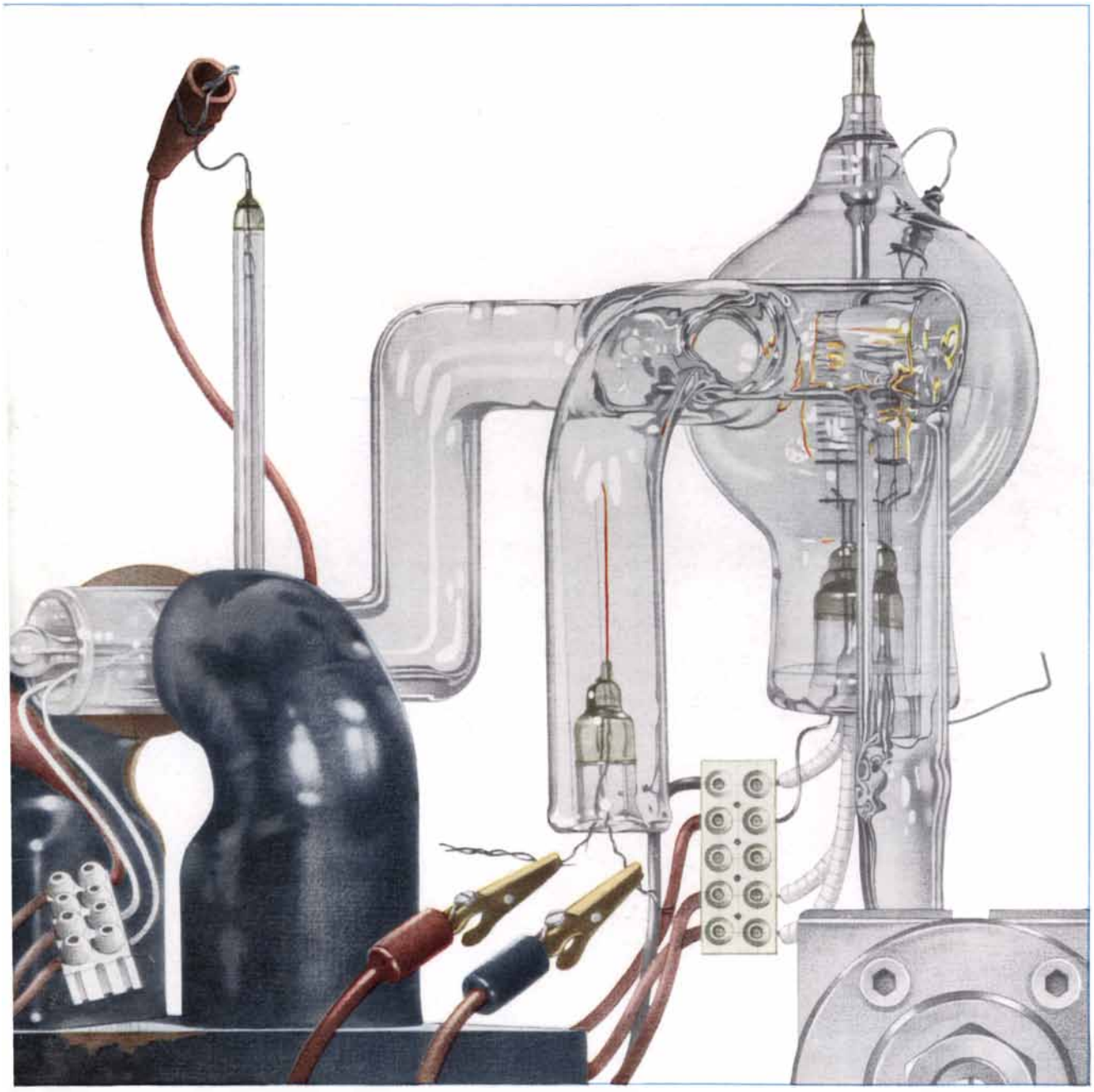
SCIENTIFIC AMERICAN



ULTRAHIGH VACUUM

FIFTY CENTS

March 1962

New satellite will peel back the sky

IBM scientists are now developing an electronic memory system for a satellite that will study the stars from high above the Earth's atmosphere.

While the sky seems transparent enough, it makes a poor window for astronomers. The atmosphere acts as a filter, blocking important information from earth-bound instruments. By putting their telescopes into orbit 500 miles above the atmosphere, astronomers hope to obtain valuable new scientific data about the age and composition of planets, stars and galaxies.

The orbiting observatory is planned for launching in 1963 by the NASA–Goddard Space Flight Center. It will contain a compact, highly reliable IBM system for processing and storing data. This system will receive radio commands from Earth, store them, and tell the observatory where to point its instruments. It will then collect the observations for periodic relay back to Earth.

Seeing the heavens more clearly will help scientists clear up many problems long unsolved. Whether you are a scientist or a businessman, IBM developments can also uncover solutions to your problems.

INTEGRATE THE DATA: this is the last lonely job in that lonely art, research. When the facts are in, there's the vital job that can be done only by a man alone with himself—interpretation. Here, the brilliant correlations, the startling insights are born. And here can lie the key to spectacular success. □ General Cable's staff is intimately familiar with the lonely art of research. Year after year, these solitary team mates report innovations in wire and cable that affect every area of society, from domestic to national defense. General Cable Corporation, 730 Third Ave., New York 17.

GCC
GENERAL CABLE CORPORATION

Established 1845 **SCIENTIFIC AMERICAN** March 1962 Volume 206 Number 3

ARTICLES

DEPARTMENTS

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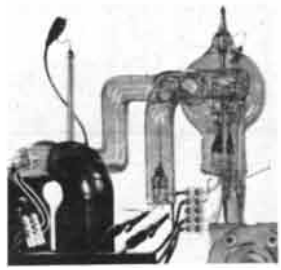

THE COVER

The painting on the cover shows the essential parts of a laboratory system for producing an ultrahigh vacuum (see "Ultrahigh Vacuum," page 78). This particular apparatus is used in the Radio and Electrical Engineering Division of the National Research Council of Canada to study the chemical adsorption of gases on metals at very low pressures. Between the poles of the magnet at left is an ionization pump that removes gas molecules from the system. The red line in the cylindrical tube in the center is a tungsten wire on which the gas is adsorbed; the wire glows because it is heated to remove gas molecules at the beginning of the experiment. The spherical bulb in the background is an ionization gauge of the Bayard-Alpert type, which is used to measure the pressure in the system. At bottom right is a metal valve through which the gas to be studied is admitted to the system.

THE ILLUSTRATIONS

Cover painting by Rudolf Freund

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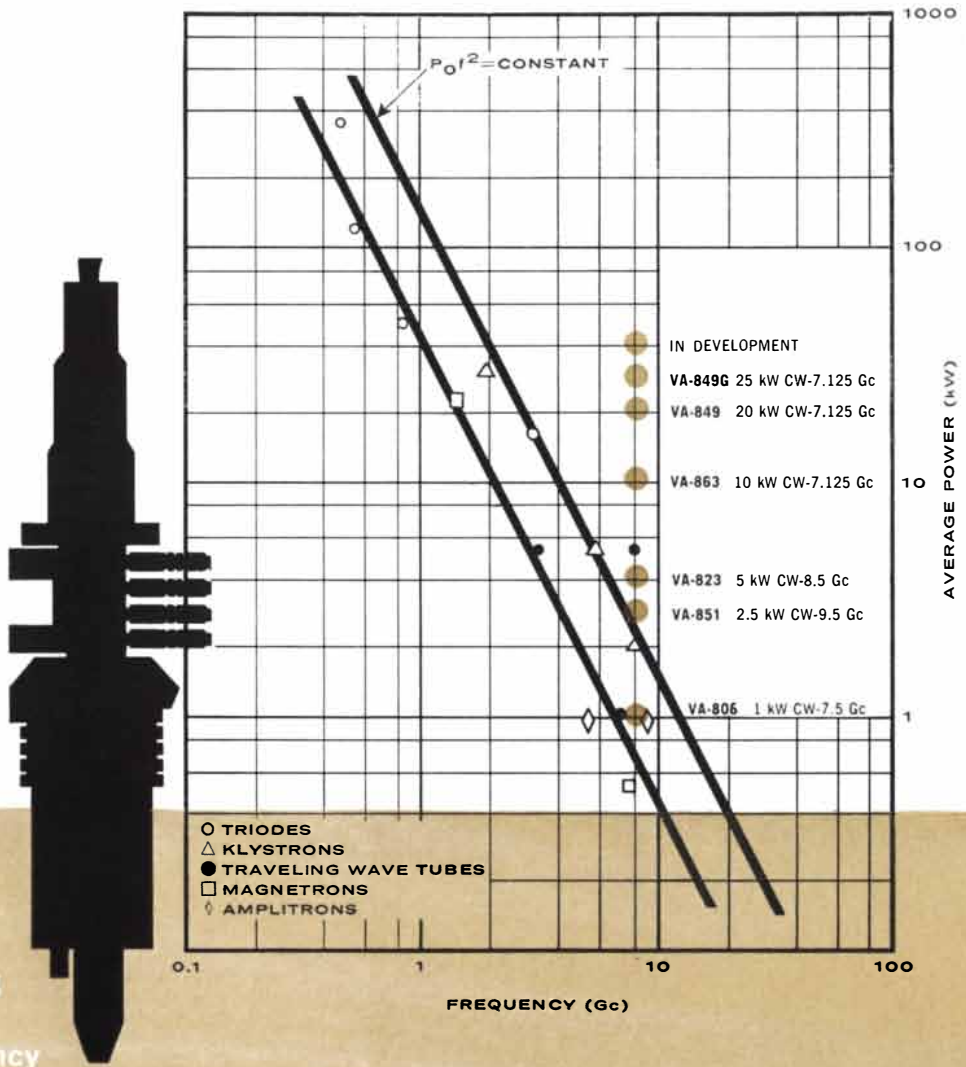
AVERAGE POWER OUTPUT AS A FUNCTION OF FREQUENCY
FOR MICROWAVE TUBES. (MODIFIED FROM NERGAARD)



Power surveys by Nergaard,* plotting power output as a function of frequency for tubes of varying powers, predicted that maximum wattage available in X-band would be less than 10 kW CW.

Varian research indicates this figure to be extremely conservative. Varian's recent introduction of the VA-849 amplifier klystron provided the industry with a tube capable of developing 20 kW CW power at 7.125-8.5 Gc. A modified VA-849 developed 51.5 kW power in the laboratory, and is now available as the VA-849G, conservatively rated at 25 kW CW. Varian accomplishments do not stop there. The company is now developing an X-band tube rated at a *minimum* of 50 kW CW.

If *your* microwave project calls for such out-ahead capability in power tube development, write Tube Division. *L. S. Nergaard, RCA Review, Dec., 1960

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PALO ALTO 7, CALIFORNIA

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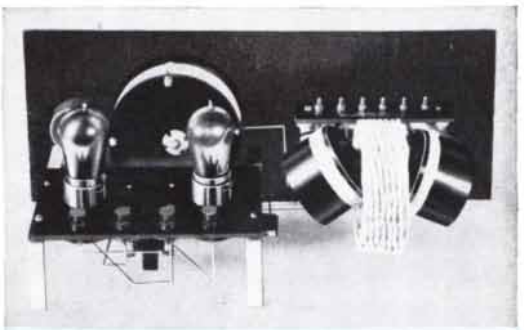
MENTAL GIANT

Inside the little device shown above is a single chip of silicon about the size of this dot: ● Built right into the chip is a complex electrical circuit—combining several transistors and resistors. A family of six of these devices can form the complete logic section of a computer. As a result, the overall size of this section can be reduced as much as 90 per cent, and the total cost as much as 70 per cent. These devices were developed—and are now produced in volume—by Fairchild.

FAIRCHILD
SEMICONDUCTOR

FAIRCHILD SEMICONDUCTOR/545 WHISMAN RD., MOUNTAIN VIEW, CALIF./YORKSHIRE 8-8161/TWX: MN VW CAL 853/A DIVISION OF FAIRCHILD CAMERA AND INSTRUMENT CORPORATION



Now a collector's item, this REL regenerative receiver of 1923/24 had one stage of detection and one of audio amplification.

FORTY

XL

40

FORTY

40

Founded in '22...Still first in '62

From that time back in the Twenties when REL achieved the first voice broadcast from a flying plane to the public (a Times Square crowd), our "firsts" fill a bulging file. Our drawing boards promise even more for the next forty years. We're charting a course to keep REL the first name in telecommunications. That's why – when you have communications problems – you should turn to REL **first!**

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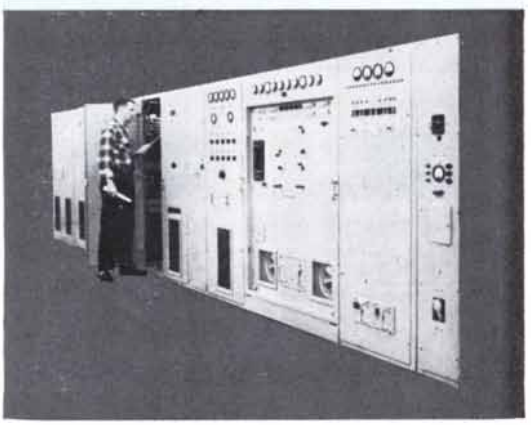
A world leader today is REL's 75 kw tropospheric scatter amplifier, many of which are in use for defense communications.

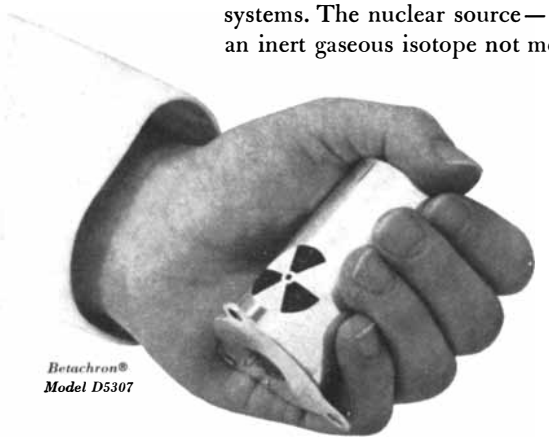


Visit REL at the IRE Show: main floor, booth 1301

Creative careers at REL await a few exceptional engineers. Address résumés to James Kelly, Personnel Director.

STATUS REPORT ON SELF-POWERED AEROSPACE DEVICES

Nuclear-Powered Components: The availability of a miniature nuclear source has made possible an entirely new genre of devices... that of self-powered components for aerospace systems. The nuclear source—the Leesona Moos Krypton 85 Battery—contains an inert gaseous isotope not metabolized by the body and quickly dispersible in air should the battery be damaged. As a result, the battery is a very practical as well as reliable unit, delivering in excess of 10,000 volts, charging linearly to 1,000 volts, and having an operating life of over ten years.



Betachron®
Model D5307

■—As would be expected, the advent of such a power source has been accompanied more recently by a new wave of components designed around it. Most of the new Leesona Moos components are aerospace-type transducers: small, lightweight, self-powered.

■—*Example I:* the Betachron® Model D5307. This is an acceleration-actuated delay timer which senses uniaxial acceleration, initiates a time delay when a certain predetermined g force has been reached, then delivers an electrical signal to the load. The time delay can be set for a minimum of 15 seconds and the maximum is limited only by duration of acceleration. Should the g level fall below the set value before the time delay is complete, the device automatically resets itself. With its highly reliable service life of 10 years, plus its unusual characteristics, the Betachron D5307 has found a number of aerospace system applications, such as data package release, parachute release, weapon sterilization, and actuation of satellite transmitters or other equipment.

■—*Example II:* The Ionoswitch™ System. This device senses altitude as a function of air density differential, initiates a time delay at the pre-set altitude, then delivers a capacitor discharge or closes a switch. It contains only one moving part and can be set for altitudes from 0 to 250,000 feet. The applications of the Ionoswitch Altitude Sensing System include stage destruct, stage separation, package release, re-entry body release, and other similar aerospace uses.

■—These are but two of a new group of self-powered aerospace devices. All are characterized by ruggedness; being unaffected by shock, vibration, or temperature cycling, and usable or storable for a period of more than 10 years, they offer a high order of reliability. Because the battery isotope is a beta emitter, only routine low-level-radioactivity handling is required. For data on these and many other novel aerospace components, both nuclear-powered and non-nuclear, write Leesona Moos Laboratories at Dept. 53.

LEESONA MOOS

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A Division of Leesona Corporation • 90-28 Van Wyck Expressway • Jamaica 18, New York • AXtel 7-4400

LETTERS

Sirs:

The work of Irenäus Eibl-Eibesfeldt on aggressive behavior of animals [SCIENTIFIC AMERICAN, December, 1961] is exciting and timely. His statements concerning the human species are questionable, however. The extrapolation of the results from animal studies to humans should be done with the utmost caution. When it is carried out, it is necessary to specify the range of generalization and limitations. Dr. Eibl-Eibesfeldt qualifies his statements about human aggression, but he is rather vague and speculative.

There are a number of studies, such as experimentally induced aggression made by social psychologists, and the numerous reports on divergent aggressive behavior in various cultures examined by anthropologists, that do not conclusively support either an innate or learning viewpoint. Similarly, studies of gregarious behavior using humans as subjects are equally inconclusive as to its origin.

I suggest that both aggressive and gregarious behavior in humans are primarily functions of learning. One of the major differences between man and other animals is the ability of man to communicate symbolically, with the subsequent establishment and transmission of sanctioned behavior. This ability, combined with the relatively long dependent period of the young human, substantially increases the role of learning in man compared with other animals. The potentialities to respond to stimuli are innate or develop through maturation, but the discriminative selection of stimuli and the mode of response appear to be learned.

Analogous to the naturalistic observations that are cited in the article, I recall my experience during a four-month period of observation in two nursery schools with children from two distinctive socioeconomic groups that are disparate in their attitude toward aggression. One group was in a nursery school sponsored by a college and consisting of children from "middle class" homes. These children exhibited virtually no incidents of interpersonal aggressive behavior; when such a rare event occurred, the teachers were quick to separate those involved.

On the other hand, the second nursery school, which was a day-care center for children of working mothers largely from a minority group and "low" socioeconomic background, was constantly the scene of multiple interpersonal aggressive behavior. In this setting the combatants were permitted to fight and the teachers intervened only when a child was in serious danger.

If one approaches the topic of aggressive behavior in humans with a learning model, I believe there is greater heuristic value as well as increased possibilities for practical application to the problems of aggressive behavior by individuals and nations.

SEYMOUR GROSS

U.S. Public Health Service Trainee
in Clinical Psychology
Minneapolis, Minn.

Sirs:

In his most interesting article on *Isimila: A Paleolithic Site in Africa* [SCIENTIFIC AMERICAN, October, 1961] F. Clark Howell speculates on the enormous quantity of stone tools found at the excavated sites: "The very profusion of the remains at Isimila constitutes a puzzle in itself. What did the people want with all those tools? . . . the quantity seems out of proportion to any conceivable need."

May I offer a solution to this puzzle—one that, I am sure, will be confirmed by the experience of many readers, not

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ACHPHENOMENON

The mind focuses upon the center cube, each face having required a distinct cut. Until that realization, the problem of proving that a minimum of six cuts is necessary to make twenty seven cubes out of one appears insurmountable. Insight, perception, Achphenomenon at work.

In our work on guidance and control systems, computers and their components, we look to engineers with ingenuity. If you're looking for an atmosphere conducive to creative thinking and the chance to explore new directions, send a resume to Mr. Nick F. Pagan, Manager Professional and Scientific Staffing.

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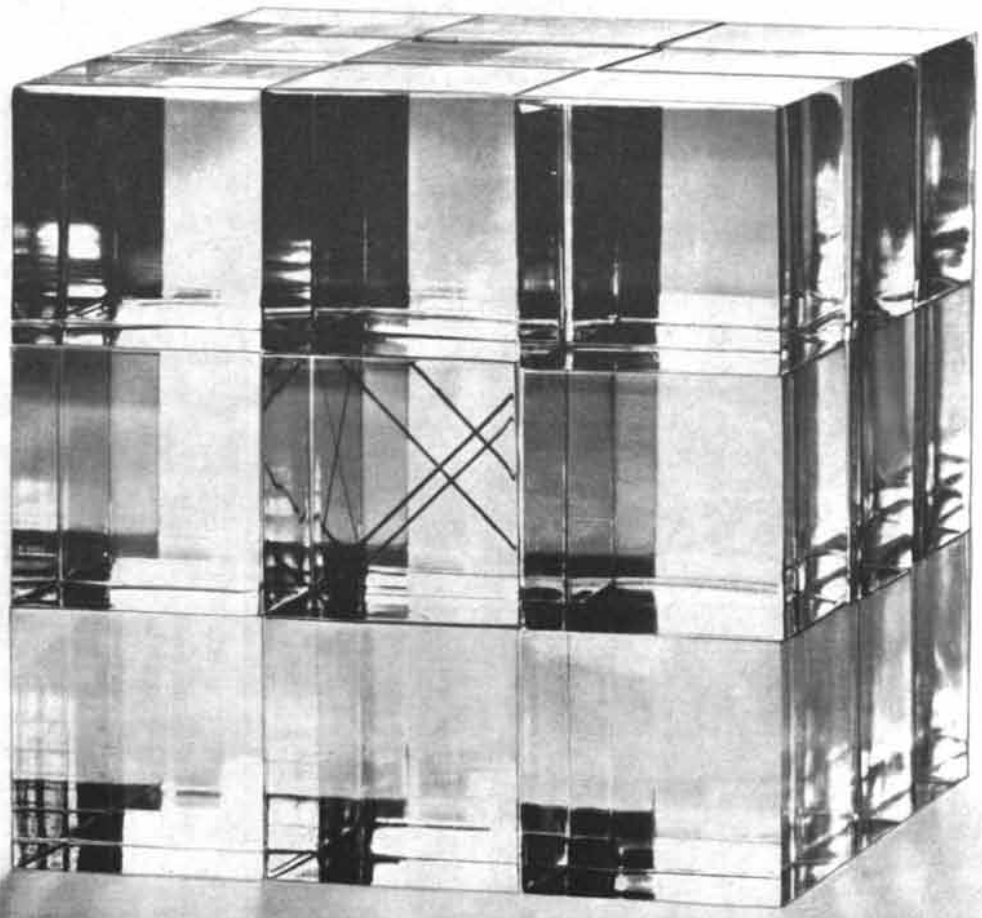

to mention that of the more advanced schools of paleolithic psychiatry.

It is a commonplace idea to the psychiatrist that when a human being, or for that matter any simian, suffers a sharp rebuff from a "superior," he may find consolation in performing a prolonged series of repetitive or routine acts. Thus a child told off by his mother may repeatedly raise a three-foot tower of blocks and laugh hysterically each time it topples and crashes; the mother told off by her husband may beat the nap off every last carpet in the house; the husband told off by his boss may line up a dozen empty whisky glasses in a row on a bar; his secretary told off in turn may sharpen 32 pencils to stiletto points.

Observation has shown that the simian drive to perform "out of proportion to any conceivable need" is greatest when the rebuff comes hard on the heels of an enthusiastic presentation of a particularly brilliant brain storm. It therefore seems fairly obvious to me that the unusually heavy output of flint tools at the Isimila sites was the result of a particularly creative strain of Acheulean tool-making artisans. Each time one of them presented a blueprint of a new model to the chief of the band, the latter must have said, "Nah! It isn't in the approved budget for the present fiscal period"—with the results that have been unearthed at Isimila by Dr. Howell and his colleagues.

M. ARRHE

UNESCO
Place Fontenoy
Paris

P.S. Further reflection has made me less sure of the validity of the above solution—not because I have found anything to disprove it but rather because I have developed two additional and equally attractive hypotheses. Both of these hypotheses depend on the assumption that Isimila was a major Acheulean armed-forces base.

The first hypothesis, to put it briefly, postulates that one of the commanding generals was bitten by the well-known stockpiling bug; the other, that Isimila was an enlisted men's replacement depot and thousands of men were kept busy there for lengthy periods while awaiting reshipment. After all, there were no cigarette butts to police in those days.

M. A.

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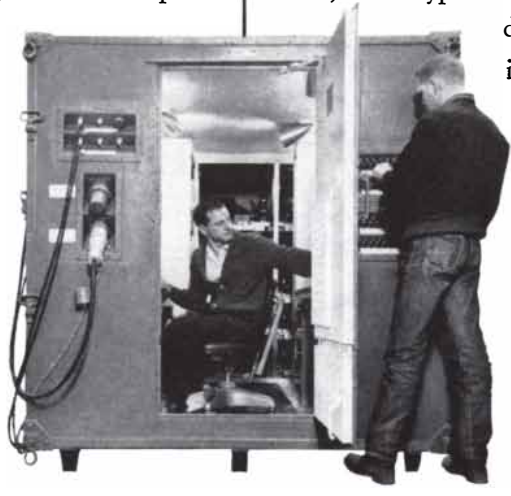

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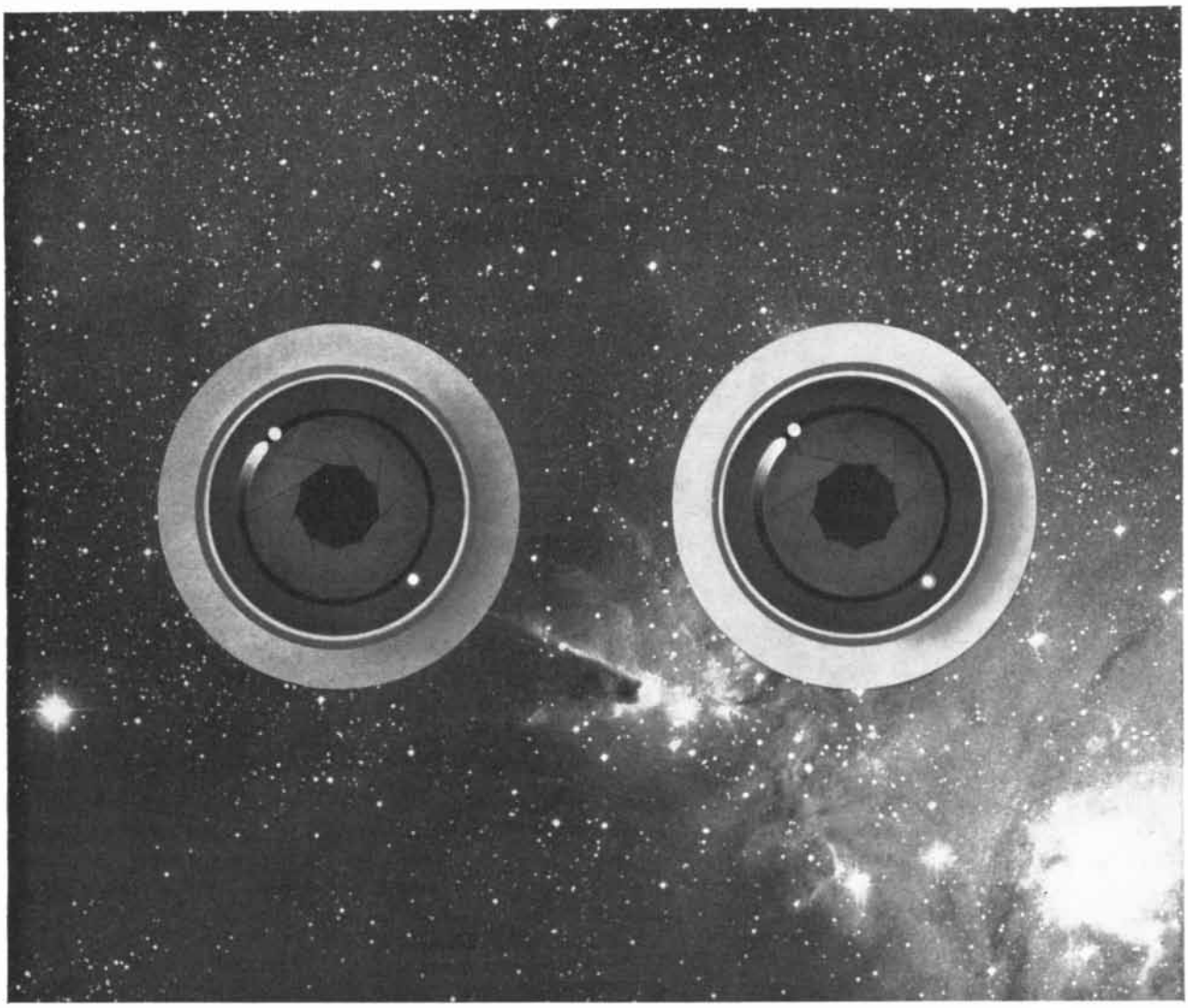

Siegler puts eyes into orbit to televise space "live"

Siegler's almost incredibly miniaturized television cameras, slightly larger than a camper's flashlight, are now designed into critical areas of space vehicles—let man *see* what happens in space, *as* it happens.

Through Siegler "eyes," ground observers can *see* fuel operation from blast-off throughout stresses of shock, acceleration and under zero gravity conditions...*see* a final stage detach or a balloon inflate and follow its performance in space visually...*see and locate* malfunction, such as a first indication of structural failure. These high reliability systems will be used more and more in missile and space programs.

In the success *or* failure of a missile or space vehicle launching, Siegler space television adds the *indispensable visual dimension*—vital *continuous* information that cannot be gained through data analysis alone.

The vital area of space television is only one phase of Siegler versatility in many fields. To today's major aerospace programs, Siegler supplies meteorological electronics including completely automatic weather stations; launch check-out; electronic communications; major space vehicle structures and many other contributions.

January 15 Echo balloon shot seen in action through Siegler "on the spot" TV

Siegler developed and produced the entire TV video system for the Echo project—camera, transmitter, receiver, monitor, kinescope, tape recorder. Observers state the TV Echo pictures were the most striking ever relayed from space.

