such as lead, tin and tungsten, have complicated Fermi surfaces with pieces of the surface in several zones. When explored by the experimental techniques described above, these metals produce a very complex picture, and analysis of the results presents a formidable problem.

The most progress has been made in lead. On the basis of De Haas–Van Alphen measurements Andrew V. Gold of the University of Cambridge has suggested a model of the Fermi surface of lead that is pictured at the left below. Although at first sight this highly intricate shape may seem rather unlikely, it has been verified by my own magnetoacoustic measurements on lead, by cyclotron resonance studies carried out by Robert C. Young of the University of Cambridge and by magnetoresistance experiments of N. E. Alekseevski and Gaidukov in the U.S.S.R.

It seems likely that before long the Fermi surfaces of most of the common metals will be known quite accurately. A great many experiments are being carried out at the moment with the present techniques, and new methods undoubtedly will be devised. Metals play an important part in modern science and technology, and a better understanding of their basic properties, apart from its inherent interest, is likely to be very useful in many branches of science. It is extremely convenient that the theory of the Fermi surface has provided a basis for experimental studies that have yielded so much information about the metals' electronic properties.

More generally, the theory and the experimental investigations of the Fermi surface provide an excellent example of the effort of science to find simplicity and order in the apparent complexity and chaos of nature.

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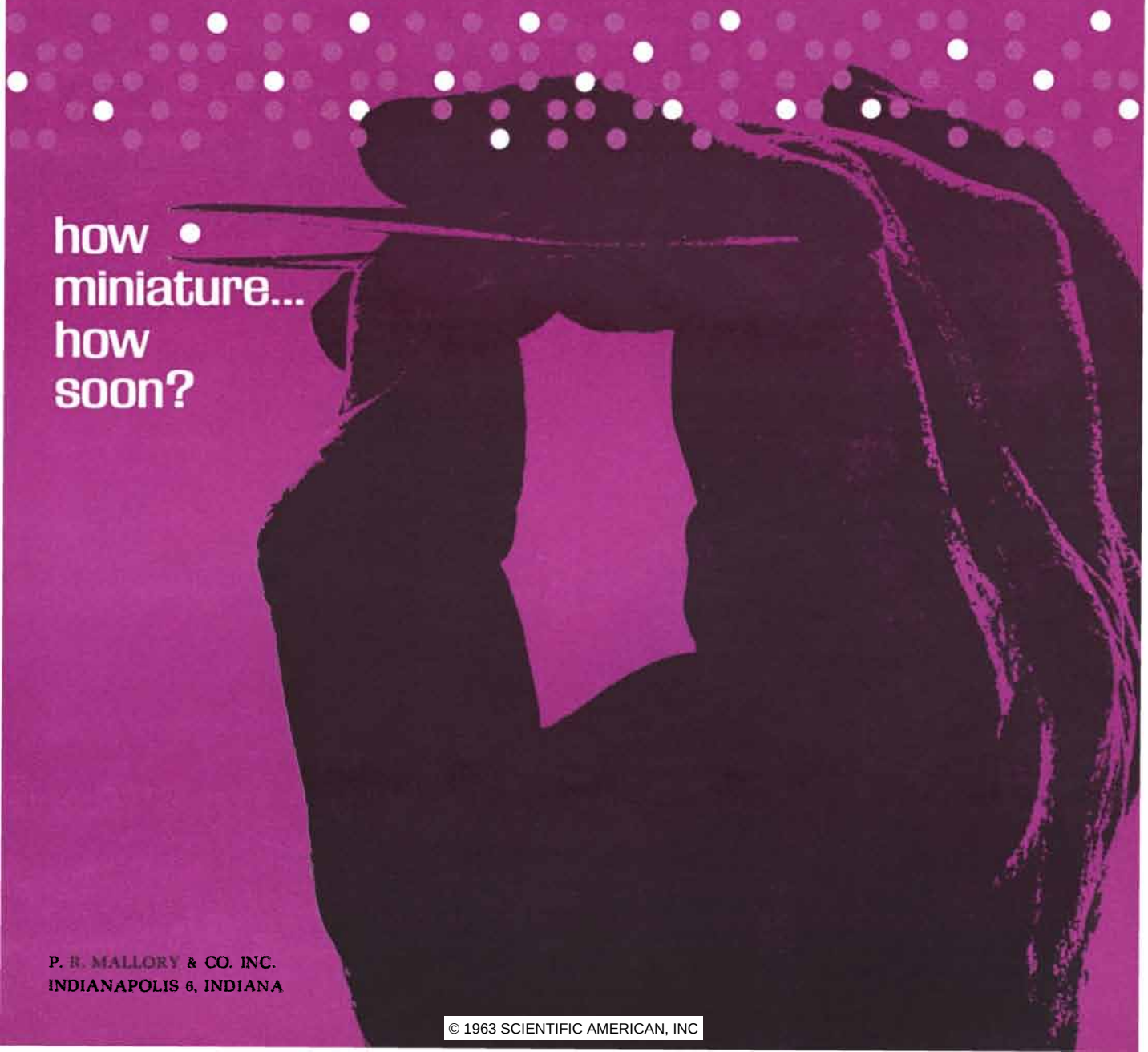

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INHIBITION IN VISUAL SYSTEMS

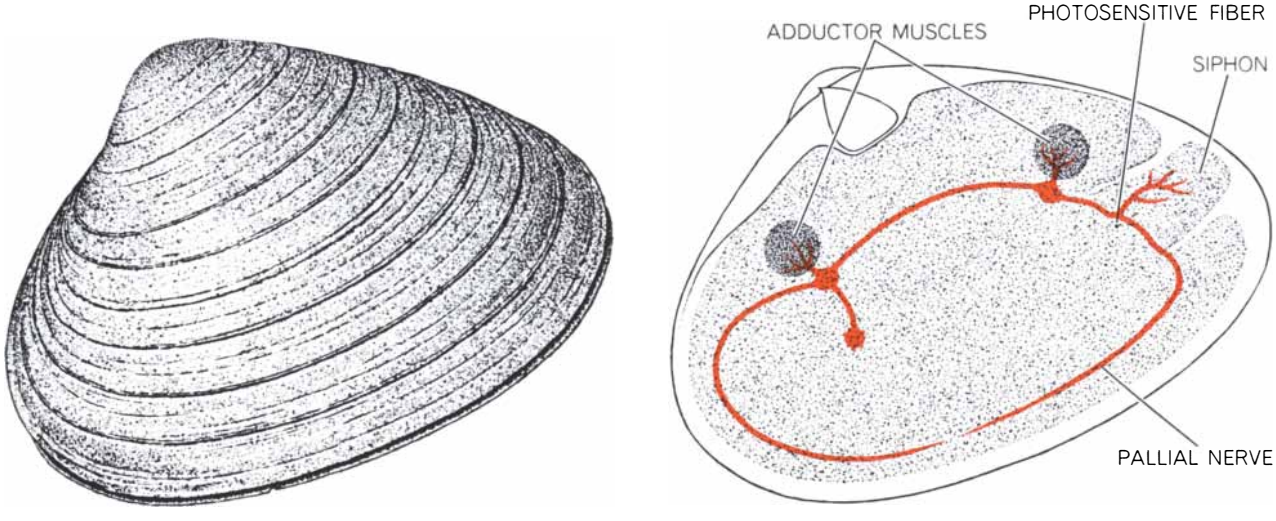
Certain kinds of sensory nerve impulses suppress or inhibit the propagation of other impulses. This property enables the human eye to see contours more clearly and clams to respond to shadows

by Donald Kennedy

The familiar analogy of the eye to the camera serves nicely to describe the physical basis of vision. It does not, however, begin to present a complete picture of the physiology of vision now emerging from comparative studies of the visual organs of mammals, insects and other arthropods and lower invertebrates. The simplistic physical model suggests that the image-forming eye acts as a straightforward transducer of the energy of light, converting a pattern of light inputs into a matching pattern of electrical energy in the form of nerve impulses. This does not account for the fact that the retina produces nerve impulses in response to shadows as well. Nor does it explain the performance of the light-receptors of certain aquatic organisms. A feather worm living in its tube in the crevice of a rock in a Pacific tide pool, or a clam with its siphon peeping unprotected from its open shell, may care little what time dawn comes or what the neighborhood looks like. But any sedentary, bottom-dwelling aquatic animal has a variety of reasons for being concerned about shadows. To such an animal a shadow may represent a cruising predator, a potential meal or even—for some freshwater mollusks—an inviting host for the strings of parasitic larvae the organism is ready to extrude on demand. If a receptor is to respond to shadows, it must be, in a real functional sense, the opposite of a light-receptor: it must respond to the onset of darkness.

The photoreceptors of this odd assortment of animals do not look much like eyes. Investigation of their physiology, however, has produced some unexpected dividends. In addition to explaining the sensory basis of some interesting behavior, this work has had a bearing on two general aspects of vision. The first is the growing realization that in many animals nerve cells—although often responsible for other functions—may be brought into service as light-receptors by being equipped with an appropriate photosensitive pigment. The second involves the question of how such rudimentary receptors serve as "shadow-sensitive" visual organs. Since they must necessarily function in response to the input of light—not to the "input" of darkness—it may be postulated that in some cases at least the energy of light might cause the discharge of nerve impulses to be inhibited and then, upon termination of the stimulus, to be released as an effective signal. Just such an "off-receptor" has been found in some mollusks.

The demonstration of this mechanism in a mollusk lends the "off-response" an unexpected universality and illuminates its importance in higher visual systems.

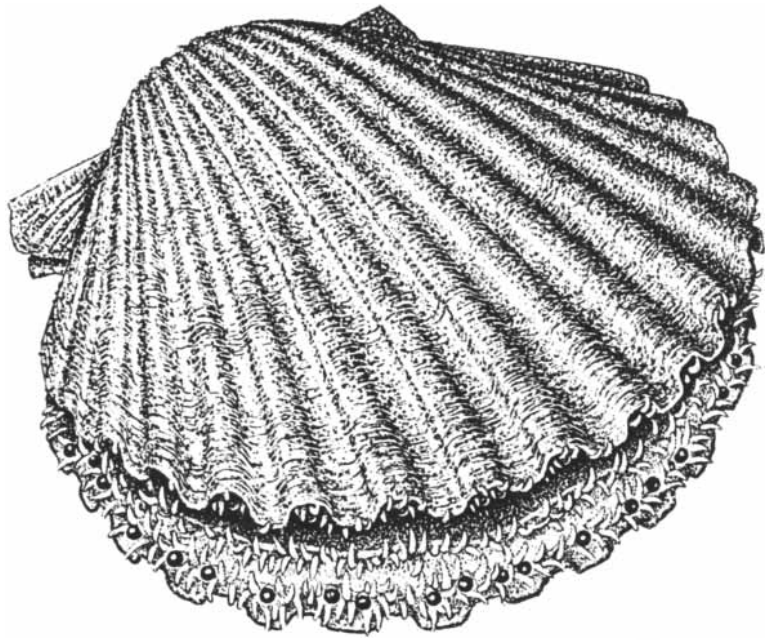


SURF CLAM (*Spisula*) abruptly withdraws its siphon and closes its shell (*left*) when a shadow passes over it. A photosensitive fiber in the pallial nerve at the base of the siphon (*right*) seems to mediate this response, which is fairly common among mollusks.

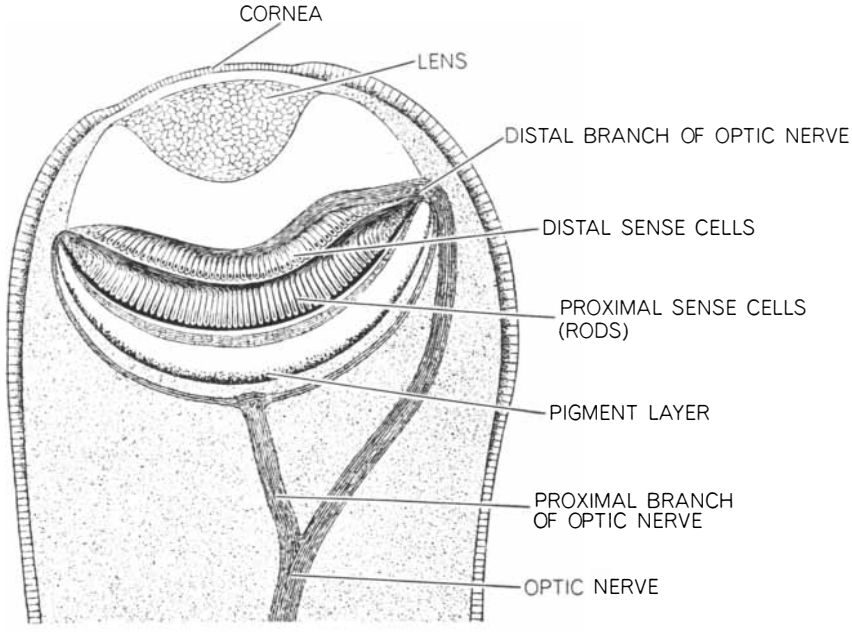
In the case of the mammalian eye it is now well established that some single fibers of the optic nerve, which conducts impulses from the eye to the brain, discharge impulses when illumination of the retina ceases. This signal is mediated by an interesting linkage in the circuitry of the retina itself. Each fiber of the optic nerve collects impulses from a receptive field that occupies a circle of retina about one millimeter in diameter, an area containing several thousand receptor cells. Activity generated in the receptor cells converges, through intermediate neurons called bipolar cells, on the neurons that form the optic nerve. The kinds of connections they make with one another depend on their location in the receptive field. In some receptive fields the center, when stimulated with a tiny patch of light, produces discharges in the optic nerve at "on"; the periphery produces discharges only when the stimulus is extinguished, or at "off." Stimulation of the peripheral zone simultaneously with the center produces both on- and off-discharges but at diminished frequency [*see top illustration on page 126*]. In essence the evidence indicates that interaction of the retinal nerve cells blocks the on-discharges from some of the light-receptors by inhibition at the synaptic junctions between the cells; the generation of off-discharges in response to a shadow results from the release of inhibition in these cells. This interaction of the retinal cells plays a vital role in the perception of movement across the visual field, in the accentuation of contrast and in the perception of shape. The off-discharge in the visual apparatus of certain mollusks arises, as will be seen, from a quite different and perhaps simpler mechanism, but the ability to "see" shadows plays a no less vital role in their life history.

Much of the work in this field stems from the original achievement of H. K. Hartline of the Rockefeller Institute, who in 1932 was the first to record impulses from single optic nerve fibers in the vertebrate eye. More recently, with his colleagues Floyd Ratliff and William H. Miller, he has shown how the responses of ommatidia, or single elements, in the compound eye of the horseshoe crab, *Limulus*, are integrated to furnish this animal with an impressively detailed view of its environment. Each ommatidium in the *Limulus* eye contains a group of eight retinula cells, which, when illuminated, evoke discharges in a single, large eccentric cell. A single independent channel of information—the eccentric cell axon—passes from each ommatidium to the brain. Each axon is connected, however, to many of its neighbors in a network of circuits located just below the bases of the ommatidia. These connections are inhibitory; activity in each ommatidium tends to suppress that in adjoining ones in much the same way as parts of the retinal receptive field in vertebrates inhibit other regions. By appropriately varying the geometry of the stimulus and the conditions of illumination Hartline and his colleagues have been able to synthesize discharges from single *Limulus* axons that mimic with remarkable fidelity the "off" and "on-off" discharges found in many vertebrate optic nerve fibers [see "How Cells Receive Stimuli," by William H. Miller, Floyd Ratliff and H. K. Hartline; Scientific American, September, 1961].

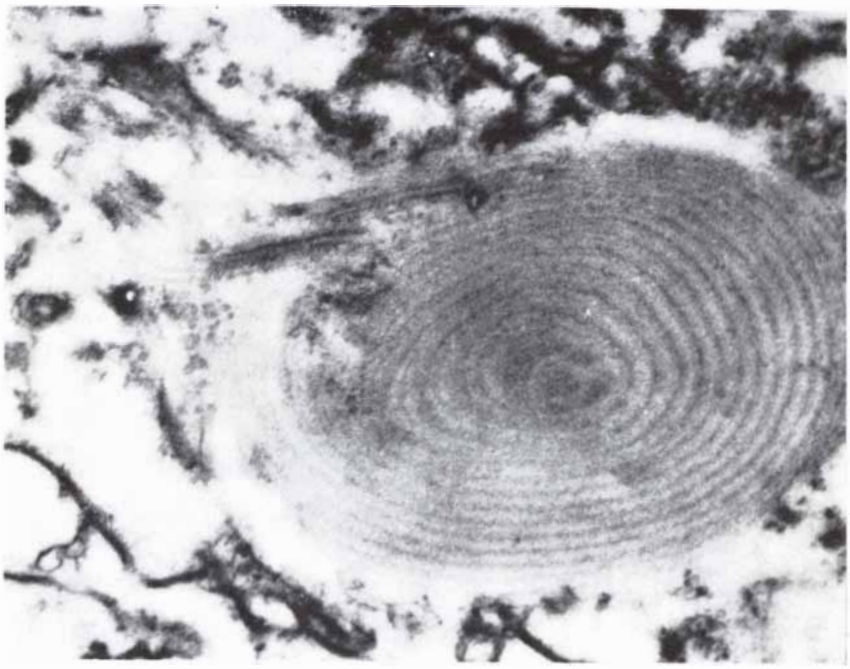
The fruitfulness of this work with *Limulus* has stimulated a number of in-



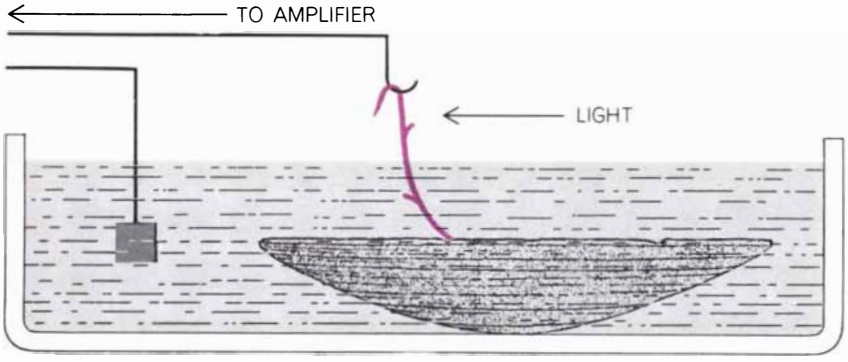
SCALLOP (*Pecten*) has a row of bright blue eyes along the mantle edge of each shell. The eyes of this mollusk are similar in structure to the image-forming eyes of vertebrate animals.



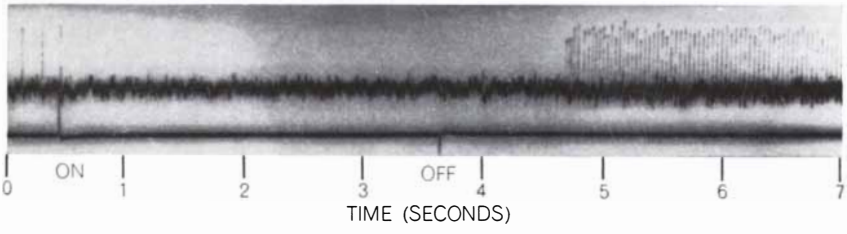
DETAIL OF SCALLOP EYE shows its peculiar double-layered retina. The proximal layer discharges impulses when illuminated; the distal layer discharges when illumination ceases.



ELECTRON MICROGRAPH made in 1958 by William H. Miller of the Rockefeller Institute showed that the "shadow-sensitive" cells in the distal layer of the scallop retina are true photoreceptors. The large oval structure is an organelle located on the surface of a single distal cell. The small dark objects at the left are ciliary stalks, simpler structures from which the organelles are derived. This mode of construction is typical of many other photoreceptors, including the retinal rods of vertebrate eyes. Magnification is 20,000 diameters.



IMPULSES ARE MEASURED by excising one end of a *Spisula* pallial nerve and placing it across an electrode. Another electrode leads from the salt-water bath in which the clam is immersed. Impulses are amplified before being displayed on a cathode ray oscilloscope.