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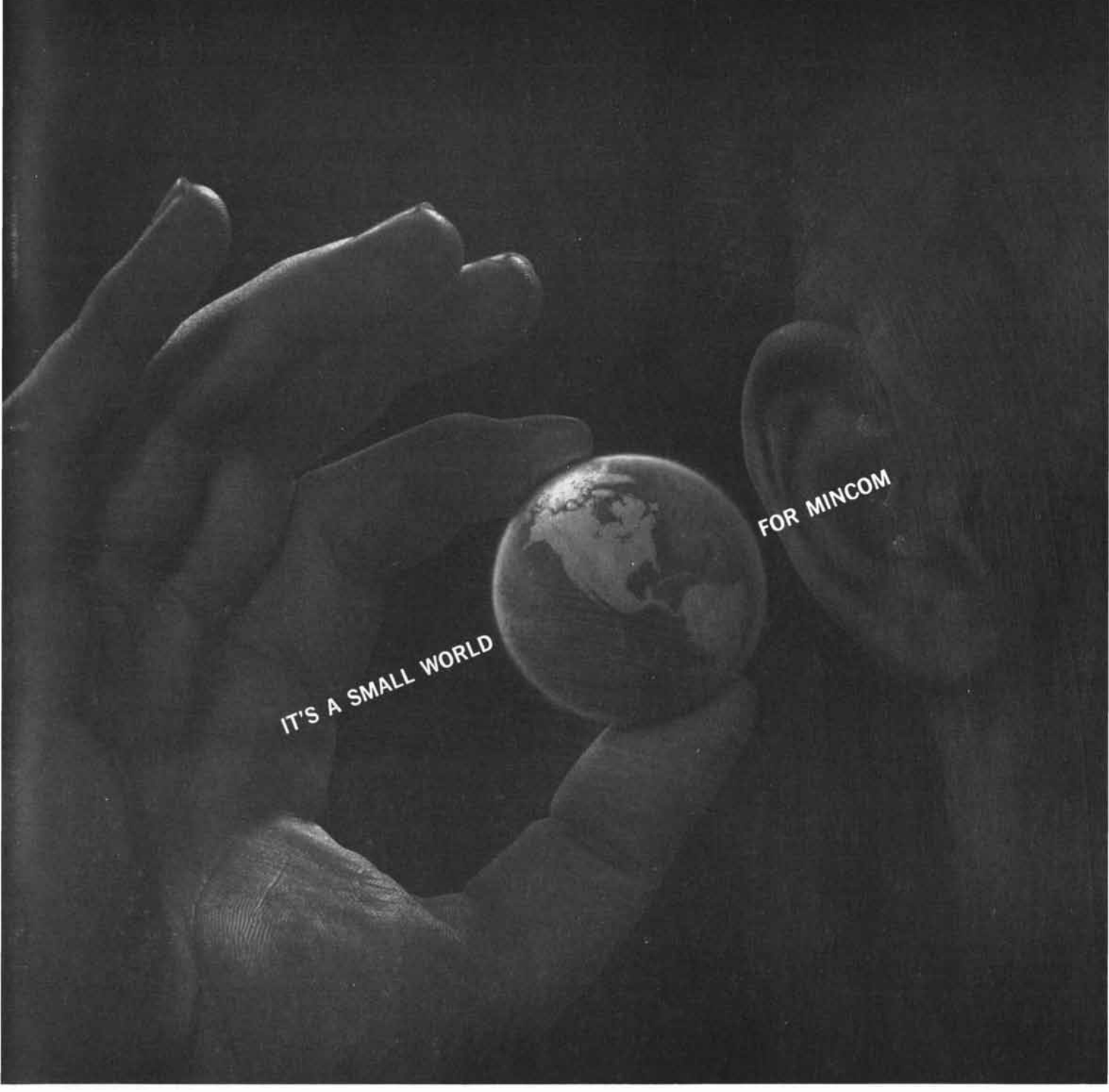

As the world gets smaller, its electronic voices grow louder. It becomes increasingly important to understand their portent.

To gather and interpret the information transmitted in these signals, Mincom provides educated ears for American and overseas listeners in facilities on many continents. These ears of Mincom are versatile and reliable—wideband magnetic-tape recorder/reproducers with an operational history second to none.

Mincom now has in quantity production four basic recorder/reproducers. Each meets a particular instrumentation requirement, ranging from 120 kc at 60 ips to 1.2 mc at 120 ips. All four utilize longitudinal recording on stationary heads for superb performance with the lowest down time average in the field.

Write today for information and specifications on:

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Mincom CMP-100	CM-100 in a mobile field unit
Mincom G-100	300 kc at 60 ips
Mincom C-100	120 kc at 60 ips

Mincom Division 3M COMPANY

Los Angeles, Washington, San Francisco, London, Geneva

The cost of miniaturization just dropped 20%

Trends can be overpowering. Once established, they're tough to reverse.

Take the cost of miniaturization, for example. As electronic packages get smaller, price tags get bigger. No one seems surprised. It's a trend.

There's a reason, of course. Tiny things are hard to build, especially within space-age reliability requirements.

Amphenol designers decided that if ever a trend needed reversing—it was this one.

"How" was another question. They knew that conventional miniaturized pin and socket connectors were about as small as they were ever going to be. The spring member in the female contact (necessary for a snug, low-resistance connection) took up valuable space and set a lower limit for practical center-to-center contact spacing. The spring was obviously holding up progress in miniaturization. It had to go.

So, it went.

►Amphenol designers developed the wire-form Poke-Home® contact, a male contact that supplies its own tension and can be crimped or welded before assembly. Overnight, contact spacing plunged from .175 inch to .100 inch. And, best of all, the new contact was less costly to manufacture. (It's built on automatic equipment.)

The trend reversal was well on its way. Amphenol designers had a new contact—the next step: putting it to work in connectors.

To answer the need for an economical micro-miniature rack and panel connector, the Micro-Rac® was unveiled. Space-saving Wire-Form contacts and an integral-body-dielectric construction made it possible to pack 20% more connections in the same space—and at nearly half the previous cost. As for reliability, after 1,000 repeated insertion and withdrawal cycles, the Micro-Rac retained its original low resistance characteristics.

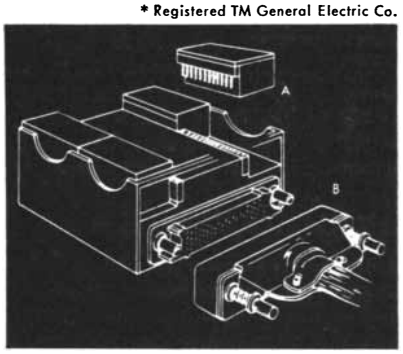
►Next came the Strip Connector, six-inch lengths of Lexan* plastic with contact holes on .100 inch centers. A do-it-yourselfer's delight, strips can be cut and stacked to suit hundreds of applications where a connector is a must—but for which no other economical connector exists. Example: strips can be stacked to form micro-miniature programming boards or instrumentation terminations. They also can be used as economical tape cable connectors, modular connectors, logic card connectors, to mention a few.

Wire-Form contacts can be used separately, too. Example: contacts can be crimped or welded to modules and plugged into special eyelet-type receptacles on printed circuit boards. Non-modular components, such as transistors, become pluggable by crimping Wire-Form contacts to their leads.

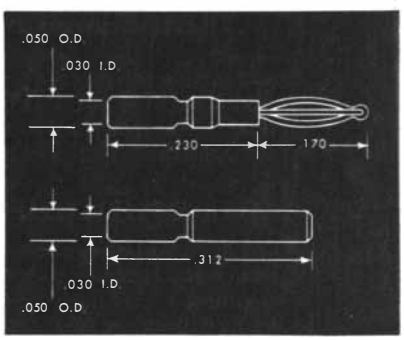
And that was that. The trend was reversed.

►If you would like more information about Wire-Form Poke-Home contacts, Micro-Rac 52- and 104-contact rack and panel connectors, Strip Connectors (or any Amphenol Connector for that matter) call your Amphenol Sales Engineer. Or, write to Dick Hall, Vice President, Marketing, Amphenol Connector Division, 1830 S. 54th Avenue, Chicago 50, Illinois.

* Registered TM General Electric Co.

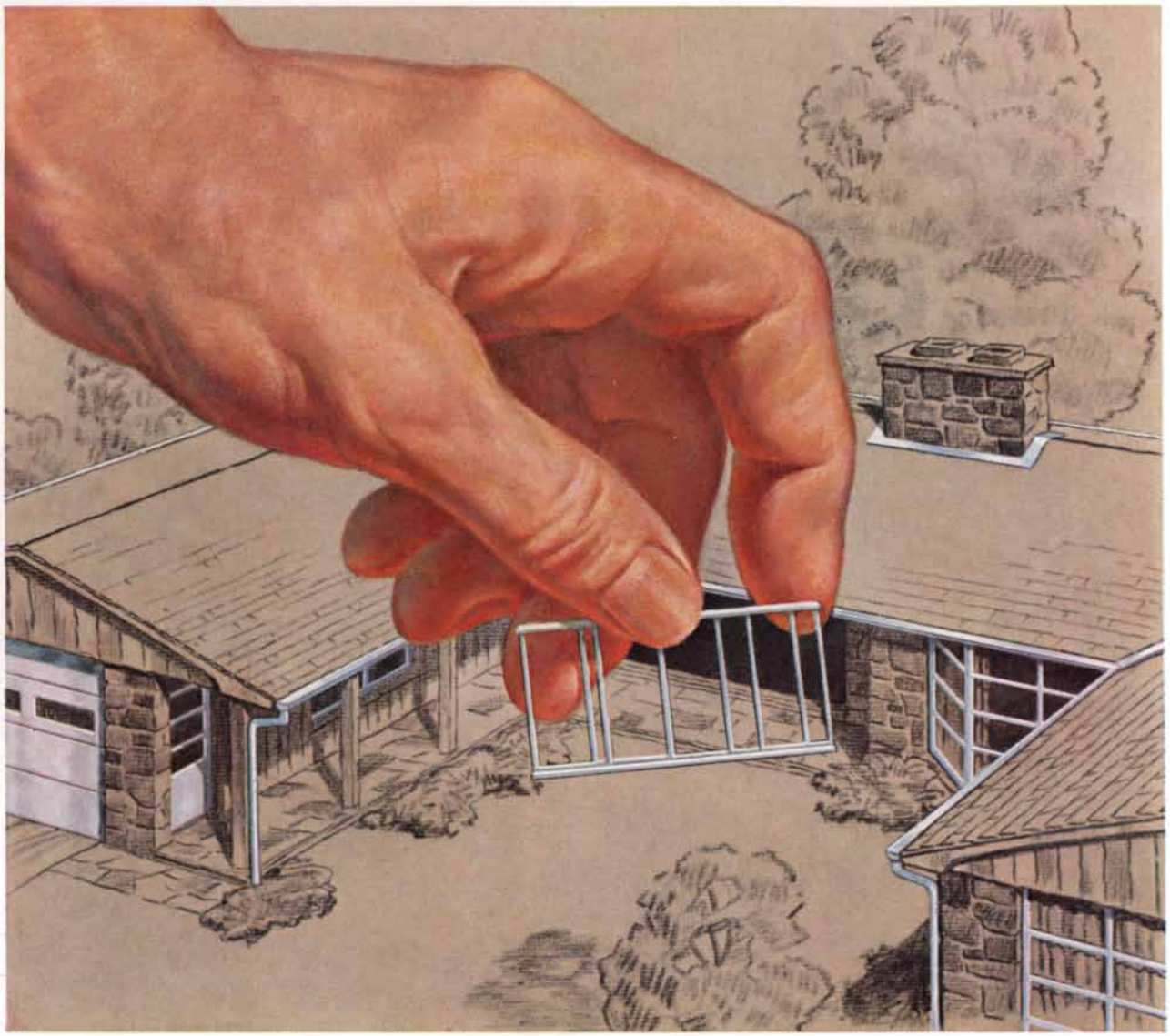


The Amphenol Wire-Form contact at work. Multi-purpose Strip Connectors (A) connect modules to chassis; Micro-Rac Connectors (B) connect chassis to cable assembly.



Acting like four spring fingers, Wire-Form beryllium-copper beam sections assure a low resistance connection (.0025 to .0030 ohm) even after 1,000 insertion-withdrawal cycles.

AMPHENOL **Connector Division** / Amphenol-Borg Electronics Corporation



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...a hand in things to come

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The men of Aerospace probe all disciplines of the space sciences. Chartered exclusively to serve the United States Government, Aerospace Corporation applies the full resources of modern science and technology to advanced space and ballistic missile systems. □ As part of the Air Force-science-industry team, the men of Aerospace evaluate and stimulate the free flow of information that results in the imaginative concepts required for national leadership in space. From concept to countdown and beyond, Aerospace provides advanced systems analysis and planning; theoretical and experimental research; general systems engineering and corresponding technical direction of programs. □ Aerospace Corporation, an equal opportunity employer, now needs more men to meet these responsibilities. Highly skilled engineers and scientists with advanced degrees, knowledgeable in interdisciplinary problem solving, are urged to contact Mr. George Herndon, Room 120, Aerospace Corporation, P. O. Box 95081, Los Angeles 45, California. □ Organized in the public interest and dedicated to providing objective leadership in the advancement and application of science and technology for the United States Government.

AEROSPACE CORPORATION

50 AND 100 YEARS AGO

SCIENTIFIC AMERICAN

MARCH, 1912: "It is much too early to give any critical account of Capt. Roald Amundsen's discovery of the South Pole. Many weeks must elapse before we are in complete possession of all his data. Yet even the laconic account that he has cabled to the press throws a flood of light on the mystery of Antarctic geography. Amundsen seems to have collected enough evidence to substantiate the theory that the great chain of mountains that extends almost uninterruptedly from Alaska to Patagonia finds its continuation in a ridge connecting Victoria Land and King Edward VII Land, which, in honor of his queen, he has named "Queen Maude's Range." The ice barrier, which had proved for a century and a half a formidable obstacle to Antarctic exploration, is found to terminate in a bay, lying between the southeast mountain range running from South Victoria Land and a range that is probably a continuation of King Edward VII Land and that extends in a southwesterly direction. Besides Amundsen's, there was the Japanese expedition under Lieut. Shirase, Dr. Mawson's Australian expedition, the German expedition under Lieut. Filchner in the *Deutschland* and lastly Capt. Scott's English expedition in the *Terra Nova,* which left New Zealand in November, 1910. The *Terra Nova* had been badly damaged by stormy weather; so badly, indeed, that the necessary repairs and the cost of making good the stores that had been lost seriously depleted the resources of the party."

"The first attempt that has ever been made to drop from an aeroplane in a parachute occurred at St. Louis on March 1. When flying with Anthony Janus in a biplane at a height of some 1,500 feet, Albert Berry climbed out of the seat and cut loose his parachute, which was suspended beneath the machine in a special case. He dropped suddenly for some 500 feet before the parachute opened, but it opened successfully and Berry reached the ground without hurt. Janus was able to control the machine when it was suddenly released of his companion's weight, and he too descended without mishap."

"The disposal of scrap iron and useless machinery that passed into the possession of the United States with the sale of the Panama Canal by the French company has netted the surprising sum of $2,112,000. In spite of the fact that a considerable amount of the French plant has been overhauled and put in service, nearly 30,000 tons of metal scrap has been shipped to the United States from the Isthmus."

"At the present time our army has but seven aeroplanes as against some 200 owned by the French war department. Recently a small appropriation of $75,000 was stopped by the Democrats in the House, whereas in France $1,500,000 has been appropriated and the government has been asked to bring the total up to $4,500,000. It is proposed to have a complete aerial regiment with 234 pilot officers, 210 observers, 42 mechanics, 1,710 noncommissioned officers and 550 privates. It is also proposed to build enough sheds to house several hundred aeroplanes. The new scheme has aroused great public enthusiasm and each city is expected to contribute toward it. Last year in the United States about $60,000 of a $125,000 appropriation was expended for aeroplanes. Germany has appropriated $4,000,000 for aviation this year, and Great Britain has set aside $800,000 for this purpose."

Scientific American.

MARCH, 1862: "On Saturday, the 8th of March, the large iron-plated rebel steamer *Merrimac* proceeded to Newport News, where some of the old wooden sailing ships of our navy were stationed for the purpose of blockading the river. After destroying the *Cumberland* the *Merrimac* turned her attention to the *Congress,* an old 50-gun frigate of 1,867 tuns. The commander of the *Congress* was soon reduced to that bitterest necessity that ever occurs in the life of a soldier, the pulling down of his flag. Most opportunely, in the course of the evening, Ericsson's iron-plated steam battery, the *Monitor,* arrived in Hampton Roads. At about 8 o'clock the next morning the *Merrimac* made her appearance. When she arrived within about a mile, the *Monitor* fired one of her guns, the shot striking the *Merrimac* but glancing harmlessly from her inclined

50,000,000 tube hours... an unusual electron tube still keeps undersea voice signals strong

Deep on ocean floors, from North America to Europe, between Key West and Havana, Florida and Puerto Rico, under the Pacific to Hawaii and Alaska—in 20,000 miles of undersea telephone cable—a special kind of electron tube is setting a remarkable record for reliability.

This four-inch-long electron tube was designed, developed and fabricated at Bell Telephone Laboratories to operate with no attention for 20 years or more. It is part of the submarine cable repeater manufactured by Western Electric which faithfully and reliably amplifies voice signals transmitted along undersea coaxial cables.

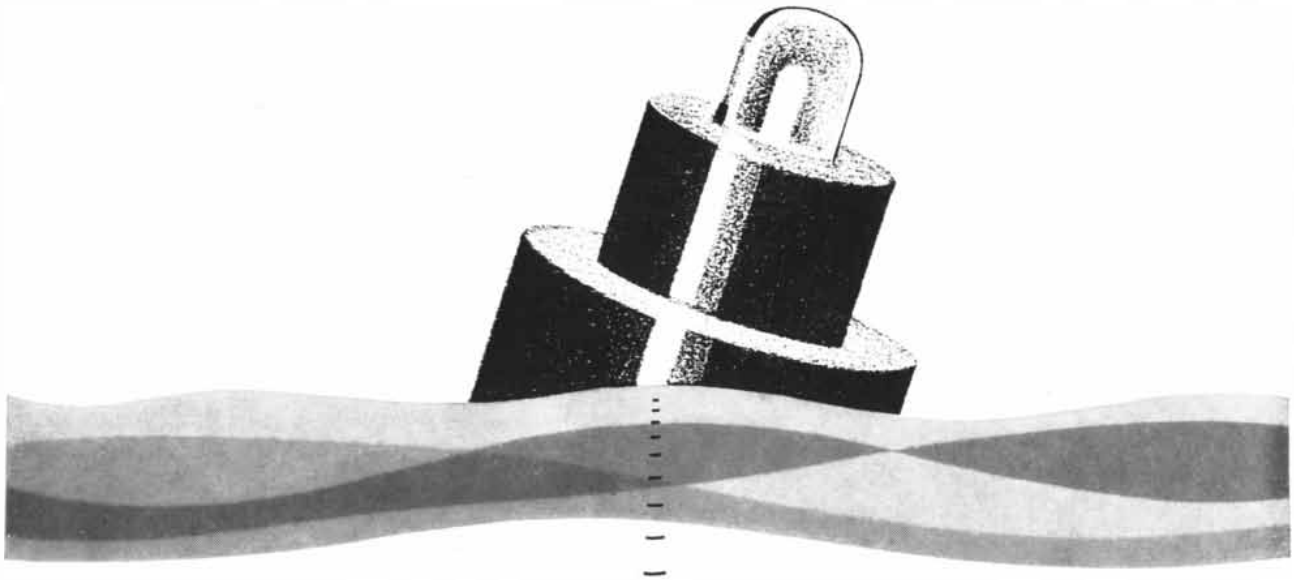
All of the 1608 tubes built into the repeaters have operated to date without failure for a total of over 50,000,000 tube hours, or an average of three-and-a-half years. The oldest have been in service since the first deep-sea repeatered telephone cable was laid 12 years ago.

Years before it was put to use, Bell Laboratories scientists and engineers began developing this undersea tube, another example of forward-looking technology that has made the Bell Telephone Laboratories the world center of communications research and development.

BELL TELEPHONE LABORATORIES

plates. When she arrived within a quarter of a mile of the *Monitor*, both ironclad vessels began to cannonade each other with all their might, still drawing more nearly together. This novel naval duel was witnessed by thousands who crowded the vessels and lined the docks in the vicinity. The vessels finally approached each other so closely that they were both covered by the same dense cloud of smoke. The *Monitor* sailed round and round her antagonist, seeking some vulnerable spot, and, it is said, succeeded in driving a shot through the sides of the *Merrimac* below the iron plates. At all events the *Merrimac* drew off to Craney Island, where she was soon surrounded by the rebel gunboats."

"The London *Photographic News* has the following summary of the present state of knowledge of spectrum analysis: —'The subject of spectrum analysis is still affording grounds for much scientific debate. At the late meeting of the Pharmaceutical Society, Dr. W. A. Miller, in his lecture on this subject, urged the necessity of still considering the views of Kirchhoff and Bunsen as theoretical, there being many points that presented anomalous features. Some spectral lines, he said, were due to the incandescent metals, but others undoubtedly belonged to the atmosphere or to the different gases in which the ignition of the metal took place. The rise of temperature too evoked different lines from the same substance. The German theory does not yet explain the facts known respecting the vapors of hydrogen, mercury, chlorine, bromine, sodium and nitrogen. It was expected that spectral observations on the corona seen during the late solar eclipse would throw considerable light upon this obscure point. Up to the present moment, however, we have not heard what results were obtained. According to Kirchhoff's theory, the sun consists of a central solid or liquid incandescent mass surrounded by luminous metallic vapors, the partial opacity of which occasioned the black lines of the spectrum. According to this theory, the light from the corona should proceed entirely from this incandescent metallic vapor and, in consequence of there being no more highly illuminated body behind it, the ordinary black lines ought to come out bright and luminous. This, if observed, would be one of the most startling results of the day, and would conclusively prove the truth of this beautiful theory, whilst the non-observance of such a reversal of the Fraunhofer line would seriously militate against the hypothesis.' "



Floating sentries spot undersea snoopers

Our coastal defenses now include a network of Sonobuoys which constantly probe for submarines by sonar. Should one of these buoys detect an undersea intruder, it flashes a radio signal that brings destroyers or patrol planes on the run.

Battery-powered Sonobuoys serve long hitches of sea duty in bitter cold that would quickly freeze the life out of ordinary batteries. Power for their sonar and radio transmitters is provided by long-lived Mallory Mercury Batteries specially designed to perform dependably in the cold. Unfazed by sub-zero temperatures, Mallory Mercury Batteries deliver unwavering power, day in, day out, to keep Sonobuoys on constant alert.

Special high-performance Mallory Mercury Battery systems are meeting many other unprecedented demands for dependable power . . . on land, under the sea, and in outer space. And for products like hearing aids, transistor radios, flashguns and flashlights, Mallory innovations provide the ultimate in battery power. These advanced developments in battery design are part of Mallory pioneering in electronics and metallurgy. P. R. Mallory & Co. Inc., Indianapolis 6, Indiana.

Imagination in electronics and metallurgy

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One of a series

Grape Jelly and the Flow of Cold Oil

As freshly made jelly cools, a gel structure forms that resists deformation. The same thing can happen to lubricating oils in extremely cold weather.

Searching for a way to insure that lubricants will function over the complete range of operating temperatures, physical chemists at GM Research have been delving into some interesting research in rheology . . . the science dealing with flow of matter. In particular, they are examining the strange influence of polymers dissolved in mineral oil systems.

Adding long-chain polymer molecules to the already complex mineral oil produces some versatile lubricants. But the polymers further complicate the fluid's viscosity under varying shearing forces and temperatures.

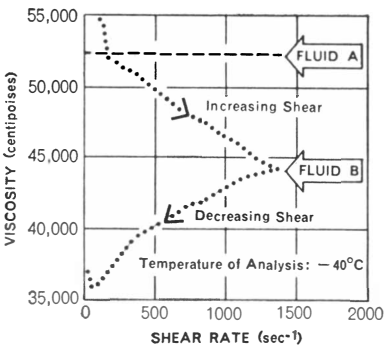
Analyzing such sticky problems has led our researchers to develop new measuring techniques (including a forced-ball viscometer that readily responds to delicate gel structures) . . . to uncover new experimental data (see graph) . . . to form new theories as to why mineral oil gels are made more rigid by some polymers, less rigid by others.

This pioneering work on low temperature oil viscosity started with thoughtful consideration of a practical problem. It is yielding basic new scientific information our technical people can use. We think it typifies General Motors constant resolve to seek and find — A BETTER WAY.

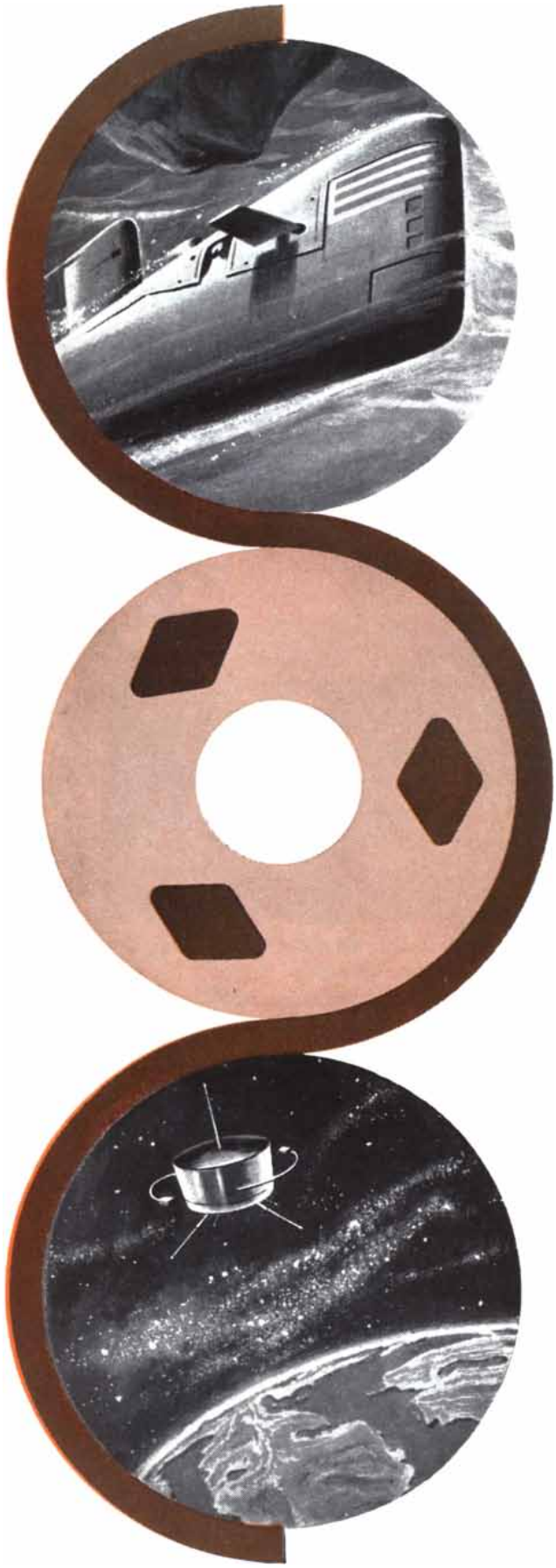
General Motors Research Laboratories

Warren, Michigan

At −25°F a ring gear in a car differential plows through a typical (SAE 90) gear oil.



Fluid A is termed a Newtonian fluid because its viscosity is independent of shearing forces. But note the unusual behavior of Fluid B, a non-Newtonian oil-polymer blend now being investigated.



SOUNDCRAFT INSTRUMENTATION TAPE IN SPACE AND UNDERSEA WITH TIROS* AND THE SEA DRAGON

The Tape Selected For The Video System In Tiros II! Orbiting with the Tiros Weather Satellite II, developed by RCA for the National Aeronautics and Space Administration, Soundcraft Tape is used exclusively in both narrow and wide angle video tape systems. Only ⅜ of an inch wide, this tape records longitudinally rather than across the width and is the result of over five years of research.

On The Nuclear Submarine, Sea Dragon, the first undersea magnetic video tape recorders also developed by RCA, used Soundcraft instrumentation tapes to record and store data on under-ice characteristics of icebergs and ice flows. As man probes deeper and deeper into the unknown, science continues to call on the world's most modern tape plant for reliable magnetic tapes.

Discover how Soundcraft's consistent record of accomplishment can be extended and applied to fulfill your recording needs. Write for complete literature.

*Soundcraft Instrumentation Tape is, of course, used in other vital space projects as well.

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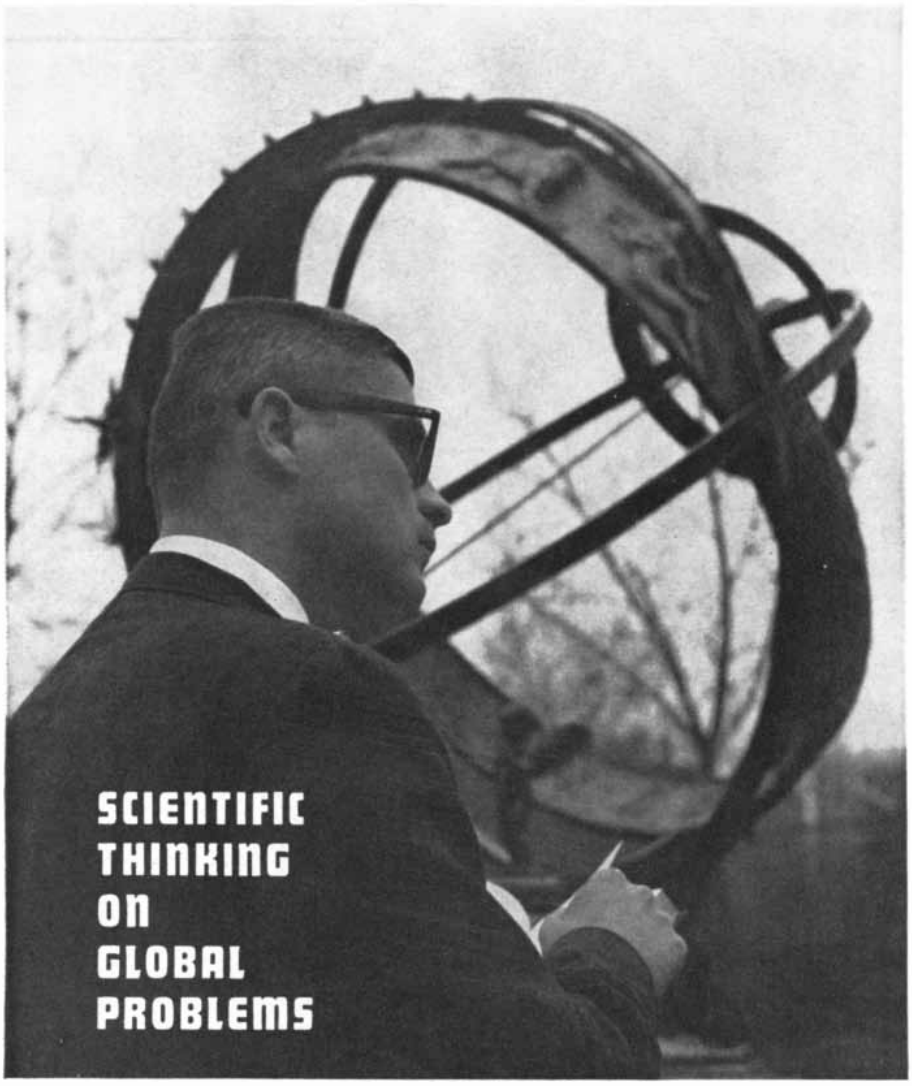

Analytical insight into world-wide problems of concern to the United States Army—this Is the constant objective of the Research Analysis Corporation.

RAC scientists utilize the techniques of operations research and systems analysis. They seek answers to questions of critical importance in strategy, tactics, logistics, intelligence, air defense, management systems, and other areas of similar significance. These answers are often prerequisite to major Army decisions.

The expanding scope and challenge of RAC's work are creating new permanent career positions of uncommon interest. We seek creative persons who enjoy solving complex problems and who can work productively as members of multi-disciplinary teams. The flexibility of assignments guarantees that each staff member can participate in a variety of study areas.

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Write to: John G. Burke, Research Personnel Officer.

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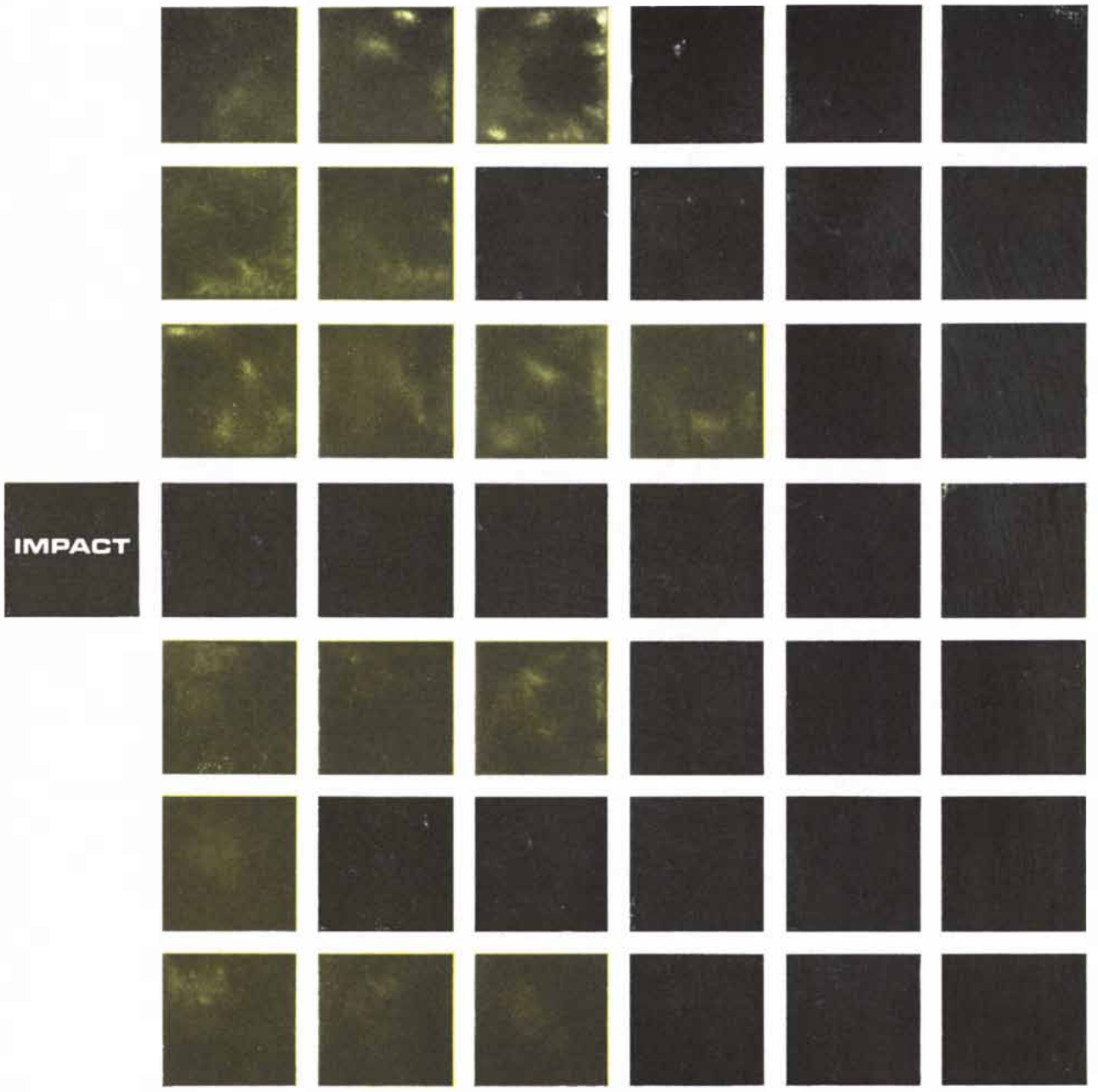
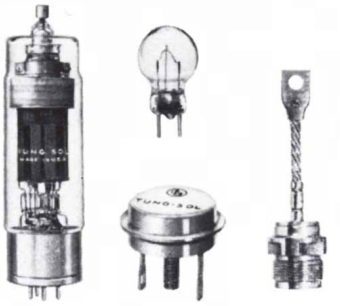


In electronic warfare, countermeasures are both shield and spear. Devices that detect enemy probes, or make invisible our own reconnaissance, obviously involve systems of the highest sophistication. But sophistication alone is not enough. Reliability is imperative.

At Tung-Sol, production and quality control techniques are oriented to high-volume production of active electronic components that are reliability-designed beyond performance specifications. Intensive evaluation procedures make certain that this safety factor is maintained in all critical parameters. And at Tung-Sol, too, long experience in the application of both vacuum tubes and semiconductors provides valuable assistance for development engineers in the selection of a component. For product performance that fully attains your objectives, consult Tung-Sol while the device is in the design stage. Tung-Sol Electric Inc., Newark 4, New Jersey.



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Here at Lockheed Missiles and Space Company, satellites and spacecraft are a specialty. From research to the reaches of space, the whole scope of space technology is being carefully investigated.

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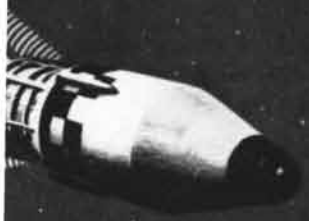
Typical of Lockheed's complete capability is the DISCOVERER series. This, with its recoverable capsule, is used to gather research material. Other military and commercial satellites and spacecraft under study, under development, or in operation, include:

An infrared missile defense alarm system • Sophisticated orbiting biomedical capsules • Lunar probes • Interplanetary exploration programs A space rendezvous system • Nuclear and other advanced propulsion systems Communications satellite systems



It is clear that the projects at Lockheed Missiles and Space Company are challenging. Moreover, its location on the beautiful San Francisco Peninsula adds gracious living and perfect climate to the many rewarding opportunities available to creative engineers and scientists.

For further information, please write: Research and Development Staff, Dept. M-32 H, 599 Mathilda Avenue, Sunnyvale, California.
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Q.

Who has the facts about accelerating a torque motor load from zero to 200 rpm in one millisecond?

KOLLMORGEN may already have the answer to your next question in optics or electromechanics.

THE AUTHORS

D. S. HEESCHEN ("Radio Galaxies") is an astronomer and currently acting director of the National Radio Astronomy Observatory in Green Bank, W.Va. Heeschen was born in Davenport, Iowa, in 1926, and he served with the Army Air Force in World War II before attending the University of Illinois, where he acquired a B.S. degree in 1949. He did graduate work in astronomy at Harvard University, was an Agassiz Fellow there from 1953 to 1954, taught for a year at Wesleyan University and received his Ph.D. from Harvard in 1955. The following year he spent as a lecturer at Harvard. He joined the staff of the National Radio Astronomy Observatory in 1956.

ERICH VON HOLST and URSULA VON SAINT PAUL ("Electrically Controlled Behavior") are respectively director of the Max Planck Institute for the Physiology of Behavior and a staff member of the institute. Von Holst, who was born in Riga, Latvia, studied at the universities of Kiel, Vienna and Berlin, obtaining his Ph.D. from the last institution. From 1939 to 1947 he was a lecturer at the University of Göttingen, taught for two years at the University of Heidelberg, and in 1949 he became director of the Max Planck Institute for Marine Biology. He has held his present post since 1954. Miss von Saint Paul studied at the universities of Innsbruck, Heidelberg and Münster. She took her doctorate at Münster in 1950. From 1950 to 1957, when she went to von Holst's laboratory, Miss von Saint Paul worked in the laboratory of Gustav Kramer at the Max Planck Institute for Marine Biology.

KOLOMAN LAKI ("The Clotting of Fibrinogen") is chief of the section on physical biochemistry at the National Institute of Arthritis and Metabolic Diseases. Born in Szolnok, Hungary, Laki attended the University of Szeged with the idea of taking a degree in medicine. During Laki's second year, however, Albert Szent-Györgyi returned to Hungary to take the chair of medical chemistry at Szeged. Laki recalls that "in the laboratory Szent-Györgyi's discoveries were making biochemical history. He took the excitement of discovery from the laboratory into the lecture room and molded new ideas right in front of our eyes." After switching from medicine to biochemistry, Laki was invited to join Szent-Györgyi's research group, and in 1936 he received his Ph.D. in organic chemistry and biochemistry. Laki taught and did research at Szeged from 1933 to 1944. From 1945 through 1947 he served on the faculty of the Institute of Biochemistry at the University of Budapest, and he spent most of 1948 as a visiting professor at the University of Leeds. Laki came to the U.S. later the same year on a special research fellowship from the National Institutes of Health. He took up his present post in 1954.

H. A. STEINHERZ and P. A. REDHEAD ("Ultrahigh Vacuum") are respectively manager of the Engineering and Development departments of the NRC Equipment Corporation in Newton, Mass., and a member of the Electron Physics Group of the National Research Council of Canada. Steinherz, who is also an instructor in vacuum technology at Boston University, acquired a B.S. in physics at Yale University in 1947. During the next four years he worked for the Westinghouse Electric Company while studying physics and mathematics at the University of Pittsburgh. From 1951 to 1955 Steinherz was a materials engineer with the General Electric Company. He joined the NRC Equipment Corporation in 1955. Redhead, born in England in 1924, took a B.A. in physics at the University of Cambridge in 1944. He was engaged in research on proximity fuzes and microwave tubes for the British Admiralty until 1947, at which time he went to the National Research Council of Canada.

WILLIAM DAVENPORT ("Red-Feather Money") is assistant professor of anthropology at Yale University. He had moved to Hawaii the year before Pearl Harbor and there became interested in Hawaiian archaeology and in the problems of Polynesian migrations through the central Pacific. These interests were further intensified during the time he spent with the Army Transport Service in the Solomon Islands, New Guinea, the Philippines and other Pacific islands during World War II. After the war he did archaeological field work for the Bernice P. Bishop Museum of Honolulu and later began studying anthropology at the University of Hawaii. He received a B.A. from that university in 1952 and a Ph.D. from Yale in 1956.

SIDNEY LERMAN ("Cataracts") is assistant professor of ophthalmology and biochemistry at the University of Roches-

ter School of Medicine and Dentistry and associate ophthalmologist at Strong Memorial Hospital in Rochester, N.Y. Lerman studied at McGill University, where he received his M.D.C.M. (Doctor of Medicine, Master of Surgery) in 1952. He served his internship and ophthalmology residency at Montreal General Hospital. He did ophthalmic research under the direction of the late Jonas S. Friedenwald at Johns Hopkins University from 1955 to 1956 and then went to Rochester.

HAROLD J. MOROWITZ and MARK E. TOURTELLOTTE ("The Smallest Living Cells") are respectively associate professor of biophysics and research associate in biophysics at Yale University. Morowitz studied philosophy, physics and biophysics at Yale, acquiring his Ph.D. there in 1951. He spent two years at the National Bureau of Standards and another two years at the National Heart Institute before joining the faculty of Yale in 1955. Tourtellotte was graduated from Dartmouth College in 1950 and took an M.S. degree at the University of Connecticut in 1953. He remained at Connecticut as a bacteriologist in the department of animal pathology, working on the physiology and serology of the pleuropneumonia-like organisms discussed in the present article. He received his Ph.D. from Connecticut in 1959 and went to Yale on a postdoctoral fellowship from the National Institutes of Health.

JAMES R. HEIRTZLER ("The Longest Electromagnetic Waves") is research scientist and head of the department of geomagnetism at Columbia University's Lamont Geological Observatory. A native of Louisiana, Heirtzler took his B.S. and M.S. degrees at Louisiana State University in 1947 and 1948 respectively. From 1948 to 1953 he studied cosmic rays and nuclear instrumentation at New York University, where he received a Ph.D. in physics in 1953. He spent the next three years teaching physics at the American University of Beirut in Lebanon. After joining the General Dynamics Corporation as a senior physicist in 1956 he became interested in electromagnetic waves having very low frequencies. He went to the Lamont Observatory in 1960.

ROBERT W. WHITE, who in this issue reviews Oscar Lewis' *The Children of Sánchez*, is professor of clinical psychology and chairman of the Department of Social Relations at Harvard University.

Let's meet the family cook, chauffeur—and dry cleaner

Remember what dry cleaning used to involve? How you would drop it off . . . wait a day or two . . . pick it up? Today, however, the Norge Division of Borg-Warner has introduced busy homemakers to a truly astounding change-of-routine—to ease and economy with Norge self-service, coin-operated dry cleaning! Now, in Norge equipped Laundry & Cleaning Village stores, the modern mother simply loads the family dry cleaning into this new kind of appliance (perhaps nine dresses or four men's suits!). In just 45 minutes, it cleans everything beautifully and virtually wrinkle-free. Her budget is helped too, by savings of up to 75% over conventional cleaning bills. There are over 1,500 Norge equipped Village stores across the country—visited, on an average day, by 60,000 people with a half million pounds of dry cleaning. Literally overnight, do-it-yourself dry cleaning has become a major new industry—established, in great measure, by the forward-minded actions of Norge/Borg-Warner. For information about investment opportunities, write P.O. Box 767, Hinsdale, Ill.

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a measurement milestone made possible by a unique new hp manufacturing process

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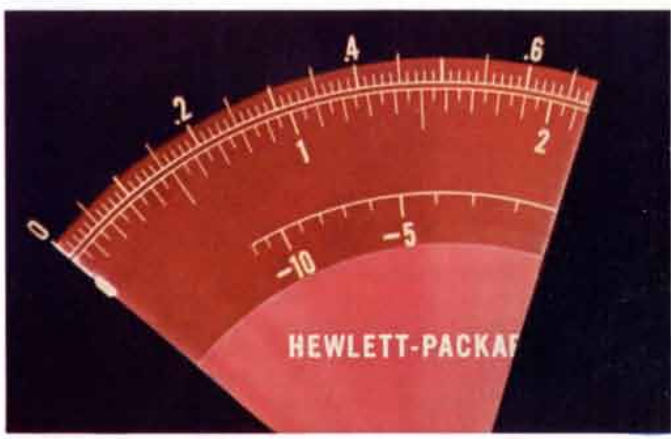

PROGRESS

IN SCIENTIFIC MEASUREMENT

is dependent on measuring tools of increasing accuracy. When today's scientist must compromise maximum measuring accuracy for the high cost of specialized measuring devices, technological progress is hampered or blocked.

Hewlett-Packard's continuing program of basic scientific research, coupled with increasingly sophisticated manufacturing techniques, provides science and industry with more accurate, more dependable measuring tools on a mass-production basis and at reasonable cost.

In precision electrical metering, the universally accepted d'Arsonval movement possesses an inherent flaw known as "tracking error."

This flaw, a product of mechanical component inconsistencies, causes variation between actual electrical quantities and the meter deflection or indication. Industry practice has been to employ preprinted scales calibrated to the movement only at given points. While the meter then reads accurately at the points calibrated, indicating errors are present elsewhere on the scale.

The only previous alternative was tedious, expensive hand calibration of meter scales.

Now hp has developed a unique system which employs a blank scale and literally custom prints each meter scale to match precisely with the electrical quantities the instrument is measuring. The hp system, also, instantly detects and rejects faulty meter movements. The result is a thoroughly reliable meter which actually provides *better* than the 1% accuracy previously claimed for the ultimate in precision electronic test meters.

In ways such as this, Hewlett-Packard seeks constantly to advance the state of the art and improve over 400 hp measuring instruments. To assist in this work, and in the development of many new, high value instruments annually, hp is continually interested in ambitious engineers desiring a stable future and a continuing opportunity for creative endeavor.

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hp 431A Microwave Power Meter

is one of the Hewlett-Packard instruments now delivered with individually calibrated meters ... provided at no increase in cost. The 431A ends zero adjustment due to time-temperature drift, quickly and accurately measures power 1 μw to 10 mw, 10 MC to 40 GC. Price 431A, $345.00.

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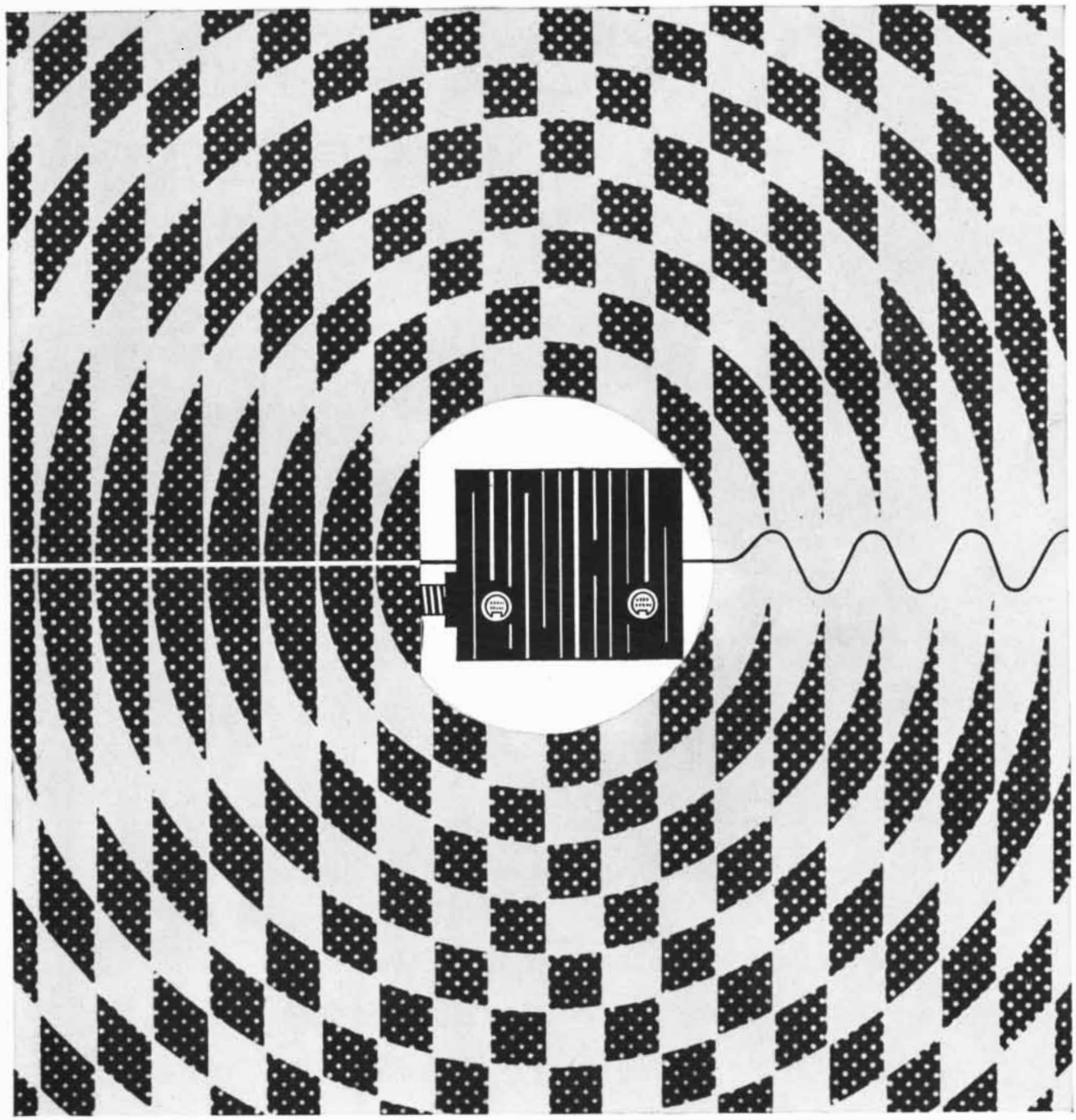

HOW 6 TRANSISTORS CAN WORK 7 TIMES HARDER WITH ONLY HALF TRYING

(a report from Delco Radio)

Sound like a riddle? Well, it was . . . almost. Here's the story.

Delco Radio engineers wanted to build a precision static inverter that was smaller, simpler, lighter, more economical and considerably more powerful than previous models.

Research hit on the idea of current feedback. Following this principle, the engineers designed an amazing inverter using only 6 transistors. Transistor utilization is stepped up 7 times, yet the transistors work at less than 50% of their capacity, run cooler, last longer.

SEE YOU AT IRE SHOW, BOOTH 1423

This new Delco 250 VA power supply converts 28 volts DC to 115 volts, 400 cps. Its circuits are a model of simplicity.

The unit is designed for continuous full-load operation at 71 degrees C. still air, yet weighs only 10 lbs., measures 6¼″ x 7⅜″ x 5″. A minimum of components assures extra-high reliability.

The 250 VA Static Inverter is practical hardware today, awaiting your inquiry. Delco Radio may be able to solve your problem in miniaturization, modules, inverters or converters, too. Write to Delco Radio Military Sales Department, Kokomo, Indiana.

DELCO RADIO
DEPENDABILITY
RELIABILITY

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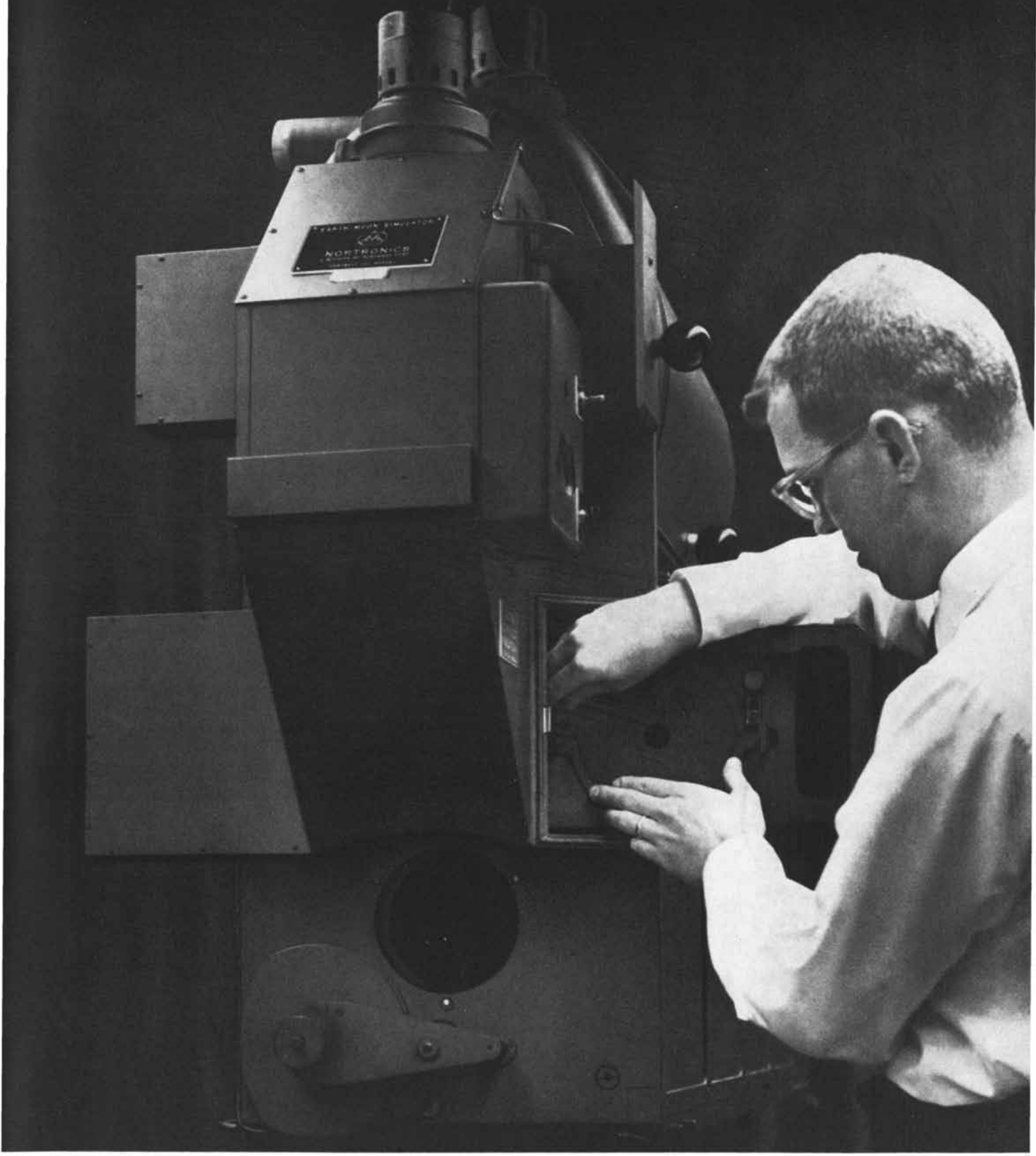

We put the earth and the moon in this box—and backed off a billion miles

This is an earth-moon simulator developed by Northrop. As its name implies, it shows us how the earth, or the earth-moon system, would look to an observer in space, from 80,000 miles all the way out to 1 billion miles. It was built to test the sensing devices which space vehicles use to track the earth, so they can guide themselves and point their communications antennas at the earth.

The earth-moon simulator is not only an important research tool, but also a major step toward quality control in space systems. It was designed and built by the Nortronics Division of Northrop. It will be used by Caltech's Jet Propulsion Laboratory, contractor to the National Aeronautics and Space Administration.

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With the development of the optical maser, or laser, (Light Amplification by Stimulated Emission of Radiation), new power has been given to light. For example, although light beams have been used for signaling since ancient times, they have been too weak and noisy for modern communications. The laser makes it possible to produce an intense, narrow beam of smooth light that will carry an almost unlimited number of messages over vast distances.

Communications is but one of many areas of science in which the laser promises revolutionary changes. The key to the development and success of lasers is optics—in new forms and of unprecedented quality.

Our capability in precision optics and its application to the development of laser components and systems is another example of Perkin-Elmer leadership in serving advanced technologies through scientific measurement and information.
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A Simple Test of Your PRESENT READING SPEED AND COMPREHENSION

THIS IS ONE OF THE FIRST TESTS IN THE
Columbia University Program in Rapid Reading

1. Read the following passage as fast as you comfortably can to discover the most important fact. Time yourself precisely with the second hand of your watch and write down the elapsed time as soon as you have finished.

"YALE's efforts to make itself a vast contributing part of New Haven are too many and too well known to require any detailing here." So reads the first sentence of an editorial in the *New Haven Register* of June 17, 1959; it is quoted here not because such statements are rarely found in the local newspapers but because they are appearing with encouraging frequency. Yet University authorities, adjusting to this very welcome popularity, were hardly prepared for a pamphlet, issued by the Southern New England Telephone Company in July, which bluntly announced that Yale is worth at least $33,000,000 annually to the New Haven community.

This highly informative financial report explained that Yale has an annual payroll of $18,000,000, paid to some 1700 faculty members and 2000 service staff workers, virtually all of whom live and shop in the New Haven area. The University spends approximately $6,000,000 annually in New Haven for supplies and equipment. Each year Yale students spend $5,000,000 locally, and this is increased by another $4,000,000 when alumni, parents and other Yale visitors are included. Then there is the extensive construction program. In 1958, for example, the University dedicated new buildings costing more than $7,000,000, and plans for the next five years call for at least $12,000,000 in additional construction.

— FROM *Town and Gown*

Reading Time: _____ **minutes** _____ **seconds**

2. Without referring to the passage above, indicate below what you consider to be the one most important fact stated in it.

_____a. Yale brings $18,000,000 per year to New Haven
_____b. Yale brings $6,000,000 per year to New Haven
_____c. Yale brings $4,000,000 per year to New Haven
_____d. Yale brings $33,000,000 per year to New Haven
_____e. Yale's building program is the only real benefit to New Haven in dollars and cents

NOW TURN TO PAGE 171 TO SEE WHAT THE RESULTS OF THIS TEST SIGNIFY

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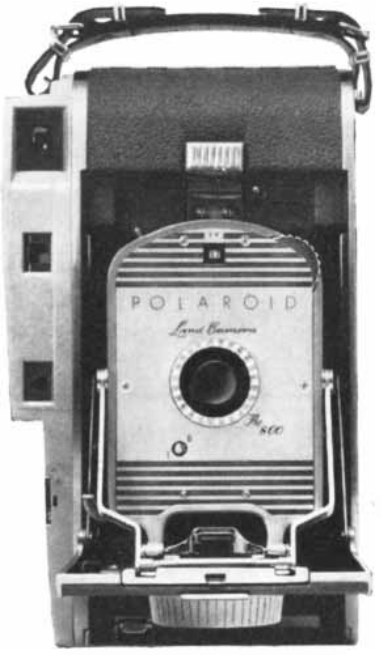
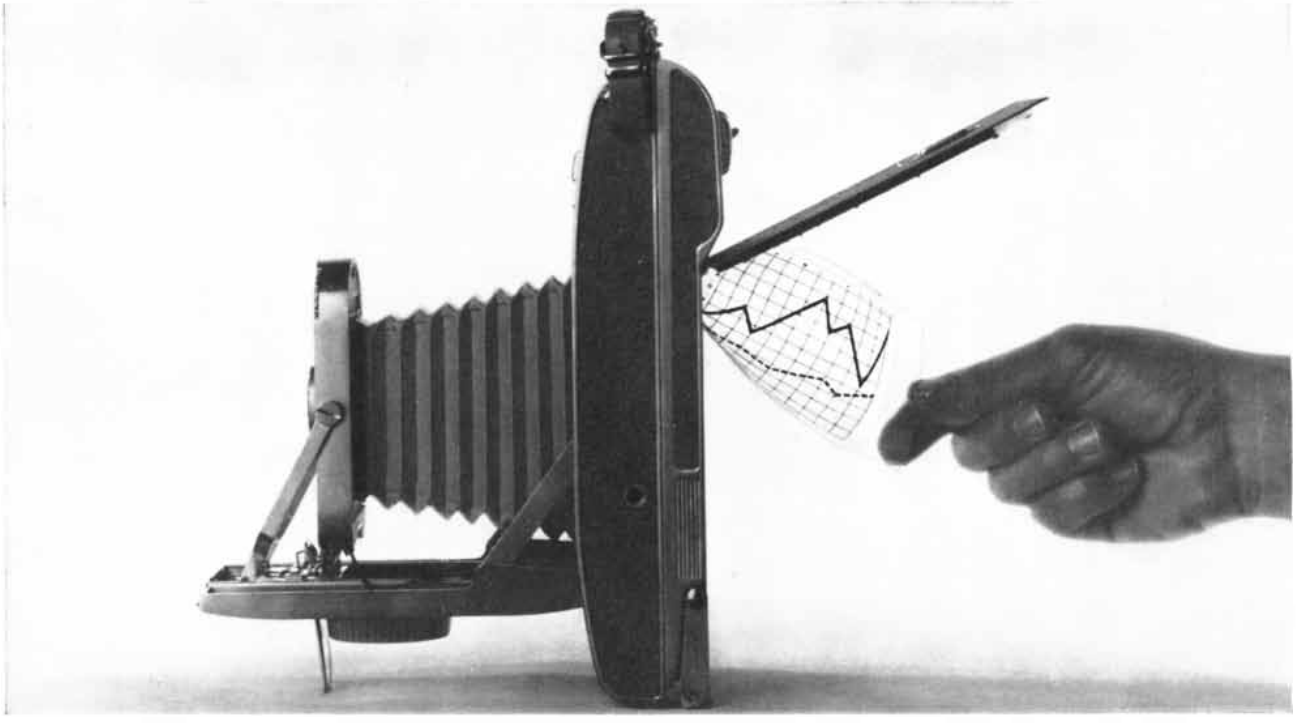


This and 55¢



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All three projection film types can be used with any Polaroid Land Camera that uses 40-series film except the J-66.

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Established 1845 SCIENTIFIC AMERICAN March 1962 Volume 206 Number 3

Radio Galaxies

Certain galaxies are extraordinarily strong sources of radio waves. Until recently it was thought that they were galaxies in collision, but now astrophysicists seek other explanations of their radiation

by D. S. Heeschen

The discovery that the earth receives radio waves from space was made by Karl G. Jansky in 1931. At first it seemed that the radio waves represented a general background emission originating within the disk of our own galaxy. Much later it became evident that some of the radio energy emanated from discrete sources, either within our galaxy or outside it. Finally, in 1951, Walter Baade, using the 200-inch telescope on Palomar Mountain, made the first identification of a discrete radio source with an optically visible object. His photographs showed that the intense cosmic source known to radio astronomers as Cygnus A coincided with the position of a galaxy—or perhaps a pair of galaxies in collision—now estimated to be 700 million light-years away. In spite of its vast distance Cygnus A emits radio waves so energetically that it had been the first "bright" region in the radio sky to be recognized as a dis-

INTERACTING GALAXIES known as 4038 and 4039 in the New General Catalogue (NGC) belong to the class of "peculiar" galaxies that are strong emitters of radio waves. NGC 4038–39, which is about 65 million light-years away, emits about 100 times more radio energy than radio galaxies classified as "normal." This photograph was made with the 200-inch telescope on Palomar Mountain.

crete source. Cygnus A was discovered in 1948 as a result of the work of J. S. Hey and his colleagues in England and J. G. Bolton and G. Stanley in Australia.