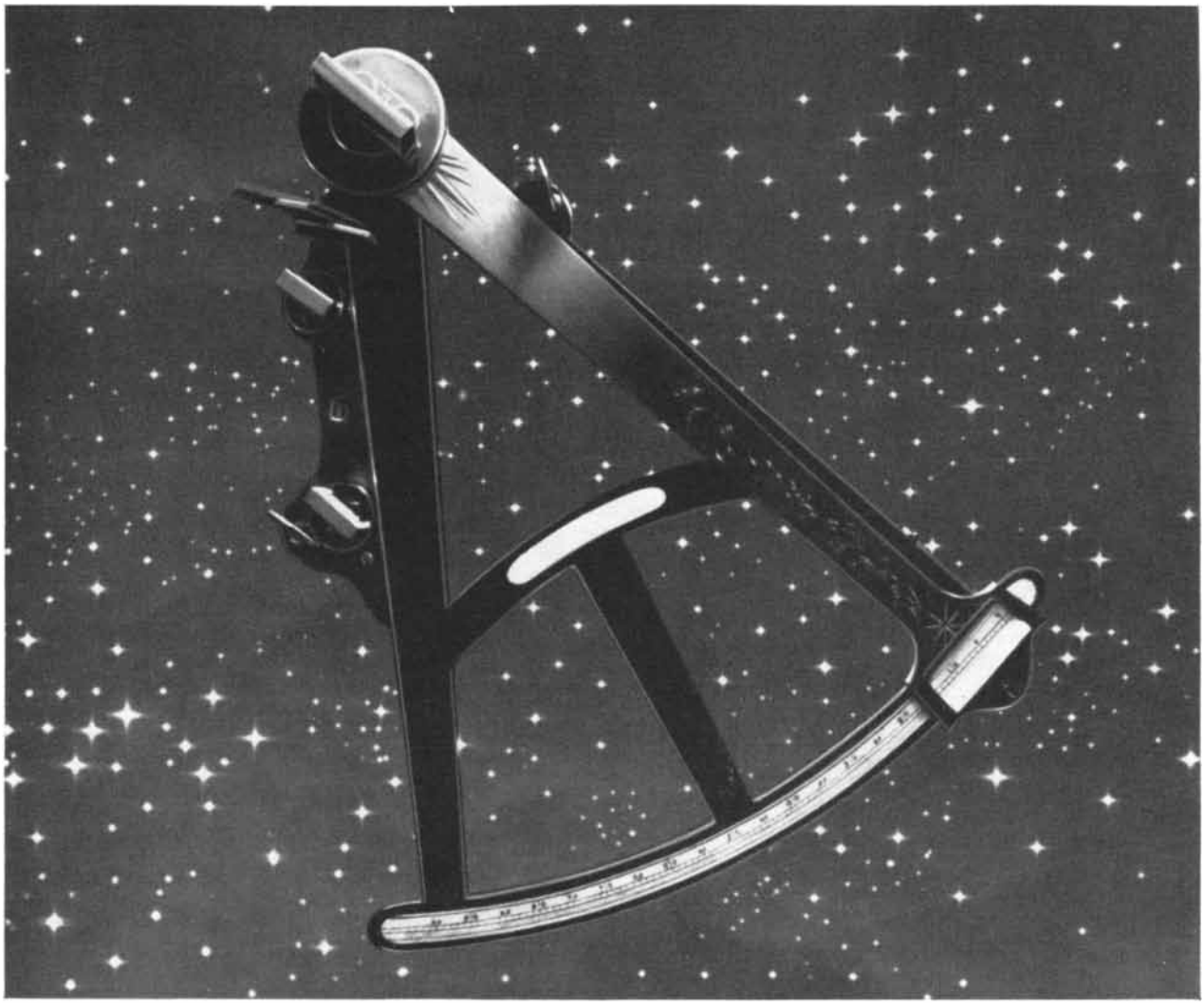
OSCILLOSCOPE TRACE obtained by the procedure described above reveals the effects of inhibition in the *Spisula* visual system. In the dark the photosensitive fiber of the pallial nerve discharges at a constant frequency of about five impulses per second. When the fiber is illuminated ("on"), this discharge ceases abruptly; shortly after the light is extinguished ("off"), a high-frequency burst of impulses (about 35 per second) passes through the fiber.

vestigators to look into the physiology of the simpler photoreceptors found in other marine invertebrates. My own particular interest in them has been to determine whether or not the "off" discharges generated by some of these primitive systems are organized in the same way as those of the vertebrate retina. A long history of investigation suggested that the bivalve mollusks were a good group in which to tackle this problem. Seventy years ago the German zoologist Wilibald A. Nagel observed that many mollusks showed pronounced reactions whenever shadows were passed over them: they would abruptly withdraw their siphons and close their valves. During the 1920's mollusks played a distinguished role in the development of understanding of the relation between photochemistry and visual response. The late Selig Hecht of Columbia University used the withdrawal response of *Mya*, the familiar soft-shell clam, to make several extraordinary predictions about the chemical processes involved in vision.

More recently, at the Marine Biological Laboratory in Woods Hole, Mass., and at Syracuse University, I have been attempting to learn something about the electrophysiological responses of the visual receptors of several species of clams including *Mya*. It proved fairly easy to record impulses in fine branches of the nerves from the siphon by the usual technique of placing them across electrodes and displaying the amplified "action potentials" on an oscilloscope. When the siphon was illuminated, grouped discharges of impulses occurred in a number of nerve fibers, both at "on" and at "off." These results were consistent with previous findings of multiple sensory endings, assumed to be photoreceptors, in the siphon well of *Mya*.

A surprise came, however, when the same kind of experiment was tried with the surf clam *Spisula*. From this bivalve, which exhibits particularly pronounced behavioral reactions to shadows, it was impossible to evoke any kind of discharge in the siphon nerves by illuminating the siphon—or anything else. But light did have a remarkable effect on the activity of a single nerve fiber of the pallial nerve. This nerve tract is a roughly circular one, passing around the edge of the mantle and past the base of the siphon into the visceral ganglion [*see illustration on page 122*]. The first observations, which were made on live clams with one end of the pallial nerve dissected for electrical recording, showed that in the dark a single nerve fiber in the tract discharges at a remarkably con-

FROM OCTANT TO STELLAR GUIDANCE



The Octant (English—18th Century)—brother of the quadrant and sextant; predecessor to today's bubble sextant. The octant was a descendant of the early cross staff and astrolabe. Sailors and astronomers held it in the hand for sighting stars. *(Cranbrook Institute of Science)*

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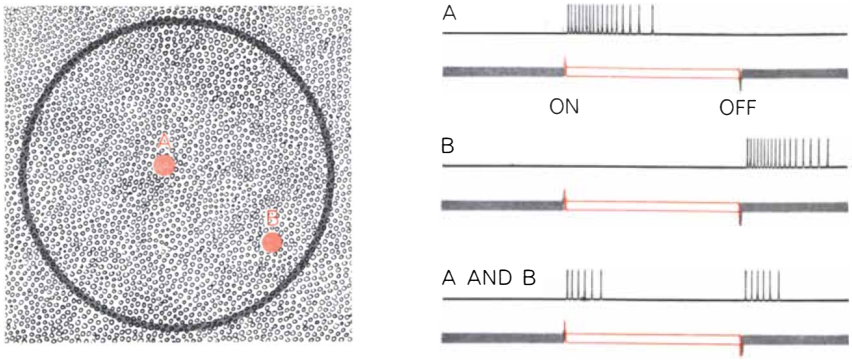
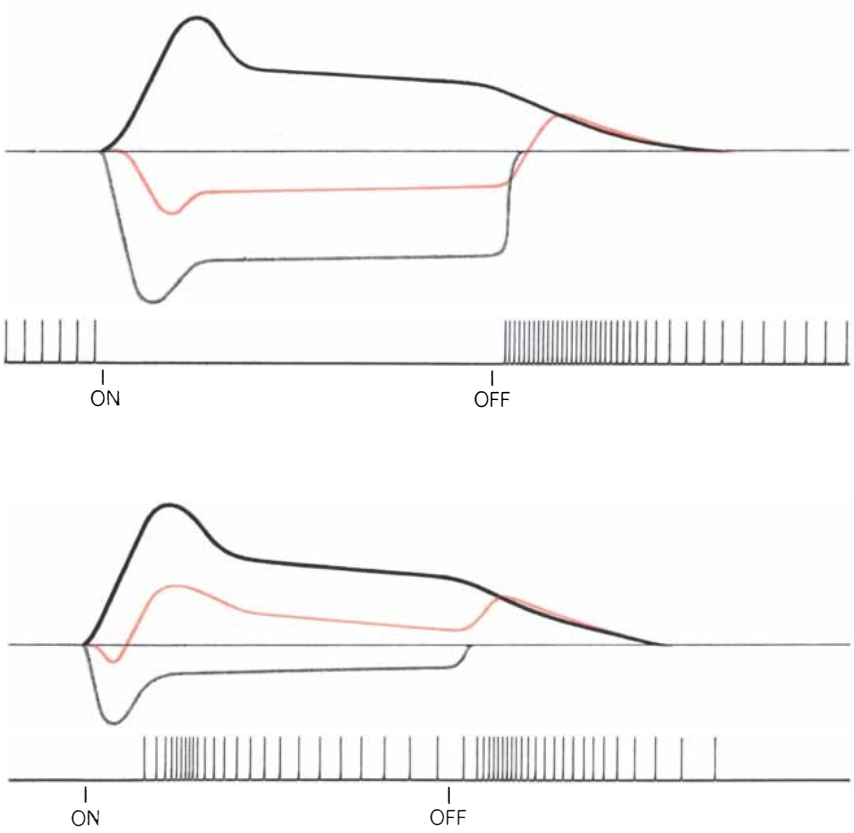


INHIBITION IN MAMMALIAN EYE is demonstrated in this schematic drawing of a small area on the surface of a cat's retina. The tiny open circles represent the tips of rods and cones, the photoreceptor cells of the retina. The large gray circle indicates the extent of the "receptive field" served by a single optic nerve fiber. This field is about one millimeter in diameter and contains several thousand receptor cells. When a beam of light is focused on receptors near the center of the field (*colored dot at A*), the fiber discharges a burst of impulses at "light on"; when the beam strikes receptors at the periphery of the field (*colored dot at B*), the fiber discharges at "light off." When the center and the periphery are illuminated simultaneously, mutual inhibition takes place in the network of neurons that connect the receptors to the optic fiber, causing diminished discharges at both "on" and "off."



INHIBITION IN *SPISULA* PHOTORECEPTOR contributes to the characteristic "shadow response" of this mollusk. When the pallial nerve is illuminated with white light (*graph at top*), the inhibitory response (*gray curve*) dominates the excitatory response (*black curve*); the net sum of these two responses (*colored curve*) remains below the "firing threshold" (*horizontal line*) and no impulses are discharged during illumination. At "off," however, the slower-decaying excitatory response raises the net sum above the firing threshold, producing a high-frequency burst of impulses in the nerve. When the pallial nerve is illuminated with red light following prolonged preadaptation to blue (*graph at bottom*), the inhibitory response, mediated by the depleted blue pigment, is accordingly reduced and the net sum of the two responses produces bursts of impulses at both "on" and "off."

stant frequency of about five impulses per second. When the nerve was illuminated, the discharge ceased abruptly. When the light was turned off, however, or when a shadow passed over the animal, a high-frequency burst of impulses appeared in the fiber [*see bottom illustration on page 124*].

It was quickly established that this response is not mediated by sensory endings in the siphon, as in the case of *Mya;* instead a nerve cell in the pallial circuit seemed to act as the receptor. A segment of pallial trunk removed from the animal and tested in the same way was found to produce the response, whereas illumination of the siphon alone, or of neighboring tissues, failed to produce it in the intact animal. Clearly a part of the nervous system itself is involved in receiving the light energy and responding to it. It does so with a sensitivity that is impressive even when compared with that of much more highly organized receptors; the threshold for inhibiting the dark discharge of the neuron is about the same as that for stimulating the cone cells of the human retina.

Many kinds of nerve cells, when released from inhibition, give one or several quick "rebound" impulses. The off-response of the *Spisula* receptor neuron is so high in frequency and so long-lasting, however, that such an explanation seemed inadequate to account for it. A clue to the mechanism actually involved came from experiments in which colored lights of high spectral purity were employed to stimulate the receptor. When blue light was used, the off-discharges of impulses were weak or even entirely absent. Moreover, if the intensity of the blue light was high enough, it produced an inhibitory blockade that halted the resumption of the low-frequency beat of the nerve for a full minute or more after the stimulus was shut off. Stimulation by red light, on the other hand, produced very strong off-responses that lasted many seconds after the light was turned off and before the nerve resumed its regular output of five discharges per second. It appeared possible, therefore, that the whole response of the nerve cell was the sum of excitatory and inhibitory components, each one mediated by a different light-sensitive pigment. According to this hypothesis the inhibitory process was particularly sensitive to short (blue) wavelengths, whereas the excitatory process was more responsive to long (red) wavelengths. During exposure to

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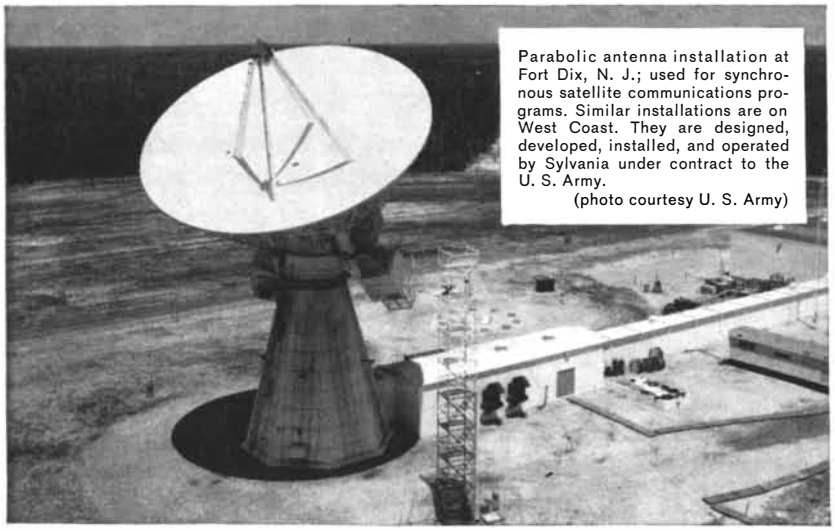

Parabolic antenna installation at Fort Dix, N. J.; used for synchronous satellite communications programs. Similar installations are on West Coast. They are designed, developed, installed, and operated by Sylvania under contract to the U. S. Army.
(photo courtesy U. S. Army)

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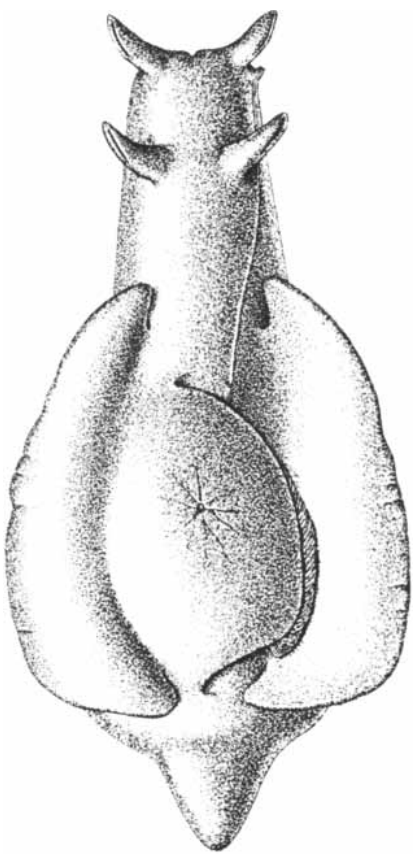
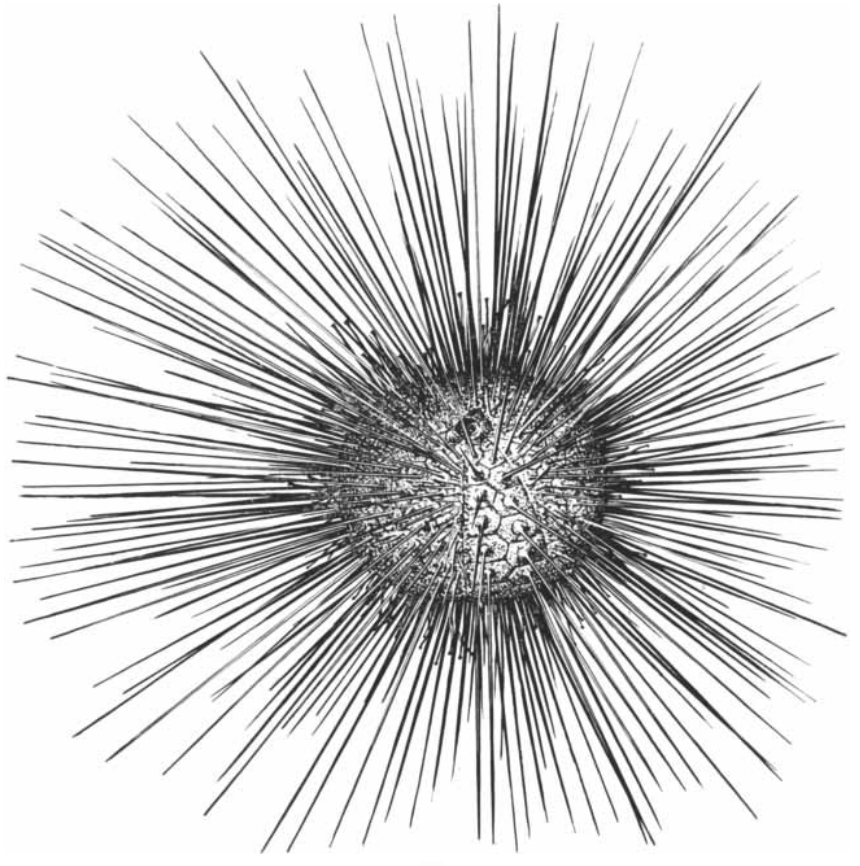
illumination the inhibitory process predominated; it decayed, however, more rapidly when the light was shut off, leaving a residual, slowly decaying excitation in its wake that produced the off-response [*see bottom illustration on page 126*]. In other words, firing of the neuron occurs only when the net sum of inhibitory and excitatory processes exceeds the firing level or threshold of the cell. These observations and deductions suggested that the inhibitory process in *Spisula* is mediated by a blue-sensitive pigment and the excitatory process by a red-sensitive one, with the two pigments overlapping considerably in absorption.

Support for this hypothetical scheme was obtained by taking advantage of the contrasting specificity of response shown by the nerve to wavelengths at opposite ends of the spectrum. All photosensitive pigments in the light-receptors of animals undergo a change when they absorb light; that is how they communicate excitation. This "bleaching" of the pigments, although reversible, can temporarily desensitize the receptor by reducing its supply of light-sensitive pigment. Thus in the familiar phenomenon of light adaptation our own eyes become less sensitive following exposure to intense illumination. By exposing the *Spisula* nerve to intense blue light for a minute or so, it was possible to reduce the inhibitory component, presumably by the bleaching of the blue-absorbing pigment. When the cell was now exposed to a red stimulus, it produced impulses at "light on" as well as at "light off." Within limits, the extent of the on-response to red light increased as the preadaptation to blue was lengthened. That the red wavelengths also excite the inhibitory process is demonstrated by the decay of the on-response under continued illumination. There seems no reason, therefore, to doubt that the off-discharge (or "shadow response") of the receptor neuron is a positive result of excitation remaining after the stimulus, although it is masked during the stimulus by a more sensitive inhibitory process. By selectively reducing the latter one reveals the former.

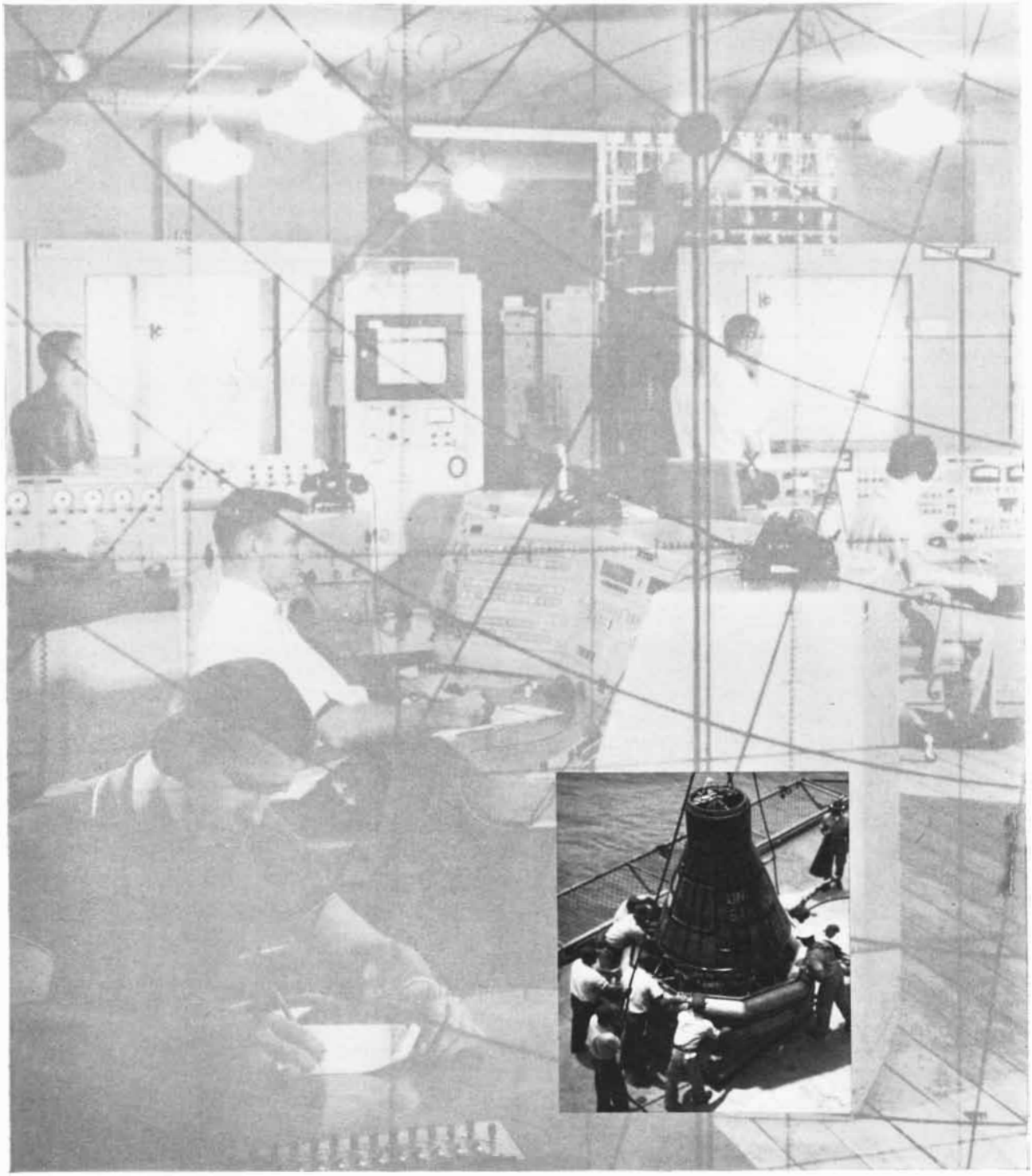
The neuron that produces the discharges recorded in these experiments is a single cell. What guarantee is there that these opposing processes are really taking place within this cell itself? Might it not be equally likely that the active cell is actually secondary, receiving and integrating primary neural messages from receptors or other nerve cells in which the inhibitory and excitatory events are segregated? Anatomical considerations suggest otherwise; the area of pallial nerve over which these responses may be produced by light is very small, and there is no evidence for the presence of any accessory receptors. Fixed, stained sections of the region do not reveal the required cluster of cells; usually a single nerve cell body appears —the likely, although not established, candidate for the photoreceptor element.

It is highly probable, then, that in the off-receptor of *Spisula* inhibition is a primary event, involving a kind of coupling between mechanisms of energy reception and transmission that is the reverse of the one usually associated with sense organs. There is another case, also involving a mollusk, in which a similar conclusion can be reached ex post facto. More than 20 years ago Hartline became interested in the strange photoreceptors of the scallop *Pecten*. These small eyes, bright blue in color,





TWO MARINE INVERTEBRATES whose photoreceptive systems resemble that of *Spisula* are depicted. Neurons located within the central nervous system of the shell-less mollusk *Aplysia* (*left*) discharge impulses both at the onset and at the cessation of illumination. The long spines of the sea urchin *Diadema* (*right*) move in response to shadows falling across certain peripheral nerves.



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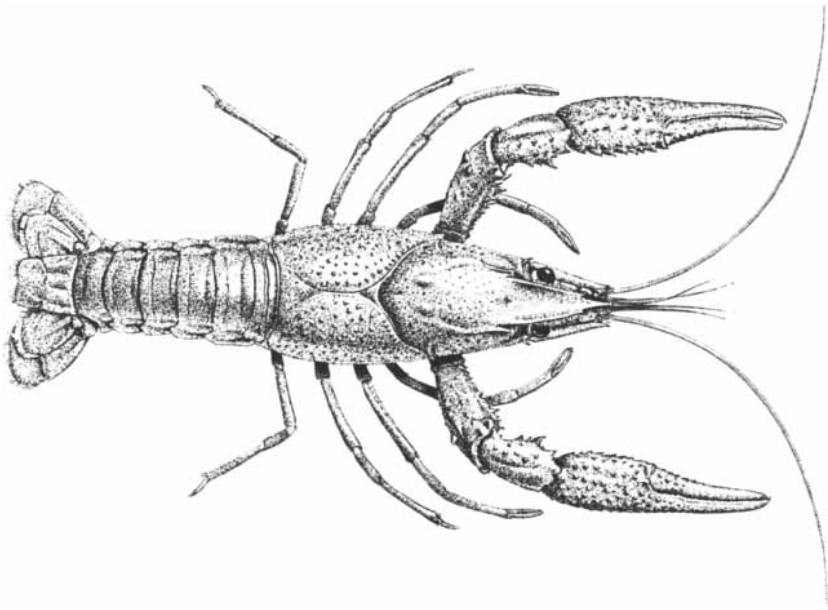

CRAYFISH (*Cambarus*) has, in addition to its typical arthropod eyes, two photosensitive nerve fibers located near the under surface of its segmented abdomen. Light passing through the translucent exoskeleton activates a pair of neurons in the last abdominal ganglion; these also serve as relays for impulses originating in the sensory hairs of the tail.

stud the edge of the scallop's mantle; each one has a tiny lens, a reflecting pigment coat and a double-layered retina. Both layers contribute bundles of fibers to the optic nerve. Hartline was able to dissect single fibers from each set, and he showed that whereas those from the inner layer discharge impulses at "on," those from the outer layer respond only to shadows. At the time it was not possible to decide whether the outer layer was truly made up of receptor cells or whether instead it consisted of a layer of second-order nerve cells. Electron micrographs made recently at the Rockefeller Institute by Miller, however, seem to answer the question. They show clearly that the outer layer is composed of primary sensory cells, which contain the typical lamellar organelles characteristic of all other photoreceptors. It is hard to avoid the conclusion that in this case too inhibition—and shadow responses—are the primary result of the absorption of light energy by the receptor. In *Limulus* or mammalian retinas, in contrast, inhibition arises as a secondary effect through the interaction of receptor cells, all of which produce on-discharges.

It is significant in connection with the evolution of vision that the receptor element in *Spisula* is a nerve cell. The idea that neurons—and other "excitable" cells—can respond to light is not new. In their laboratories at Lyons and in Monaco, A. Arvanitaki and her husband, N. Chalazonitis, have found that in the mollusk *Aplysia,* as in *Spisula* and others, neurons within central ganglia often possess a rich variety of intracellular pigments. Some of these neurons change the frequency of spontaneously discharged impulses when they are illuminated. In certain cells the effect is excitatory; in others light appears to reduce the impulse frequency. Such findings form a kind of precedent for the operation of the photoreceptor system I have described. It may be that *Spisula* has merely taken advantage of a general property of its neurons by moving one to the periphery, making it more sensitive and using it as a functional receptor.

If this has happened in one mollusk, why not in others? It would be of great advantage if receptors could be found that combine the accessibility and large size of the *Aplysia* neurons and the interesting sensory properties of the *Spisula* cell. In such a system one might hope to correlate impulse discharge (or the lack of it) with those local changes in membrane potential that are known to control the generation of conducted impulses in nerve cells. We are hopeful that the right organisms have now been found: John Barth of our laboratory at Stanford University has succeeded in recording with microelectrodes from inside single receptor neurons in the eyespots of several species of Pacific coast nudibranchs. These gastropod mollusks have no shell; their eyespots sit above the brain, and they generally consist of a tiny lens with a cluster of a dozen or more large nerve cells beneath it. The cells may depolarize and fire impulses when the light goes on, just as primary sensory cells from a variety of other systems do. In some cases, however, they exhibit complex changes in membrane potential, including increases as well as decreases. When increases in membrane potential occur, the cells are inhibited from discharging spikes; and in some cells the interaction of these opposite effects produces off-responses much like those in *Spisula.* Like *Spisula,* some nudibranchs also show pronounced behavioral responses to shadows. Barth is now working out the wavelength dependence of these responses.

Light sensitivity on the part of neurons raises a still more interesting prospect. It may be that photosensitivity is not the unique endowment of highly specialized receptor cells with a complex fine structure but a much more basic property. In the sea urchin *Diadema,* for example, N. Millott of the University of London has shown that the spine movements with which the animal responds to shadows are elicited only when the stimuli fall directly on certain peripheral nerves.

At Stanford we have also been working on certain neurons in the ventral nerve cord of the crayfish. Although these cells function as perfectly conventional interneurons, relaying impulses to the brain from mechanically sensitive receptors on the tail, they have the additional function of responding to light that falls on the last abdominal ganglion through the translucent exoskeleton. Thus the same element serves as a second-order unit for one sensory system and as a primary receptor for another. Only one nerve fiber in each half of the nerve cord exhibits these responses; we are now able to isolate the specific fiber by fine dissection from the nerve. The endowment of photosensitivity is no "accident"; in every case the same interneuron (in terms of its other functions) serves as the photoreceptor.

Nor does this complete the list of excitable cells that show "incidental" photosensitivity. The heart muscle of certain snails, muscle fibers in the pupil of many vertebrates, the brain cells of some insects, and even smooth-muscle cells from the walls of arterioles in mammalian skin are all light-sensitive. The ubiquity of this property, surely only partly represented by our present inventory, may perhaps urge physiologists to look for relations between normal pigmented constituents of cells and the important events that lead to the excitation of nerve and muscle membranes.

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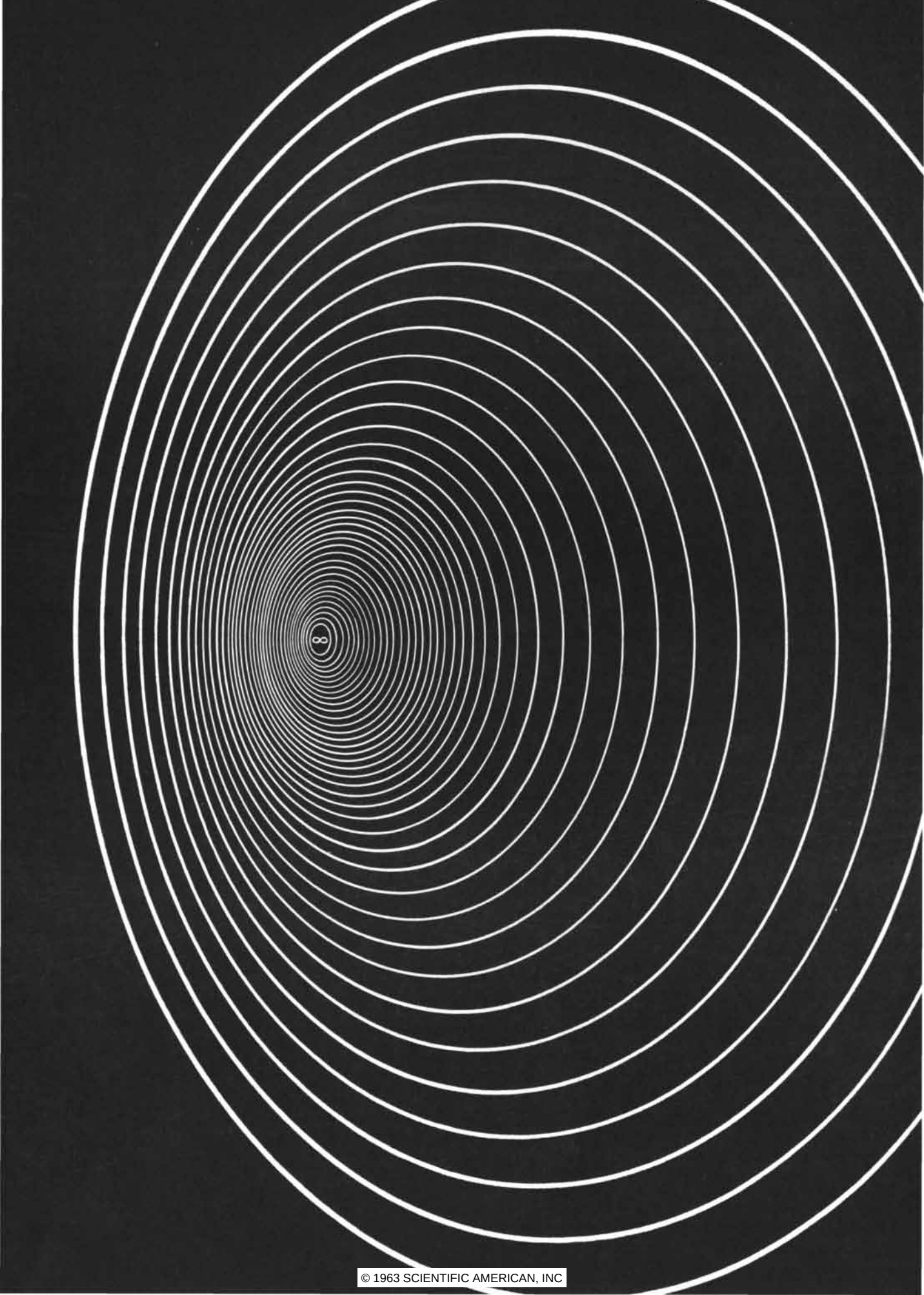

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MATHEMATICAL GAMES

Topological diversions, including a bottle with no inside or outside

by Martin Gardner

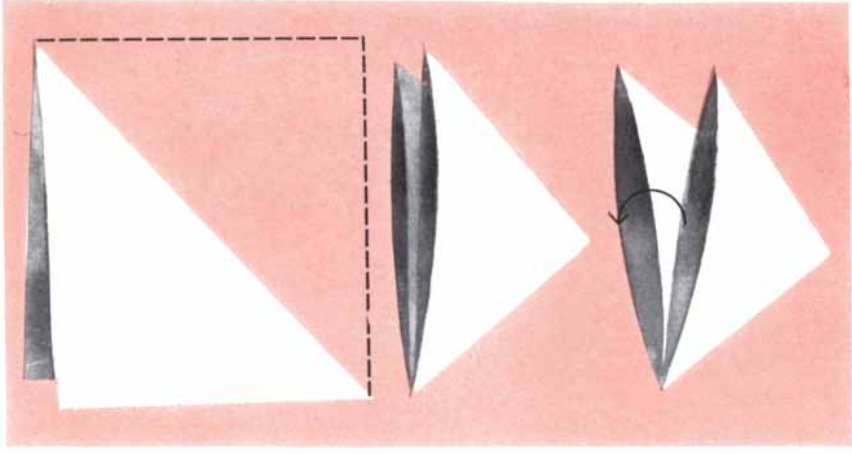
Three jolly sailors from
Blaydon-on-Tyne
They went to sea in a bottle by Klein.
Since the sea was entirely inside
the hull
The scenery seen was exceedingly dull.

The Space Child's Mother Goose,
by Frederick Winsor

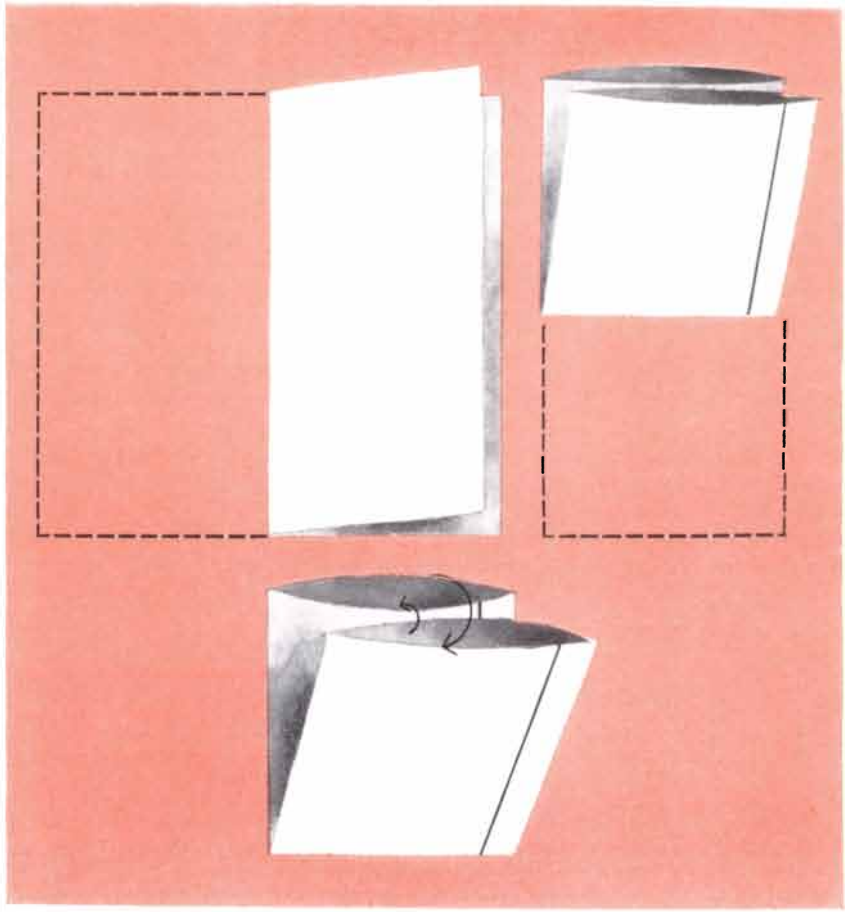
To a topologist a square sheet of paper is a model of a two-sided surface with a single edge. Crumple it into a ball and it is still two-sided and one-edged. Imagine that the sheet is made of rubber. You can stretch it into a triangle or circle, into any shape you please, but you cannot change its two-sidedness and one-edgedness. They are topological properties of the surface, properties that remain the same regardless of how you bend, twist, stretch or compress the sheet.

Two other important topological invariants of a surface are its chromatic number and Betti number. The chromatic number is the maximum number of regions that can be drawn on the surface in such a way that each region has a border in common with every other region. If each region is given a different color, each color will border on every other color. The chromatic number of the square sheet is 4. In other words, it is impossible to place five differently colored regions on the square so that each pair has a boundary in common. (This should not be confused with the famous four-color theorem, which involves maps with any finite number of regions.) The Betti number, named after Enrico Betti, a 19th-century Italian physicist, is the maximum number of cuts that can be made without dividing the surface into two separate pieces. If the surface has edges, each cut must be a "crosscut": one that goes from a point on an edge to another point on an edge. If the surface is closed (has no edges), each cut must be a "loop cut": a cut in the form of a simple closed curve. Clearly the Betti number of the square sheet is 0. A crosscut is certain to produce two disconnected pieces.

If we make a tube by joining one edge of the square to its opposite edge, we create a model of a surface topologically distinct from the square. The surface is still two-sided but now there are two separate edges, each a simple closed curve. The chromatic number remains 4 but the Betti number has changed to 1. A crosscut from one edge to the other,



Möbius surface constructed with a square

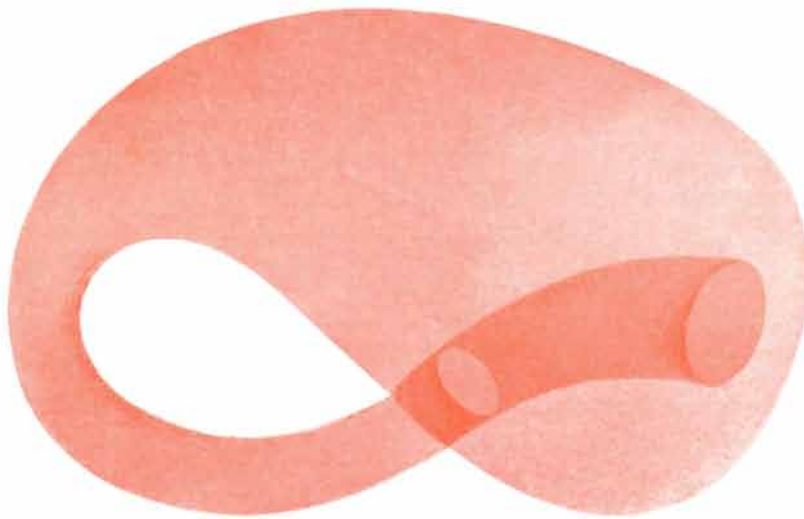


Torus surface folded from a square

although it eliminates the tube, allows the paper to remain in one piece.

A third type of surface, topologically the same as the surface of a sphere or cube, is made by folding the square in half along a diagonal and then joining the edges. The surface continues to be two-sided but all edges have been eliminated. It is a closed surface. The chromatic number continues to be 4. The Betti number is back to 0: any loop cut obviously creates two pieces.

Things get more interesting when we join one edge of the square to its opposite edge but give the surface a half-twist before doing so. You might sup-



Klein bottle: a closed surface with no inside or outside

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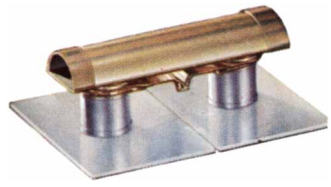

Segment of thermoelectric module used i electric power generation (shown approxi mately one-half actual size).

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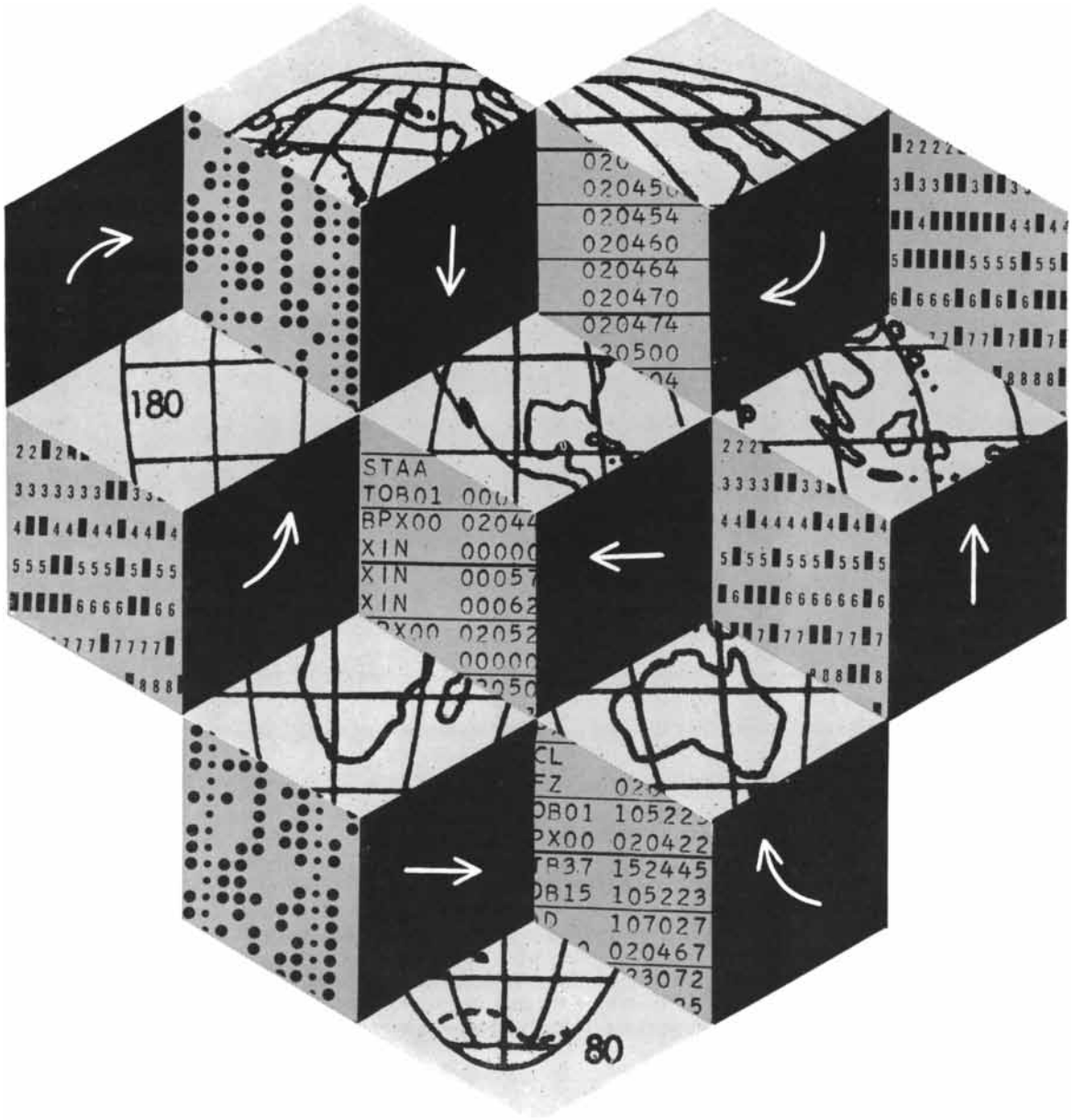


21-901

pose that this cannot be done with a square piece of paper, but it is easily managed by folding the square twice along its diagonals, as shown in the illustration on page 134. Tape together the pair of edges indicated by the arrow in the last drawing. The resulting surface is the familiar Möbius strip, first analyzed by A. F. Möbius, the 19th-century German astronomer who was one of the pioneers of topology. The model will not open out, so it is hard to see that it is a Möbius strip, but careful inspection will convince you that it is. The surface is one-sided and one-edged, with a Betti number of 1. Surprisingly, the chromatic number has jumped to 6. Six regions, of six different colors, can be placed on the surface so that each region has a border in common with each of the other five.