Baade's identification of Cygnus A with a remote galaxy opened new areas of astronomical investigation and introduced astrophysicists to a new type of celestial object. Both the appearance and the spectrum of the galaxy were most peculiar, and of equal peculiarity was the fact that the galaxy was radiating more energy at radio than at light, or optical, wavelengths. The nature of the physical processes going on in this and other radio galaxies today presents one of the most fascinating and puzzling problems of astronomy.

Several thousand discrete radio sources have now been catalogued with the aid of the large radio telescopes in Cambridge, England, and Sydney, Australia. Some of the sources are associated with relatively nearby objects in our own galaxy, such as emission nebulae, composed of intensely hot interstellar gases, and other nebulae that are the remnants of supernovae. Other sources, like Cygnus A, have been identified with extragalactic objects, and there is now considerable evidence that the majority of radio sources are associated with galaxies other than our own. Sources as powerful as Cygnus A could be detected by radio telescopes even if they were far beyond the range of present optical telescopes, and presumably some of the radio sources not yet identified with visible objects are too distant to be seen.

About 100 of the discrete radio sources have now been identified with visible galaxies. These radio galaxies can be loosely divided into two groups, the "normal" and the "peculiar," according to their optical and radio characteristics. The division between the two groups is not sharp, and at present there is no unambiguous way to specify whether a radio galaxy is normal or peculiar. The terms are useful, however, and in the following paragraphs I shall try to define them by describing some observable features of the galaxies to which they apply.

All the bright nearby spiral galaxies, such as the familiar galaxies in the constellations of Andromeda and Triangulum, are weak radio sources. Most of what we know about their radio emission is due to the work of R. Hanbury Brown and C. Hazard in England and B. Y. Mills in Australia. Part of the radio emission from these galaxies is associated with the visible disk of the galaxy and part originates in an extended halo that often occupies a volume 10 or more times greater than that of the visible disk. Judging from the results of observations of the nearer galaxies, it is reasonable to expect that most of the spiral galaxies, and probably the irregular galaxies as well, are weak radio emitters. These are the normal radio galaxies.

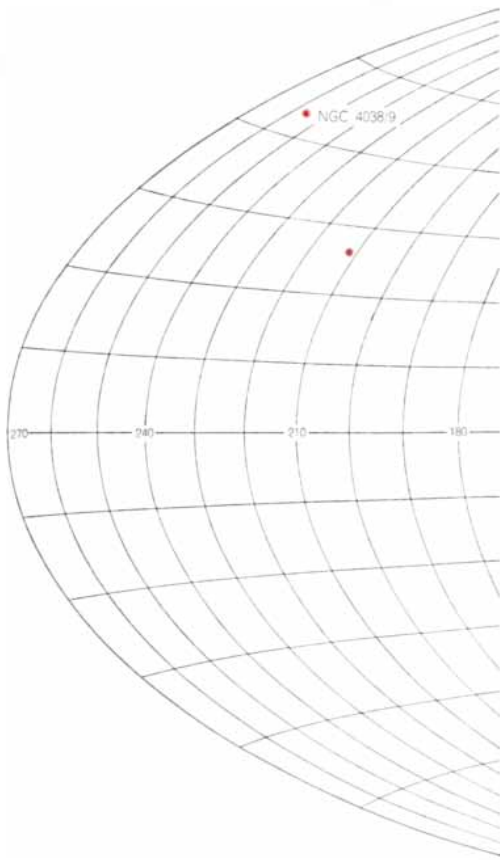
The total energy emitted in the radio-frequency region of the spectrum by a normal radio galaxy is on the order of 10^{38} ergs per second, or, to use a more familiar measure of radio power, 10^{28} kilowatts. This is about 1,000 times the radio output of the most intense radio sources within our own galaxy, but it is still only about a millionth of the energy that galaxies emit at optical wavelengths.

Some galaxies of standard appearance emit significantly more than 10^{28} kilowatts of radio power. For example, the spiral galaxy NGC 1068 emits about 10^{30} kilowatts of radio energy, or about 100 times more energy than the radio galaxies classified as normal. Moreover, the radio emission is concentrated in a source of small diameter at the center of the galaxy. If there is any emission from an extensive halo, it is too weak to be detected with present instruments. The optical spectrum of NGC 1068 shows intense, broad emission lines that suggest a high degree of energetic, chaotic activity in the nucleus of the galaxy. It is tempting to try to connect this phenomenon with the enhanced radio emission, but several other spiral galaxies whose optical spectra exhibit the same features do not show enhanced radio emission.

NGC 1068 is one of the weaker of the galaxies that have come to be known as peculiar radio galaxies. They are peculiar in that they emit radio waves much more intensely than do the normal spiral galaxies. Although many of them also have visual or spectral peculiarities of one sort or another, this is not invariably the case. The well-known elliptical galaxy M 87 is another example of a peculiar radio galaxy. The radio emission from M 87 is almost 100 times more intense than that from NGC 1068. The emission appears to come from two concentric sources, approximately centered on the visible galaxy: a small and intense core, and a large and less intense halo. On long-exposure photographs M 87 appears as a normal giant elliptical galaxy. Short-exposure photographs, however, reveal the presence of a bright jet extending from the galactic center [*see middle illustration on page 46*]. The jet is suggestive of material being ejected with high energy from the nuclear region of the galaxy. Observations made with the 200-inch telescope by Baade have shown that the light radiated from the jet is strongly polarized. As we shall see, this observation has important consequences for the interpretation of radio emission from extragalactic radio sources.

A number of other intense radio sources have been identified with elliptical galaxies that have a normal appearance. On the other hand, some comparatively close giant elliptical galaxies have no detectable radio emission. It now appears that only a small fraction of normal-looking elliptical galaxies emit enough radio energy to be called peculiar. Whether or not the peculiar ones also have jets similar to that seen in M 87 is not known, since the jet of M 87 would not be easily detectable at the distances of other elliptical galaxies that are strong radio sources. It seems likely, however, that the phenomenon responsible for the jet in M 87 is related to the cause of the intense radio emission from this object.

Many radio sources have been identified with galaxies that cannot easily be



MAP OF RADIO GALAXIES shows the location, in galactic co-ordinates, of 45 of the

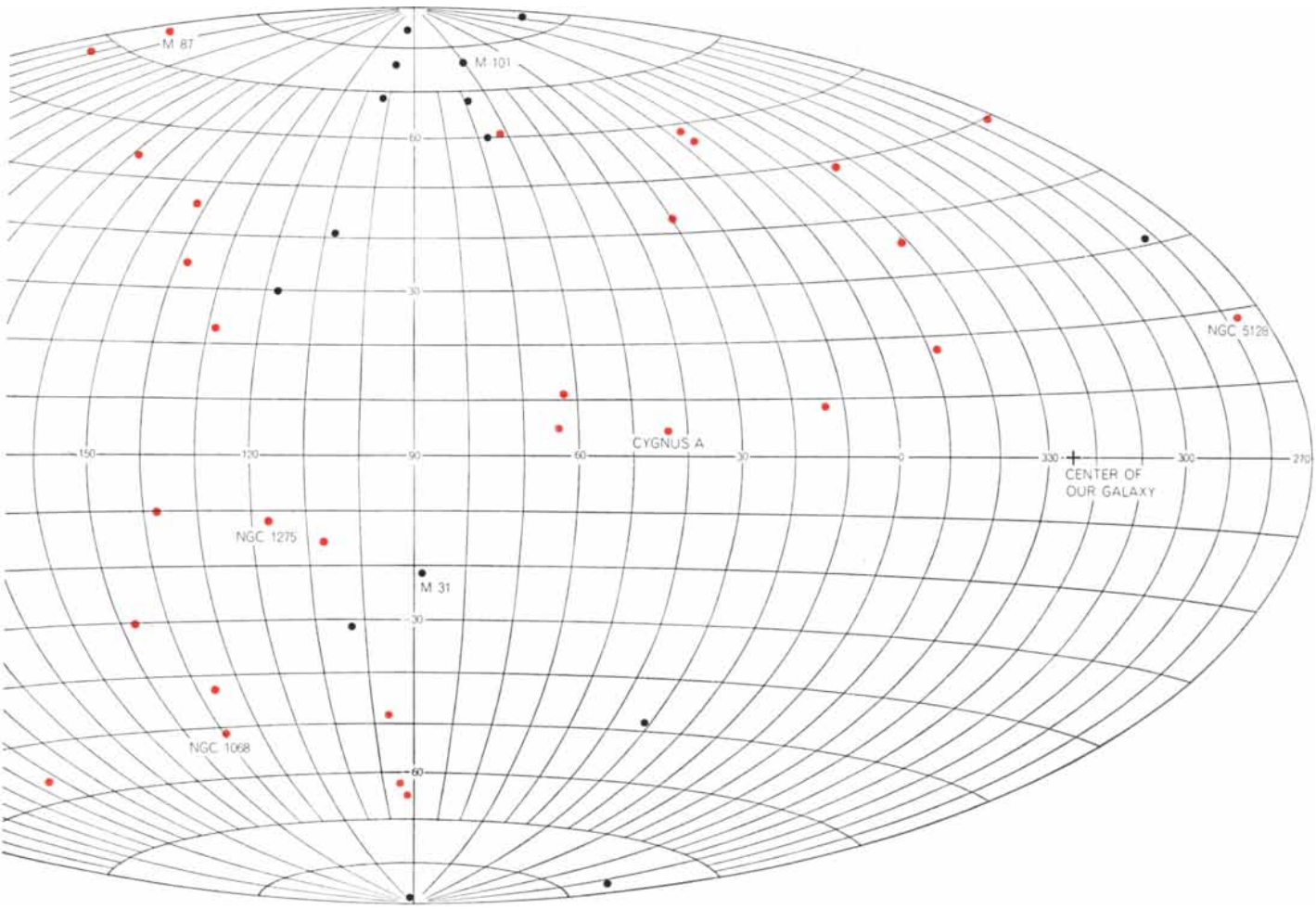
classified by the usual scheme, which is based solely on form. The galaxy associated with the source Cygnus A, for example, appears visually as two nuclei in contact, surrounded by a faint common envelope [*see illustration on page 45*]. This has been interpreted variously as two galaxies in collision, a single galaxy whose nucleus is splitting apart and a single galaxy with a peculiar lane of dust across its central region. The radio emission from Cygnus A is about 10^{34} kilowatts, a million times more than that from a normal radio galaxy. NGC 5128 is another example of a radio galaxy whose visual features cannot readily be interpreted [*see bottom illustration on page 46*]. It looks like an elliptical galaxy with a band of dust running through its center. Several other radio galaxies are now known whose appearance is similar to that of NGC 5128 and Cygnus A.

A striking feature of these powerful radio sources is the spatial distribution of their radio emission. In Cygnus A the radio emission originates not in the region of the visible object but in two regions symmetrically placed on each side of the galaxy at distances of about 100,000 light-years! NGC 5128 has four regions of radio brightness, two resembling those in Cygnus A and two lying closer to the central portion of the galaxy. All four emissive regions lie approximately on a line running through the center of the galaxy and perpendicular to the dark absorbing band. Recent observations at the California Institute of Technology and at Jodrell Bank in England have shown that many radio galaxies are similar to Cygnus A in that they have two radio-emitting regions of approximately equal intensity. Whether or not some of these radio galaxies may be more complex, like NGC 5128, cannot at present be determined. With available equipment the complex brightness distribution of NGC 5128 can be observed only in nearby sources.

To summarize, there seem to be at least three different types of peculiar radio galaxy: normal-appearing spiral galaxies with enhanced radio emission, like NGC 1068; normal-appearing elliptical galaxies, perhaps with central jets like M 87, or with some other peculiarity; galaxies with a complex radio brightness distribution and a peculiar unclassifiable visual appearance, like that of NGC 5128 or Cygnus A. The intensity of radio emission from the last two types may range from only slightly more intense than a normal galaxy (10^{28} kilowatts) all the way up to 10^{34} kilowatts, a range of more than 10^{5}.

To this list of types of radio galaxy we might also add objects such as the twin galaxies NGC 4038–39. Photographs suggest that this close pair of galaxies is in strong gravitational interaction. The pair has a weak radio output, of an intensity comparable to that from NGC 1068. Several other pairs of interacting objects of this general appearance have also been identified with radio sources.

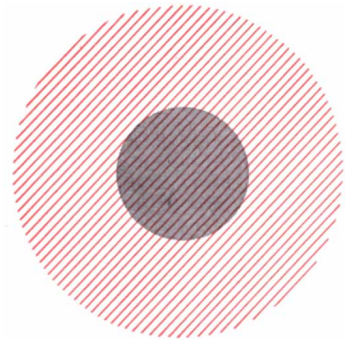
This classification of radio galaxies into four general categories may or may not be meaningful. It is not at all certain that the four categories represent four



most carefully studied radio sources lying outside our galaxy. The normal radio galaxies are indicated by black dots; peculiar galaxies, which emit from 100 to approximately a million times more radio energy than do normal galaxies, are shown by colored dots.

distinct types of radio source. Nor is it clear that all radio galaxies can properly be placed in one of the four categories. We must keep in mind that barely 100 radio sources have so far been identified with galaxies, and almost every one appears unique in some sense. Thus it is quite possible that the physically important unifying features have not yet been recognized. The above groupings do, however, serve to classify the major observed characteristics of peculiar radio galaxies, whether or not the groupings have physical significance.

The radio energy emitted by most galactic and extragalactic radio sources increases in intensity with increasing wavelength. This is described as a nonthermal distribution of energy because it is just the opposite of the distribution expected from a body of hot gas, such as a star. In a hot gas interactions between electrons and protons arise as a result of random thermal motions, and these motions produce radiation in both the optical and radio regions of the electromagnetic spectrum. The intensity of this thermal emission remains essentially constant over a wide range of wavelengths, but beyond a certain point the intensity decreases as the wavelength becomes greater. Only the radio sources associated with the emission nebulae of our own galaxy exhibit this typical thermal emission spectrum. All other discrete radio sources have a nonthermal spectral distribution. The mechanism for producing such a spectral distribution remained for many years one of the major puzzles of radio astronomy.



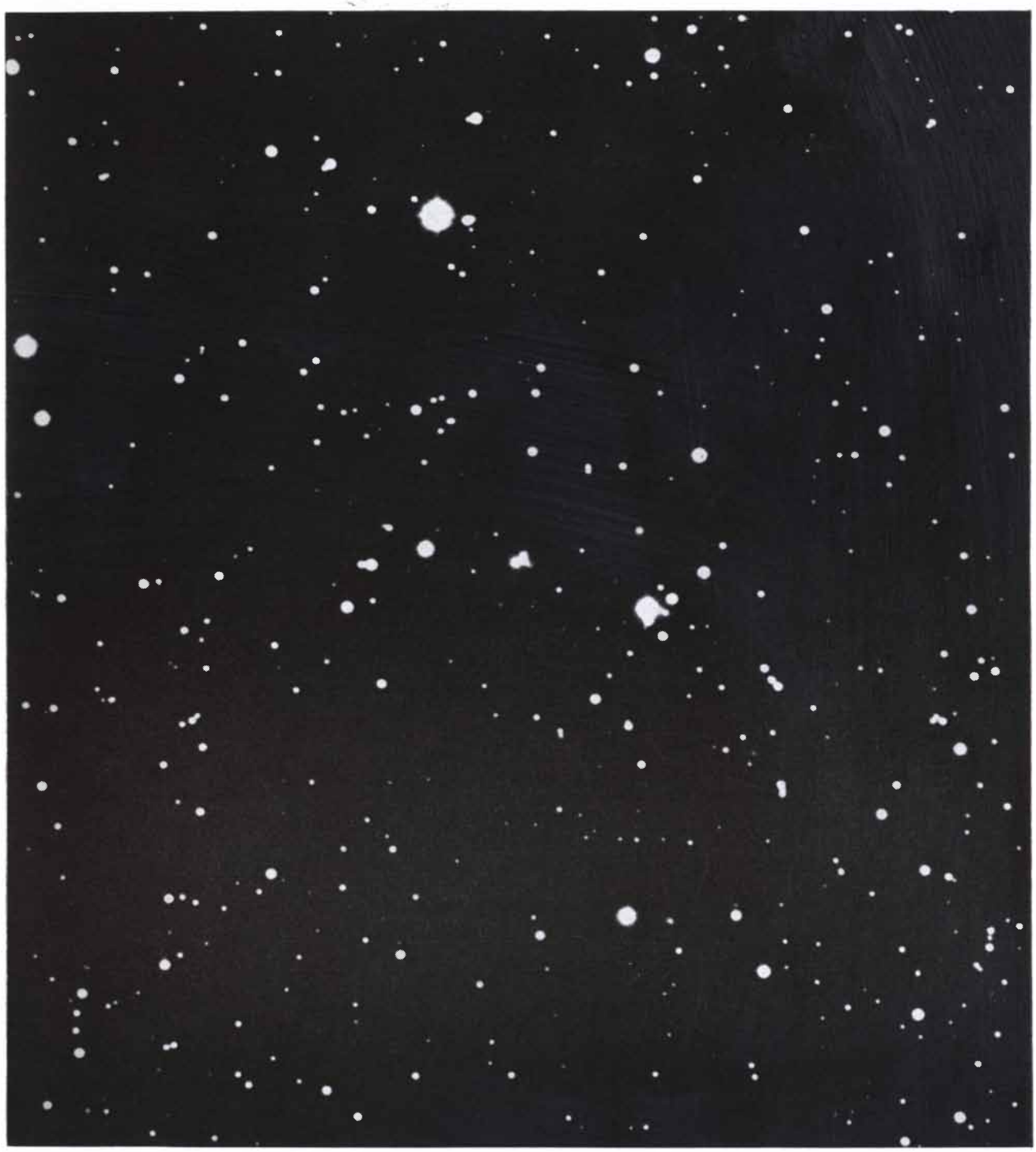
The first plausible mechanism was developed in 1953 by the Soviet astrophysicist I. S. Shklovsky. He theorized that the radio emission and much of the optical emission from the Crab nebula, the remnant of a supernova and a strong radio source in our own galaxy, was produced by the interaction of energetic electrons and a magnetic field associated with the nebula. A relativistic electron (that is, an electron moving with a speed close to that of light) spiraling around a line of magnetic force is known to emit intense radiation in a narrow band of wavelengths determined by the energy of the radiating electron and the strength of the magnetic field [*see top illustration on page 48*]. This radiation is sometimes called synchrotron radiation, because it is produced when electrons are accelerated in the magnetic field of a synchrotron. In the weak magnetic fields found in interstellar space, electrons with energies in the range of one billion to 10 billion electron volts radiate at radio wavelengths, whereas electrons of higher energy radiate at optical wavelengths. The spectral distribution of the radiation produced by this mechanism is similar to the energy distribution of the electrons. Since the known energy distribution of cosmic rays is similar to the radio-frequency spectral distribution of the Crab nebula, Shklovsky concluded that relativistic electrons with essentially the same energy distribution as that of cosmic rays were responsible for the optical and radio emission from the Crab nebula. He also predicted that the optical emission from the Crab nebula would show a high degree of polarization, because this is another characteristic of the synchrotron radiation.

The prediction was beautifully confirmed by the Soviet astronomers V. A. Dombrovsky and M. A. Vachakidze and the Dutch astronomers Jan H. Oort and Theodore Walraven. Light from the Crab nebula was indeed highly polarized. Oort and Walraven also made a detailed investigation of the radio and optical emission characteristics of the Crab nebula and showed that many of the hitherto puzzling features of its radiation could be easily explained by the synchrotron mechanism.

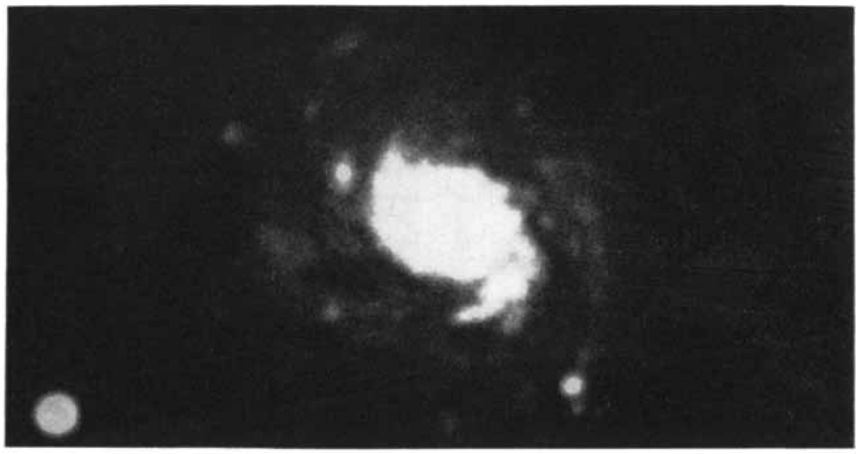
These findings led naturally to the idea that the synchrotron mechanism may also account for the radiation from radio galaxies. So far, however, the only direct evidence indicating that this mechanism may be at work in radio galaxies is the important observation by Baade of the polarization of light from the jet of M 87. Although the radio spectra of radio galaxies generally show an even steeper rise in intensity with increasing wavelength than that of the Crab nebula, the spectra are still similar to the energy spectrum of cosmic rays. The synchrotron mechanism is the only one proposed so far that offers a reasonable explanation of the strongly nonthermal distribution of radio energy from extragalactic sources.

NORMAL RADIO GALAXY NGC 5457 (also known as M 101) is a well-developed spiral galaxy, about eight million light-years away. The photograph was made with the 200-inch telescope. In the diagram above the photograph the gray area represents the visible portion of the galaxy. The colored area shows the much larger halo from which radio waves emanate.

All discrete radio sources, both galactic and extragalactic, emit a fairly smooth continuum of radio-frequency energy; that is, the intensity of emission varies smoothly with frequency. The only observable absorption or emission line is the well-known line of the un-ionized hydrogen atom, which occurs in a



STRONGEST EXTRAGALACTIC RADIO SOURCE is the peculiar galaxy, or pair of galaxies, known as Cygnus A. In this photograph, made with the 200-inch telescope by Walter Baade, Cygnus A is the object in the center that looks like two galactic nuclei in contact. The radio emission associated with Cygnus A is shown in color in the diagram above the photograph. The radio-emitting regions lie some 100,000 light-years to each side of the visible nuclei. Cygnus A itself is about 700 million light-years from the earth.



NGC 1068, a late spiral 40 million light-years away, emits 10^{30} kilowatts of radio energy, which makes it peculiar. The photograph was made with 60-inch telescope on Mount Wilson.

M 87, 40 million light-years away, emits 10^{31} kilowatts of radio energy. A luminous jet extends from its center. Photograph was made with the 120-inch telescope at Lick Observatory.

NGC 5128, 15 million light-years away, emits 10^{31} kilowatts of radio energy. The dark absorbing band running through the galaxy is presumably dust. Photograph was made with 200-inch telescope. Radio appearance of these three galaxies is depicted on opposite page.

narrow band of wavelengths centered at about 21 centimeters. Over all the rest of the observable radio band—from about one centimeter to 10 meters—the spectrum is continuous.

If one plots the intensity of the radio emission (expressed logarithmically) against wavelength, one obtains a sloping line that is nearly straight. The slope, which reflects how rapidly the intensity changes with wavelength, is called the spectral index. A spectral index of -1, for example, indicates that the intensity is proportional to wavelength, whereas a spectral index of -2 means that intensity increases as the square of the wavelength. The indices carry a minus sign because in the usual way of plotting them the curves slope to the left [*see illustration at bottom left on page 48*].

The spectral characteristics of the radio emission from radio galaxies can provide clues as to the nature of the galaxies. The spectra of all known radio galaxies, both normal and peculiar, are essentially similar. The extreme range of their spectral indices is from about $-.2$ to -1.2, but the majority have spectra with indices in the range $-.6$ to -1.2. In many cases the spectral index of a radio galaxy is approximately constant over the entire observed radio-frequency range. In other cases, however, the plotted index takes the form of a bowed curve, being steepest at the short-wavelength end of the spectrum and less steep as the wavelength increases. The spectral index of Cygnus A varies in this way from about -1.2 for wavelengths in the neighborhood of three centimeters to about $-.5$ for wavelengths of 600 centimeters.

It is quite remarkable to find that the spectra of radio galaxies are so similar in view of the great diversity in their optical appearance. The basic similarity of their radio spectra has two implications. First, the radiation mechanism is probably the same in all radio galaxies. It is unlikely that different radiation mechanisms in different sources would give rise to such similar spectra. And presumably this radiation process is the synchrotron mechanism.

Second, there must be a continuing supply of relativistic electrons to replace those whose energy is dissipated through the radiation process. If this were not so, we would expect to find a wide range of spectral indices just because of this energy loss. The rate at which a relativistic electron loses energy by the synchrotron mechanism is proportional to the square of its energy, and the wavelength at which most of this energy is radiated is inversely proportional to the

square of the electron energy. Thus electrons responsible for the radiation at short radio wavelengths lose energy much more rapidly than those responsible for radiation at longer wavelengths. If at some stage in the life of a radio galaxy the supply of relativistic electrons were abruptly cut off, the short-wavelength emission would decline more rapidly than the radiation at longer wavelengths. This would lead, in a short period of time, to a spectral index that is very steep at short wavelengths. That no such steep spectra have been observed implies a continuing supply of electrons, for periods long compared to the decay time of the short-wavelength emission.

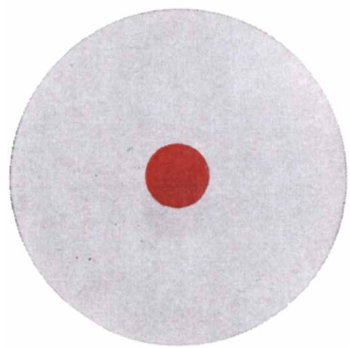
This does not necessarily mean that intense radio emission from radio galaxies is a long-lived phenomenon. The lifetime of an electron radiating at a wavelength of 10 centimeters is only of the order of 100,000 to a million years, depending on the magnetic-field strength. If relativistic electrons are supplied to the source for 10 million years, the resulting spectrum would conform to those we observe.

The change in spectral index with wavelength observed in the case of Cygnus A and several other sources finds a ready explanation in terms of the synchrotron mechanism if relativistic electrons are being continuously produced. At an early stage in the radio life of a galaxy the intensity of emission at a particular wavelength will be proportional to the total number of electrons with the appropriate energy for radiating at that wavelength. As time goes on and the supply of relativistic electrons increases, the intensity of emission at a particular wavelength will increase in proportion. The electrons are also losing energy through radiation, however. At some time, after a sufficient number of electrons have been produced, the rate of loss of energy by radiation will just compensate for the additional energy being supplied by production of relativistic electrons. At this time the intensity of emission will stop increasing and will remain approximately constant so long as electrons continue to be produced to replace the energy lost by radiation. Now the time required to reach this equilibrium condition increases with increasing wavelength. Therefore if we consider the entire spectrum of wavelengths, we will find an initial period in which the intensity at all wavelengths increases steadily so long as more and more electrons are being injected into the system. After some time, however, equilibrium will be reached at short wavelengths, and from then on the output intensity at these wavelengths will not increase, whereas at longer wavelengths the intensity will continue to increase. Thus the short-wavelength portion of the spectrum becomes steeper than the long-wavelength part. Over a period of time the equilibrium point, where the spectrum changes from that of the initial injection spectrum to that of equilibrium, moves further and further to longer wavelengths. It turns out that the difference in slope between the initial injection spectrum and the steeper equilibrium spectrum is just .5. This is approximately the change in slope that is observed in some radio galaxies with spectra that steepen at shorter wavelengths.

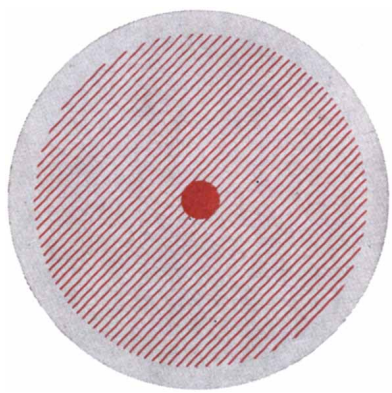
If the magnetic field of a source can be determined in some fashion, the wavelength of maximum change of slope can be used to determine the approximate age of the source. Some estimate for the strength of the magnetic field in Cygnus A can be obtained by assuming roughly equal division of energy between the magnetic field and either the relativistic electrons or the primary cosmic rays. These assumptions yield a magnetic-field strength on the order of 10^{-4} gauss. By relating this figure to the spectrum of Cygnus A one obtains an age for this radio source of only 400,000 years. If the basic assumptions are even approximately correct, Cygnus A has been a peculiar radio galaxy for a brief period indeed as astronomers reckon time.

The difference of .5 between an initial injection spectrum and the final equilibrium spectrum is also interestingly close to the range in spectral indices shown by the majority of radio galaxies. Perhaps most sources have the same injection spectrum, with the differences in spectral index from one source to another then being due to differences in evolutionary age.

A number of theories have been proposed to explain radio galaxies. Normal radio galaxies can be understood fairly well in terms of known phenomena. Several investigators have shown that the cosmic ray flux in our own galaxy is sufficient to supply, by collisions with the atoms of the interstellar gas, the relativistic electrons needed to account for the observed intensity of radio emission. This is probably the case in other normal galaxies. According to this theory relativistic electrons are produced in the disk of a galaxy, where the interstellar gas is concentrated. Once produced, however, they cannot be confined to the disk and diffuse out into a halo two or three times larger than the disk. The dimensions of the halo are determined by the galactic magnetic field, which controls the distribution of relativistic electrons. Cosmic rays provide a continuing source of electrons for a long time, since the probable lifetime of a galactic cosmic ray proton is at least a billion years. On the basis of this picture a normal galaxy should emit radio energy for a long time, provided that cosmic rays do not escape from the galaxy in any appreciable number. If this notion is

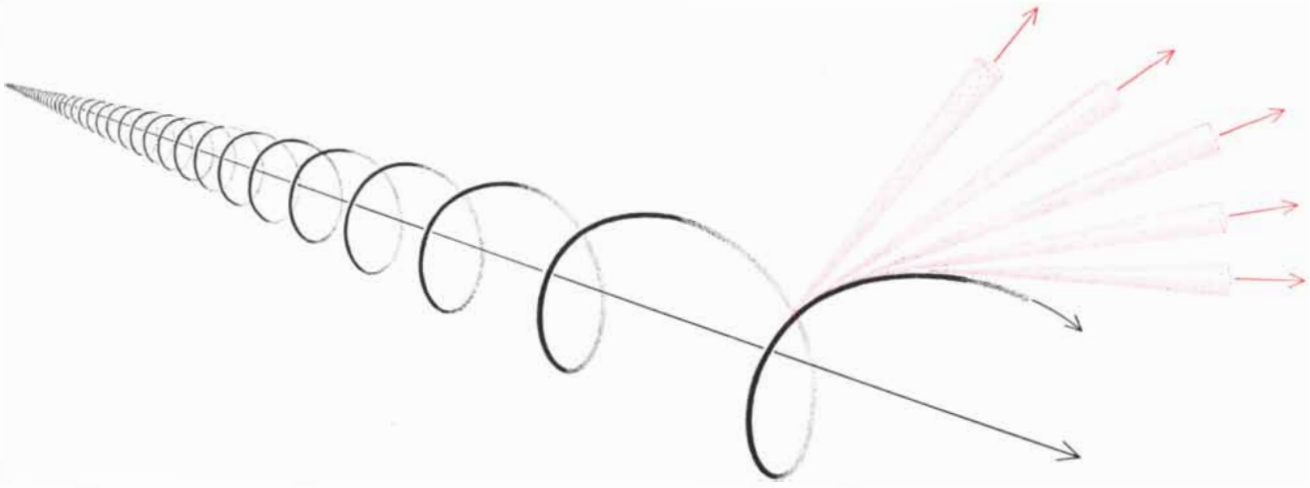


NGC 1068 emits most of its radio energy from a small central source (*color*). Gray area represents optically visible galaxy.