When both pairs of the square's opposite edges are joined, without twisting, the surface is called a torus. It is topologically equivalent to the surface of a doughnut or a cube with a hole bored through it. The top illustration on page 136 shows how a flat, square-shaped model of a torus is easily made by folding the square twice, taping the edges as shown by the solid gray line in the second drawing and the arrows in the last. The torus is two-sided, closed (no-edged) and has a chromatic number of 7 and a Betti number of 2. One way to make the two cuts is first to make a loop cut where you joined the last pair of edges (this reduces the torus to a tube) and then a crosscut where you joined the first pair. Both cuts, strictly speaking, are loop cuts when they are marked on the torus surface. It is only because you make one cut before the other that the second cut becomes a crosscut.

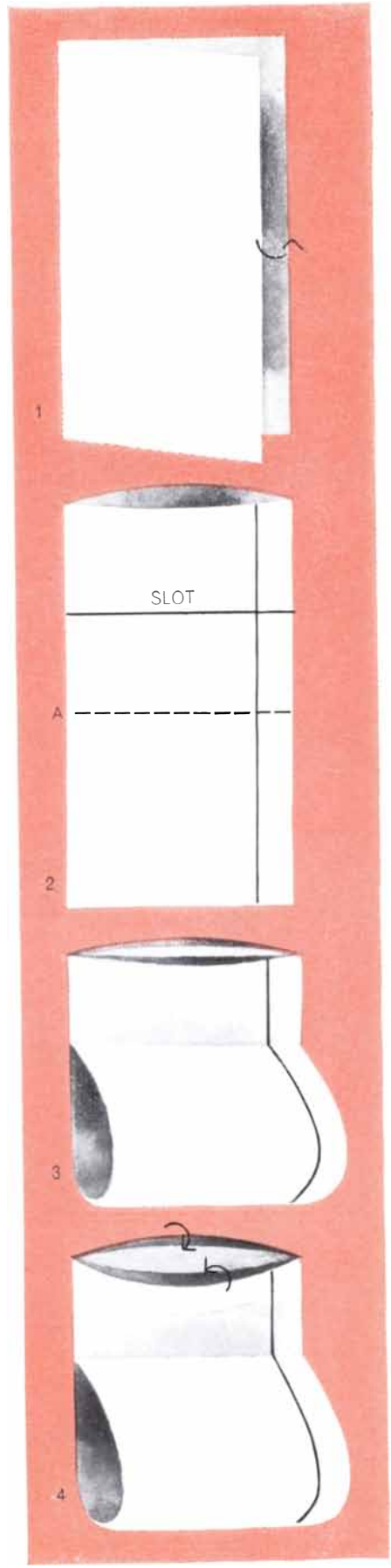
It is hard to anticipate what will happen when the torus model is cut in various ways. If the entire model is bisected by being cut in half either horizontally or vertically, along a center line parallel to a pair of edges, the torus surface receives two loop cuts. In both cases the resulting halves are tubes. If the model is bisected by being cut in half along either diagonal, each half proves to be a square. Can the reader find a way (before the answer appears in this department next month) to give the model two loop cuts that will produce two separate bands interlocked like two rings of a chain?

Many different surfaces are closed like the surface of a sphere and a torus, yet one-sided like a Möbius strip. The easiest one to visualize is a surface known as the Klein bottle, discovered in 1882 by Felix Klein, the great German mathematician. An ordinary bottle has an outside and inside in the sense that if a fly were to walk from one side to the other, it would have to cross the edge that forms the mouth of the bottle. The Klein bottle has no edges, no inside or outside. What seems to be its inside is continuous with its outside, like the two apparent "sides" of a Möbius surface.

Unfortunately it is not possible to construct a Klein bottle in three-dimensional space without self-intersection of the surface. The bottom illustration on page 136 shows how the bottle is traditionally depicted. Imagine the lower end of a tube stretched out, bent up and plunged through the tube's side, then joined to the tube's upper mouth. In an actual model made, say, of glass there would be a hole where the tube intersects the side. You must disregard this defect and think of the hole as being covered by a continuation of the bottle's surface. There is no hole, only an intersection of surfaces. This self-intersection is necessary because the model is in three-space. If we conceive of the surface as being embedded in four-space, the self-intersection can be eliminated entirely. The Klein bottle is one-sided, no-edged and has a Betti number of 2 and a chromatic number of 6.

Daniel Pedoe, a mathematician at Purdue University, recently wrote *The Gentle Art of Mathematics*. It is a delightful book, but on page 84 Professor Pedoe slips into a careless bit of dogmatism. He describes the Klein bottle as a surface that is a challenge to the glass blower, but one "which cannot be made with paper." Now, it is true that at the time he wrote this apparently no one had tried to make a paper Klein bottle, but that was before Stephen Barr, a science-fiction writer and an amateur mathematician of Woodstock, N.Y., turned his attention to the problem. Barr quickly discovered dozens of ways to make paper Klein bottles. He is currently at work on a book of topological recreations, to be published later this year by the Thomas Y. Crowell Company. It will be crammed with all sorts of elegant new topological models folded out of paper. Here I will describe only one of Barr's Klein bottles; one that enables us to continue working with a square and at the same time follows closely the traditional glass model.

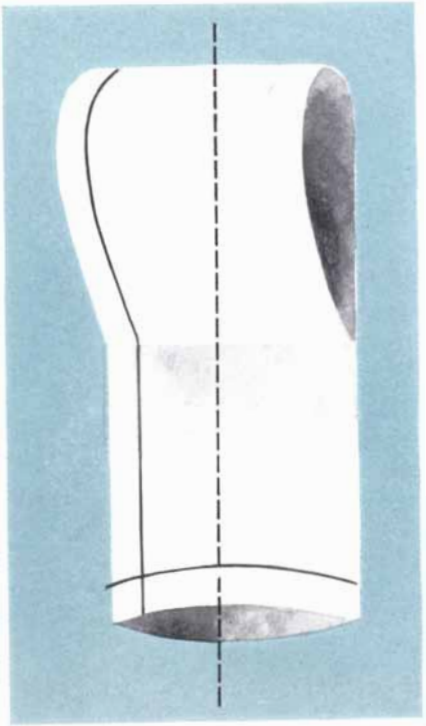
The steps are given in the illustration at the right. First, make a tube by folding the square in half and joining the right edges with a strip of tape as



Folding a Klein bottle from a square

shown in Step 1. Cut a slot about a quarter of the distance from the top of the tube (Step 2), cutting only through the thickness of paper nearest you. This corresponds to the "hole" in the glass model. Fold the model in half along the broken line *A*. Push the lower end of the tube up through the slot (Step 3) and join the edges all the way around the top of the model (Step 4) as indicated by the arrows. It is not difficult to see that this flat, square model is topologically identical with the glass bottle shown in the bottom illustration on page 136. In one way it is superior: there is no actual hole. True, you have a slot where the surface self-intersects, but it is easy to imagine that the edges of the slot are joined so that the surface is everywhere edgeless and continuous.

Moreover, it is easy to cut this paper model and demonstrate many of the bottle's astonishing properties. Its Betti number of 2 is demonstrated by cutting the two loops formed by the two pairs of taped edges. If you cut the bottle in half vertically, you get two Möbius bands, one a mirror image of the other. This is best demonstrated by making a tall, thin model [*see illustration below*] from a tall, thin rectangle instead of a square. When you slice it in half along the broken line (actually this is one long loop cut all the way around the surface), you will find that each half opens out into a Möbius strip. Both strips are par-



Bisected bottle makes two Möbius strips

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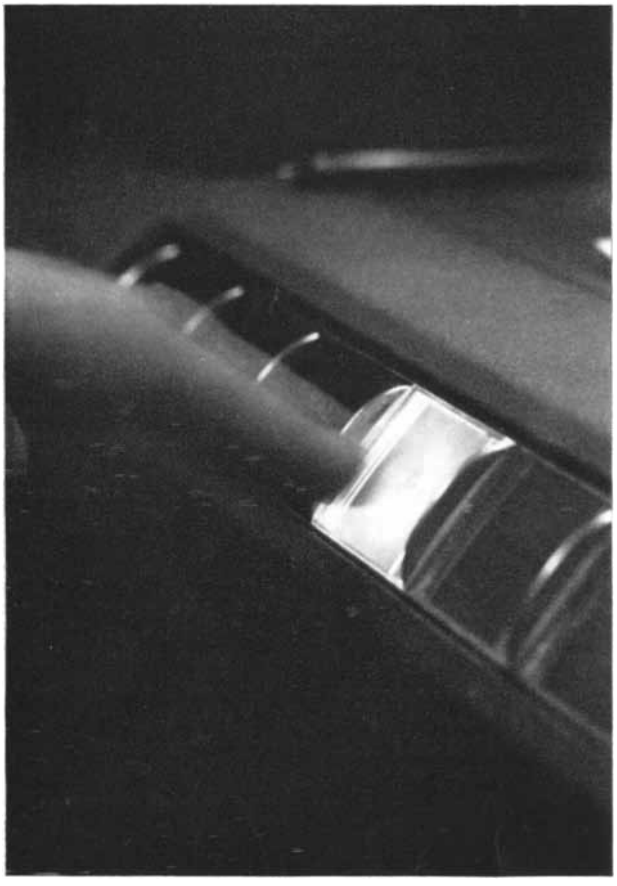

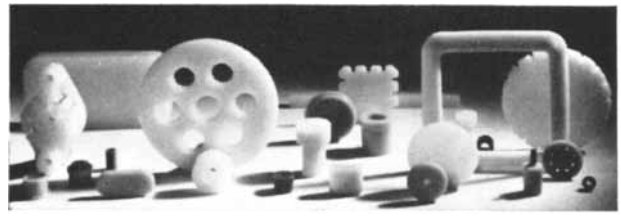

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- include a drawing of the part, with critical dimensions indicated.
- which of these properties are important – thermal, physical, optical, chemical, electrical?
- projected volume
- price goal
- your timing

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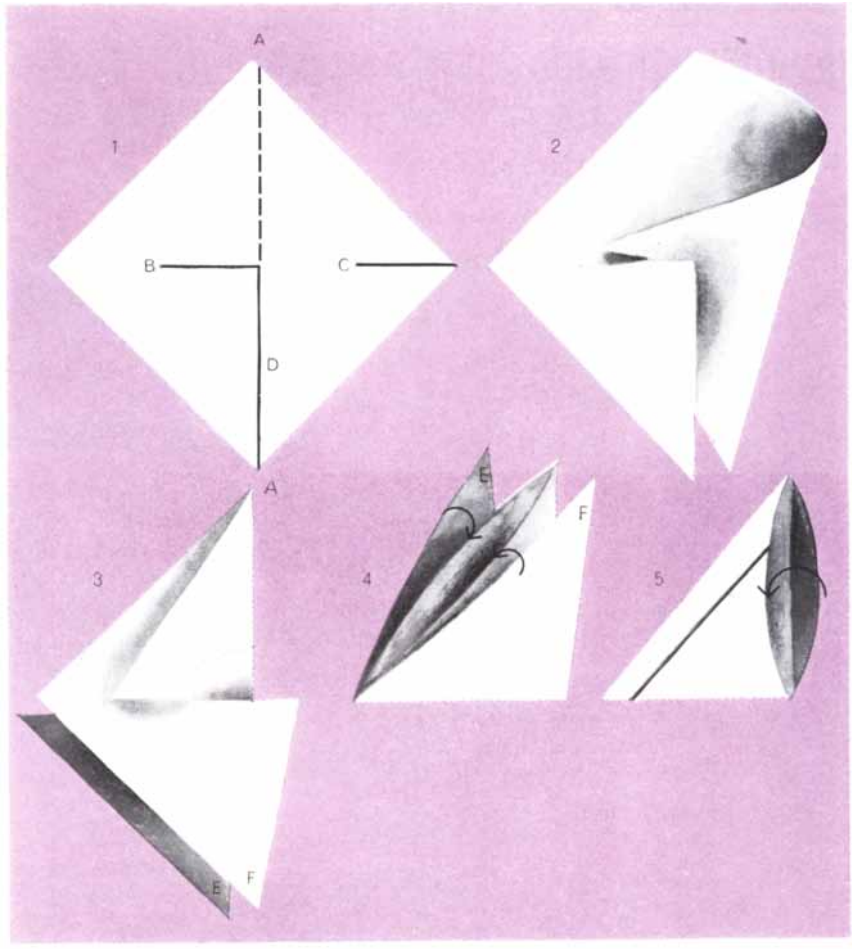

Folding a cross-cap and projective plane from a square

tially self-intersecting, but you can slide each strip out of its half-slot and close the slot, which is not supposed to be there anyway.

If the bottle can be cut into a pair of Möbius strips, of course the reverse procedure is possible, as described in the following anonymous limerick:

A mathematician named Klein
Thought the Möbius band was divine.
Said he: "If you glue
The edges of two,
You'll get a weird bottle like mine."

Surprisingly, it is possible to make a single loop cut on a Klein bottle and produce not two Möbius strips but only one. A great merit of Barr's paper models is that problems like this can be tackled empirically. Can the reader discover how the cut is made?

The Klein bottle is not the only simple surface that is one-sided and no-edged. A surface called the projective plane (because of its topological equivalence to a plane studied in projective geometry) is similar to the Klein bottle in both respects as well as in having a chromatic number of 6. As in the case of the Klein bottle, a model cannot be made in three-space without self-intersection. A simple Barr method for folding such a model from a square is shown in the illustration above. First cut the square along the solid black lines shown in Step 1. Fold the square along the diagonal *A-A'*, inserting slot *C* into slot *B* as shown in Steps 2 and 3. You must think of the line where the slots interlock as an abstract line of self-intersection. Fold up the two bottom triangular flaps *E* and *F*, one on each side (Step 4), and tape the edges as indicated.

The model is now what topologists call a cross-cap, a self-intersecting Möbius strip with an edge that can be stretched into a circle without further self-intersection. This edge is provided by the edges of cut *D*, originally made along the square's diagonal. Note that unlike the usual model of a Möbius strip, this one is symmetrical: neither right- nor left-handed. When the edge of the cross-cap is closed by taping it as shown in Step 5, the model becomes a projec-

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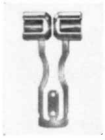

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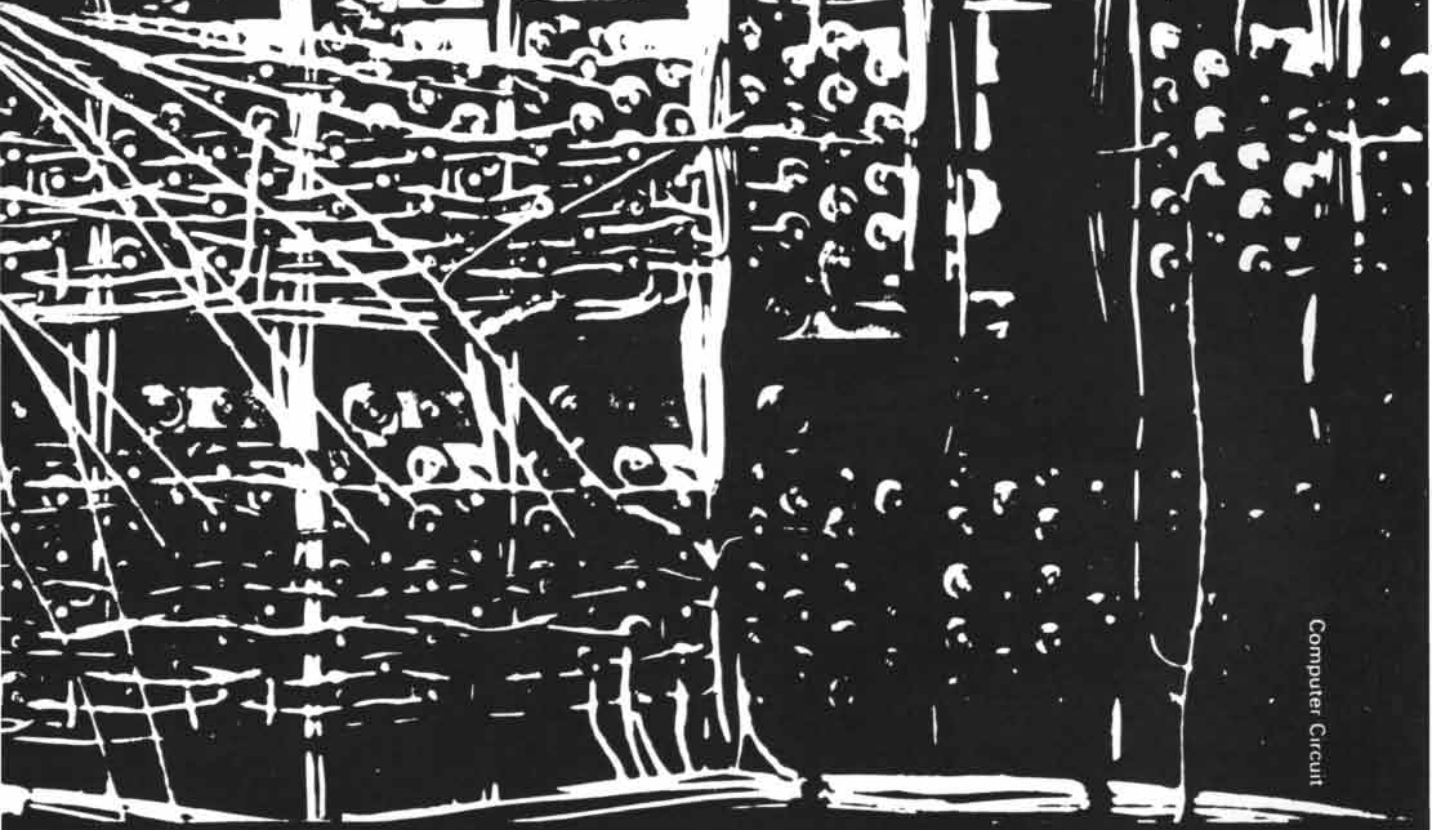

Computer Circuit

Lincoln Laboratory, a research center of the Massachusetts Institute of Technology, conducts investigations in advanced electronics directed toward the solution of problems of national defense and space exploration. The *General Research* program provides a background of experience and ideas for programs concerned with specific defense and space problems, as well as a continuing source of contributions to electronics science and technology. All qualified applicants will receive consideration for employment without regard to race, creed, color or national origin. Lincoln Laboratory, Massachusetts Institute of Technology, Box 18, Lexington 73, Massachusetts

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tive plane. You might expect it to have a Betti number of 2, like the Klein bottle, but it does not. It has a Betti number of 1. No matter how you loop-cut it, the cut produces either two pieces or a piece topologically equivalent to a square sheet that cannot be cut again without making two pieces. If you remove a disk from anywhere on the surface of the projective plane, the model reverts to a cross-cap.

The chart at the right summarizes all that has been said. The square diagrams in the first column show how the edges join in each model. Sides of the same color join each to each, with the direction of their arrows coinciding. Corners labeled with the same letter are corners that come together. Broken lines are sides that remain edges in the finished model. Next to the chromatic number of each model is shown one way in which the surface can be mapped to accommodate the maximum number of colors. It is instructive to color each sheet as shown, coloring the regions on both sides of the paper (as though the paper were cloth through which the colors soaked), because you must think of the sheet as having zero thickness. An inspection of the final model will show that each region does indeed border on every other one.

Last month's problem was to determine the length of the red stripe on a barber's pole, given that the pole is four feet high and that the stripe cuts the elements of the pole (vertical lines parallel with the axis) at a constant angle of 60 degrees.

If a right triangle is wrapped around any type of cylinder, the base of the triangle going around the base of the cylinder, the triangle's hypotenuse will trace a helix on the cylinder. Think of the red stripe of the barber's pole as the hypotenuse of a right triangle, then "unwrap" the triangle from the cylinder. The triangle will have angles of 30 and 60 degrees. The hypotenuse of such a triangle must be twice the altitude. (This is easily seen if you place two such triangles together to form an equilateral triangle.) In this case the altitude is four feet, so that the hypotenuse (red stripe) is eight feet.

The interesting part of this problem is that the length of the stripe is independent not only of the diameter of the cylinder but also of the shape of its cross section. The cross section can be an irregular closed curve of any shape whatever; the answer to the problem remains the same.

SURFACE	CHROMATIC NUMBER	SIDES	EDGES	BETTI NUMBER
SQUARE (OR DISK)	4	2	1	0
TUBE	4	2	2	1
SPHERE	4	2	0	0
MÖBIUS STRIP	6	1	1	1
TORUS	7	2	0	2
KLEIN BOTTLE	6	1	0	2
PROJECTIVE PLANE	6	1	0	1

Topological invariants of seven basic surfaces

THE AMATEUR SCIENTIST

How to generate free radicals and collect them for analysis

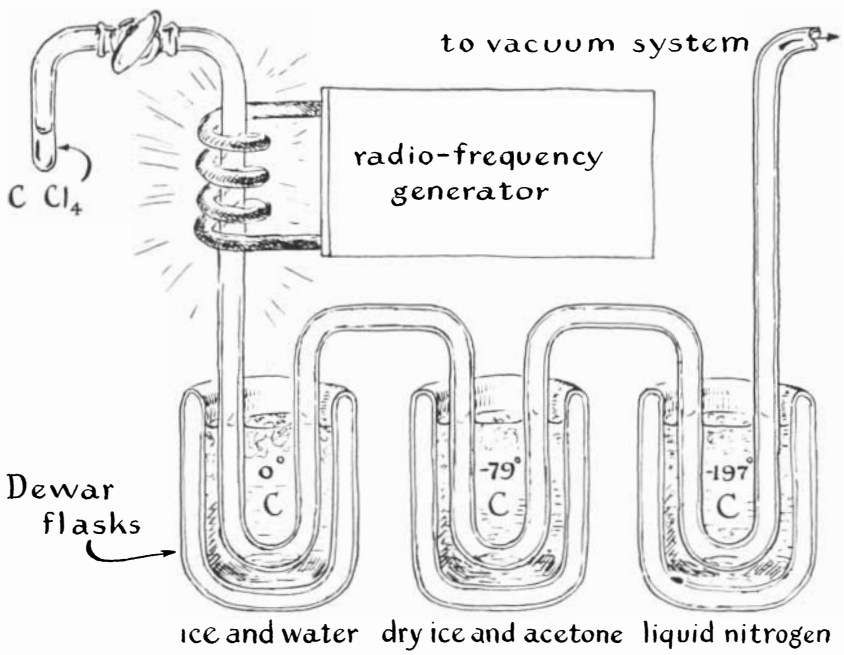
Conducted by C. L. Stong

Among the most interesting constituents of matter are the molecular fragments known as free radicals, the ephemeral debris of molecules shattered by some energetic process such as heat, ultraviolet light, chemical reaction or electric discharge. When isolated and preserved, some free radicals emit light spontaneously. Others exhibit strange patterns of spectral absorption. All are highly reactive chemically. Free radicals can be generated in quantity merely by striking a match. The flame consists of a seething atmosphere of both molecular fragments and whole molecules that continuously collide, merge, dissociate and recombine while migrating toward the cool surrounding air, where the end products of the reaction emerge as a mixture of stable molecules. At the temperature of flame and at normal atmospheric pressure few fragments escape immediate collision with their neighbors, and none survive for more than a few thousandths of a second. Although the generation of free radicals poses no difficulty, the problem of unscrambling the mixture and preserving the unstable reaction products is another matter.

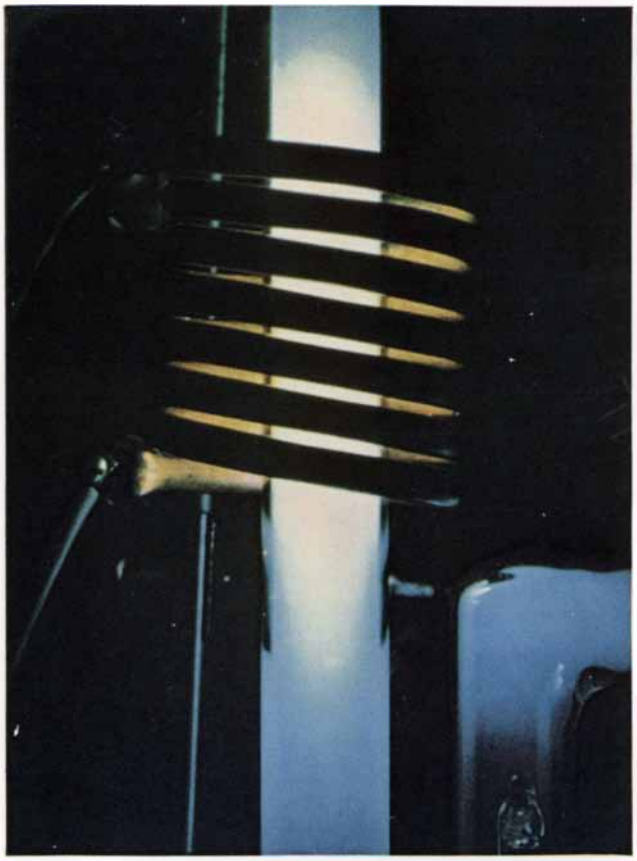
Reasonably stable free radicals were prepared by chemical methods at the turn of the century, but techniques for coping with the more interesting and reactive types are a recent development. In one ingenious procedure raw material in the form of gas at low pressure is piped through a high-frequency electromagnetic field that breaks up the molecules; the free radicals then migrate into an evacuated vessel and condense on a cold surface [see "Frozen Free Radicals," by Charles M. Herzfeld and Arnold M. Bass; SCIENTIFIC AMERICAN, March, 1957]. An apparatus based on this principle was constructed last year by Fred Swift of Maquoketa, Iowa, now a student at the State University of Iowa. Instead of using a single condensing surface Swift equipped his system with a series of three traps: U-shaped glass tubes that are maintained at progressively lower temperatures. The apparatus was constructed primarily for decomposing carbon tetrachloride into free radicals and collecting the more or less stable reaction products according to the temperature at which each condenses.

"Essentially," writes Swift, "the apparatus consists of five parts: a vessel from which carbon tetrachloride or some other compound is introduced into the system at low pressure, a tube in which the vapor is bombarded by a high-frequency electromagnetic field, the radio-frequency generator, a series of three traps respectively maintained at temperatures of 0, — 79 and — 197 degrees centigrade and a pair of vacuum pumps for exhausting the system. To make an experimental run the storage vessel is first charged with a few milliliters of carbon tetrachloride and the Dewar flasks that surround the traps are filled, in the order of their temperature, with ice water, a mixture of dry ice and acetone, and liquid nitrogen. The system is then evacuated, the power is applied and the vapor of carbon tetrachloride is decomposed at controlled pressure. After the materials have reacted and condensed, all three traps are immersed in liquid nitrogen to freeze the products, and helium is admitted until the pressure of the system is in equilibrium with atmospheric pressure. The traps are then disconnected and the products are removed for analysis.

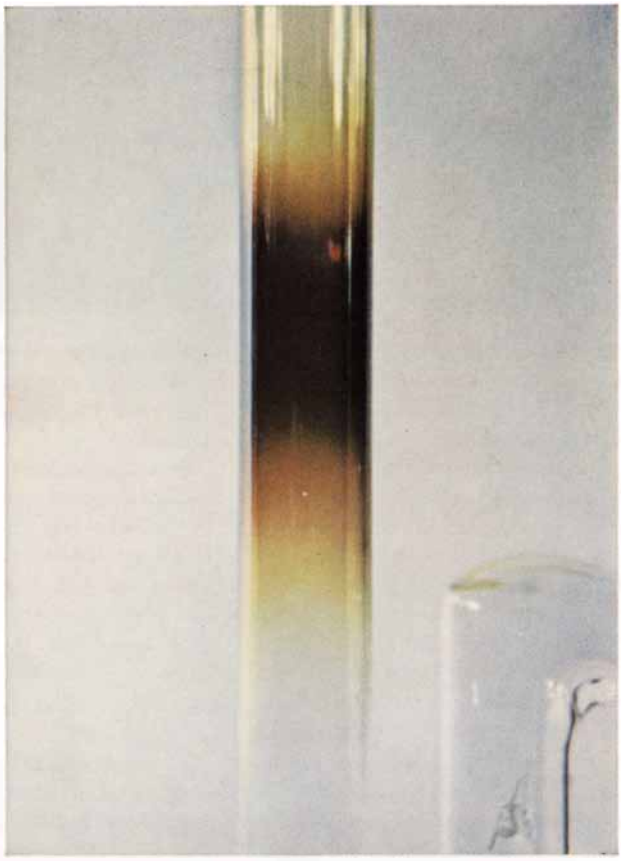
"The radio-frequency generator develops a maximum output of 600 watts at a fixed frequency of 14 megacycles. It consists of a seven-megacycle crystal-controlled oscillator, a frequency doubler, final amplifier and appropriate power supplies. The output can be continuously adjusted from 0 to 600 watts by means of a variable transformer that



Schematic arrangement of reaction system

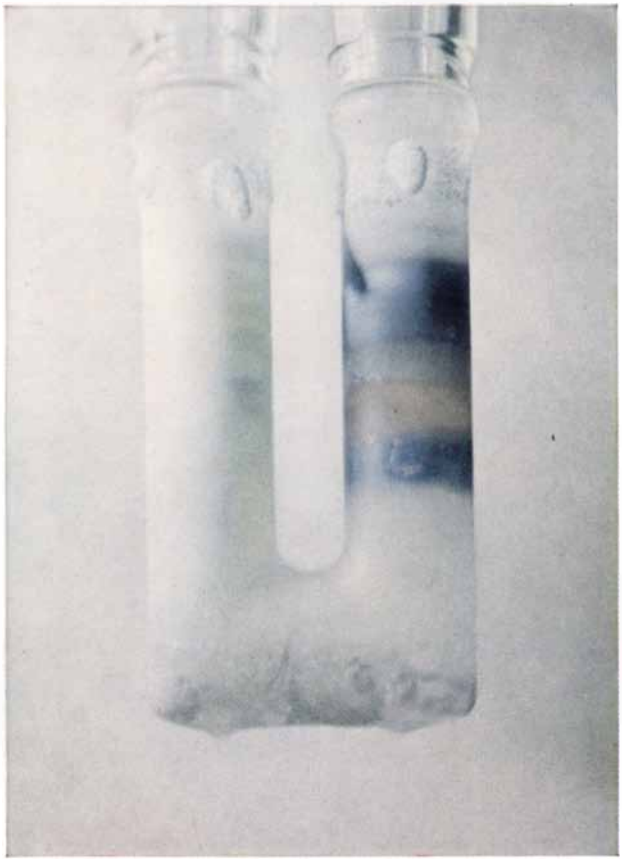


Vapor of carbon tetrachloride ionized by high-frequency field

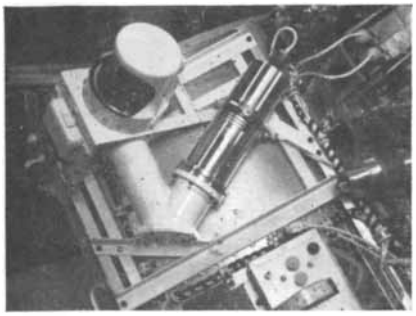


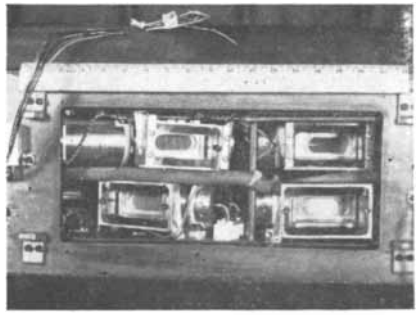
Bands of reaction products condensed from vapor at 20 degrees C.

Hexachloroethane and tetrachloroethane condensed at — 78 degrees



Dichlorocarbene and dichloroacetylene condensed at — 195





Here, in Lockheed Missiles & Space Company's Physical Sciences Laboratories, scientists are engaged in a comprehensive space physics research program embracing experimental and theoretical work in space radiation, aurora, atmospheric structure, geomagnetic micropulsations, x-ray astronomy, and the propagation of electromagnetic waves in space. Experimental programs include the measurements of geophysical and space properites, both in space and in the laboratory.

Currently, measurements of variations on the earth's magnetic field are being made at remote islands in the Pacific Ocean, providing clues to the effect of solar activity on its shape and stability. The influence of solar wind on the geomagnetic field is also being investigated in laboratory experiments, by bombarding magnetic fields with clouds of highly ionized gases.

Scientists at Lockheed are engaged in a continuing program of designing and placing density gages, mass spectrometers, ion traps, and similar instruments on space vehicles to measure the density, composition, and temperature of matter in space. These experiments lead to a better understanding of the chemical reactions occurring in the atmosphere high above the earth.

Important investigations of the low energy x-rays emitted by stars are being carried out and interpreted to give information on the structure of stellar coronas.

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Continuing investigation of matter and forces in space

energizes the high-voltage power supply for the final amplifier and can be varied through the full range of power without influencing the frequency to which the unit is tuned. The final amplifier is also designed to operate under a wide range of loads without affecting the tuning. The alternating-current output of the generator flows through a coil of copper tubing that surrounds the glass tube conducting carbon tetrachloride from the storage vessel to the traps. The ends of the coil are connected to the amplifier through capacitors for insulation from the dangerously high voltage that energizes the final stage. The electronic apparatus was made entirely from parts for amateur radio transmitters.

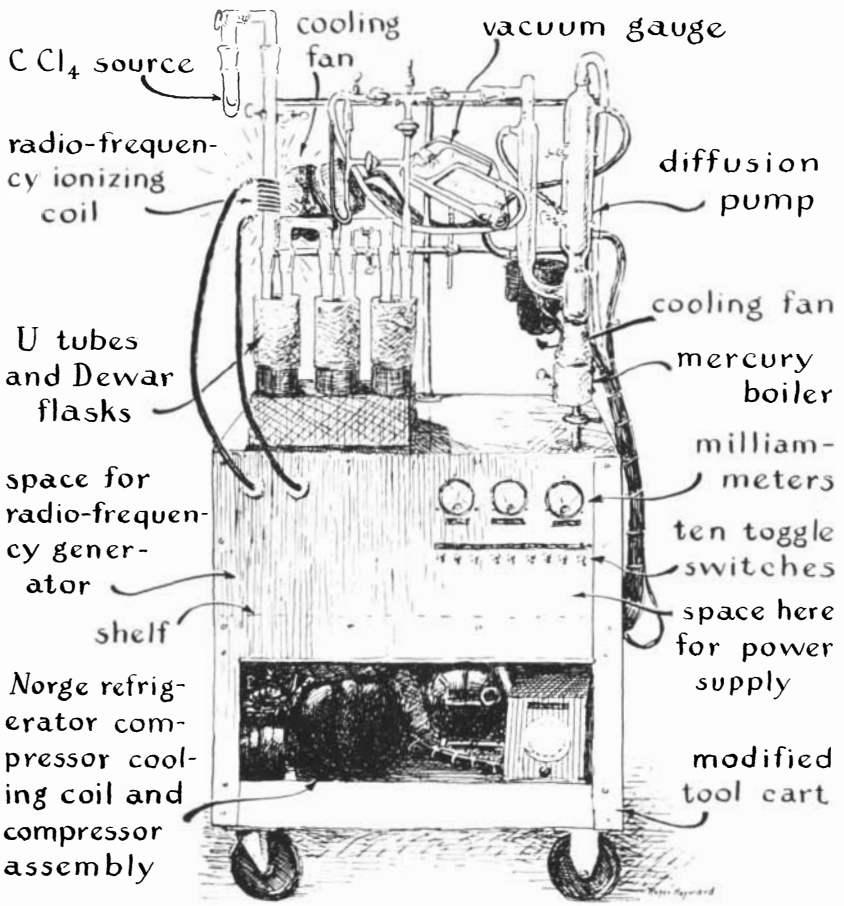
"The vacuum system includes a mechanical fore pump and a single-stage mercury diffusion pump. The fore pump was not easily acquired. I first tried to reverse a small compressor of the piston type but could not make it produce a vacuum better than 40 millimeters of mercury. The sealed rotary compressor from a Frigidaire was then converted for operation in reverse by sealing the oil-bypass line and removing the intake check valve and screens. At its best this unit produced a vacuum of two millimeters. Three Norge Rollator compressors were then converted. Two of the units had been operated with sulfur dioxide and contained a large amount of sludge. The third, in which Freon 12 had been used, was much cleaner. The oil seals on the shafts were polished with fine emery paper, all screens and intake check valves were removed and new gaskets were installed. The three pumps were then filled with Welch Duo-Seal vacuum-pump oil and tested. The unit that had used Freon performed best, producing a vacuum higher than .1 millimeter at 600 revolutions per minute. I found that refrigerator compressors are inferior to conventional fore pumps in two respects: their pumping speed at pressures below one millimeter is relatively low, and lubricant is drawn into the system when vacuum is maintained at the input of the idle pump.

"My diffusion pump is of the water-cooled type. Running water could not be used, however, because the apparatus was designed for portable operation. The pump was therefore equipped with a refrigeration unit removed from a discarded soft-drink cooler. The evaporator coil of this particular unit was manufactured as an integral part of a heat exchanger that included a second coil for cooling water. The heat exchanger was wrapped with insulation to prevent the condensation of water vapor; alcohol was circulated through it and the jackets of the diffusion pump by a small rotary pump from a washing machine.

"Pressure in the system is measured by a sealed-end manometer calibrated from 50 millimeters to one millimeter of mercury and a McLeod gauge calibrated from one millimeter to .001 millimeter. The McLeod gauge is of the Stokes type, in which mercury is forced into the capillary tubes by tilting the unit 90 degrees [see "The Amateur Scientist," SCIENTIFIC AMERICAN, January, 1959, and March, 1960]. Only the glass part of the gauge was bought. The supporting framework and bearing were improvised from aluminum strip and pipe. Pressure is determined by the McLeod gauge by first trapping part of the residual gas in a vessel of known volume, then compressing it by means of a mercury column into a capillary tube closed at the outer end. Simultaneously the mercury is allowed to rise in an identical capillary that is connected to the vacuum system under measurement. Pressure is indicated by the relative height to which the mercury rises against the gas trapped in the sealed capillary. The gauge is calibrated by determining the volume of the trapping vessel and the cross-sectional area and length of the capillaries. I made the volume determinations by measuring the amount of water required to fill the respective parts of the gauge.

"The evacuated portion of the apparatus is constructed of sections of Pyrex glass that are interconnected by tapered joints. It includes stopcocks for controlling the flow of raw material from the dispensing vessel, for connecting the vacuum gauges and pumps and for admitting air or helium to the system as desired. All joints and stopcocks are lubricated with Apiezon vacuum grease. The discharge region in which the raw material is dissociated by high-frequency bombardment consists of a straight section of tubing with an outside diameter of 20 millimeters supported near the ends so that the excitation coil of the generator can be moved to any position along the tube.

"I experienced no particular difficulty in handling the cold fluids that are used for refrigerating the traps. The liquid



Apparatus for fractionating carbon tetrachloride

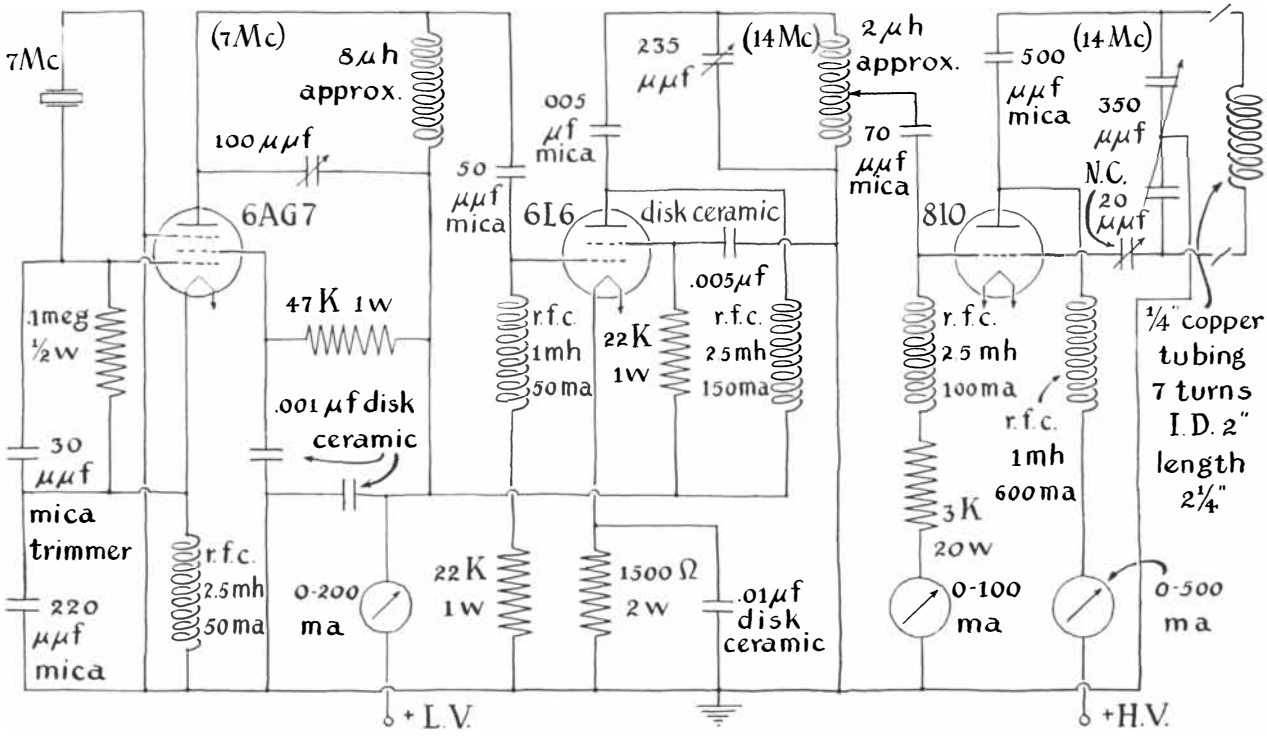
nitrogen was received and kept in a 15-liter Dewar flask. A simple dispensing apparatus was improvised out of copper tubing and a small air compressor for transferring liquid nitrogen from the shipping container to the appropriate trap. A long section of tubing, bent over at the top for a spout, and a shorter length connected to the air compressor were inserted in a rubber stopper that fitted the shipping container. Compressed air entering the short tube forced liquid nitrogen up through the spout as needed. I found that some care must be taken in handling dry ice and acetone. When the mixture absorbs heat too quickly, carbon dioxide forces acetone out of the container, damaging the equipment and presenting a fire hazard.