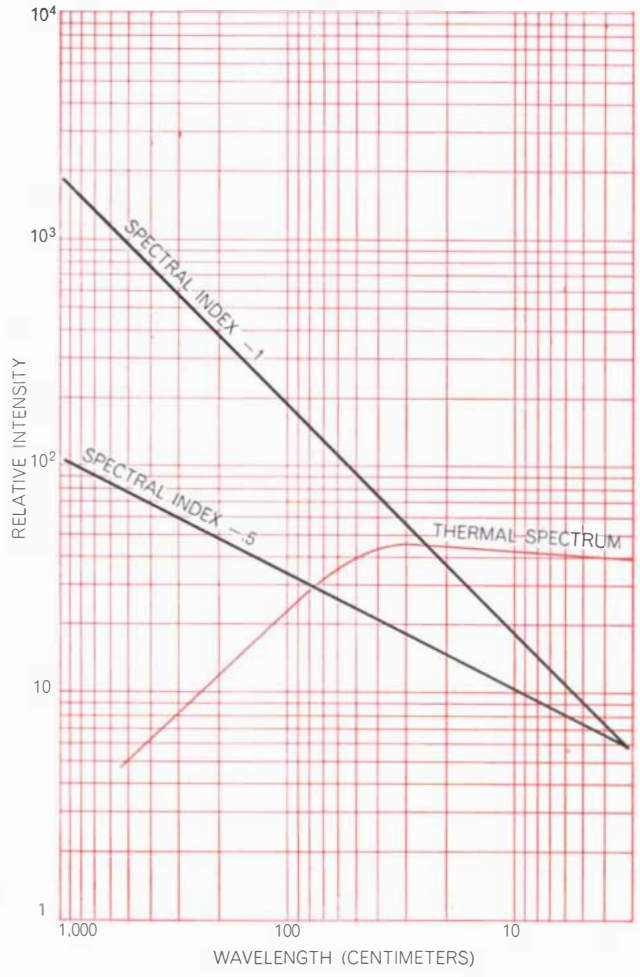


M 87 emits radio energy from two concentric sources, an intense core and a weaker halo slightly smaller than the visible galaxy.

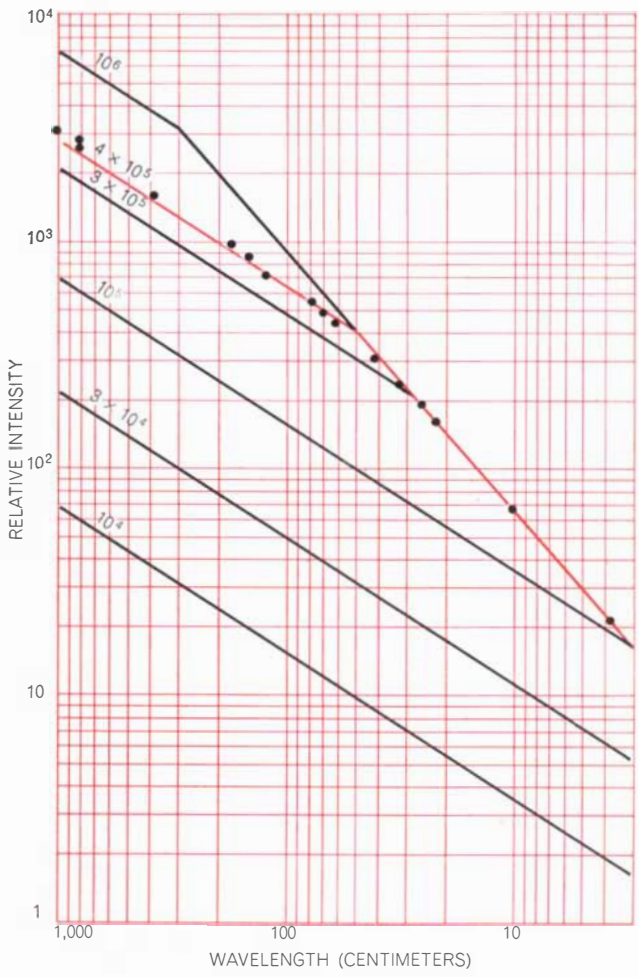
NGC 5128 shows four regions of radio brightness, two small and intense, that lie roughly on a line running through center of galaxy and perpendicular to the dust band.



SYNCHROTRON MECHANISM has been proposed as the source of most radio energy detected by radio telescopes. When a high-speed electron spirals around a line of magnetic force, it continuously radiates a cone of energy in the direction of its motion. Under suitable conditions of electron energy and magnetic-field strength the radiation falls in the radio region of the spectrum.



SPECTRA OF RADIO GALAXIES are generally "nonthermal." This means that the intensity of emission increases with wavelength, in contrast with a typical thermal spectrum (*color*), in which the intensity falls sharply beyond a certain wavelength. Spectra of radio galaxies usually lie between the two black lines.



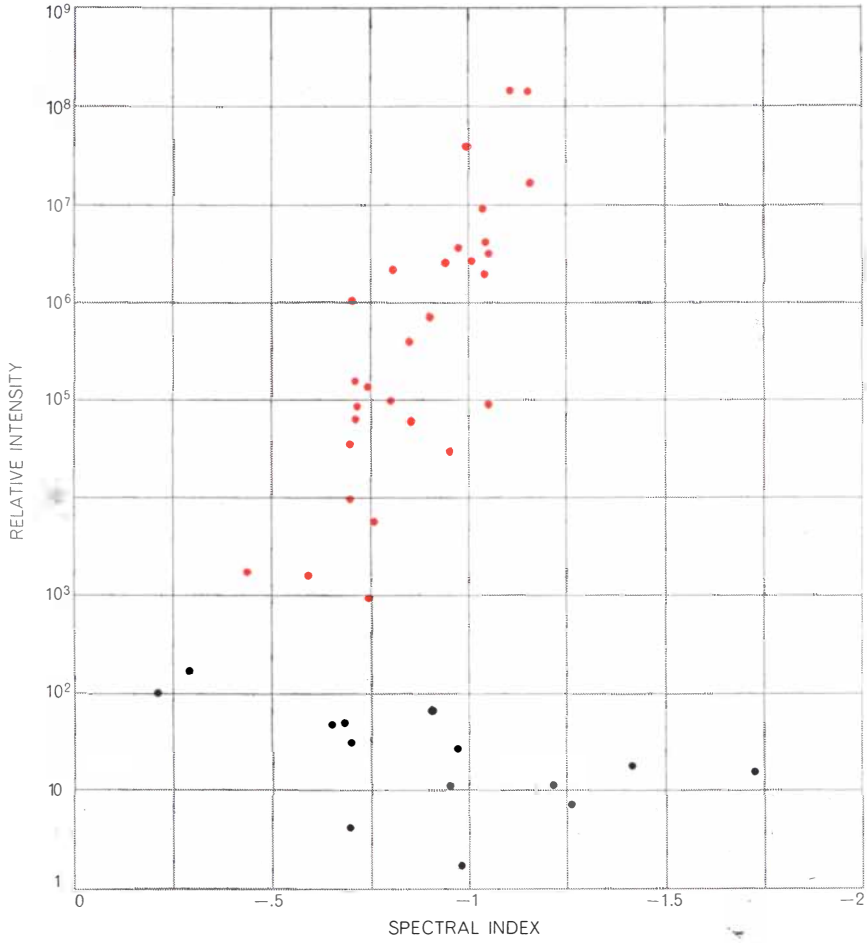
AGE OF CYGNUS A as a radio source can be estimated by computing a series of curves showing how the spectral index would change with time (*figures on curves represent years*). The dots show the observed intensity of Cygnus A at various wavelengths and indicate an age slightly greater than 4×10^5 (400,000) years.

correct, the source of cosmic rays is the remaining big unknown.

Explaining the peculiar radio galaxies is more difficult. One of the earliest suggestions was that the radio emission from Cygnus A and other intense radio sources is somehow produced as a result of the collision of two galaxies. The visual appearance of Cygnus A suggests that it may be two galaxies in collision, and the optical spectrum shows broad emission lines of highly excited atoms, suggestive of a turbulent, high-temperature gas, which might result from such a collision. Although the collision hypothesis is still tenable on observational grounds, it is not much help to the radio astronomer. The total kinetic energy of the collision of two massive galaxies would have to be converted into energy of relativistic electrons in order to explain the intense radio emission of Cygnus A and other intense sources. No method of accomplishing this is known.

Two other interesting suggestions have recently been made to explain the intense radio emission of Cygnus A and other peculiar galaxies. Geoffrey Burbidge of the Yerkes Observatory has suggested that a supernova explosion occurring in a region of high stellar density within a galaxy may trigger a chain reaction of other supernova explosions. Intense radiation from the first explosion falling on neighboring stars would cause nuclear reactions in the atmosphere of these stars. These nuclear reactions would in turn create disturbances that would travel inward to the center of the star and make it explode. The relativistic electrons needed for radio emission are produced either directly in the explosions or indirectly by collisions between cosmic ray protons produced in the explosions and the interstellar gas.

An entirely different proposal has been made by the Soviet physicist V. L. Ginzburg. Ginzburg suggests that intense radio emission may be associated with the formation of a galaxy. In this picture an original gas cloud—a protogalaxy—contracts and breaks up into smaller gas clouds that subsequently form the stars of the galaxy. In the process gravitational energy is released that generates cosmic rays. Since the amount of interstellar gas would be large in the early life of a galaxy, before star formation had proceeded very far, collisions between cosmic rays and the gas atoms would be common. The collisions would provide the large number of relativistic electrons necessary for intense radio emission. If this hypothesis is correct, intense radio emission is a fairly short-lived phenomenon that occurs rather early in the life of a galaxy.



SPECTRAL DIFFERENCES are found between normal and peculiar radio galaxies. The normals (*black dots*) vary widely in spectral index and fall at the lower end of the intensity scale. Most peculiar radio galaxies (*color*) have a spectral index lying between −.6 and −1.2, and all emit substantially more radio energy than do the normal radio galaxies.

Any theory for explaining the peculiar radio galaxies runs into two grave difficulties. What is the ultimate source of their enormous radio output? And how is that vast energy transported some tens of thousands of light-years from the galactic disk, allowing radio waves to originate far outside the visible limits of the galaxy? If the radiation is produced by synchrotron emission, the energy stored in the magnetic field and in relativistic electrons must be on the order of 10^{45} kilowatt hours (10^{60} ergs) for the most powerful radio sources. This is an appreciable fraction of the total nuclear energy of a galaxy. How are these electrons produced? If the electrons start off at low energy and are raised to relativistic energies by some acceleration process in the galaxy, the energy involved in the acceleration mechanism must be considerably greater than the final total energy of the relativistic electrons, because all known acceleration mechanisms are comparatively inefficient. If, on the other hand, the electrons are produced as the result of collisions between cosmic ray protons and an interstellar gas, the total cosmic ray energy in the galaxy must also be at least one or two orders of magnitude greater than the relativistic electron energy. We are forced to conclude, therefore, that the mechanism underlying the intense radio emission from such objects as Cygnus A must be able to draw on a large fraction of the total energy of the object.

The two hypotheses mentioned above provide sources for the energy: nuclear reactions in one case and gravitational contraction in the other. Whether one or the other can also explain the observed distributions of radio emission and the various optical features, or whether additional theories will be required, remains to be seen. The unraveling of the processes that occur in radio galaxies has turned out to be an extraordinarily baffling problem. Its solution will undoubtedly lead to a deeper understanding of the history of galaxies and the universe.

Electrically Controlled Behavior

By energizing electrodes placed in various regions of a chicken's brain, the animal can be made to carry out most of the actions in its normal repertory. The technique clarifies the nature of drives

by Erich von Holst and Ursula von Saint Paul

We all recognize that many human actions are controlled by drives, which we can steer but which we cannot easily ignore. We become hungry, thirsty, sleepy; we crave affection; sometimes we are angry or frightened. If we classify an action as controlled by drives when it is not planned or directed by conscious intelligence, then we can maintain that nearly all kinds of animal behavior, and rather large portions of human behavior, are drive-controlled. Often we are not aware of why we act as we do. This lack of awareness takes a number of forms.

A boy who stops in front of several grocery stores on his way home from school may not realize that it is hunger that makes the window displays so attractive to him. He may remember only later that he has missed his lunch that day. In this example the drive accentuates whatever is most important among the things that can be perceived.

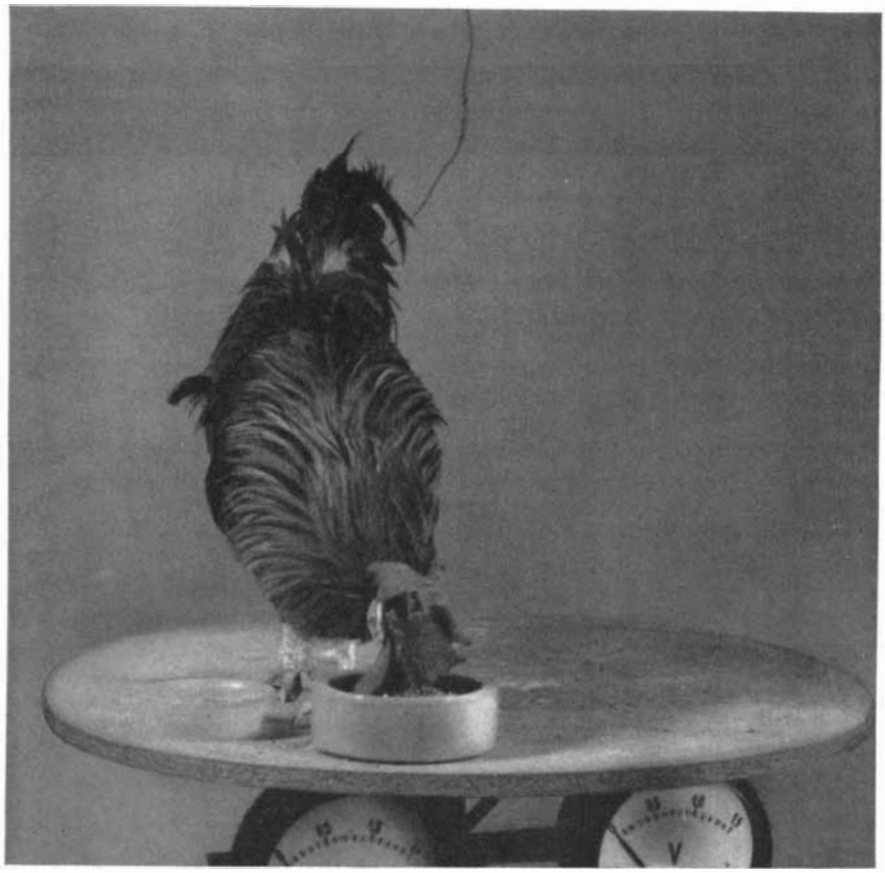
A man who is kept waiting by a young lady may approach a complete stranger, thinking her to be the person he is expecting. He does not realize that it is his longing that transforms the stranger into the person he is expecting; he is only annoyed by his poor eyesight. Here the drive has led to a change in perception, an illusion.

A child who wakes up crying with fear in a strange room, quite sure that he sees a tiger, does not know it is his own fear that creates the animal, which disappears as soon as the light is turned on. Here the drive produced a hallucination.

Thus our moods, feelings, drives and wishes constantly color and change the so-called objective world around us. Our actions are guided by a variety of unconscious drives on which are superimposed those needs and wishes of which we are aware.

Presumably animals other than man have no awareness of drives. Moreover, if a drive in an animal is fully satisfied, it cannot be elicited by any stimulus. On the other hand, the longer a drive is held in check, the more urgent it becomes and the wider is the range of stimuli that will elicit the corresponding behavior, be it eating, sexual activity, flight or care of another animal of the same species. In many kinds of behavior if the drive is held in check too long, the behavior pattern will begin in the total absence of the appropriate stimulus.

An example is described by the eminent student of animal behavior Konrad Z. Lorenz. When a captive starling accustomed to receiving its food from a dish was allowed to fly freely, it performed, as if in pantomime, the entire pent-up cycle of catching an insect in the air. It would appear to fixate on an insect, swoop down on it, catch it and



URGE TO FLEE is elicited by a weak electric current delivered by an electrode implanted in the brain stem of a rooster. Before stimulation (*left*) the rooster feeds calmly. On stimulation (*center*) the rooster fixates intently on a nonexistent object approaching from

swallow it—all in the absence of an insect. It is hard to believe that in such cases an animal does not have a hallucinatory perception of the absent prey.

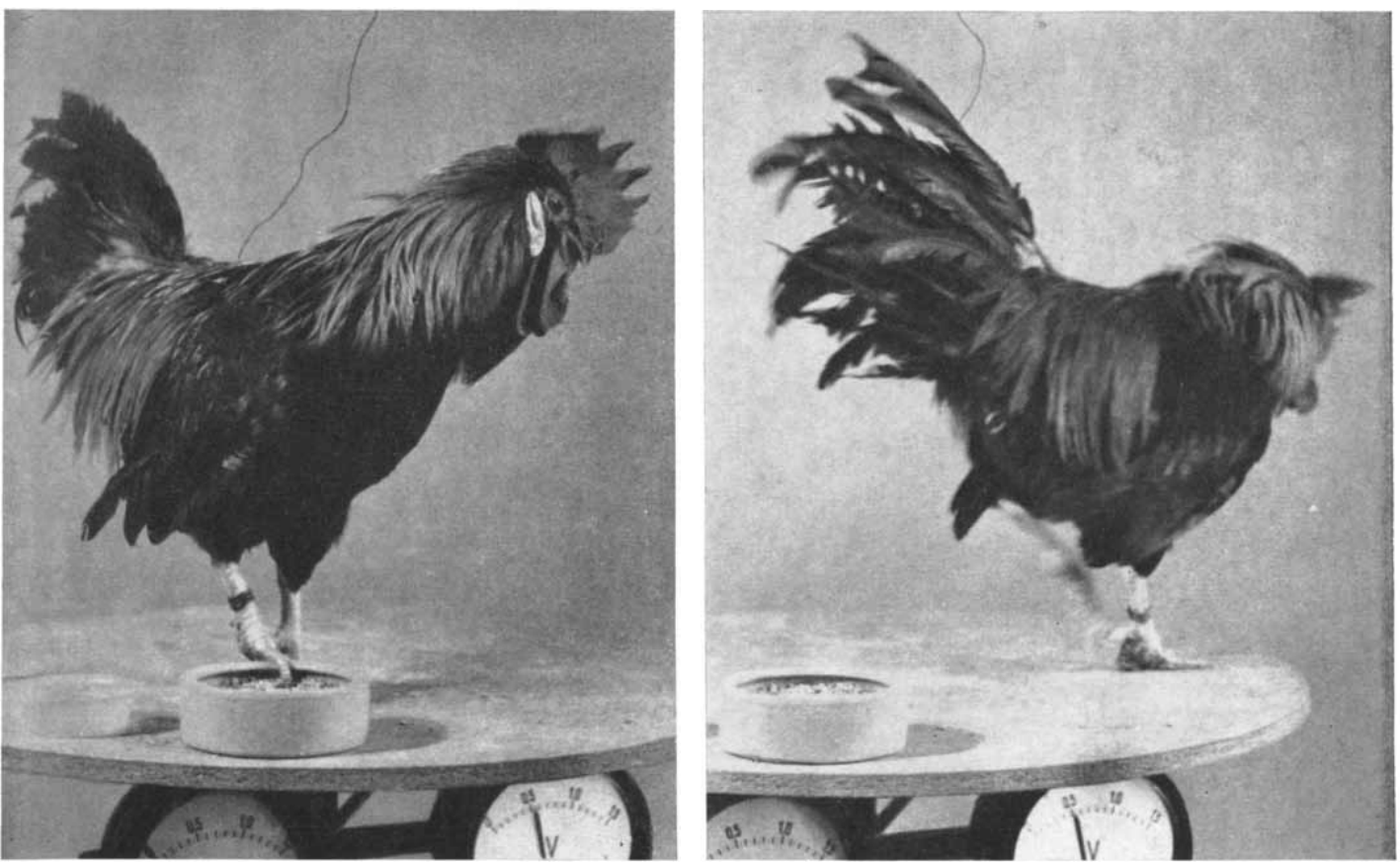
We know from observations of people with brain damage, from electrical stimulation of regions of the brain in patients undergoing brain surgery while conscious, and particularly from the celebrated experiments on cats by Walter R. Hess of Zurich, that in mammals the chief center for the regulation of drives lies in a part of the brain stem called the diencephalon. When various areas of the brain of a surgical patient are stimulated, a number of spontaneous desires and feelings and their corresponding perceptions are elicited. Hess implanted electrodes in the brain stem of cats and found that in the presence of the appropriate object he could stimulate the cats to eat, attack or flee. If the stimulation was very intense, the animal would chew inedible objects or attack a human observer instead of a natural enemy. The cats behaved as they would have if the corresponding drives had been abnormally pent up. Perceptual accentuation, illusion and hallucination all seem to have been involved in these experiments.

Hess began his pioneering studies in the early 1930's and in 1949 shared the Nobel prize for medicine and physiology. His methods allowed him to identify many reactive regions in the brain stem. He sacrificed his animals following stimulation, cut their brains into serial sections and mapped the points of effective stimulation, which had been stained. Certain moods or drives, such as fatigue, turned out to be associated with specific zones, whereas others were related to larger regions or interspersed with the locations associated with other drives. Unfortunately simple spatial separation into discrete centers, each representing one specific function, is not to be found.

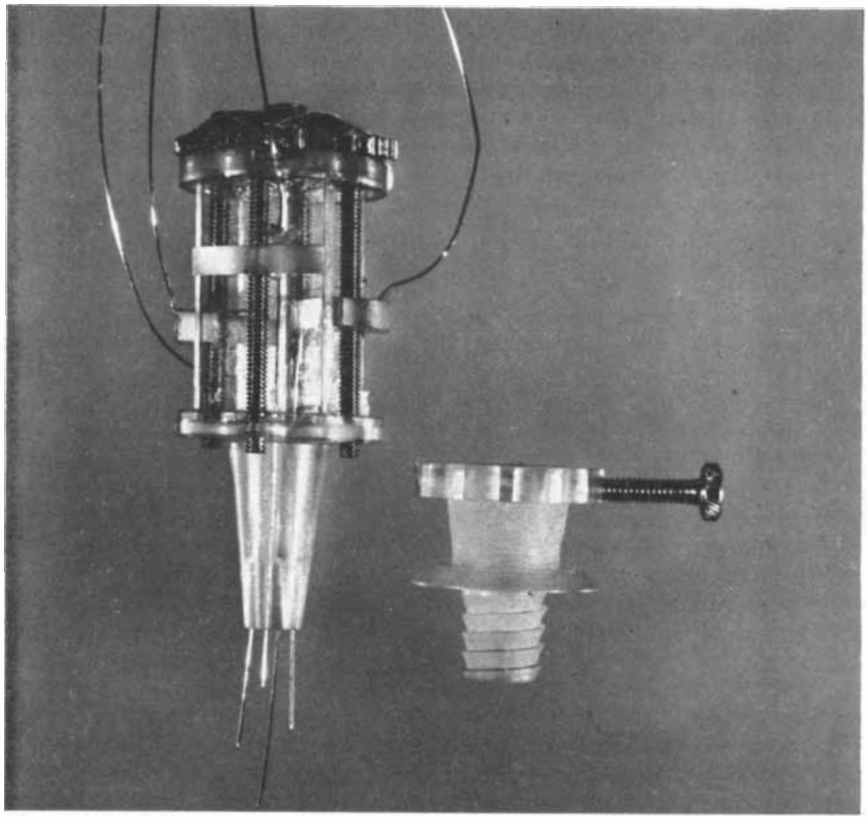
Such localization of function in the nervous system has considerable importance for the physician. The physiologist, however, must remember that localization studies answer the question of "where" but not the questions of "how" and "why." In order to answer these physiological questions one must try to penetrate into the dynamics of the drive mechanism. It is on this topic that I wish to report.

There are two methods of studying the way in which animal behavior is controlled by drives. The first is careful observation of one species over many years and under various conditions. In this way one acquires expert knowledge that enables one to predict with some certainty how an animal of this species will behave in a particular situation. Predictive ability of this sort is largely intuitive; it cannot be reduced to its components or used to make measurements. Analysis and measurement become possible, however, with the second method, namely the technical mastery of electrical stimulation of regions in the brain stem. Even with this method a detailed understanding of the species and its behavior remains indispensable. To recognize the delicate interplay of drives one must be able to judge the significance of individual behavior sequences, as seen under normal conditions, and to appreciate their place within the animal's behavioral repertory.

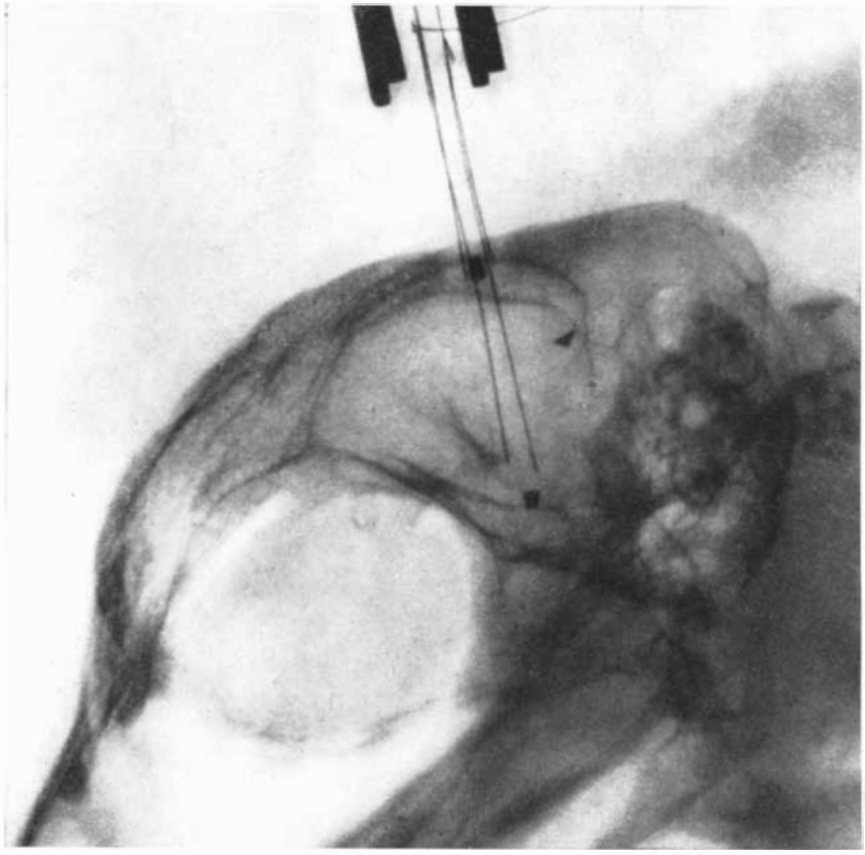
The richest inventory of behavior can be found among animals that form social groups. In addition to the egoistic drives that every organism needs for survival, these animals display a variety of altruistic drives for regulating their social interactions, which are not unlike



a distance; the object gets closer as the stimulus increases in strength and duration. (The stimulus voltage can be read on the meter at right.) Finally (*right*) the rooster jumps away fearfully. On repeated stimulation the frightening object always seems to come from the same direction. These photographs were made by the authors at the Max Planck Institute for the Physiology of Behavior.



STIMULATING APPARATUS consists of a plastic fitting (*right*), which heals in place after being threaded into the skull of an animal, and an electrode carrier (*left*), which goes into the fitting. The carrier holds four electrodes, the lengths of which are adjustable.



X-RAY VIEW shows electrodes penetrating the brain of a chicken. The drawing at the bottom left on the opposite page delineates the brain and the brain stem region. The electrodes and the stimuli they carry cause no pain, and the experiments do the animal no harm.

human social behavior. Such a species, the domestic chicken, has served as our experimental subject at the Max Planck Institute for the Physiology of Behavior in Seewiesen, Germany.

Chickens have a large repertory of gestures and a language consisting of several dozen "words." To be sure, their language is not learned, as is the language of man; their sounds and the understanding of these sounds are inborn. In the chicken yard there is a definite "pecking order" among the hens, which has been established as the result of fights in early youth. The hen of highest rank is entitled to the best sleeping place and the best food; the others take what is left in sequence. Transgression by a hen of lower rank is punished by pecking and the pulling of feathers.

The rooster is both ruler and cavalier. He warns the others with several distinct sounds against approaching enemies on the ground or in the air. He defends the hens against attackers, announces the presence of food, seeks out a nesting place for the young hen who is ready to mate and summons her with gentle, whispering sounds. Half-asleep, he watches over the sleeping flock. The call "cock-a-doodle-doo," which each rooster emits in his own distinctive fashion, may be freely translated to mean: "Here I am, ready to stand by you as mate and defender." Rival males are threatened and fought with vigor; the defeated rooster leaves the scene and may hide for days. All these forms of behavior, which I have merely sketched, are accompanied or preceded by specific gestures or sounds that tell the expert much about what is happening. It takes years to recognize and appreciate the complex social activity of the chicken yard. But until one understands chicken society there is no point in using electrical stimulation methods to study the role of drives in behavior.

At our institute these methods begin with anesthetizing a chicken and inserting in its skull a small threaded plastic fitting that remains in place permanently. To conduct an experiment we introduce into an opening in the fitting a small device bearing four electrode wires, each of which can be positioned in the brain by a screw [*see top illustration at left*]. The electrodes can be inserted while the animal is conscious, since the brain itself is totally insensitive to touching or probing. The damage done by this procedure is so slight that the experimental animal remains normal and healthy after 100 or more experiments extending over a period of years.