"To make the apparatus portable and self-contained, all the components were mounted according to function on a three-tiered tool cart 32 inches high, 28 inches wide and 20 inches deep. The cart was modified by bolting a quarter-inch steel plate to the underside of the bottom tray for extra strength and by adding a set of rubber casters. The fore pump, refrigerator system and variable transformer occupy the bottom tray. The radio-frequency unit was placed on the middle tray. The reaction system, together with the diffusion pump and necessary apparatus supports, was on top [*see illustration on preceding page*].

"A small laboratory was set up in which to analyze the reaction products. The problem of analysis consists in determining the atomic ratios of two-element compounds that can be dissolved in water and whose constituent elements are known. The major items of equipment include an analytical balance, a centrifuge and a drying oven. A used balance was obtained and renovated by cleaning the knife edges and replacing the level, which was badly corroded, by a hand level. Weights were then made up and calibrated against a set of standards. The drying oven is merely a box of sand heated by an infrared lamp. A test tube containing the sample is placed in the hot sand and its temperature is determined by a thermometer. In making an analysis a three-milliliter test tube is weighed after drying; the sample, purified by vacuum recondensation if necessary, is added and the tube is weighed again. The sample is then dissolved in water and one of the ions is precipitated.

"After being washed and centrifuged the sample is dried in the temperature-controlled oven. Because the precipitate is known, the highest temperature at which it can be dried is determined by its heat of formation. The precipitate and test tube are weighed. Since the total weight of the compound and the weight of one of its elements are determined by this analysis, the atomic ratio can be calculated. A simple formula can then be written and the substance identified. The melting and boiling points of the sample are determined by a method that requires only minute amounts of material. The sample is placed in a small capillary tube, the ends of which are sealed in a gas flame. The tube is then placed in a beaker of mineral oil and heated gradually over a hot plate controlled by a variable transformer. An electric stirrer keeps the temperature of the oil uniform. The temperature is indicated by a thermometer immersed in the oil; changes in the state of the sample are observed visually.

"A spectrophotometer has also been constructed for identifying products by their characteristic spectral absorption. Light from a tungsten lamp passes through the sample, is diffracted by a replica transmission grating and is analyzed by a photoelectric cell. The mechanical parts of the instrument were salvaged from an old spectrometer of the Bunsen type. All lenses were replaced by adjustable slits made from safety razor blades and the optical system was lined with black felt to minimize internal reflection. The spectrum is scanned by rotating the tube that holds the photocell through an appropriate angle with a motor-driven jackscrew. The output of the photocell,



Schematic diagram of radio-frequency generator

Basic Research at Honeywell
Research Center
Minneapolis, Minnesota

The Measurement of Surface Roughness by Radioactive Adsorbents

Roughness of surfaces affects several parameters including physical movement, magnetic properties and rate of reaction. Radioactive adsorbents now offer a means of accurate repeatable measurement of roughness on a molecular scale.

Scientists have long known that the degree of surface roughness has a profound effect on the physical movement between surfaces, on the physical and chemical properties of materials and on the rate of reaction with a reacting agent. If the degree of roughness could be accurately and quickly measured, the characteristics of the surface could be predicted.

The problem facing the scientist is similar to the topographer measuring a mountain range but the scientist is dealing with a molecular scale in attempting to measure the true profile of a surface.

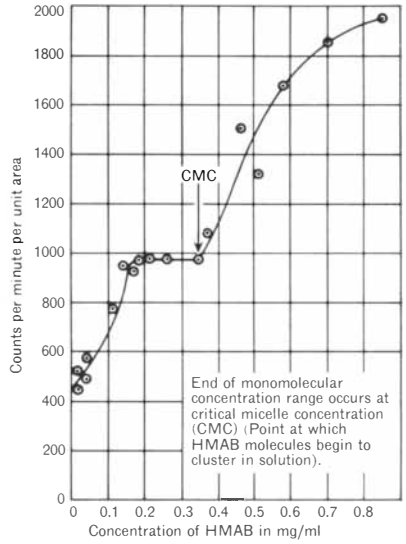
Langmuir, in 1918, discovered that certain gases were adsorbed on a surface in certain cases as a monomolecular layer. In a closed system he would measure the amount of gas adsorbed by the surface. Knowing the area of each gas molecule he could then determine the surface area. The technique was limited in its sensitivity and did not apply to multi-layer adsorption. Langmuir extended his technique to liquids when by dipping a clean glass plate in oleic acid floating on water, he found that the surface was covered with a monomolecular layer of the acid. With diffraction techniques he was able to make a rough measurement of the surface.

Today progress is being made using the new techniques of radioactive tracing.

If a species that would be adsorbed as a monomolecular layer is tagged with a radioactive material of known specific activity (number of counts per unit weight), measurement of the counts on the surface will yield the number of molecules adsorbed. Thus, as with Langmuir's technique, if the area occupied by an adsorbed molecule is known, the total surface area or roughness can be calculated.

Stearic acid was the adsorbent usually used but it would not stick on some surfaces and could not be used on many materials.

FIG. 1



ADSORPTION ISOTHERM OF HMAB ON ALUMINUM AT 25° C.

Honeywell scientists were particularly concerned with measuring the surface roughness of glass and searched for a rapid technique that would work in an aqueous solution. Since detergents are known to coat materials they were considered as a promising group to be tried. They offered wider applications and could be used on plastics, glass and metals. By varying the concentration of detergent it was found that there is a range in water at which the detergent is adsorbed as a monomolecular layer (See Fig. 1.). Hexadecyltrimethylammonium Bromide (HMAB) was chosen and tagged with C^{14}. The radioactivity of the detergent adsorbed on the glass surface was measured and from this the number of molecules on the surface was determined, and thus the area was calculated.

Accurate measurement of surfaces has led to some interesting insights into surface characteristics.

In thin Permalloy films the effect of moderate roughening did not change the coercive force. Upon further roughening, however, there was a sharp rise in coercive force.

When the surface of the substrate was varied by unidirectional scratching a phenomenon known as bi-axial anisotropy (two easy directions of orientation by a magnetic field) was noted for the first time in the material. In addition, aging of the surface was observed as the investigation proceeded.

Measurement of the surface area has also permitted Honeywell scientists to determine the effect of varying roughnesses of glass on the speed of movement of mercury — leading to predictable response in faster-acting mercury switches.

Further understanding of the effect of surface roughness is looked for as the surface area measurement techniques are refined.

If you are actively engaged in work in this field and wish to know more about Honeywell's techniques you are invited to correspond with Dr. Joseph Kivel, Honeywell Research Center, Hopkins, Minnesota.

If you are interested in a career at Honeywell's Research Center and hold an advanced degree, you are invited to write Dr. John Dempsey, Director of Research at this same address.

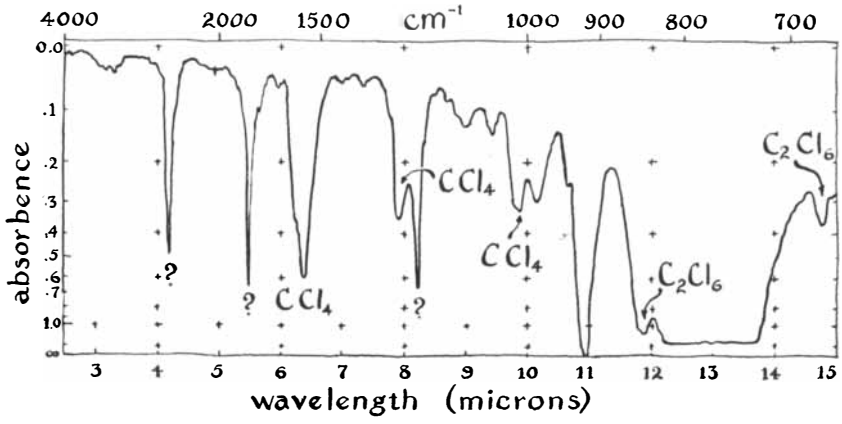
Honeywell

which varies between a tenth and a hundredth of a microampere, drives a three-stage direct-current amplifier that includes a negative-feedback circuit for minimizing both drift and distortion. Output, proportional to the spectral characteristics of the sample, is indicated by a microammeter. The characteristics of the instrument were determined by scanning the spectrum without a sample and plotting the amplified photocurrent against the wavelengths of the spectrum. This standard graph is then added to graphs subsequently made of samples in order to correct for variations in the spectral emission of the light source and the spectral sensitivity of the photocell. In addition to these instruments I had access to an infrared spectrophotometer through the co-operation of a local organization. The resulting graphs made by professional workers have been most useful in identifying some of the reaction products.

"Although the apparatus was constructed for experimenting with chemical reactions, I made a number of preliminary tests with air, mercury, helium and vaporized compounds in order to learn how the various components of the system worked physically and, in particular, to become familiar with the effects that occur in the section exposed to the high-frequency field. When an ionizing reaction is initiated in this region, at pressures that enable a gas or vapor to emit light, effects of two distinctly different types are observed. High power applied to the vapor of carbon tetrachloride at a pressure between one micron (.001 millimeter) and 50 microns of mercury causes an intense glow, rich in ultraviolet light, that fills most of the available space. The tube of the final amplifier draws a high current but the over-all strength of the high-frequency field is low. When the power is lowered, the character of the glow changes abruptly to that of a conventional high-voltage discharge and is confined to the region near the coil. The current to the final amplifier decreases and the intensity of the field increases. A discharge of the low-power type can be maintained in the case of carbon tetrachloride at pressures between .1 micron and five millimeters. Both types of discharge appear to be effective in decomposing test materials. I used the low-power type in most experiments, however, because less heat is produced by the discharge and better temperature control is possible.

"Tests were also made of various substances before I selected carbon tetrachloride for extensive experimentation. A series was run on aluminum chloride, for example. The sample had to be heated to 50 degrees C. to develop a vapor pressure high enough to sustain a glow in the high-frequency field. As the reaction progressed a yellow deposit condensed in the first trap that could not be analyzed because it decomposed on contact with the air. In addition a coarse, silver-gray powder accumulated in the first and second traps. This material appeared to be aluminum chloride that had recrystallized before entering the discharge region and had then acquired a coating of metallic aluminum. This would explain why the heavy particles were swept through the system without condensing.

"Similar difficulties were experienced with other compounds that required heating for the development of adequate vapor pressure. All recrystallized or changed in some other undesirable way when entering the lower temperature of the discharge region. The glass tubing of these sections could not be warmed conveniently because expansion induced by the heat could break the tapered



Infrared spectrogram of fractionated carbon tetrachloride

joints. This limits the apparatus to experiments with substances that develop adequate vapor pressure at room temperature.

"Other considerations also restrict the choice of specimen materials. When a compound of very low vapor pressure at room temperature is used, decomposition proceeds slowly and the yield is correspondingly small. If the vapor pressure is substantially below one micron —too low for the discharge to exist— the total pressure can be increased and decomposition carried out by admitting helium as a carrier gas. Conversely, test substances must not develop a higher pressure at the temperature of the system than will sustain ionization. Finally, the vapor pressure of the most volatile product expected must be negligible at the lowest trap temperature to prevent harmful products from entering the vacuum gauges and the pumps.

"Carbon tetrachloride meets all these requirements. In a typical experimental run the supply vial is filled, connected to the system and periodically immersed in a bath of dry ice and acetone as required to maintain a vapor pressure between two and five millimeters. The material is decomposed at a rate of about 10 milliliters per hour. The first product forms on the wall of the discharge tube, its composition depending on the temperature of the glass. At room temperature or higher the product is dark brown and nonvolatile. When it forms below 10 degrees C., it is a colorless solid that can be sublimed in high vacuum. I did not succeed in collecting enough of either substance for analysis, but they appear to be polymers of carbon and chlorine.

"A clear viscous oil collects in the first trap. The infrared spectrum of this oil is characterized by six medium-sized to high peaks at 11.8, 12, 12.3, 13, 13.4 and 13.6 microns. When the oil is allowed to stand, it crystallizes into colorless crystals that melt at between 65 and 67 degrees C.

"Two fractions collect in the second trap. The least volatile was identified as hexachloroethane from its sealed-tube melting point and infrared spectrum. The second was established to be tetrachloroethylene by comparing its boiling point and infrared spectrum with those of a known sample.

"Two products collected in the third trap, one condensing on the wall of the entering arm of the U and the other at the bottom. The first substance breaks down into a variety of substances when evaporated at room temperature followed by recondensation at — 190 de-

grees C. The principal constituents of the decomposed mixture are tetrachloroethylene and carbon tetrachloride. A small amount of hexachloroethane is also present, along with a highly volatile constituent that appears to be dichloroacetylene. The product collected at the bottom of the third trap is a pale yellow crystalline substance that melts at slightly below − 100 degrees C. and contains chlorine plus a small amount of dichloroacetylene. The mixture appears to be identical with material previously identified as dichlorocarbene. It reacts readily with air to yield phosgene, and on being stored at room temperature it yields a mixture of compounds, chiefly hexachloroethane.

"The mixture of all fractions collected in the third trap was aged for two months in a sealed ampoule free of oxygen. Infrared spectra of the decomposed residue indicated the presence of hexachloroethane and possibly a small quantity of hexachlorobenzene. No tetrachloroethylene could be detected in spite of the fact that it is one of the products of the material that condenses in the entering arm of the third trap.

"The positions of the traps and relative variations in the temperatures of the interconnecting tubing have a major effect on reactions. Condensation in sharply defined bands is encouraged by uniform temperature in a specific section and the composition and yield of products both by the velocity at which the dissociated material migrates from the discharge section to the traps and by the temperature of intervening zones.

"The technique of decomposing carbon tetrachloride by a high-frequency field appears to have several advantages over the conventional procedure of passing vapors at a pressure of one micron or less over tungsten or carburized tungsten heated to temperatures ranging from 1,200 to 2,000 degrees C. When vapors are decomposed by a high-frequency field, pressures of several millimeters and a high rate of flow can be maintained. All molecules are fragmented and the yields are much higher. In addition manipulation is greatly simplified and the process requires only a few watts of power.

"One characteristic of the radio-frequency generator was responsible for a side effect of possible interest to anyone who undertakes this experiment. The final amplifier radiates harmonics that interfere with television reception. Accordingly our neighbors firmly suggested that I find something else to do except between 1:00 A.M. and 7:00 A.M."

Remote Area Conflict

The Research Analysis Corporation has been expanding its activities in the field of Remote Area Conflict (encompassing counterinsurgency, guerrilla and counterguerrilla action and other types of irregular and unconventional warfare). As a consequence, RAC can now offer outstanding new career opportunities for work in scientific problem-solving of high challenge and complexity.

The threats and implications of Remote Area Conflict are clear and steadily growing. We must learn how to prevail decisively in wars that have no front lines, no clearly defined friendly and enemy territory . . . and to achieve objectives which are political, economic, and social as well as military.

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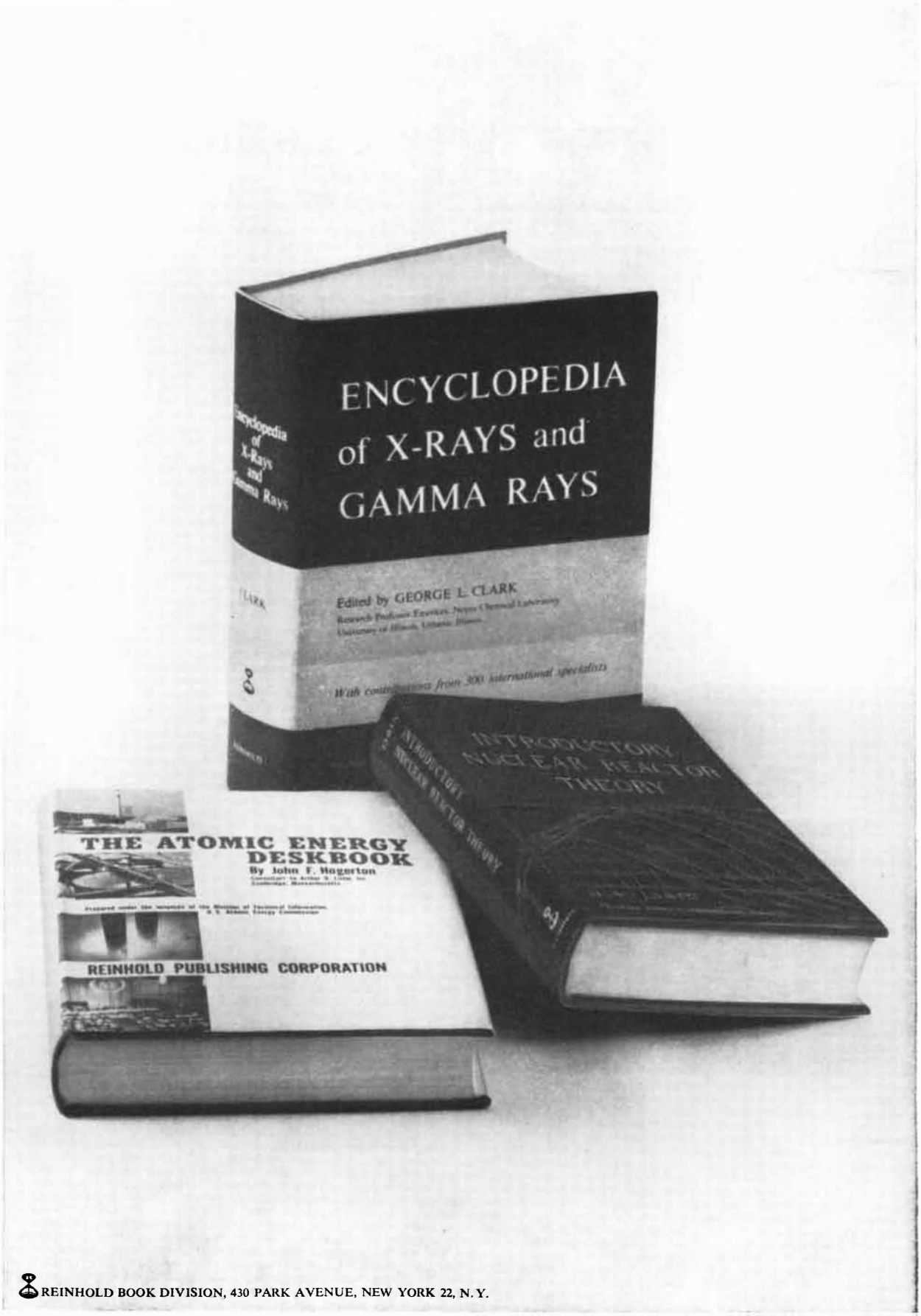

Three Significant Reinhold References on Atomic and Radiation Science.

Clark:
ENCYCLOPEDIA OF X-RAYS AND GAMMA RAYS

Edited by George L. Clark, Research Professor Emeritus, Noyes Chemical Laboratory, University of Illinois. 1963, 7 x 10, approx. 1200 pages, $35

300 specialists, representing the "who's who" of radiation science, have pooled their vast wealth of experience to produce this major scientific encyclopedia, under the editorship of a professor with more than forty years in the radiation field.

The 350 articles included represent many areas of this tremendous subject, by authors from all parts of the world. Many are from colleges of medicine and dentistry; others are from hospitals, clinics, research institutes, and government agencies involved in atomic energy research. The book includes such recent topics as atomistics, nuclear materials and reactors, space, missile, aeronautical, astrophysical and astronautical projects. The more conventional types of industry are represented by scientists writing on alloys, automotive materials, light elements (e.g., beryllium, magnesium, carbons), cement and other building materials, chemicals, clay products, electronics, foods, drugs, polymers and plastics, and many others. The most advanced stages, mathematical and theoretical, of such widening and deepening segments of knowledge as McLachlan's Information Theory, Bonart's Fold (Faltungs) Integrals and the Paracrysalline State, Hauptman's Phase Problem, and Rudman's Line Breadth Analysis, are covered in this important book.

The guiding principle of this encyclopedia was to cover every conceivable phase of X and G radiation. This has been achieved with the thoroughness and clarity that is the hallmark of all Reinhold scientific encyclopedias. The excellent coverage of topics in the public eye makes for reading as newsworthy as today's headlines. There is an accurate evaluation of the biological consequences on the survivors of the 1945 Nagasaki and Hiroshima atomic bombings, plus accounts of the latest strides in X-ray microscopy, flash radiography and high-speed cineradiography.

Pin-pointing specific information is easy. All articles are listed alphabetically under the key word of the title. Other significant words in the title, or important sections in the text not expressly indicated, are appropriately listed, with reference to the actual location of the article, in a continuing topical index throughout the book, in addition to a conventional index at the end of the volume.

The "Encyclopedia of X-Rays and Gamma Rays" surpasses all other printed works on the subject. Surely it is the definitive work on the half-century-old radiation field.