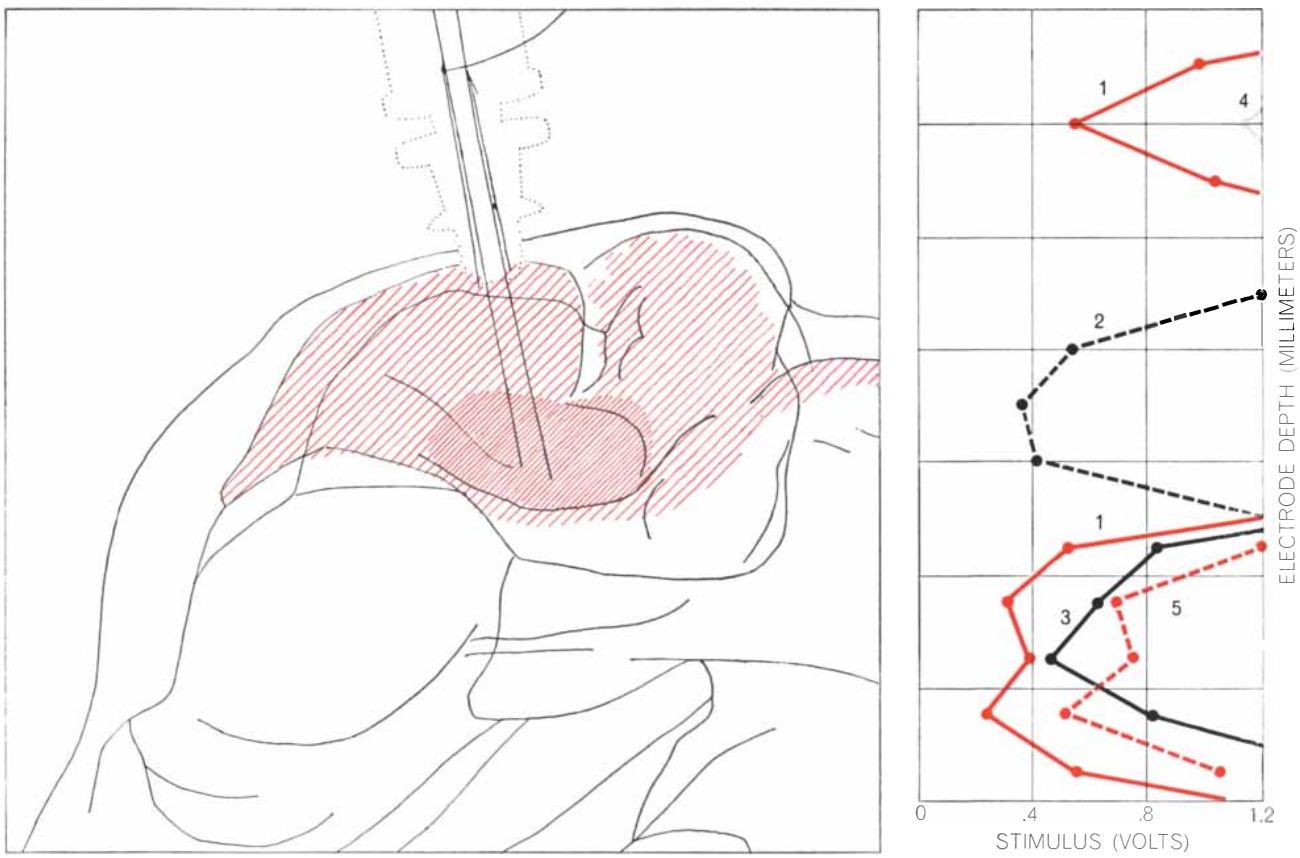
The initial experiment is to advance an electrode slowly into the brain stem, applying at intervals a low-voltage alternating current (usually of 50 cycles). We observe the animal's reaction closely and record, often with motion pictures, the behavior that is elicited as the tip of the electrode reaches different levels. When the electrode tip is still some distance away from a reactive structure, a relatively strong current will be needed to evoke a particular response. As the electrode tip penetrates deeper, the response can be evoked with less and less current: the threshold decreases. As the electrode tip moves away from this response zone the threshold increases again. One thereby obtains, on traversing the brain stem, a varying number of threshold curves for different types of behavior [*see illustration at right below*]. If an interesting reaction is encountered, the electrode is left at this depth and is allowed to remain for hours or days in the animal's skull.

The chickens are kept on a table to which they have become accustomed before testing, and they are connected with fine wires to the stimulating apparatus. Alternatively the animals are equipped with a tiny radio receiver, weighing about 25 grams, and are permitted to wander about freely. The remote-control procedure is valuable for studying behavior within a social group.

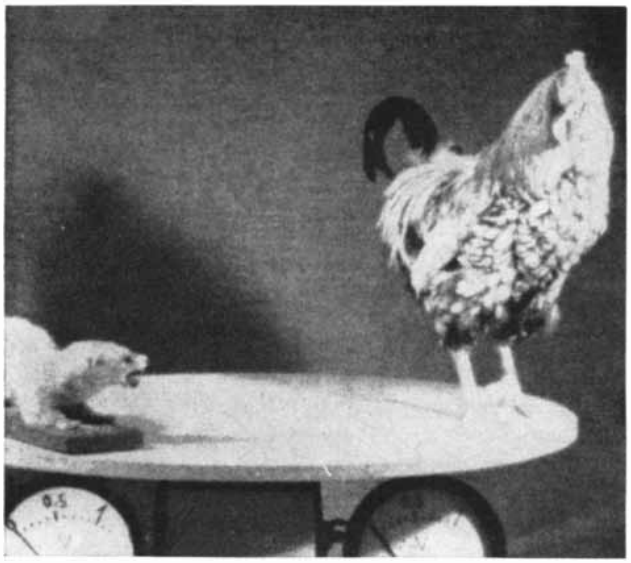
By stimulating the brain stem in this way we have evoked almost all the forms of activity and vocalization familiar to those acquainted with chickens. We have also obtained various composite forms of behavior, some of which do not occur in nature. The natural modes of behavior can be classified provisionally into simple movements and complex behavior sequences. Simple movements are, for example, sitting, standing, preening, grooming, looking about alertly, and stretching the neck as if peering at something in the distance. The last response is sometimes accompanied by a special call used to warn against airborne predators. Other simple responses are scratching with one foot, which is part of a courtship sequence, and the various orienting attitudes such as turning the head to the right or left or moving it up or down.

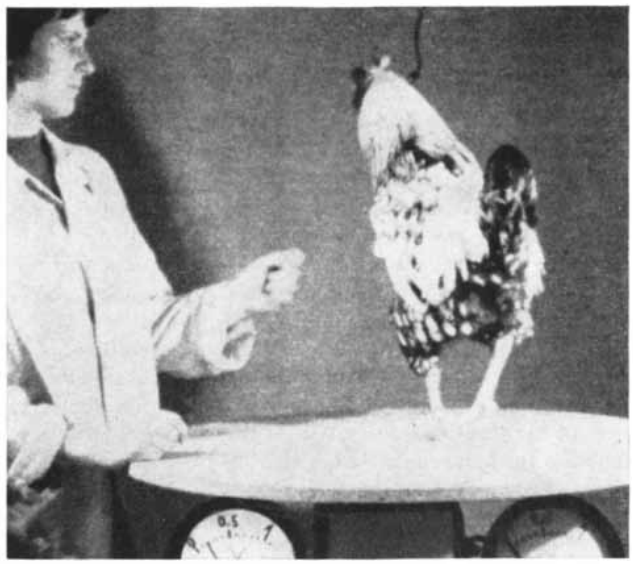
More complex behavior sequences include seeking and eating food, seeking and drinking water, escaping from predators on the ground, escaping from flying predators, the sequence of settling down and falling asleep and the sequence of guiding a hen to a nest, which is of course performed only by the rooster. These complex activities consist of a chain of different individual movements that are all related to a single goal. For example, a series of steps is interposed between an initiating stimulus, delivered to the "sleep" region in a waking and active rooster, and the final stage of deep sleep. The animal stops eating, looks around and walks; it flutters its eyelids, yawns and sits down; it fluffs its plumage, retracts its head and closes its eyes. All these effects—each of which, incidentally, can be evoked individually from other foci—are subordinated to a single drive, that associated with fatigue or the desire to sleep. Another meaningful series, having to do with disgust, is depicted at the top of page 56. Here also individual components can be evoked by stimulating other specific regions of the brain stem.

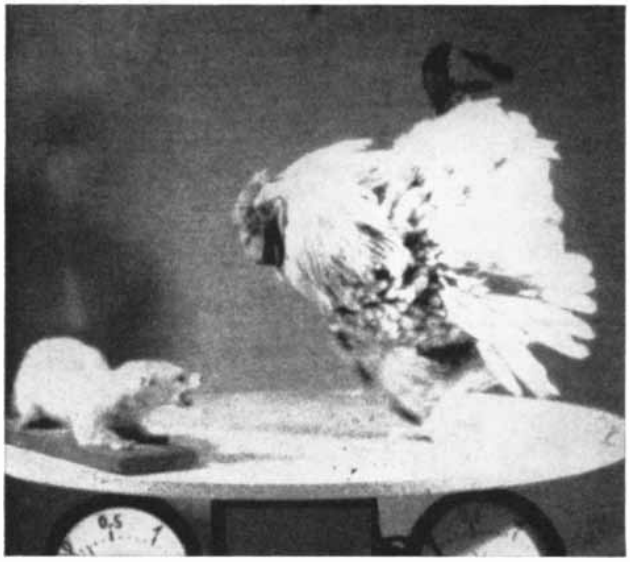
The ability to evoke at will either individual movements or complex drive sequences has theoretical significance. In the case of individual movements

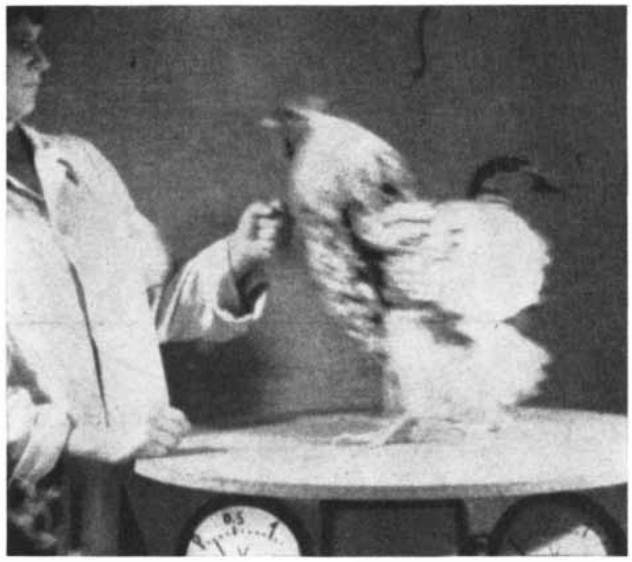


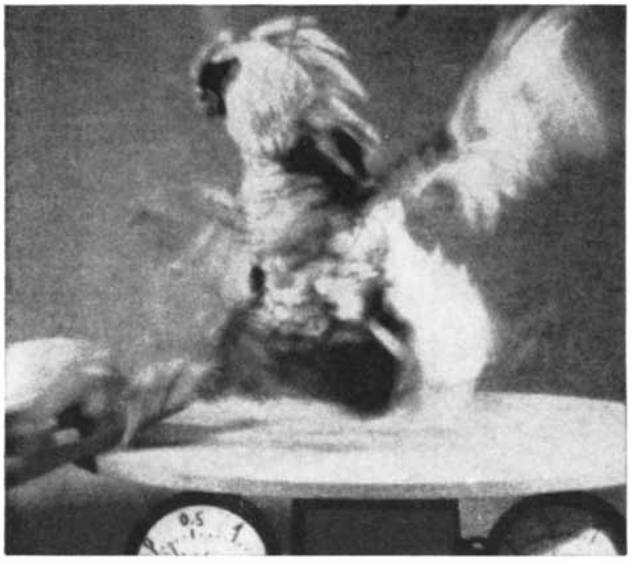
REGION STIMULATED AND RESPONSES are shown in these two illustrations. The brain is indicated (*left*) by colored hatching, and the brain stem, the region actually stimulated, is doubly hatched. As an electrode is lowered gradually to different depths and activated, the animal may respond in various ways. The charted responses (*right*) are: *1*, alertness; *2*, watchful staring; *3*, shaking the head; *4*, turning to left; *5*, turning to right. Overlapping represents responses at the same depth but at different sites.

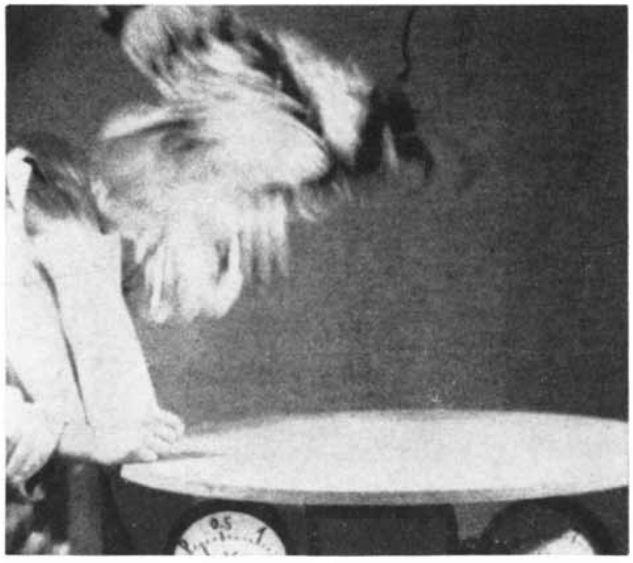












ATTACK ON AN "ENEMY" can be elicited by a particular stimulus. In the absence of the stimulus (*top*) the rooster ignores the stuffed predator. When the stimulus is applied, the bird turns on the stuffed animal and attacks it furiously, spurs flying.

ATTACK ON A FRIEND, the rooster's keeper, is provoked if the natural "enemy" is absent and if the stimulus used in the film sequence shown at left is prolonged. The rooster prefers to aim its attack at the keeper's face rather than at her hand.

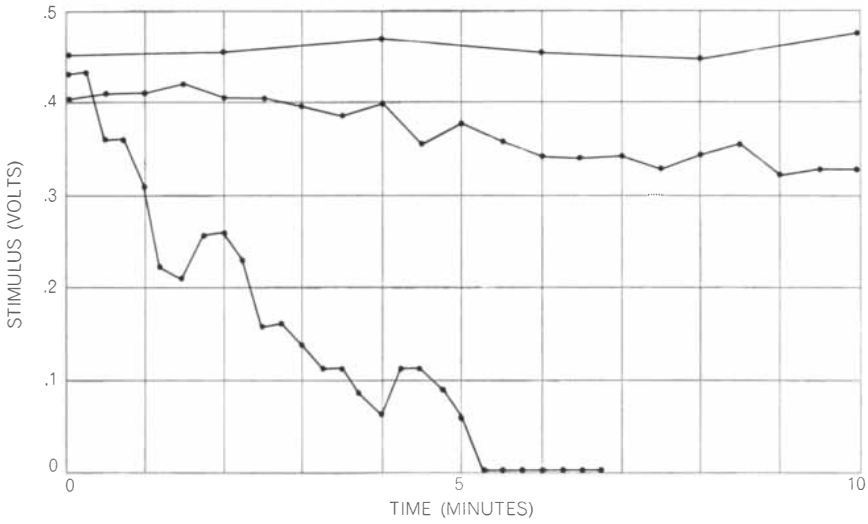
the stimulus merely furnishes an impulse for a particular movement; in the case of the drives the stimulus sets up a goal that can be attained in different ways, depending on external circumstances. It is not always easy to decide, however, whether a stimulus activates an isolated movement or an entire drive sequence. Many complex behavior sequences occur in their entirety only under certain external circumstances. To be sure, escape reactions can be evoked in the absence of the appropriate external object (or its substitute) if the brain stimulation is sufficiently intense. In such cases it is probable that the absent object of fear is being hallucinated. Hallucination, or apparent hallucination, does not seem to occur, however, when aggressive behavior is evoked by stimulation. Let me explain further.

Chickens exhibit different kinds of attack behavior. For example, stimulation of a certain region of the brain activates the characteristic attack that one hen makes against another hen of lower rank. If the stimulated hen is confronted with another hen (alive or stuffed), it pecks at the other hen and pulls its feathers. When a human hand is proffered as a substitute object, it is pecked in the same way if the stimulation has been increased somewhat. When no object is provided, however, and if the brain stimulation is strong, the hen looks about in great excitement and pecks the ground several times, much as an angry man may hit a table with his fist if the object of his anger is out of reach. But the other part of this form of natural attack, the plucking of feathers, is missing.

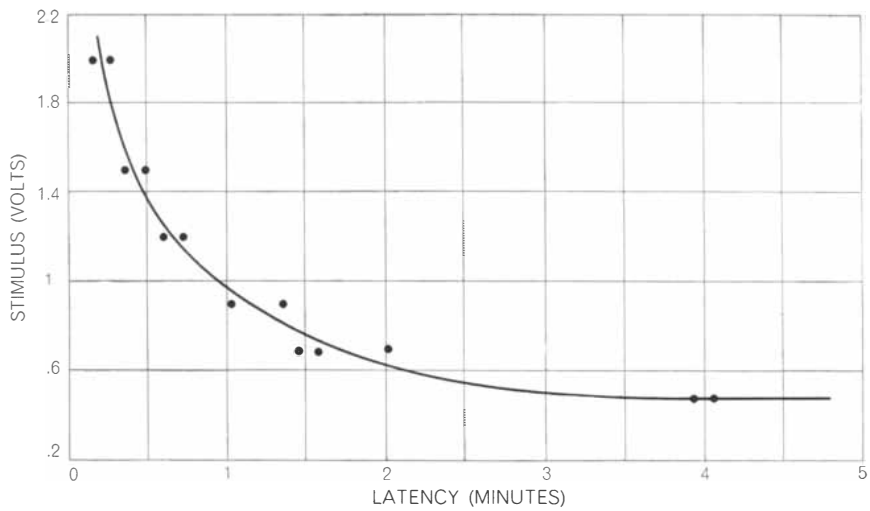
A totally different form of aggression is directed against natural enemies of the species. The behavior that accompanies this drive never arises unless an enemy, real or artificial, is present. The three photographs at the left on the opposite page, taken from a motion picture, shows an electrically stimulated rooster attacking a small stuffed predator. Before stimulation the rooster had hardly noticed that an "enemy" was present. The stimulation brought out the full behavioral sequence: alertness, visual fixation, approach, attitude of rage, attack with spurs and triumphant call.

The second series of motion-picture frames on the opposite page shows the behavior of the same rooster toward a keeper who had always been treated as a friend. After sustained stimulation the rooster flew up and attacked the keeper's face with its spurs. (The human face is apparently a better substitute for an enemy than the human hand.) If all substitutes for an enemy are lacking—when there is, so to speak, no hook on which to hang an illusion—the rooster exhibits only motor restlessness. Moreover, the same motor restlessness is observed if one stimulates brain areas associated with hunger, thirst, courtship or fighting under conditions in which the environment does not permit the unreeling of the entire behavior sequence. For this reason it is often necessary to vary the external conditions to be sure which particular behavior sequence—which complex drive—has in fact been activated.

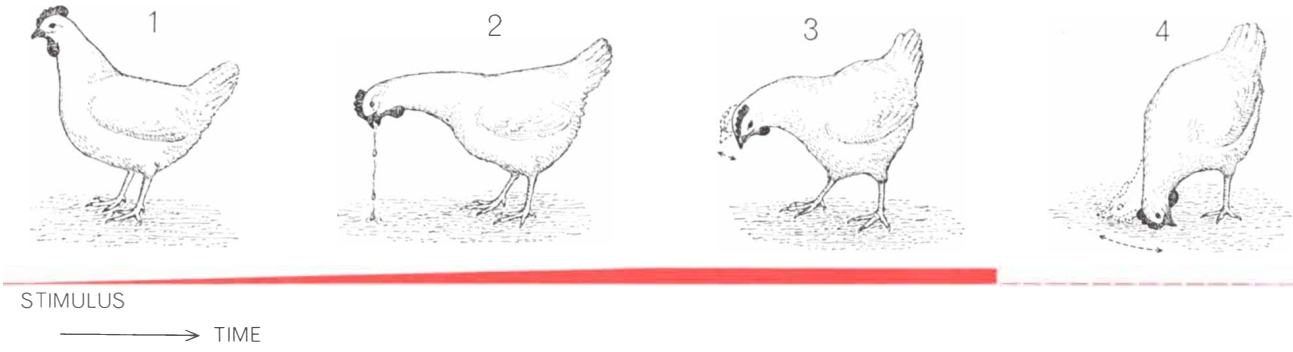
Simple behavior patterns other than motor restlessness can be observed in a variety of complex drive systems. Sitting down occurs whether the hen simply wants to sit down, to incubate eggs or to go to sleep. Standing up marks the onset of all those behavior sequences that entail a change in position. A particular excited cackling (poh-poh-poh) accompanies a number of behavior sequences that involve a mood of anxious tension. Another kind of cackling that sounds oddly like scolding (cock-cock-cock-colay) accompanies various forms of relaxation of function, such as landing after a brief flight or "relief" after laying an egg. The frozen stance, with head pulled in, can be an element in the behavior toward a predator threatening from the air (in which case the chicken seems to feign death), or it can be an attitude of humility brought on by a rival of superior strength. Even the pecking



EFFECT OF STIMULATION FREQUENCY is found by plotting the threshold voltage needed to elicit "attentive reconnoitering" in a sleepy hen. The voltage is raised slowly; the dots indicate the voltage reached when the hen's head begins to move. If the stimuli are two minutes apart (*top curve*), the threshold voltage is virtually the same each time. If the stimuli are only 30 seconds apart (*middle curve*), the threshold voltage tends to drop. If the stimuli are closely spaced (*bottom*), the hen becomes fully awake in about five minutes.



EFFECT OF VOLTAGE STRENGTH is found by plotting the interval between stimulus and response, called the latency. In this case the response is a warning call (clucking).

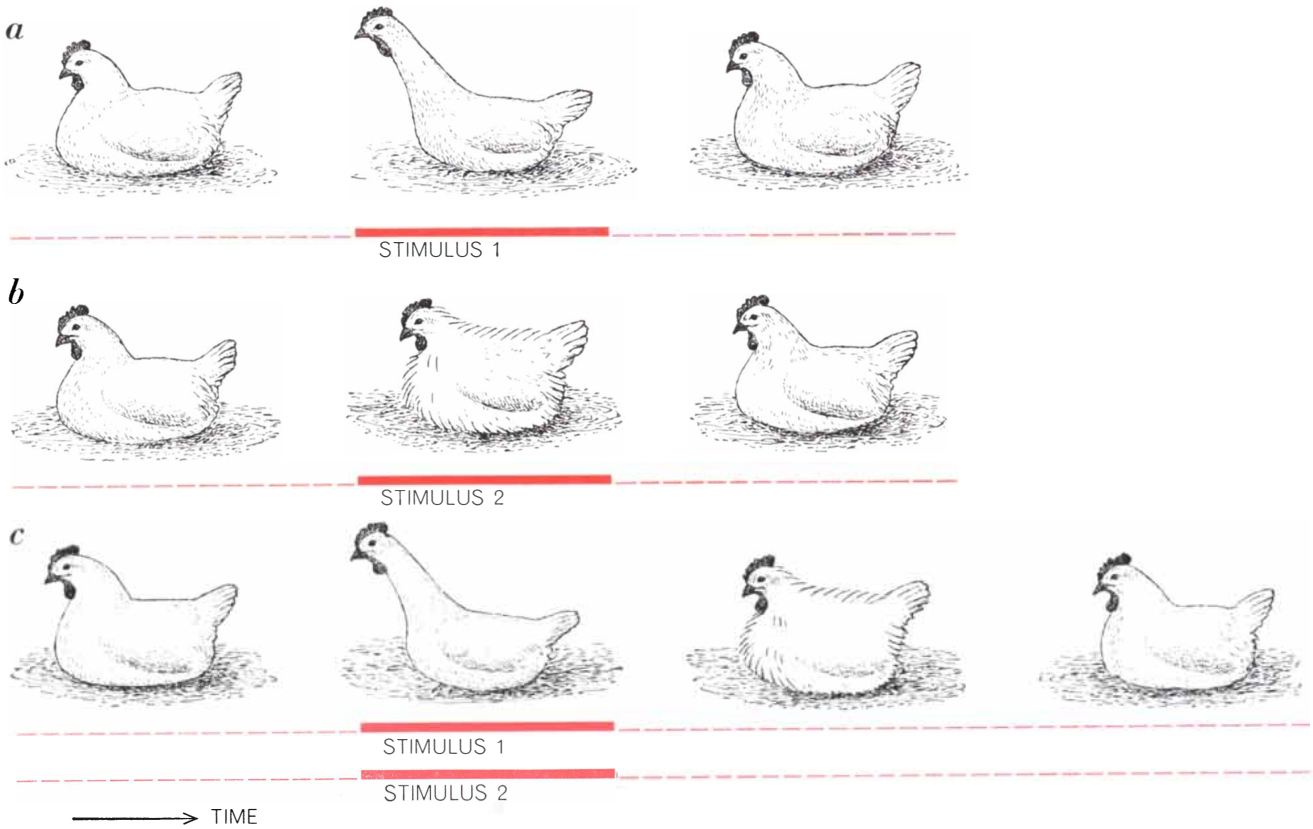


"DISGUST REACTION" can be elicited by stimulating the hen's brain stem in the appropriate place. The hen, which has been eating, stops (*1*), spits out the food in its beak (*2*), shakes its head (*3*) and wipes its beak on the ground before eating again (*4*).

of food on the ground can be either an element in the behavior associated with hunger or an element of fights between rivals. Fighting cocks tend to peck hastily at food or, if a rival is present, they peck the bare ground. The latter form of pecking, known as displacement pecking, is a threatening gesture [see "The Fighting Behavior of Animals," by Irenäus Eibl-Eibesfeldt; SCIENTIFIC AMERICAN, December, 1961].

From such observations we can conclude that a fairly large number of movements or behavior elements are subordinated to a smaller number of more complex drives. The drives employ the repertory of simple movements as a means of reaching various goals. The existence of such a hierarchic system of drives is well supported by the observation that only the complex "high level" drives give the impression of completely spontaneous activity. In contrast, the individual acts induced by stimulation, such as particular sounds, head-turning, sitting down, pecking, swallowing and the like, all have a certain mechanical character, as if they did not concern the animal as a whole.

Before turning to our experimental attempts to combine drives, I should say something about thresholds and the variation in the strength of the current needed to evoke particular forms of activity. During and after stimulation there are conspicuous changes in behavior. When a particular behavior is evoked in a given brain region for the first time, the threshold is usually quite high; that is, one has to apply a strong stimulus in order to elicit the behavior. With rapidly repeated or protracted stimulation the threshold decreases markedly and may even fall to zero, in which case the activity may continue for a fairly long time without further stimulation [*see upper illustration on preceding page*]. Later on, if the stimulus is maintained over a



COMBINATION OF TWO STIMULI may result in the suppression of the weaker response, followed by its delayed expression. One stimulus causes the hen to flatten its feathers and stretch out its neck (*a*). A different stimulus induces it to fluff its feathers (*b*). Combination of the two elicits the two responses in succession, but the second does not appear until all stimulation has ended (*c*).

period of time, the threshold gradually rises again and often becomes so high that, for several minutes or as much as an hour afterward, the particular behavior cannot be elicited.

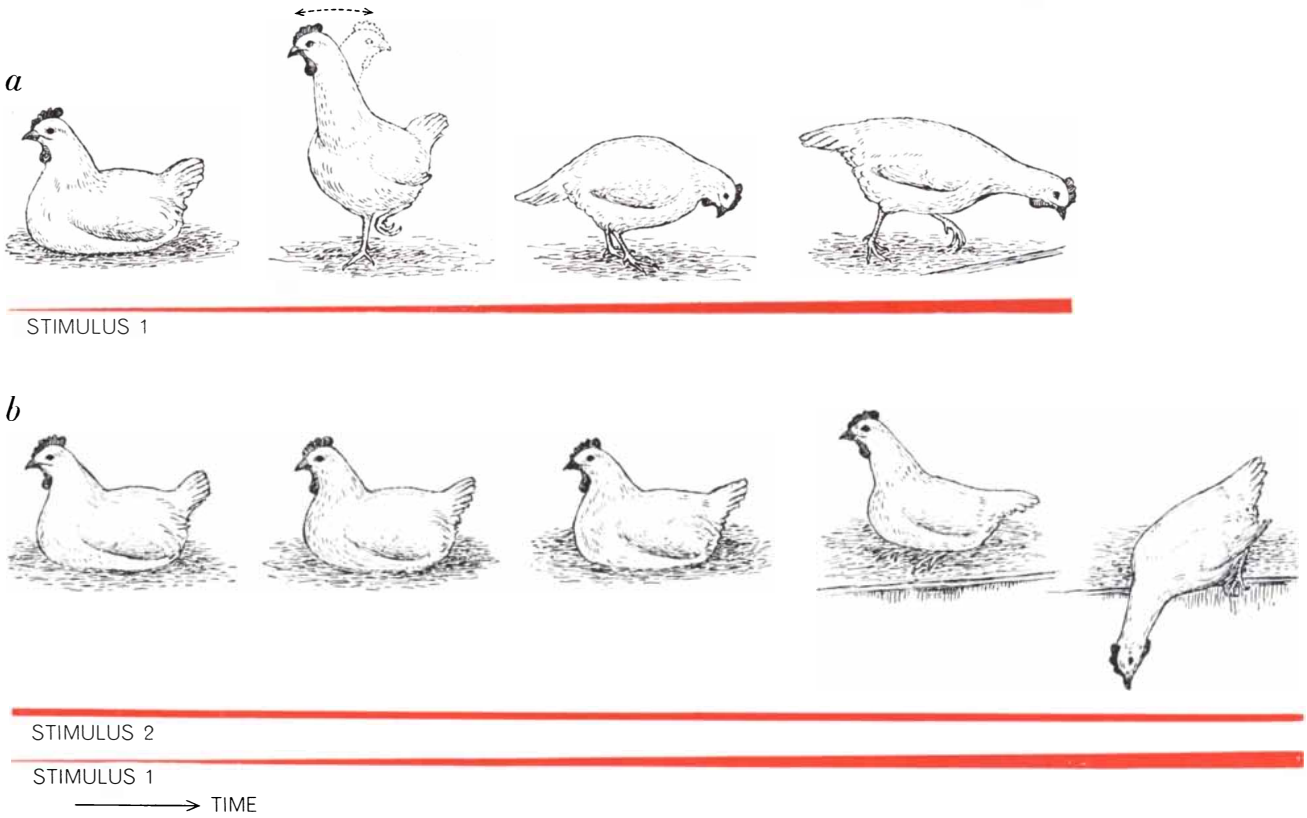
By combining brain stimuli in certain ways we have found that the initial decline in threshold and its subsequent rise are attributable to two different processes. The initial decline in threshold represents a change in what can be called central set, or predisposition, so that it favors a particular activity to which the animal was initially more or less indifferent. Simultaneously there is a rise in threshold for other activities that are antagonistic to the one evoked. For instance, if by stimulation one makes a sleepy animal hungry and it begins to eat, the threshold for inducing sleep has been concurrently increased. Similarly, if an animal that spontaneously exhibits a slight tendency toward flight is made sleepy by the appropriate brain stimulation, the threshold for flight is simultaneously increased. These shifts in central set represent a shift in dynamic balance. In contrast, the kind of increase in threshold that occurs after prolonged activation of a particular behavior represents a form of central blocking, or central adaptation, that makes the animal increasingly less sensitive to the continuing stimulation. This blocking occurs in the brain stem close to the stimulated region, whereas the central change of set seems to take place higher in the brain, closer to the cortical regions associated with motor activity.

In addition to these quantitative changes in behavior, qualitative changes also appear. I shall cite only one striking example. In roosters a number of behavioral states manifest a certain underlying depressive quality, such states as the desire to escape, crying, "freezing," warning, reconnoitering, scolding. If, through appropriate stimulation, one of these activities is maintained over a period of time, there is usually a change five to 10 seconds after the end of the stimulation that transforms the depressive mood into a euphoric, self-assured one. The rooster stands up alertly, flaps its wings and crows. In much the same way, people often feel happy and cheerful after a prolonged depression.

The foregoing illustrates the necessity for controlling conditions carefully if one hopes to discover exact relationships between stimulus and response. Fortunately such control is attainable, and it is possible to maintain a desired mood over long periods without change. Clear stimulus-response relationships then become evident. For many types of behavior we have been able to draw simple curves showing the interval between onset of the stimulus and onset of the response—that is, showing latency as a function of stimulus strength [*see lower illustration on page 55*]. For example, with a stimulus current of about .5 volt the latency in a given response may be four seconds; with four times the voltage the latency may be only about .2 second. In general we find a simple reciprocal relationship between stimulus intensity and stimulus duration.

In addition to latency we can measure such variables as the speed of a motor sequence, the frequency of a rhythmic repetitive movement or the length of time a given kind of behavior continues beyond the end of the stimulation. Reproducible quantitative relationships can be observed in all these cases. The freely moving animal, steered by the experimenter in its spontaneous activities, proves to be a complicated yet precisely functioning physical apparatus.