Hogerton:
THE ATOMIC ENERGY DESKBOOK

by John F. Hogerton, Consultant to Arthur D. Little, Inc. 1963, 7 x 10, 673 pages, $11

This is the first book of its kind on this subject, a monumental dictionary-encyclopedia that brings together in one volume more than 1000 subject entries on the principles and applications of atomic energy. Major topics are covered in full length articles; definitions of terms are given clearly and briefly. All entries have been carefully reviewed and brought up-to-date just prior to publication. They are alphabetically arranged and liberally cross-referenced; two appendices permit the reader to locate specific topics quickly and easily. The Deskbook, prepared under contract between Arthur D. Little, Inc., and the U. S. Atomic Energy Commission, is primarily concerned with U. S. peaceful uses of atomic energy, but also includes information on military applications and foreign atomic energy programs. Technical Principles, Program Information, Framework of Law and Policy are thoroughly covered. Businessmen, students, scientists and engineers will find it a comprehensive reference — a unique work of vital interest on the most important subject of our age.

Isbin:
INTRODUCTORY NUCLEAR REACTOR THEORY

by Herbert S. Isbin, Department of Chemical Engineering, University of Minnesota. The Reinhold Chemical Engineering Series Consulting Editor: Charles R. Wilke, University of California at Berkeley. 1963, 6 x 9, 640 pages, $22.50

Ideal for reference and self-study, this new book on reactor theory will be an essential part of your working library. *Introductory Nuclear Reactor Theory* covers basic principles and theory in a clear and concise manner, and presents hard-to-find material on reactor dynamics, characteristic dimensions, and applications to homogeneous and heterogeneous reactors. It includes an extensive bibliography, analyses of current literature, and auxiliary material. This important work provides new insight and valuable perspective for the scientist and engineer concerned with the expanding complex of nuclear engineering.

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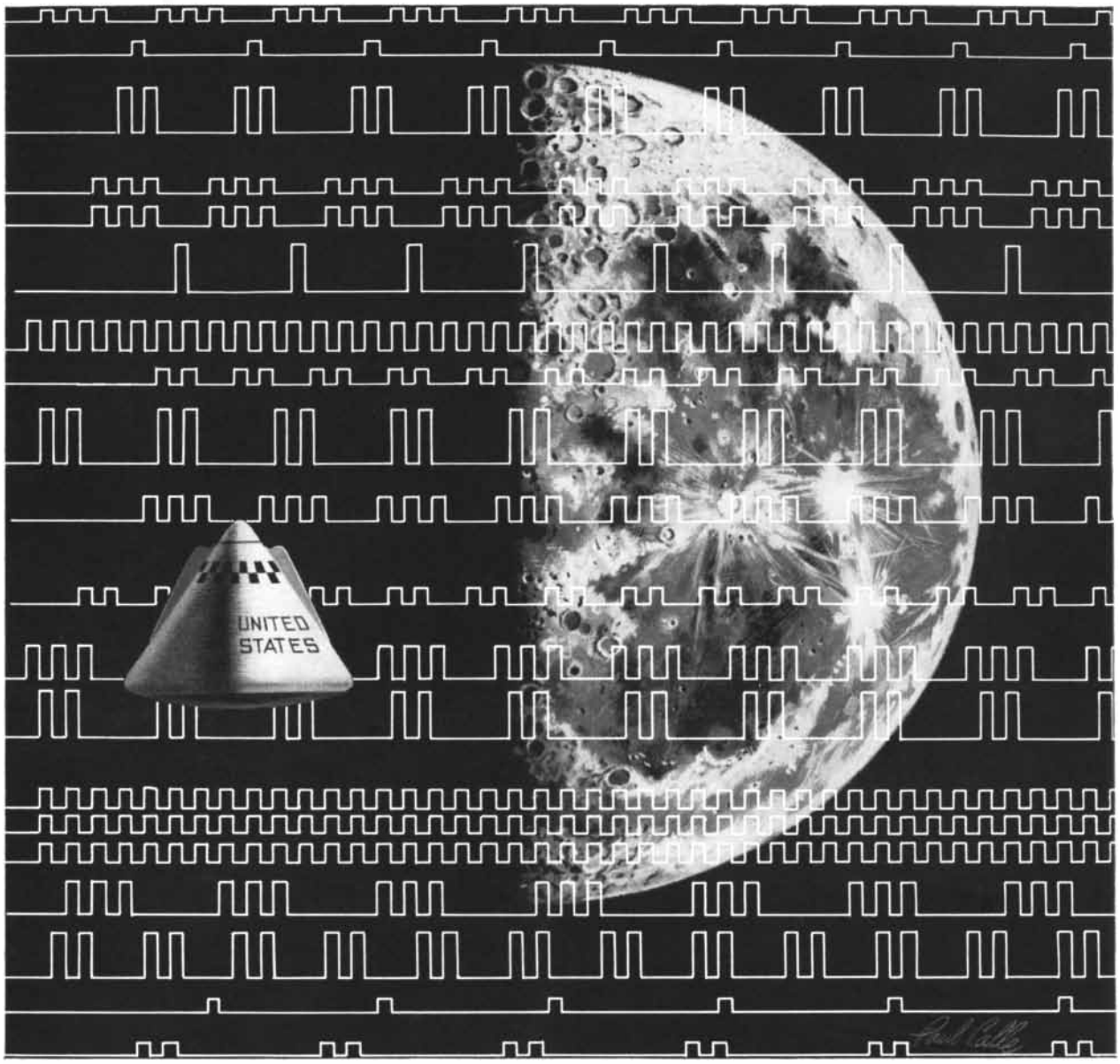

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BOOKS

An anthology of writings about psychology, including the perceptions of creative writers

by Edwin G. Boring

THE WORLD OF PSYCHOLOGY, edited by G. B. Levitas. George Braziller, Inc. ($17.50).

The World of Psychology, with its two volumes, 1,152 pages and more than half a million words, undoubtedly constitutes some kind of world, but among psychologists only those who investigate personality would think that the title is appropriate. A better name for the book would be *Personality: Facts and Models,* and perhaps for accuracy one ought to say *Literary Models.* The editor's scheme has been to set up 15 principal topics, grouped under three heads, and to reprint under each topic between four and a dozen excerpts from the writings of important authors, giving the factual accounts first and following them with the literary models. Altogether there are 88 excerpts from 86 authors, with Freud and Ernest Jones cited three times each and Aristotle, St. Augustine, Swift, Browning, Kafka and Sartre twice. Many of the selections make fascinating reading, and no wonder—one can have for the picking Henry James, William James, Proust, Thomas Hardy, D. H. Lawrence, Dostoevsky, Voltaire, William Blake and Aldous Huxley.

The collection seems designed primarily for enjoyment. It is doubtful that the publishers expect any reader (except perhaps the reviewer, poor soul) to read the collection through. They, practical men that they are, say "it is a superb book for browsing and casual reading," and indeed it is. If, however, it is wisdom as well as pleasure that you seek, then you must be your own teacher: the editor emerges only briefly with an abbreviated introduction to each topic, a Delphian prelude that leaves you guessing as to how some of the excerpts explain the topic. Still, the scheme of having the factual pieces first and the literary illustrations second suggests a didactic intent—one that could have been realized if the editor had furnished more guidance, say a total of 75 pages instead of 15. Such an addition would not have made it necessary to increase the size of these fat volumes: there are at least 60 other pages that could be omitted without loss, pages whose didactic contribution is thin enough to be negligible.

There may be some who will say that the title of this book does not claim too much, but there can be no doubt that personality is a much smaller subject than psychology. *Psychological Abstracts,* which classifies the factual and theoretical contents of psychology for the use of psychologists, uses 132 topics. *The World of Psychology* touches on 18 of them and emphasizes only four. Quite an exciting psychological anthology could be put together from the topics omitted here, but it would be one that did not lend itself to literary examples.

It is plain that the editor does not find physiology very interesting. The editor, it happens, is a woman: Gloria B. Levitas, who writes book reviews for the *New York Herald Tribune* and studies anthropology, although one would never know this from these jacketless volumes, neatly fitted into a taciturn box. Is it possible that women are less interested than men in the nervous system and the glands, the sense organs and the muscles? It would appear that Mrs. Levitas, at least, prefers to provide information about how the people who own these organs behave. She is quite well informed about psychoanalysis, and she must know a great deal about literature or she could never have coaxed all these lovely literary models out of what is to the ordinary psychologist sheer oblivion.

Is there anything in these volumes other than facts and literary models? The most factual facts that Mrs. Levitas has for us are those of Walter B. Cannon on the physiology of emotion, as he expounded them in *Harper's* in 1922. These principles are simply presented as being true. There they stand, without addition or correction. Something else, however, enters in when Ernest Jones supplements Cannon on fear, guilt and hate. His theory-infiltrated exposition, which speaks with the assurance of fact and needs a little glossary to make it intelligible even to most psychologists, is rather like a painting that an artist creates and hangs for viewing, hoping it will impart a message of truth. Psychoanalysis lacks the validity of experimentally verified fact, so perhaps one can say that *The World of Psychology* contains facts, pictures and models. A case history can also be regarded as a picture, and a number of enlightening ones are provided in these volumes.

How does the literary model work? Can one really psychoanalyze Hamlet and so learn about human nature? The novelist stores up case histories in his notebooks, his memory and his unconscious, and he writes these observations into his characters. To use a model you have to trust it, at least for the time being. So here you may trust the writer who made the model as knowing more about human nature than you do yourself; or you may rely on experts who say they find the model valid; or you may trust your own intuition that a real person would act, given particular circumstances, just about as this fictional character did. The model is the great 20th-century substitute for the 19th-century theory. It is an "as if." It does not claim to be true but asserts itself as a plausible hypothesis. It is to be used *pro tanto*—for as long as it works—and it is abandoned or modified when new knowledge makes the demand. Certainly the literary models in this book have the advantage of rendering some of the subtleties of personal dynamics explicit, even though they may represent many more mechanisms of character than are indicated by the titles under which they are subsumed. Judith Merril's Toby means something specific about the logic of childhood. Conrad Aiken's Paul makes clear something about what schizophrenia is like from the inside. And so on for at least 30 other good literary models that these volumes provide.

It is too bad that there are no citations

given for the excerpts. Even if the volumes were meant only for browsing and enjoyment and not for wisdom and instruction, there might have been this concession to scholarship—even scholars browse. It takes quite a little research to discover when a given excerpt was written. There is a list of acknowledgments at the beginning of Volume I, in small type and arranged alphabetically by publisher, but it often gives the date of a volume of collected works and it omits reference to what is already in the common domain. In general the earlier writer is represented first: Aristotle before Proust, Descartes before Pavlov, Kraepelin before Freud; but not always. Erik Erikson is put ahead of Kraepelin, Aldous Huxley ahead of Kipling, Sartre ahead of Henry James.

Had the dates been given and the historical order maintained or deviation from it explained by the editor, it would be possible to chuckle over some of the anachronisms. Mark Twain's story of how a group of people stalled by a blizzard in a train avoided starvation by cannibalism according to democratic parliamentary procedure could have been funny as an example of 19th-century humor. Poe's horror story about William Wilson is unimpressive in these post-Freudian days, when one can no longer horrify a reader simply by telling him how horrible the situation is. And is Voltaire's *Candide* amusing any more except when one considers its date? St. Augustine undoubtedly felt guilty about his boyish greed for apples and freely lets us perceive his feelings, but today he only seems naïve. Hawthorne's "The Birthmark" is 19th-century scientific nonsense and has no business here except to make a historical point. Actually it comes after Sartre's 1948 story "Intimacy," which in turn follows Maurice Vaisberg's 1961 existential account of schizophrenia. Even the great Leibniz' discussion of freedom and determinism seems unsophisticated unless it is taken in its historical perspective. Surely some of these items could have been spared.

Even more dispensable are the items that are irrelevant, trivial and unintelligible. Here nominated for exclusion as irrelevant are Lewis Carroll's "He thought he saw an Elephant/... He looked again, and found it was," presented as an illustration of how perception under attitudinal influence transcends its sensory core; Browning's "Soliloquy of the Spanish Cloister," as explaining the expression of the emotions; Yeats's "Sailing to Byzantium," as a good illustration of fatalism. Nominated as unintelligible are Kafka's seven-line fable of the mouse ill-advised by the cat, Allen Ginsberg's "Howl" and (of all things) Emerson's "Ode Inscribed to W. H. Channing." Undoubtedly these items are intelligible to people other than Kafka, Ginsberg, Emerson and Mrs. Levitas, but that they will edify the majority of the readers of this book seems highly improbable. Nominated for sheer silliness is Alan Nelson's "The Shopdropper," which concerns what happens if you get magic kleptomaniac gloves on wrong side out so that you are compelled to take things to shops and leave them there. To proceed from Aristotle to Hardy or D. H. Lawrence or Sartre makes sense—one moves from one kind of good sense to another. To move from the sublime to the ridiculous commands no attention at all.

Perhaps, however, one should consider the success or failure of the various sections of the book. The first half of the first volume is called "The Worlds of Perception" and starts off with "The World of the Child": a formal brief background by Rousseau, a splendid excerpt from the current work of Jean Piaget, which shows how the logic of the child differs from the rational life of the adult, and then a model by Judith Merril, the story of a boy who seeks to find and help his father by disastrously secreting himself in a rocket before it is launched—a moving tragedy that makes you feel the child's world is somehow right, wrong as it may be objectively.

"The Worlds of the Blind and the Deaf" shows how visual dreams persist for the blind who have had vision in early childhood, but the account of deafness deals psychoanalytically with the ear as a bodily orifice and has no place in this setting. Nor does William James's contribution about giddiness in deaf-mutes and their inability to swim under water have anything to do with their deafness, pertaining as it does to the static sense, which is also located within the inner ear. Jacob Twersky's stories of how the blind adapt to their environment are excellent, but Carson McCullers' 15,000 words on the intimacy between two deaf-mutes, one the ruling slave of the other, has little to do with the business in hand.

Taste and smell are not clearly presented because the editor suggests that smell is a degenerating sense in man, whereas a selection from George G. Wayne and Arthur A. Clinco indicates that it may be suffering from social taboo. E. B. Titchener should have been quoted here on the lack of degeneration in this wonderfully acute sense, but unfortunately he never published at length on the subject he championed so well in his lectures. Since there is little else to say on this topic, the capacity of smells to revive memories is stressed, and in this regard O. Henry's moving and tragic story of the mignonette-scented handkerchief fits in handsomely.

The next section deals with what has been called "the new look in perception": perception as it is subjectively influenced by attitude and wishes. Mrs. Levitas, however, introduces the new look by way of Francis Bacon's idols, which is just right. The last section on perception might better have been left out. It deals with extrasensory perception and paranormal phenomena: Aristotle on prophetic dreams, H. H. Price on apparitions and Daniel Defoe's story "The Apparition of Mrs. Veal." To condemn this line of intransigent wish-projection is to expose oneself to the charge of scientific bigotry, but will the long history of failure to establish rigorous conditions under which these phenomena occur never discourage those who cannot be content with a world robbed by science of all magic?

The second half of the first volume is labeled "Man and His Emotions" and begins with "The Expression of Emotions": Cannon on their physiology, Harold Jones and his wife on their maturation, Ernest Jones, as already noted, on how to obscure the issue with psychoanalytic jargon. Then we have Freud himself on humor, a bit out of the psychopathology of everyday life, and Otto Klineberg on Chinese facial expression of meanings. There are two splendid short stories, one by Graham Greene and the other by D. H. Lawrence, the former showing the irrational fear of a little boy of parties and the latter the inner life of a woman who learns of her husband's sudden death in an accident.

Next we come to the psychoses: a good case history of a schizophrenic child by Erik Erikson; the great Kraepelin's classic description of the psychoses; and two first-class stories by Conrad Aiken and Janet Frame, each depicting schizophrenia vividly from the point of view of the patient. One feels that here fiction speaks true. Then there are the neuroses: Edward Strecker's clear and excellent primer of psychoanalytic dynamics; Erich Fromm on how the child, accepting rational authority, fights to free himself from irrational authority; Gordin Raf's analysis of a case history of kleptomania; Freud on Dostoevsky; Theodore Dreiser's story "The Hand," concerning a paranoid delusion; and Dostoevsky's "The Gambler," about the

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dominating compulsion from which there is no escape.

The second volume is devoted to "Identity and Motivation" in seven sections, of which the first two illustrate determinism and freedom. Determinism is represented seriously by Plato, Descartes, Pavlov and Freud, and in literary model by Voltaire's *Candide,* Oliver Goldsmith's "Asem," Kafka's "The Hunter Gracchus" and Eugene Zamiatin's "We." Freedom on the sober side is argued by Cicero, Leibniz and Nietzsche. Mrs. Levitas thinks that existentialism carries with it a necessity to believe in freedom, and she cites Vaisberg's existential case history of a schizophrenic and Sartre's "Intimacy." Nathaniel Hawthorne furnishes a preposterous anticlimax.

There follow "The Power Seeker and the Security Seeker," "The Guilt-Ridden," "The Alienated" and "The Religious Man." For power- and security-seeking we have Alfred Adler, Martha Wolfenstein on the effects of cultural differences, and stories by Aldous Huxley and Rudyard Kipling. St. Augustine comments on guilt, Theodor Reik on myth in relation to belief, Ernest Jones on the death of Hamlet's father, and then there is a magnificent story by Philip Roth about a lawyer who, pressed into anti-Semitic action by his clients, atones for it by wearing Hasidic clothes. The best items among the seven in the section "The Alienated" are Mason Griff's analysis "The Commercial Artist," a study from real life of the opprobrium suffered by a fine artist who cannot make his living at his vocation and the counteropprobrium he dispenses when he turns to commercial art in order to live; Sartre's intimate story of the child who is developing as a Nazi and an anti-Semite; Robert Louis Stevenson's account of François Villon's code of honor as contrasted with that of a conventional warrior knight's—the two alike yet the one alienated from society and the other not; and Henry James's "The Figure in the Carpet," the story of the secret source of genius in a Great Man, a secret in whose existence his worshiping disciples so ardently believed, yet a secret that had no real existence after all.

So far the stories in the collection are either unpleasant, tragedies or centered at least on the problems and difficulties of mankind. For this same reason the psychology of personality was born as part of abnormal psychology, and the daily press stresses accidents and disasters as being what interest people most. It is easy to produce unpleasantness in the laboratory: pain or even frustration will do the trick. There is no sure way to produce pleasantness. Nevertheless Mrs. Levitas has found it possible to end her collection on a cheerful note: "The Whole Man," by which the editor means the healthy man, the emotionally mature man, the well-adjusted man, and certainly not the normal man if normal means average or most frequent. The factual side of this final exposition is A. H. Maslow's "Self-Actualizing People," people whose goal is self-realization, who have few fears, conflicts or anxieties, who perceive reality readily and vividly, who work hard for change but accept with patience the slowness of social change. The fictional model is C. E. Montague's story "Action," in which a mountain climber, a successful businessman but alone in the world, decides on suicide arranged as a mountaineering accident and then is brought back to an appreciation of living by accepting responsibility for rescuing two other climbers whom he finds on the edge of disaster. In this manner Mrs. Levitas has contrived to compile an anthology with a moral; she leaves the reader who finishes the book not mired in the Slough of Despond but safely extricated to follow the path of progress in the way only a Whole Man can.

Short Reviews

THE ARCHITECTURE OF MATTER, by Stephen Toulmin and June Goodfield. Harper & Row, Publishers ($7.50). The second book of a series—the first being *The Fabric of the Heavens*—that aims to retell the story of the evolution of scientific ideas from a fresh point of view. The authors review the various theories of animate and inanimate matter that were advanced from ancient times up to the present—the history, in other words, of physics, chemistry and biology. No attempt is made at a comprehensive chronological survey; instead, in unraveling into separate strands a tangled skein of problems, Toulmin and his wife emphasize three recurrent themes. The first is the contrast between theories that "treat the development of living creatures as the pattern characteristic of all material change, and those that find the fundamental pattern in the behavior of passive, inanimate objects"; the second is the contrast between structural and functional theories; the third is the oscillation between "atomistic" and "continuum" theories. This is a difficult plan to execute. History does not tell itself, nor does it fit tidy formulas. All the same, the book provides a frequently skillful, sometimes brilliant exposition of

high lights, turning points and breakthroughs in the growth of scientific knowledge. One is impressed by the felicity of the examples and by the lively clarity with which significant experiments and ideas are explained. The story is nonetheless uneven. Sometimes the authors stumble, and the reader is left still reaching for understanding of why a particular advance occurred at the time it did, what led up to it and how it influenced the work that followed. Perhaps too much has been attempted in a limited space. A partially impressionistic account of the evolution of ideas may produce more bewilderment than comprehension. It would be quite unfair, however, to belittle this book or to depreciate the sense of intellectual adventure and excitement that pervades it. No other history of science is so consistently challenging.

CHILDREN WHO KILL, by Lucy Freeman and Wilfred Hulse. Berkeley Medallion (50 cents). Five accounts of murders committed by young people, and one account of an unconsummated murder, psychotherapy having been successfully applied after the attempt. The "children" in the title is largely a psychological designation: two of the murderers are over 20 and the others range up to the late teens. The six subjects include middle-class as well as economically deprived youngsters, individuals of high intelligence (I.Q.'s of 118, 132 and 135) as well as of average and low-average. The authors underline the fact that psychopathology and violence express themselves in the lives of the affection-deprived whether or not they are endowed with worldly goods or intellectual gifts.

THE SCIENTIFIC PAPERS OF JAMES PRESCOTT JOULE. Dawsons of Pall Mall (10 pounds 10 shillings). A facsimile reprint of Joule's collected scientific papers, first published in 1884 by the Physical Society of London. Joule was not only one of the greatest physicists of the 19th century, particularly noted for his researches in electricity and the mechanical equivalent of heat (the physical unit of work equivalent to 10 million ergs is named for him), but also a singularly lucid writer and lecturer, so that his experimental procedures can be followed step by step and most of his papers are a joy to read.

THE LOGICAL SYSTEMS OF LESNIEWSKI, by Eugene C. Luschei. North-Holland Publishing Co. ($10). This book gives an account of the work of the

Polish logician Stanislaw Lesniewski (1886–1939), who with Jan Lukasiewicz and Tadeusz Kotarbinski founded the Warsaw center of research in logic, philosophy, semantics and the foundations of mathematics. Various circumstances, among them the intrinsic difficulty of his writings (the logician Z. Jordan, for example, has spoken of the "somewhat excruciating experience of going through Lesniewski's writings") and the effects of the war, which included not only the dispersal of the Warsaw center but also the destruction in an air raid of another Polish logician's 1,000-page manuscript that reconstructed a part of Lesniewski's systems, have made his work much less well known than that of his colleagues and pupils such as Lukasiewicz and Alfred Tarski. Lesniewski's basic achievement is described as a "construction of a completely formalized system of logic comparable in scope and power to [Whitehead and Russell's] *Principia Mathematica* as logical foundation for classical mathematics." Luschei gives an introductory review of Lesniewski's work and a technical exposition of the "complete architectural blueprints" for his standard logical systems.

THE BEHAVIOR OF DOMESTIC ANIMALS, by E. S. E. Hafez. The Williams and Wilkins Co. ($13.50). An unendingly interesting co-operative survey of present knowledge of the behavior of domestic animals. In addition to general articles on domestication and the evolution of behavior, the genetics of behavior, the relation between physical and social environment, behavior patterns and behavioral mechanisms, behavioral pharmacology and techniques of measurement and evaluation, there are separate chapters on different mammals and birds. In these one can find information on such matters as the feeding patterns of ducks, how turkeys fight, the distress and pleasure noises made by chickens, the spatial orientation of cats, the learning capacity and social hierarchy of dogs, the vices of horses and their methods of communication, the love life of swine, the play of cattle, the polygamy of rabbits and the tendency of whole rabbit populations to behave like lunatics by frisking and leaping in the air, kicking their legs, rolling on their backs and throwing themselves against one another. Photographs and diagrams.

ANIMAL DISPERSION IN RELATION TO SOCIAL BEHAVIOR, by V. C. Wynne-Edwards. Oliver & Boyd Ltd (55 shillings). This large, learned and well-argued book advances and supports by examples a grand generalization about biology that, if true, is of the highest importance. Very briefly, the argument runs along these lines. It is an accepted belief, following Malthus and Darwin, that the upper limits of various animal populations in any region are fixed by the total available food supply. A variety of factors can of course intervene to increase or decrease the supply, to select animals that possess an advantage over others in obtaining food, in doing with less, in finding substitutes, in enlarging their food-gathering domain and so on. But it seems almost a truism that when there is not enough food to go around, some members of the population will die of starvation. Wynne-Edwards introduces an intriguing modification of this view. If, he says, animal populations were limited primarily by the blind and brute mechanism of starvation, this would lead to innumerable instances of "hopeless instability," to sudden and precipitous falls in animal populations after the actual starvation point had been reached. Such catastrophes, it is said, occur only rarely; thus a strong prop for the accepted theory is removed. Instead, he suggests that the higher animals, particularly the vertebrates and insects, live in "sufficiency" rather than always on the edge of poverty; that they are able to control population densities in order to achieve this balance; and that their method of achieving it is to substitute "conventional goals of competition—territorial rights and social status—in place of any direct contest for food itself." In short, by their social behavior they are able to match their numbers to the available food supply. Many examples are given from different parts of the animal kingdom to support the theory; also discussed are various supplementary topics bearing on the central theme, such as methods of communication among animals, migrations, longevity, mimicry and cannibalism. Biologists will undoubtedly have much to say about Wynne-Edwards' generalization, and even the ordinary reader can find points where the chain of argument does not hold together as well as could be wished. But this is a readable book with an engrossing theme and it deserves serious attention.

EARLY AEROPLANES: 1907–18, illustrated and described by Roy Cross. The Stephen Greene Press ($18). An attractive color-plate book that portrays leading examples of early airplanes. A brief descriptive essay accompanies each illustration. In the group are the Wright Flyer of 1907; the fragile 25-horsepower Blériot XI of 1909, the first plane to fly across—or perhaps one should say to cough its way across—the English Channel; the 50-h.p. Antoinette, which had an eight-cylinder steam-cooled Vee engine with an array of pipes reminiscent of a small church organ; the 1910 Light Henri Farman, which looked like a cross between a water bug and a bathtub; the motley of military craft, which began to resemble modern planes, that were flown during World War I. Among the last were the Albatros Scout, the Sopwith Camel (which had a service ceiling of 18,000 feet), the 220-h.p. Spad S.13, the famous 1918 Fokker D-VII and the immense and clumsy Handley-Page 0/400, which had two 12-cylinder, 360-h.p. Rolls-Royce engines and could carry a bomb load of 16 112-pound bombs—a forerunner of the bombing craft of our own age.

MOUNT EVEREST: FORMATION, POPULATION AND EXPLORATION OF THE EVEREST REGION, by Toni Hagen, G.-O. Dyhrenfurth, Christoph von Fürer-Haimendorf and Erwin Schneider. Oxford University Press ($8). The contributors to this volume, first published in German in 1959, present a detailed picture of the highest point on the surface of the earth, once known as Peak 15 but later (1856) named Mount Everest after Sir George Everest, the head of the Survey of India from 1823 to 1843. Hagen, a geologist who has lived for many years in Nepal, discusses the evolution of the mountain; Dyhrenfurth, a geologist, geographer and pioneer of Himalayan exploration, chronicles the ascents of the peaks around Everest and the final triumph of Hillary and Tensing in 1953; von Fürer-Haimendorf, professor of Asiatic ethnology in the University of London, who long sojourned in this part of the world, describes the life, habits, home and country of the Sherpas; the famous mountaineer Schneider provides a folding map of Everest based on his own cartographic researches and photographs. Included are a number of exceptionally beautiful plates and full bibliographies.

SIMULATION IN SOCIAL SCIENCE: READINGS, edited by Harold Guetzkow. Prentice-Hall, Inc. ($5.25). Simulation is a general approach to the study and use of models. The readings in this volume deal with the use of models in economics, political science, psychology and sociology, also with military and industrial operations. Within the past few years the method, which is certainly not

TO BE PUBLISHED IN SEPTEMBER, 1963: an issue of SCIENTIFIC AMERICAN devoted to the single topic of

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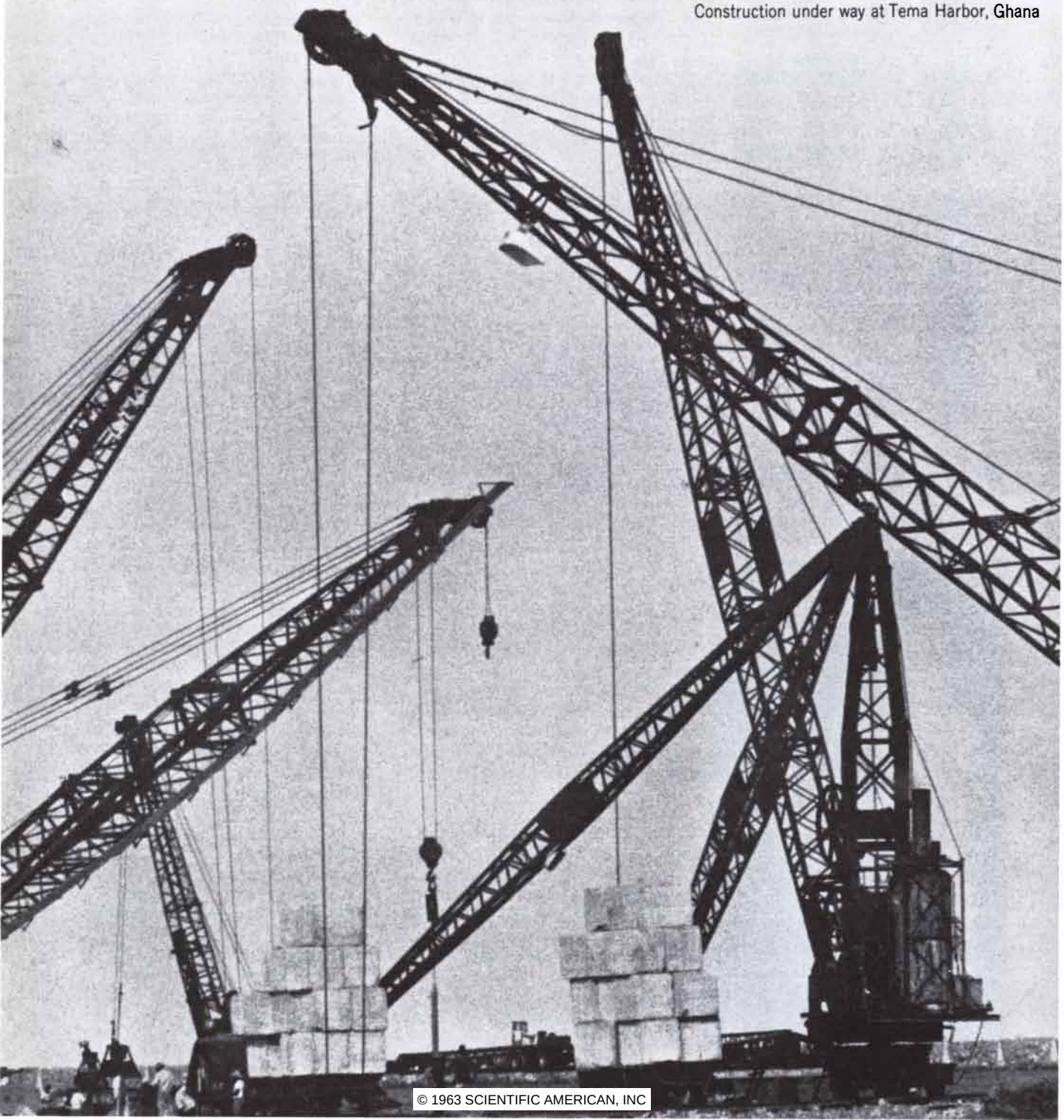

Construction under way at Tema Harbor, Ghana

new, has become fashionable and large sums of money have been spent on simulation-research programs, many of which are nebulous and pretentious. It is one thing to construct a dynamic flight simulator for Air Force training from which student pilots can learn, and quite another to attempt to simulate "thinking" by means of computers, to simulate by question-and-answer methods and by organizational models "bureaucracies," management problems and administration procedures. Among the better examples discussed in this volume is a computer simulation of peak-hour traffic in a bus terminal in which Monte Carlo methods were introduced, the purpose being to arrive at a better understanding of passenger and bus arrivals, to promote efficient scheduling in order to reduce waiting lines and to make the best use of parking facilities.

A GUIDE TO SCIENTIFIC READING, compiled and edited by Hilary J. Deason. Signet Science Library (60 cents). This paperback, prepared under the auspices of the American Association for the Advancement of Science, is a successor to the same organization's widely consulted volume *An Inexpensive Science Library*. From a list of some 18,000 paper-bound books the compilers have chosen more than 900 of the best in various branches of science and technology. Each book is succinctly described and the necessary bibliographical data are given. No one interested in science, whether student, teacher or general reader, can afford to overlook this tidy register of information about the literature of science.

A TREASURY OF SCIENTIFIC PROSE, edited by Howard Mumford Jones and I. Bernard Cohen. Little, Brown and Company ($6.75). Selections from the writings of British scientists during the first 60 years of the 19th century, at which point, according to the editors, the trend to mathematization "got the upper hand in the physical sciences" and therefore closed the door to the ordinary reader. Some 18 selections represent the writings of, among others, William Paley, Charles Babbage, John Herschel, John Dalton, Humphry Davy, Michael Faraday, James Prescott Joule, Charles Lyell, John Playfair, William Whewell, Charles Darwin and James Clerk Maxwell. Readable and entertaining but a source of at least two puzzles: why no less than two editors and an assistant (Everett Mendelsohn) are needed to put together an anthology of 365 pages with a few short notes; and why this volume, all of whose material is in the public domain, and with only a half dozen or so simple illustrations or diagrams, should cost $6.75.

THREE ESSAYS ON THE THEORY OF SEXUALITY, by Sigmund Freud. Basic Books, Inc. ($3.95). A new translation by James Strachey of Freud's three essays "Sexual Aberrations," "Infantile Sexuality" and "The Transformations of Puberty," which are thought to rank with *The Interpretation of Dreams* as the most influential of his contributions. They also provoked the most vehement opposition. The translation is based on the German sixth edition of 1925 and shows how much Freud's ideas changed over a period of 20 years, during which the essays were frequently revised. The editor has indicated with dates every alteration of substance introduced into the work between 1905 and 1925.

Notes

SCIENCE, ETHICS AND POLITICS, by Albert Szent-Györgyi. Vantage Press ($2.50). A collection of essays and lectures dealing with atomic war, disarmament and the social responsibilities of science. Szent-Györgyi has the rare ability to get to the heart of complex issues, to express himself simply, forthrightly and with warm human sympathy.

PHOTOGRAPHIC LITERATURE, edited by Albert Boni. Morgan & Morgan, Inc., in association with R. R. Bowker Co. ($22.50). A bibliographic guide to world literature in all fields of photography: technical, scientific, industrial, historical, artistic, professional and commercial.

AN OUTLINE OF EUROPEAN ARCHITECTURE, by Nikolaus Pevsner. Penguin Books, Inc. ($2.25). Now in its seventh edition, this survey keeps getting bigger and better. A hard-cover "Jubilee" edition costing $30 was published in 1960 and is still in print; this new paperback, with fresh material and beautiful illustrations, is offered at an irresistible bargain price.

BIOELECTRICITY, by E. E. Suckling. McGraw-Hill Book Co., Inc. ($8.75). A simply written book, addressed to physicians, physiologists and biologists, that explains the electrical behavior of living tissue and the methods invented to record and interpret these phenomena.

THE INTERPRETATION OF ULTRASTRUCTURE, edited by R. J. C. Harris.

Academic Press ($14). Based on a symposium held in Bern, Switzerland, in 1961, this volume, the first symposium of the International Society for Cell Biology, presents a critical analysis of current studies of the fine structure of the living cell.

STUDIES IN MATHEMATICAL ANALYSIS AND RELATED TOPICS, edited by Gabor Szegö, Jerzy Neyman and others. Stanford University Press ($10). These essays in honor of the distinguished mathematician George Pólya consist of some 60 research papers, all published for the first time, by leading mathematicians from the U.S. and Europe. The essays are as varied in content as Pólya's own contributions to pure and applied mathematics, a list of which is also included in this *Festschrift*.

THE AMAZON, by Emil Schulthess. Simon and Schuster, Inc. ($15). A photographic survey of the Amazon: the lands it waters, the mountains and forests it traverses, the people who live on or near its shores. The photographs, some in color, some black and white, are stunning; there is an informative accompanying text by Emil Egli.

PROBLEMS OF EXTRA-GALACTIC RESEARCH, edited by G. C. McVittie. The Macmillan Co. ($11). Proceedings of the International Astronomical Union Symposium No. 15, consisting of 35 papers on all aspects of present-day observational work on galaxies outside our own Milky Way system.

SYMBOLIC LANGUAGES IN DATA PROCESSING. Gordon and Breach Science Publishers, Inc. ($34.50). This book consists of 50 lectures presented at a symposium on the current and future roles of symbolic languages in the computer art, held in 1962 at the International Computation Centre in Rome.

MICROORGANISMS INDIGENOUS TO MAN, by Theodor Rosebury. McGraw-Hill Book Co., Inc. ($15). An exhaustive, scholarly review, the first of its kind, of the voluminous world literature on bacteria, fungi, protozoa and their kin; in short, of the small creatures that live on or inside us, which are either essential to our health or harmful to it.

ZUGBEANSPRUCHTE KONSTRUKTIONEN: VOLUME I, by Frei Otto and Rudolf Trostel. George Wittenborn, Inc. ($38.50). This architectural monograph deals with stressed structures that incorporate cables, nets, membranes of rub-

ber and plastic, pneumatic inflated surfaces and so on. Many descriptions, illustrations and practical computations.

FIVE FAMILIES, by Oscar Lewis. Science Editions, Inc. ($1.95). A soft-cover reissue of Lewis' moving and highly readable account of the daily lives of the men, women and children of five Mexican families.

CONTINENTAL DRIFT, edited by S. K. Runcorn. Academic Press ($12). Various contributors deal with the hypotheses of large displacements in the earth's crust. Included are such topics as paleoclimatology and continental drift, movements in the earth's crust as indicated by earthquakes, mountain-building hypotheses, thermoconvection in the earth's mantle and magnetic evidence of horizontal displacements in the floor of the Pacific Ocean.

EVOLUTION OF STARS AND GALAXIES, by Walter Baade. Edited by Cecilia Payne-Gaposchkin. Harvard University Press ($6.75). Mrs. Payne-Gaposchkin has edited a series of lectures that the late Walter Baade gave at the Harvard College Observatory in the fall of 1958. Addressed to students of astronomy, this is an informal, personal but quite technical summing up of our knowledge —to which Baade himself made major contributions, such as the discovery of two stellar populations—of the processes of development in stars and galaxies.

THE HORMONES IN HUMAN REPRODUCTION, by George W. Corner. Atheneum Publishers ($1.65). A soft-cover reissue with the original plates and diagrams of a popularization of the subject of hormone function in human reproduction. This is the kind of survey—accurate, vivid in its descriptions, lighted with imagination—that only a master can write.

A STUDY OF THINKING, by Jerome S. Bruner, Jacqueline J. Goodnow and George A. Austin. Science Editions. John Wiley & Sons, Inc. ($1.95). A soft-cover reissue of a well-received investigation of thinking, illustrated by some 30 original experiments.

THE ATOM, by Sir George Thomson. Oxford University Press ($1.50). The sixth edition, brought up to date with its illustrations redrawn and their number substantially increased, of a deservedly popular introduction to the physics of the atom.

INDEX OF ADVERTISERS

JULY 1963

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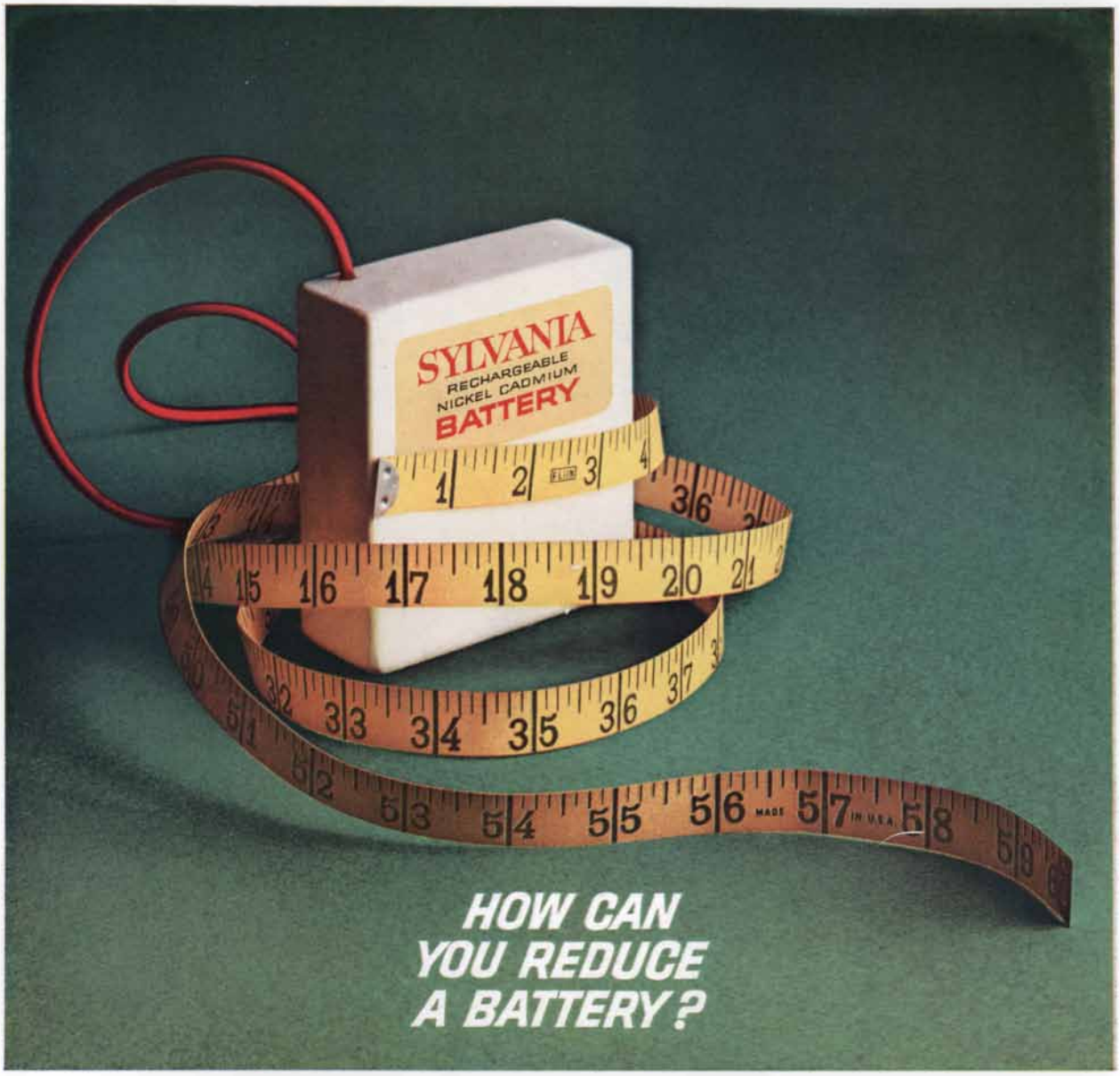

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