All this had to be considered before we could turn to the problem of combining different drives. Such a combination is achieved by means of two differ-



ANOTHER COMBINATION OF STIMULI leads to suppression of certain components of one of the responses. Gradual activation of an urge to flee in a sitting hen (*a*) causes the hen to stand and look about alertly before it finally jumps. When a continuous stimulus for sitting is applied at the same time (*b*), the hen becomes restless but keeps sitting until it finally jumps away.

ent electrodes that activate different drives concurrently in different regions of the brain. For safety's sake this is done by stimulating one region intermittently and the other region during the intervals. In this way only one region is physically stimulated at a time, although two drives are activated simultaneously. If the alternation of the two stimuli is between four and 10 per second, the physiological effects in both regions become perfectly continuous.

When two drives are intermingled in this way, several types of interplay can be observed. The simplest type results when two different elementary movements are stimulated: one movement is simply added to the other without mutual influence. If, for example, one stimulus makes the chicken sit down and the other makes it look to the left, then the chicken does both simultaneously. Similarly, one can combine pecking and head-turning, rising and cackling, sitting down and preening, and so on.

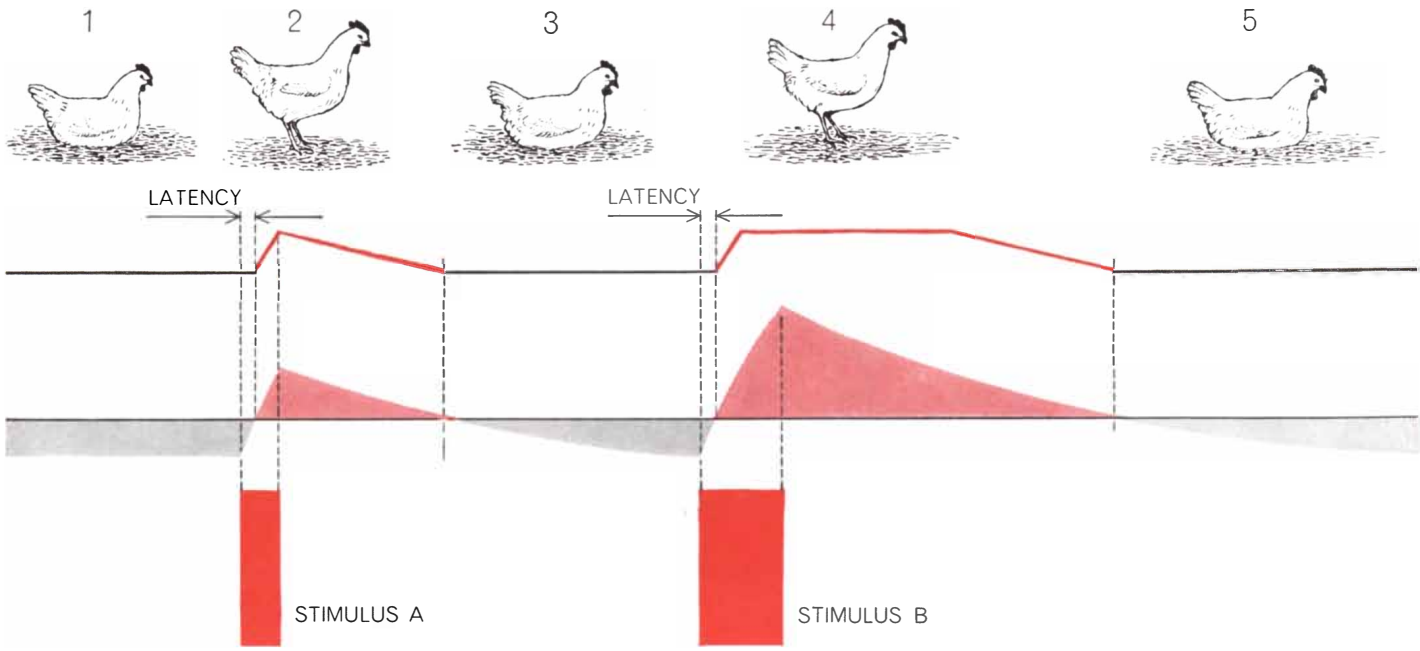
More interesting is a combination in which the animal strikes a balance, so to speak, between the two forms of behavior. For instance, one can combine reconnoitering (peering into the distance, with neck stretched and head immobile) with a totally different searching gesture (in which the head sweeps quickly back and forth). This combination results in a compromise movement in which the neck protrudes only a little and the head moves only slightly.

In a fairly rare type of combined reaction both forms of behavior appear in full strength but alternate rhythmically. An example would be eating and reconnoitering: the animal makes a few pecking movements, then raises its head abruptly to look about, pecks and looks about again. When two responses are mutually antagonistic, an attempt to evoke them together will lead to mutual cancellation, provided that the two brain stimuli have been properly adjusted. Thus a stimulus to turn to the left can be exactly canceled by a stimulus to turn to the right.

In an even rarer type of combined reaction two stimuli lead to a new type of behavior containing elements not normally evoked by either stimulus alone. So far we have found only one particularly clear example of this reaction. One of two stimuli induces the hen to peck aggressively; the other induces it to take flight, with its feathers smoothed down. Both stimuli together, if properly balanced, induce neither attack nor flight. Instead the hen emits piercing cries and rushes frantically back and forth with its feathers raised and its wings spread. In nature this behavior would occur if the hen were confronted by an antagonist of superior strength near its nest, where it would not be inclined to flee.

A frequent result of combining two stimuli is that the stronger drive suppresses the weaker one, even though more voltage is applied to evoke the weaker drive. One can often show that the weaker drive has been activated but that its expression has somehow been blocked. One stimulus makes the hen appear anxious, stretch out its neck and flatten its plumage; the other stimulus induces it to fluff up its plumage (a component of grooming). If the relative strength of the two stimuli is appropriate, the animal acts, on simultaneous delivery of both stimuli, as if only the first stimulus were present. If both stimuli are stopped at the same time, the fluffed-up plumage appears afterward. Evidently this response too must have been activated during the period of stimulation, although it remained latent.

The phenomenon of suppression exhibits still other peculiarities. Complex drive systems, which consist of several behavior elements, are rarely suppressed as a whole; instead their components are eliminated successively, as if they had different thresholds for suppression. If one slowly activates a tendency to flee in a chicken that has been sitting quietly on the ground, there appear successively, like links in a chain, the following movements: attentive alertness, getting up, walking about, freezing and finally jumping away. The sequence mimics flight from an air-borne predator. Let us now deliver to another region of the brain in the same chicken a stimulus inducing a strong tendency to sit while simultaneously activating the tendency to flee. At first nothing happens, until the urge to flee becomes quite intense. Then



URGE TO STAND, induced by electrical stimulation, can be made to override a spontaneous urge to sit. If the stimulus (*A*) is strong but brief, the chicken stands up quickly and promptly sits down again (*1, 2, 3*). If the stimulus is repeated at the same strength but is maintained twice as long (*B*), the chicken remains standing for an appreciable time (*4*). With a weaker but longer stimulus (*C*), the bird gets up more slowly and remains standing for a still longer time (*6*). Note, however, that the time the bird

the chicken suddenly jumps away as the last phase of the suppressed escape sequence erupts explosively. This behavior resembles the natural behavior of a bird that continues to incubate its eggs in the nest as an enemy comes gradually closer. The bird jumps from the nest only at the last moment.

So far I have discussed only those drive combinations that result from two kinds of brain stimulation. It is possible, however, to activate and combine two different drives by inducing one form of behavior through an environmental stimulus (visual or auditory) and letting it interact with an artificially induced drive. One can say that there is no essential difference between these two methods, and the situation is no different when brain stimulation is combined with a spontaneous drive. It is easier, however, to make measurements if both drives are associated with voltages. These facts strongly suggest that stimulation of the brain stem indeed sets off, in the responding centers, what are essentially complete and normal processes. The effects of stimulation are therefore not mere imitations of natural processes. They are not "pseudoaffective" states but genuine drives.

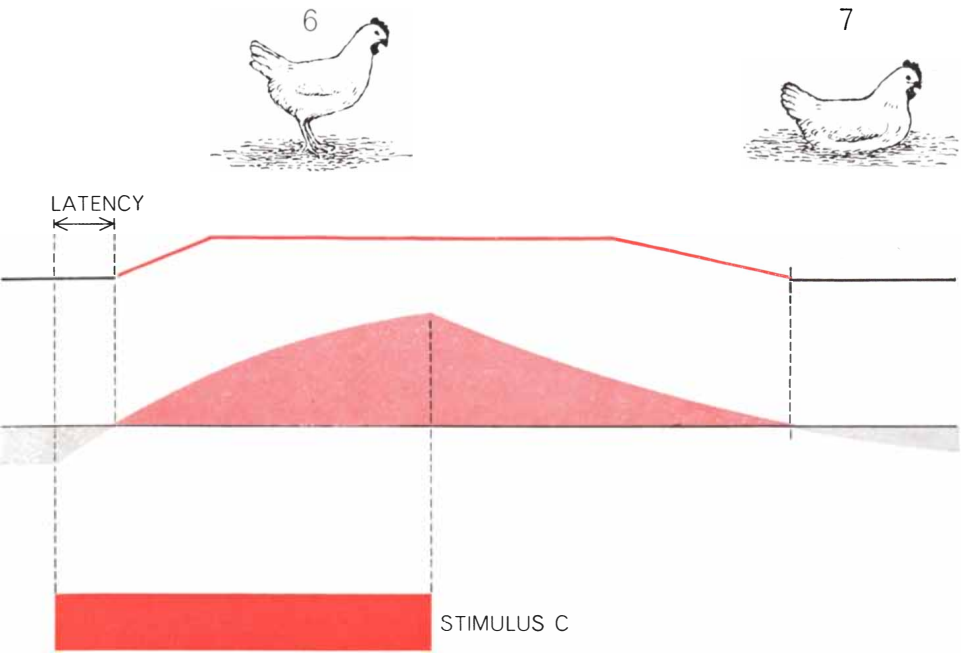
I shall now attempt to give a somewhat more detailed theoretical interpretation of what goes on within the nervous system when two drives interact. Let us consider a simple case of antagonism between drives, for example the one found in a hen that has a spontaneous urge to sit (because it is in the "incubating mood") but that can be induced to get up by stimulation of a particular brain region. The illustration on the bottom of these two pages depicts the situation. We stimulate such a hen, which sits spontaneously, three separate times to make it stand. The three stimuli differ in intensity and duration.

We record all those aspects of resulting behavior that can be measured: the latency, the speed with which the animal gets up and the length of time that the animal continues to stand after cessation of the stimulus. All these values are represented schematically in the upper curve of the illustration. One can see how the latency depends on the strength of the stimulus, as already discussed. One can also see how the speed with which the animal gets up (steepness of the curve) depends on strength and duration of the stimulus. In theory one could reduce all these data by ascribing them to a single process, which is depicted by the intermediate curve. The horizontal zero line should represent that central condition in which standing and sitting are in equilibrium. Below this line the central drive to sit is dominant; above the line the drive to stand is dominant. The stimulus for getting up alters this central state; when the drive for sitting becomes zero, the threshold has been reached and the animal begins to stand up.

If the stimulus for getting up is intense, the threshold is reached rapidly and the latency is short. If the stimulus for standing is weak, the curve rises less steeply, intersects the zero line later, and the latency is prolonged. The steepness of this rising curve similarly determines the speed with which the animal gets up. The length of time it remains standing after the stimulus to stand up has been turned off depends only on the height reached by the central drive level for standing.

The intermediate curve shown in the illustration may seem to be nothing but a hypothetical construct. But if we now fit the chicken with a second electrode to activate sitting, we can see that the intermediate curve does in fact represent something real. We deliver a stimulus for sitting, at various times, while the animal is spontaneously standing and measure the strength of the stimulus needed to induce the animal to sit down at any given moment. The values obtained are in complete agreement with the intermediate curve, which had at first been based on mere conjecture. In other words, there must be, within the central nervous system, some kind of process that takes the course described by the form of our intermediate curve. It is too early to say anything about the nature of this process, whether it is chemical or electrical or whether it is a combination of both (which is the most likely).

As one can see, it is possible to measure the inner dynamics of drives in a rather complicated animal and thereby measure processes that ordinarily elude us when we simply observe behavior; so far as we are concerned an animal that sits is merely sitting; a rooster that crows is merely crowing; a hen that eats is merely eating. But observation alone cannot as a rule tell us how strongly the animal "feels inclined" to sit, crow or eat. We do not know how strong the inner drives are at any given instant or what other drives may be operating. A more detailed analysis of these central phenomena is likely to reveal a complicated interplay of forces. It is only infrequently the case that two drives, such as those that involve sitting and standing, are mutually antagonistic. On the whole the momentary situation within the brain is much more like a knot of numerous threads that pull in the most diverse directions. The organism comprises a bundle of drives, which support one another or oppose one another to greater or lesser extent. "Spontaneous" activity is the result of a continual and shifting interplay of forces in the central nervous system.



remains standing when the stimulus has been turned off is about the same after each of the last two stimuli. Evidently some process in the central nervous system of the chicken takes the form of the intermediate curve. The colored area above the "zero line" symbolizes the urge to stand; the gray area below the line symbolizes the urge to sit.

THE CLOTTING OF FIBRINOGEN

When blood clots, the soluble protein fibrinogen is converted into insoluble fibrin by the action of thrombin. The molecular events of the process have been traced in considerable detail

by Koloman Laki

"Your blood coagulates beautifully." With these words the army surgeon was able to fortify the courage of the badly wounded ambulance driver Frederic Henry in Ernest Hemingway's novel *A Farewell to Arms*. In real as well as fictional crises of injury and surgery these are reassuring words. In the process of coagulation the blood forms a clot; the clot plugs the wound and helps to stop the loss of blood.

This vital process raises just the sort of question the biochemist likes to deal with nowadays. A substance that is flowing freely in solution in the blood at one instant forms a stable mechanical structure in the next. At sufficient magnification the clot appears as "a meshwork of beautiful needles," to quote the description of W. H. Howell of Johns Hopkins University, who was the first to look at a clot in the ultramicroscope (in 1914). Here is a visible demonstration of the relationship between the chemical activity of molecules and molecular architecture that is at the heart of every investigation in molecular biology. In the case of the clotting process investigation is now approaching a full description of this relationship, to the extent of locating and resolving the sites of chemical activity in the structure of the molecule. The work has even wider significance because it reaches into the secrets of how large molecules build up other ordered fibrous structures in the cell and in the multicellular organism.

Clotting is easily observed in the test tube. Freshly drawn blood remains fluid only for a few minutes, then suddenly it solidifies—it clots. If care is taken to prevent contact between the blood and the wounded tissue and the blood is drawn into a silicone-coated test tube, it will remain fluid for a long time. Removal of the blood cells by centrifugation leaves a slightly yellowish fluid called plasma. From our point of view plasma is essentially a .9 per cent salt solution containing 70 grams of dissolved proteins (albumins and globulins) per liter. If the plasma is poured into an uncoated test tube, it soon clots. Clotting is therefore a property of the plasma.

The clot can be removed from the test tube in one piece. On handling or compression, a yellow fluid oozes out. This fluid, called serum, contains only 66 grams of protein per liter; the missing 4 grams of protein is the material, called fibrin, that forms the structure of the clot. The clot is some 99 per cent water, but its fibrous structure is so finely ramified that the clot feels firm to the touch.

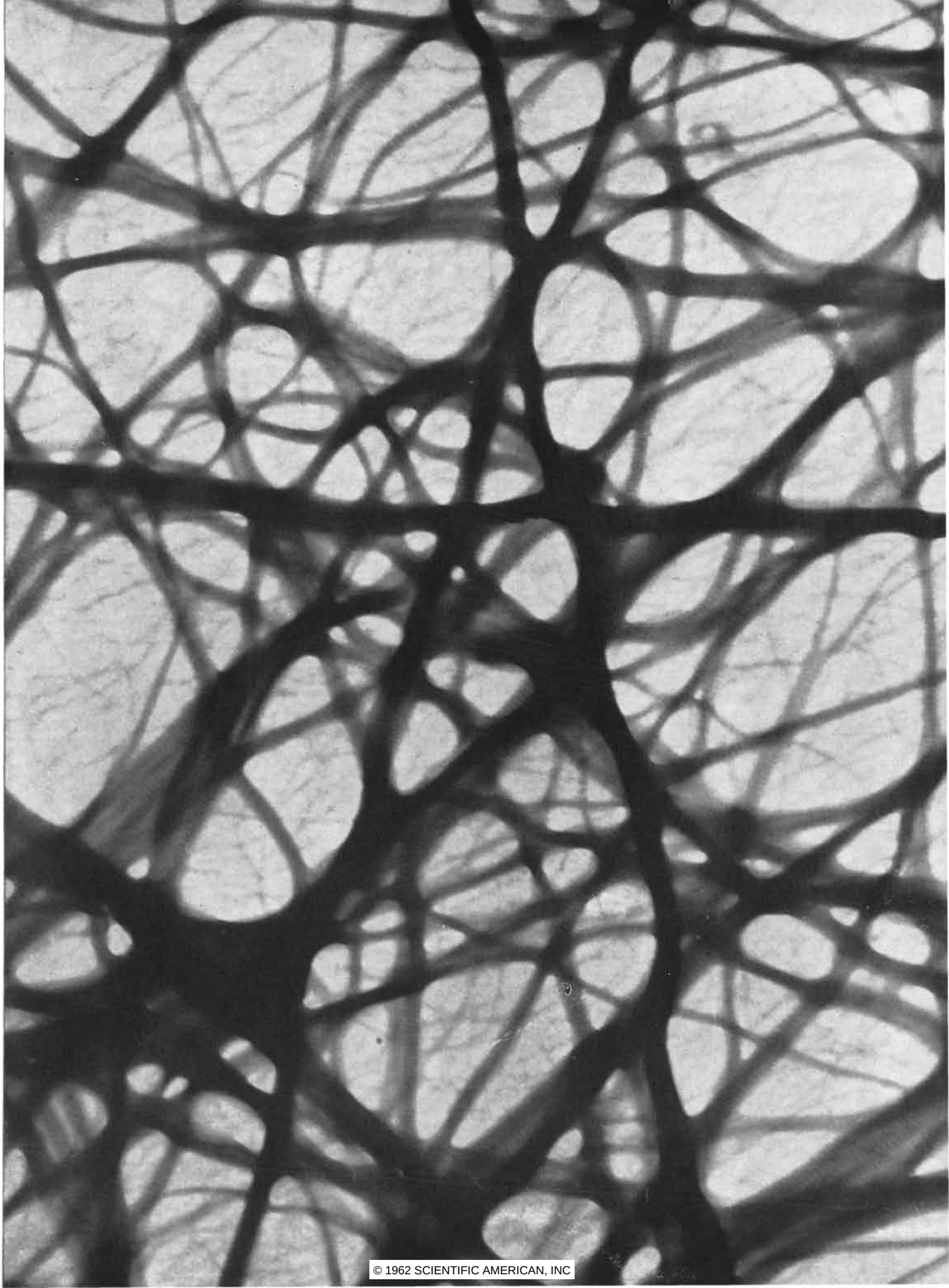
In its dissolved state in the blood the clot-forming protein is called fibrinogen. By various means this material can be isolated from the other blood proteins. With the addition of a little serum a purified solution of fibrinogen can be made to clot. This experiment demonstrates that there is an agent in the serum (but not in the plasma) that brings about the transformation of fibrinogen to fibrin.

The agent is called thrombin. Since there can be no such agent in the active state in the circulating blood, it was postulated around the turn of the century that thrombin was present in the form of a precursor called prothrombin. The isolation of prothrombin, a protein, by Walter H. Seegers of the Wayne State University College of Medicine in 1938 has fully confirmed this notion. When the blood leaves the circulation and comes into contact with the surface of a wound, a test-tube wall or other foreign surface, prothrombin is converted to thrombin. Perhaps 10 other "clotting factors" are involved in this reaction; the absence of one or another of them underlies hemophilia and other "bleeding" afflictions. This aspect of clot formation is not nearly so well understood as the conversion of fibrinogen to fibrin by the action of thrombin, which is the subject of the present article.

Both fibrinogen and thrombin are now available on the market as white powders, and they can be put to work in the laboratory by dissolving them in suitable salt solutions. A drop of thrombin solution added to the fibrinogen solution causes the latter to clot. No matter how little thrombin is added, the entire mass of fibrinogen present goes into the clot; with smaller amounts of thrombin the reaction merely takes longer. If the clot is wrung out, the liquid is found to contain the thrombin originally added to the solution; thrombin is not consumed in the clotting reaction. This simple experiment provides unmistakable proof that thrombin is one of the biological catalysts called enzymes.

Since thrombin makes the independent molecules of fibrinogen link up together in long fibers, investigators made the early guess that it would prove to be one of two kinds of enzyme: a denaturase or a polymerase. As a denaturase it would unfold the chains of amino acid units that compose the fibrinogen molecule; the entanglement of these chains would then form the fibrin meshwork. On the other hand, if thrombin were a polymerase, its function would be to introduce bonds between the fibrinogen molecules and thereby

BLOOD CLOT is a three-dimensional network of long protein fibers of fibrin formed from fibrinogen. This electron micrograph, made by Clinton Van Zandt Hawn and Keith R. Porter at the Rockefeller Institute, magnifies the fibers some 46,000 diameters.



build up the long fibrin strands. Enzymatic reactions of both kinds are well known in nature.

It turns out—largely as the result of an approach initiated 16 years ago by Daniel Bagdy, Laszlo Lorand, Elemer Mihalyi and myself, working in the laboratory of Albert Szent-Györgyi at the University of Budapest—that thrombin is neither a denaturase nor a polymerase. Its action is of a more modest sort, and it is the peculiar structure of the fibrinogen molecule itself that dictates the organization of the fibrin fibers. We adopted the strategy of taking a close look at the starting material, the fibrinogen molecule, and then at the end product, the clot, and from this before-and-after comparison gained clues to the true function of thrombin.

The fibrinogen molecule, like other protein molecules, is a repeating chain of amino acid units that carry various distinguishing side groups and are linked by identical peptide bonds (—CO—NH—). A typical fibrinogen, from the blood of cattle, has a molecular weight of 330,000 (roughly 330,000 times the weight of the hydrogen atom) and a length of 600 angstrom units (an angstrom unit is one ten-millionth of a millimeter). It is therefore a rather large protein. Altogether it consists of some 2,700 amino acid units, and these are grouped in six chains of about 450 units each. Little is known about the sequence in which the units are arranged. Although the amino acid units of the carboxylic (—COOH) ends of the chains remain to be identified, it has been established that at their amino ($-NH_2$) ends two of the chains terminate in tyrosine, two in glutamic acid and two in threonine.

A little more is known about the three-dimensional structure of the molecule. It appears that only short lengths of the chains, adding up to about 30 per cent of their total length, are ordered into the regular structure of the so-called alpha helix, which gives protein fibers their longitudinal rigidity. The chains are otherwise coiled and folded on themselves. The presence of some 30 sulfur-to-sulfur bonds, however, indicates that these coiled and folded sections are not free to take up all possible configurations; such bonds establish cross links between chains and so set up strong restrictions.

This portrait of the molecule, drawn by the indirect but powerful methods of modern chemistry, is handsomely confirmed by the electron microscope. In electron micrographs the molecule appears as three globules strung together on a fiber. The globules, corresponding to the folded portions of the chain, each have a molecular weight of about 100,000, the end globules being somewhat larger than the middle one. From other observations it appears that the connecting fiber, which includes most of the helical segments of the chains, gives the molecule a rodlike stiffness.

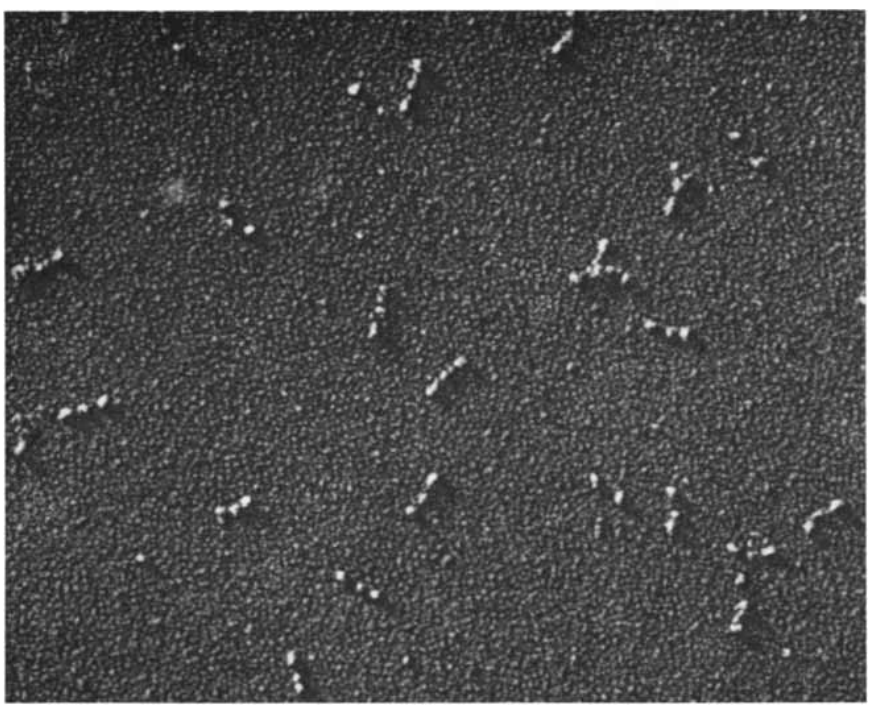
This is the "before" picture of the fibrinogen molecule. The "after" picture of the fibrin clot shows significant changes. In an electron micrograph the clot appears as a network of protein strands of various widths. The thinnest look like a string of beads: nodose filaments with large and small globules alternating along their length. Evidently these filaments are the result of end-to-end aggregation of the fibrin molecules. In contrast to fibrinogen, fibrin has a fourth, smaller globule; apparently one of the large end globules of fibrinogen has given rise to an extra smaller one.

Of the wider strands in the network of the clot, the most common is one that has the significant width of 730 angstrom units. This corresponds to the length of the fibrin molecule and suggests that such strands are formed by side-by-side aggregations of the molecules. Electron micrographs bear out this deduction, showing the alternation of large and small globules across the strands and not along their length as in the filaments.

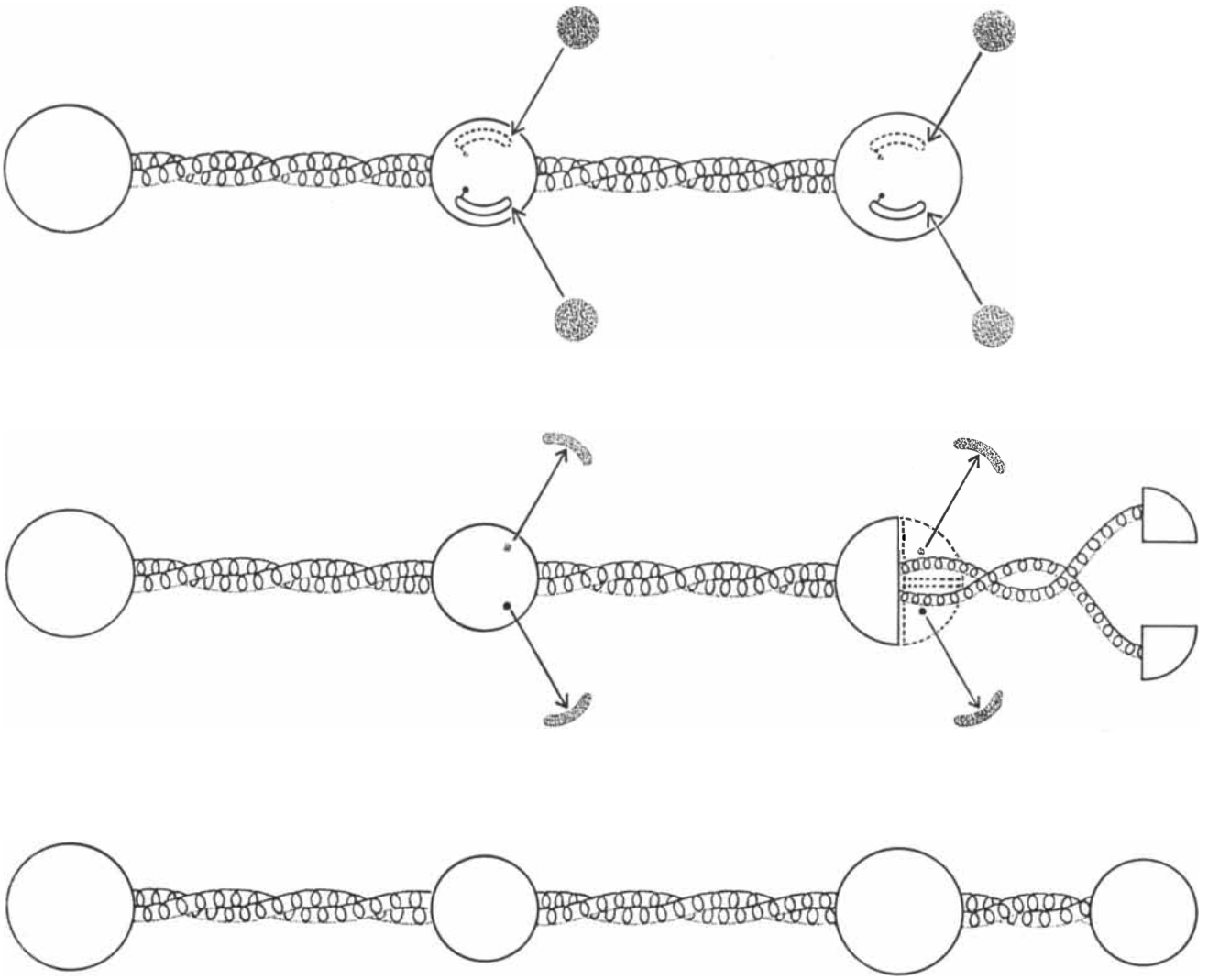
With the clot itself there are only a few things one can do, such as study its elastic properties. Some years ago, however, the late W. T. Astbury and his colleagues at the University of Leeds performed a significant experiment of this kind. Twisting the clot fibers into a thread, they found that fibrin molecules thus oriented give an X-ray diffraction pattern like that of hair and similar protein fibers. This was conclusive evidence that the clot is not a denatured protein and that thrombin is not a denaturase.

While we were still in Budapest, Mihalyi and I found that a clot made with purified materials can be dissolved in a urea solution and—more important—that the clot will regenerate when the urea is removed from the solution. This finding opened the way to many new experiments. Of itself it demonstrated that thrombin is not a polymerase, for it was clear that thrombin had nothing to do with the regeneration of the three-dimensional network of the clot.

On the other hand, it was also clear that thrombin must do something to the fibrinogen molecules that makes them give up their independent existence and seek each other out to form the network structure. Since urea dissolves fibrinogen as well as a clot, it was possible to compare the molecules of fibrinogen and fibrin to each other directly, subjecting them to the same procedures of chemical and physical analysis. From such comparison we found that the weights of the



FIBRINOGEN MOLECULES, here magnified approximately 150,000 diameters, appear as triads of globules. Helices between the globules do not show up. The electron micrograph was made by Cecil E. Hall and H. S. Slayter of the Massachusetts Institute of Technology.



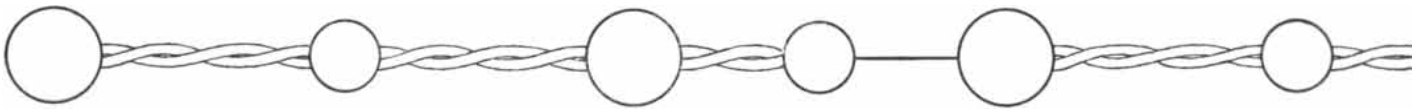
FIBRINOGEN BECOMES FIBRIN through the action of the enzyme thrombin. Thrombin molecules (*gray circles in drawing at top*) attack the peptide bonds (*at sites indicated by arrows*) connecting the four peptides (*sausage-shaped objects*) to the second and third globules of the fibrinogen molecule. The weak hydrogen bonds holding the other end of the peptides then break easily and two peptides (peptide B) are removed from the second globule and two (peptide A) from the third; a fourth globule begins to form (*middle drawing*). Completed fibrin molecule (*bottom*) consists of four globules and is slightly longer than the original fibrinogen.

two molecules are essentially the same. Whatever the thrombin did to the fibrinogen molecules, it left their size practically unchanged.

The first indication of what happens came when we measured the electrical properties of the two molecules, as expressed on the familiar hydrogen potential (pH) scale. From the finding that fibrin is more basic (that is, has a higher pH), we concluded that fibrinogen must release negative charges under attack by thrombin. Mihalyi calculated that fibrinogen must lose 14 negative charges. At about the same time Kenneth Bailey at the University of Cambridge and Lorand at the University of Leeds found that the glutamic acids at the ends of the amino acid chain of bovine fibrinogen are replaced by glycine when the fibrinogen is converted to fibrin. The investigators were even more pleased that the glutamic acid showed up in the solution squeezed from the clot.

Thereafter the story unfolded quickly. The glutamic acid was found to be part of a peptide—a short chain of amino acid units—that is severed from the fibrinogen by the action of thrombin. Our group at the National Institutes of Health and other investigators soon identified another peptide resulting from the action of thrombin, this one including the amino acid threonine. Altogether it appeared that thrombin severed four peptides from the fibrinogen molecule—two including glutamic acid (called peptide A) from the ends of one pair of peptide chains, and two including threonine (called peptide B) from the ends of another pair. The severing of these peptides clearly accounted for the loss of the 14 negative charges. But it did not until recently explain Mihalyi's finding that fibrin carries more amino end groups than fibrinogen does. Jules A. Gladner and J. E. Folk, working with me at the National Institute of Arthritis and Metabolic Diseases, have now shown that the answer lies in the fact that the amino end of peptide B is masked by an acetyl group. Thus of the six peptide chains in fibrinogen only four carry free amino end groups. (In fibrin all six chains carry amino end groups.)

The severing of peptide groups by thrombin marked it plainly as a proteolytic enzyme. It is therefore a member of the large class that includes the familiar



END-TO-END ASSOCIATION of the three fibrin molecules depicted here is representative of the thin nodose filaments (consisting of many molecules) that appear in blood clotting (*see illustration at bottom left*). This end-to-end association is one of two types of

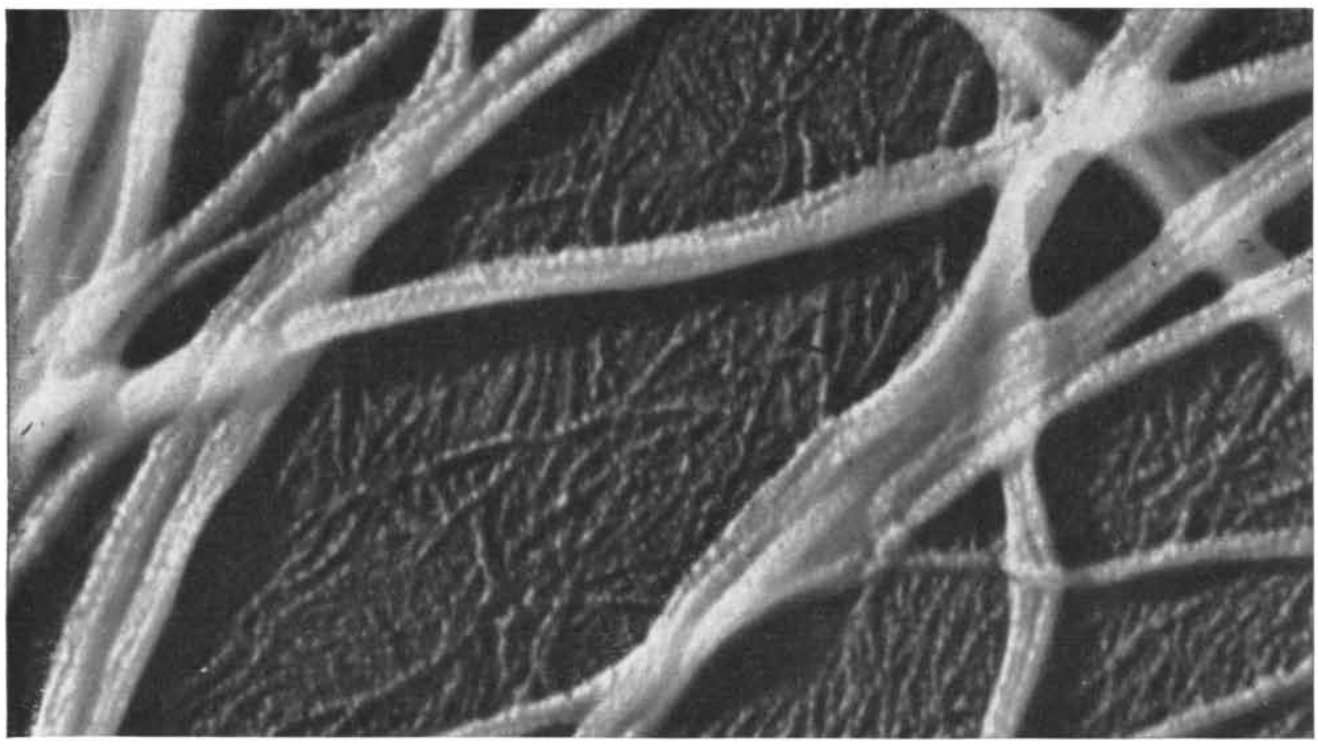
digestive enzymes, such as pepsin and trypsin, whose function is to break down proteins. This conclusion has been demonstrated by Gladner and myself with the help of the powerful poison diisopropylphosphorofluoridate (DFP), which was stockpiled as a "nerve gas" during World War II. DFP becomes bound to these enzymes. By labeling it with radioactive atoms it is possible to identify just those amino groups to which the DFP binds. These experiments show that thrombin has the same sequence of amino acids at its active site—aspartic acid, serine, glutamic acid and glycine—as many of the other proteolytic enzymes do.

Compared with the action of trypsin and chymotrypsin, however, the action of thrombin is highly specific and limited. Whereas the other proteolytic enzymes will break down fibrinogen completely, thrombin splits off only the peptides A and B. Recently Folk, Gladner and I have shown that in so doing thrombin selectively splits a glycine-arginine bond. Hoping to find an answer to this limited action of thrombin, Gladner and Folk in a series of elegant experiments determined the amino acid sequence of peptides A and B. But they found nothing here to explain the limited specificity of thrombin. According to Yehuda Levin, who came from the Weizmann Institute of Science in Israel to work with us, the action of thrombin is restricted by the unique folding of the fibrinogen molecule. He has shown that thrombin will split off other peptides when the structure of fibrinogen is denatured by heat, exposing other bonds to the action of the enzyme.

Recent studies by Mihalyi at the National Heart Institute have definitely confirmed that thrombin splits about four peptide bonds in each fibrinogen molecule. Careful measurement of the thermodynamic balance in these reactions has revealed that three or four weak hydrogen bonds that also serve to attach each of four peptide groups to the fibrinogen molecule are also broken in the process.

The next task was to determine which parts of the fibrinogen give up these peptides. The first clue came from the work of Ignacio Tinoco, Jr., and John D. Ferry at the University of Wisconsin. To locate the sites on the molecule from which negative charges are removed by the splitting off of the peptide groups, they compared the orientation of fibrinogen and fibrin in a strong applied electric field. From the way both molecules oriented themselves in the electric field it was possible to deduce that the peptides (carrying the charges) must have been removed from near the middle of the fibrinogen molecules. If they had been removed from one end, the fibrin would have shown a very different orientation. Other evidence indicates that this observation is associated with the release of peptide B. The suggestion that peptide B is therefore split from the middle of the molecule, specifically from the middle globule, is sustained by the further observation that the release of peptide B is associated with side-by-side aggregation of the fibrin molecules.

Meanwhile Birger Blombäck and Torvard C. Laurent of the Royal Caroline Institute in Sweden have demon-



FIBRIN CLOT, magnified approximately 80,000 diameters in this electron micrograph made by Hawn and Porter, shows both side-by-side association (*thick, crisscrossing strands*) and end-to-end association (*thin filaments in background*) of fibrin molecules.

aggregation that fibrin molecules can form. The small fourth globule of one molecule is connected to the large first globule of another by a hydrogen bond (*straight line*). The succession of large and small globules gives the filaments their nodose characteristic.

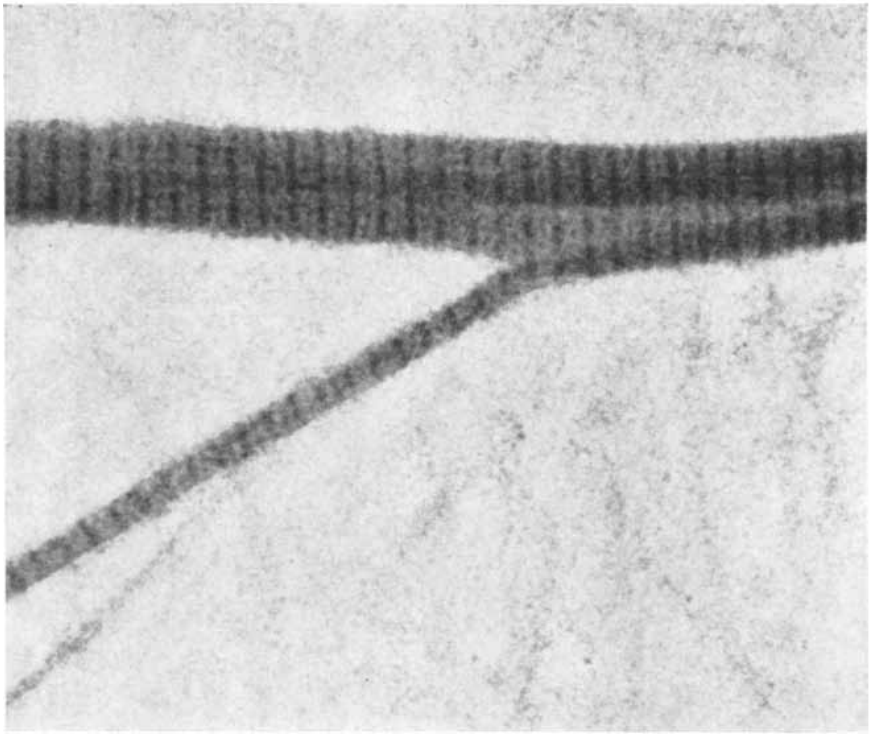
strated that an enzyme in snake venom removes only peptide A. The resulting clot shows mainly end-to-end aggregation. This strongly indicates that the site of peptide A is one of the end globules of the fibrinogen molecule.

It is now possible to reconstruct the events that attend the thrombin-fibrinogen reaction. The thrombin molecule, about a twentieth the size of the fibrinogen molecule, has just been released from bondage (that is, prothrombin has been converted to thrombin) and is surrounded by perhaps 1,000 fibrinogen molecules. In the rapid turnover of events in the molecular world it encounters a fibrinogen molecule perhaps a trillion times per second. Once in a million times it hits a susceptible bond holding either the A or B peptide to the fibrinogen. Subsequent thermal agitation ruptures the hydrogen bonds, releasing the peptide into solution. The release of peptide A appears to have the incidental effect of initiating the formation of the fourth globule of the fibrin molecule. Two pieces of the third globule presumably come loose, still attached to the parent molecule by peptide chains, to form the fourth globule. Eventually the thrombin makes four successful hits on the fibrinogen. At that point the enzyme ceases to influence the course of events. The fibrinogen molecules, some of them still under attack by thrombin at sites not yet activated, have meanwhile begun to form the network structure. But the formation of that structure and the polymerization of the fibrin molecules proceed as entirely independent processes.

The nature of the bonds that tie the fibrin molecules together into the filaments and strands of the clot can be demonstrated easily. Simple heating of the clot causes its dissolution; on cooling the clot forms again. The same dissolution and reconstitution of the clot follows alteration of the pH. Such experiments provide clear evidence that the fibrin molecules are linked up by hydrogen bonds. Harold A. Scheraga at Cornell University and Julian M. Sturtevant at Yale University have measured the heat that is generated by the polymerization reaction when the clot forms. They find that it comes to 44,000 calories per gram molecular weight of fibrin molecules. Since the formation of eight to 10 hydrogen bonds releases that much heat, it is fairly certain that this is the number of hydrogen bonds holding the molecules together. Mihalyi and Scheraga have shown that the bonds form between a tyrosine amino group on one molecule and a histidine on the other. This linkage explains why the clot disappears when the pH is either too low or too high. At low pH the histidine captures a hydrogen ion from the solution and therefore is unable to share the hydrogen of the tyrosine. At high pH tyrosine loses its hydrogen to the solution and so has no hydrogen to share.

For all the randomness that characterizes the process, a high degree of order obtains in the polymerization of the fibrin molecules. This becomes evident when the strands are stained with an agent called phosphotungstic acid. Remarkably regular cross striations then appear on the wider strands, spaced at 120 angstroms and 240 angstroms apart down the length of a strand. Since the staining agent has an affinity for the amino acid arginine, it is apparent that the striations mark concentrations of arginine in the molecules. At present we cannot explain how the cross striations come to be spaced at such regular intervals. It is clear, however, that the molecules must be precisely oriented to one another down the length of the chain. This suggests that they must also be complementary in shape. Remembering that the fibrinogen of cattle, and undoubtedly the fibrinogen of other species, is duplex in constitution—that is, made up of apparently three pairs of identical strands—we propose that the molecule consists of two nearly identical halves. To account for the spacing of the striations one may picture each molecule in a strand rotated at 90 degrees to its neighbor next in line.

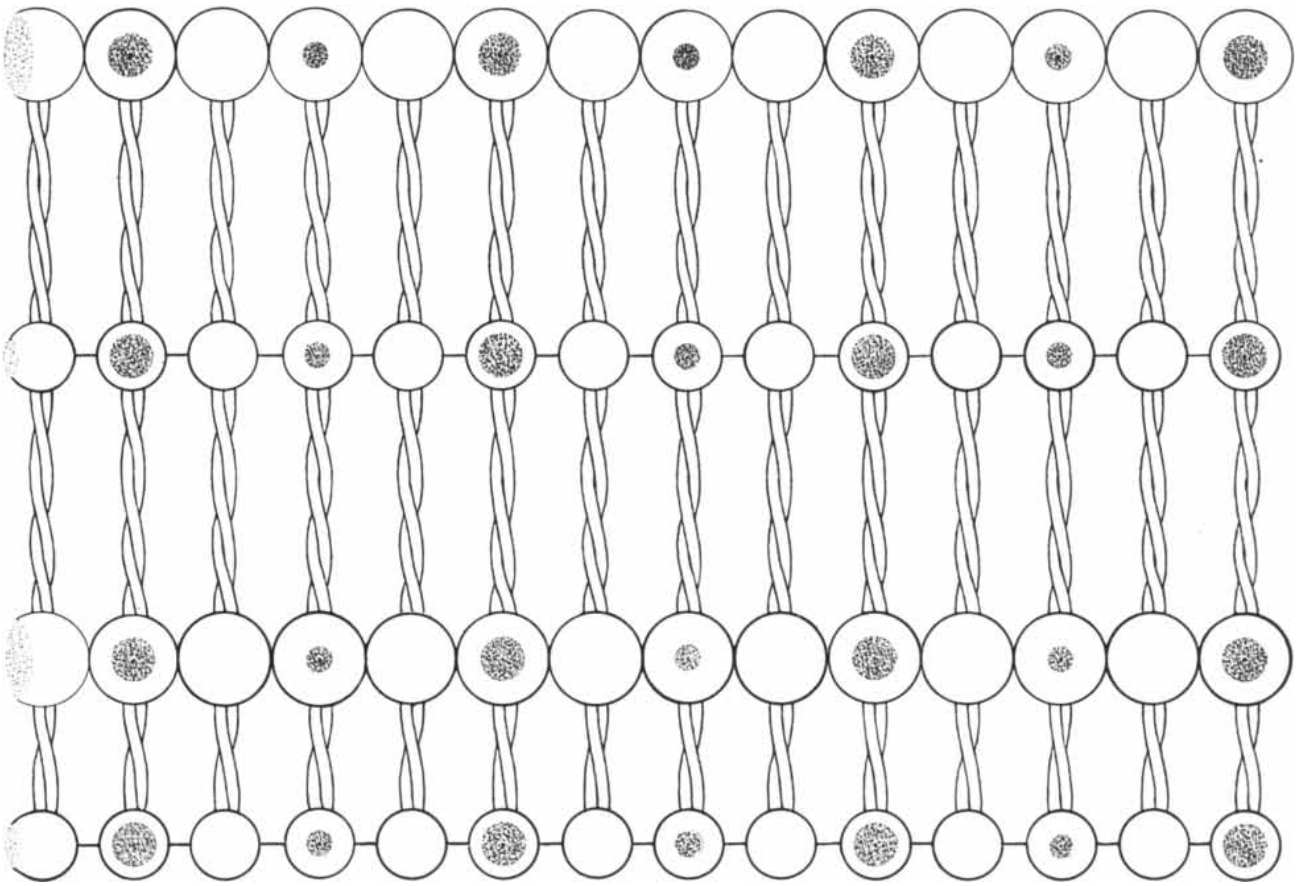
One final question must be answered: Does the clotting of fibrinogen in these test-tube experiments have anything to do with the clotting of blood plasma? The answer is yes and no. Yes, because, as John R. Shainoff and Irvine H. Page at the Cleveland Clinic have shown, the same peptides are released when blood clots. No, because the clotting of blood



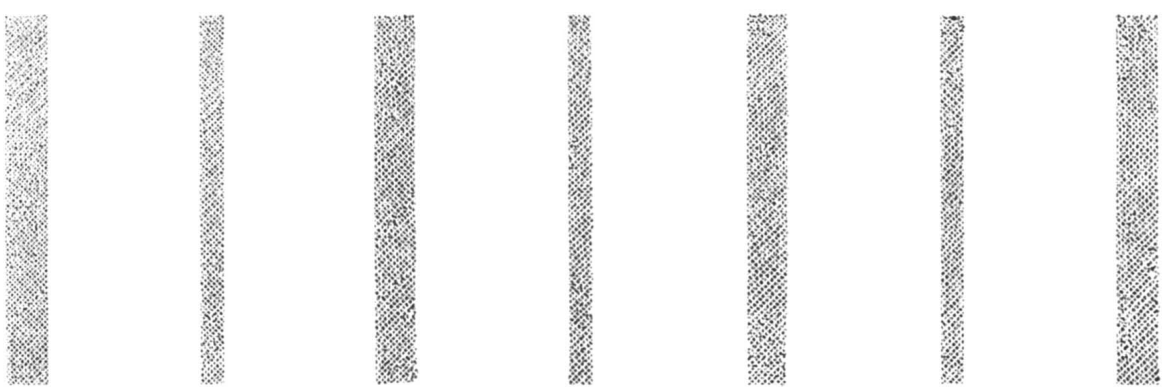
CROSS STRIATIONS in side-by-side association (magnified 187,000 diameters in this micrograph made by Hall) appear when phosphotungstic acid is used to stain the fibrin.

or plasma is irreversible; the presence of a factor that Lorand and I have discovered in the bovine plasma makes the clot insoluble in urea. A few months ago Ariel G. Loewy at Haverford College reported the isolation of this factor from human plasma. This finding gains significance from the observation that the Laki-Lorand factor greatly facilitates the healing of wounds and that it is missing from the blood in certain diseases. In the living organism, furthermore, it appears that peptide B has an important function. We have found that this peptide from bovine fibrinogen augments the contraction of a section of artery from a rabbit. Such contraction in capillary vessels would help to reduce the flow of blood.

This story of fibrinogen should not end without mentioning that the clotting of fibrinogen goes on to a small extent in the blood vessels all the time. Presumably peptide B or its analogue in different animals is therefore constantly being liberated in the bloodstream. If so, it might serve to keep the capillaries in a "state of readiness." But this may be a double-edged sword: it is possible that too much readiness is a contributory factor in high blood pressure. Finally, these studies offer the hope of understanding the formation of the abnormal clot—the thrombus—that is the largest cause of death in the U.S. today.



SIDE-BY-SIDE ASSOCIATION of fibrin molecules is depicted. The molecules are held together by hydrogen bonds (*straight lines*). Bonds between large globules are not shown. The shaded areas on globules represent sites to which phosphotungstic acid is specifically attracted. The use of this acid to make fibrin fibers visible also results in cross striations (*see illustration below*).



PERIODIC DEPOSITION of phosphotungstic acid on fibrin molecules gives rise to the cross striations that appear in electron micrographs. The distance between two thick striations is 240 angstrom units; that between thick and thin striations, 120 angstrom units.

Kodak reports on:

speed trials at the raster . . . a mysterious dance that might not interest everybody . . . visual happiness for sober purposes

Honest physical labor

It is possible to earn a living as a physicist without dealing in deep questions. With so many occasions arising today where a c-r tube image is to be transformed into a photographic image, the ranking of film speeds for this purpose is useful work, and it makes the time pass pleasantly between breakfast and supper. Here is what we found:

RELATIVE SPEED

to a 525-line raster, two interlaced fields lasting 1/30 sec over-all, measured at a net density of unity (Transit time of the electron beam past a given point of the phosphor = 5×10^{-8} sec)

***Normal development:* 4 minutes in Kodak Developer D-19 at 68 F.**

Phosphor	P11	P4	P15	P16	P24
FILM					
Kodak Photoflure, Blue Sensitive	2400	180	60	200	83
Kodak Cineflure Kodak Photoflure, Green Sensitive Kodak Linagraph Ortho	1800	500	250	130	240
Kodak Royal Ortho (sheet)	1000	250	130	80	130
Kodak Linagraph Pan Kodak Tri-X Negative	900	320	120	82	120
Kodak Linagraph Shellburst	500	180	60	48	73
Eastman High Speed Positive	360	51	25	45	28
Kodak Royal-X Pan Recording	320	150	65	23	47
Eastman Fine Grain Sound Recording	123	17	5.2	41	4
Eastman Television Recording	*100	11	5.2	7.5	5.2
Eastman Fine Grain Release Positive	35	4	2	6	2
Kodalith Ortho, Type 3	32	5	8	5	8
Kodak High Contrast Copy	20	12	6	4	5

*Arbitrary basis of scale.

Surprised?

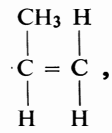
Just to show that there is a little more to this than you might think, we invite attention to what happens to the figures when the same developer acts for 15 minutes:

Phosphor	P11	P16	P24
FILM			
Kodak Royal-X Pan Recording	6300	600	1200
Kodak Photoflure, Blue Sensitive	5400	500	220
Kodak Cineflure Kodak Linagraph Ortho	4100	250	360
Kodak Royal Ortho (sheet)	3900	220	400
Kodak Tri-X Negative Kodak Linagraph Pan	2600	200	370
Kodak Linagraph Shellburst	2400	190	260
Eastman High Speed Positive	630	82	25
Eastman Television Recording	250	19	14

You are not supposed to get excited and order a carload of film on the basis of these figures. First you are supposed to write for the pamphlet "P-37" to Eastman Kodak Company, Special Sensitized Products Division, Rochester 4, N. Y. There is more to picking a film than just speed. Don't ever forget that.

The polyallomeric state

It now appears that an asymmetric molecule like propylene,



can link with other monomers to form high polymers that are quite distinct, quite crystalline, quite stereoregular, and yet show scant respect for Dalton's Law of Definite Proportions, the old law which made an orderly science out of chemistry.

Tenite polyallomers are more orderly than they ought to be. Though the proportions of the monomers that go into them are as infinitely variable as the constitution of $12-a-pound pipe tobacco, our polymerization process strongly discourages molecular randomness of spatial configuration. Somehow the asymmetric units of the chains, whatever their relative numbers, manage to work out a well coordinated geometrical arrangement for themselves. We wish we knew just how this happens. There must be *some* explanation for the distinctiveness of the results.

Scientifically interesting though all this may be, we would have found something else to write about here were not this new class of plastics ready to take its place in industry alongside Tenite polypropylene, polyethylene, polyester, butyrate, propionate, and acetate.

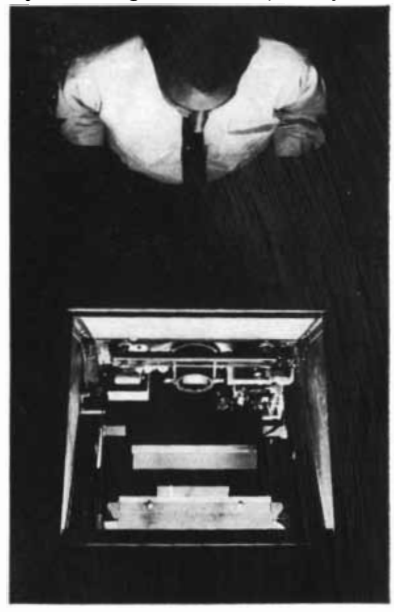
The gentlemen of the plastics-molding trade will lay their money on the line for various Tenite polyallomers not for the pleasure of seeing molecules do new tricks but for high impact strength, flexibility at low temperatures, desirable color properties, good moldability, good resistance to blushing when bent or stretched, and a very low molded density that's nice when you are buying by the pound and selling by the gross.

To be entered on the list of those interested in Tenite polyallomers, write Eastman Chemical Products, Inc., Kingsport, Tenn. (Subsidiary of Eastman Kodak Company).

The eye-to-brain business

Electronics is helpful in image presentation but not sufficient. Here are entered the realms of psychology and psychophysics, sciences in which our foundations, for safety's sake, have to go down to bedrock.

Visual engineering is often handicapped in that it sounds dull. (The object seen gets attention, rarely the



seeing itself.) In the picture above, you are looking inside an experimental viewing device of ours. An image is to be projected on the translucent screen. No matter how sharp the original picture and no matter how good the projection lens, the simple machinery behind the screen can *always* yield a noticeable improvement in the sharpness. It does this by introducing time as an integrating factor to cancel out optical noise due to microscopic local random discontinuities of intensity that are inherent in efficient transmitting diffusers.

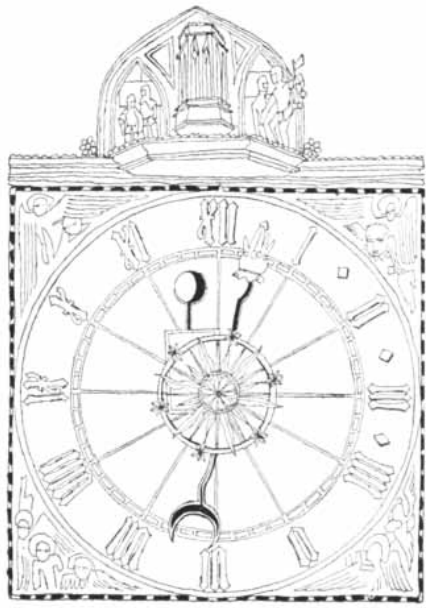
It also makes the screen more pleasant to stare at. Staring at a screen for long hours of utmost concentration imposes different psychological conditions from those an engineer encounters when he takes a look and decides everything is good and sharp and that's that. Position along the comfort-annoyance axis strongly affects systems that utilize eyes as a gateway to brains.

We think presentation equipment needs to be updated to the potentialities of present information-gathering systems. We can help because the science and engineering of visual happiness are and have long been very sober business for us. You can talk this business with Eastman Kodak Company, Advanced Planning Department, Apparatus and Optical Division, Rochester 4, N. Y.

Kodak
TRADE MARK

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

SCIENCE AND



One Van Allen Belt

A revised picture of the Van Allen belt is emerging out of the data transmitted back to earth from satellites launched last year. Instead of the two distinct belts of charged particles that have been envisaged up to now, there appears to be just one deep, doughnut-shaped radiation band around the earth, containing an assortment of electrons and protons with energies ranging from 50,000 electron volts up to several hundred million electron volts (Mev), all caught in the earth's magnetic field.

The concept of two Van Allen belts arose from the fact that the first satellites to penetrate the region carried only high-energy particle detectors. The presence of particles of lower energy was not discovered until suitable detectors were carried into what used to be thought of as the outer belt by the satellite *Explorer XII* and into the inner belt by a rocket probe, called *Injun 1*, sent up by the State University of Iowa. Fifty-thousand-volt electrons as well as protons with energies of several hundred thousand electron volts were found in both the inner and outer regions.

James A. Van Allen (for whom the belts were named) and his Iowa associates now think of the earth as being surrounded by a "magnetosphere," a single radiation zone beginning 400 miles above the Equator and extending out to about 40,000 miles. Protons with energies up to several hundred million electron volts are found out to 4,000 miles, and electrons with energies of several Mev beyond that. Low-energy electrons and protons are encountered throughout the entire magnetosphere, by exploring vehicles, at rates of 10 million to a billion particles per square centimeter of exposed surface per second. The outer boundary of the magnetosphere is not fixed but moves back and forth in response to the interplay of the solar wind—clouds of charged particles from the sun—and the earth's magnetic field, which traps the particles to form the radiation belt. A region of great turbulence therefore marks the transition from the magnetosphere to interplanetary space.

Breaking the Code (Continued)

Swift progress continues to be made in solving one of the deepest problems in biology—explaining how the genes control the synthesis of proteins and thereby the hereditary characteristics of all organisms. Last month it was reported in these columns that two groups of workers had shown how more than a dozen of some 20 amino acids, the building blocks of proteins, are identified by different groupings of four molecular subunits, called bases, that act as the symbols in a code within the giant molecule of ribonucleic acid (RNA). The RNA molecule, in turn, is a direct letter-for-letter transcription of the sequence of code symbols, also bases, in deoxyribonucleic acid (DNA), the giant molecule that constitutes the genes of an organism. The two groups of workers that had broken the code were Marshall W. Nirenberg and J. Heinrich Matthaei at the National Institute of Arthritis and Metabolic Diseases and Carlos Basilio, Peter Lengyel, Severo Ochoa and Joseph F. Speyer at the New York University School of Medicine.

Both groups have now worked out the RNA code sequence for 19 of the 20 amino acids commonly found in proteins, and the N.Y.U. group has predicted the 20th [*see illustration on opposite page*]. The N.Y.U. investigations have been published in a series of four papers in the *Proceedings of the National Academy of Sciences*, the latest in the March issue. The Nirenberg-Matthaei work has been reported in *Biochemical and Biophysical Research Communications.*

THE CITIZEN

Meanwhile workers in the Cavendish Laboratory at the University of Cambridge have exploited a genetic mapping technique to clarify the general nature of the code. The British studies were made by F. H. C. Crick, Leslie Barnett, Sydney Brenner and R. J. Watts-Tobin, who reported the work in *Nature*. The British team lists four main findings:

1. A group of three bases (or, less likely, a multiple of three bases) is needed to code one amino acid.

2. The code consists of a simple sequence of bases and is not of the overlapping type, in which a given base could appear in two or more sequential code "words."

3. The sequence of bases is read from a fixed starting point, each triplet in

AMINO ACIDS	RNA BASES
PHENYLALANINE	UUU
ALANINE	UCG
ARGININE	UCG
ASPARTIC ACID	UAG
ASPARAGINE	UAA, UAC
CYSTEINE	UUG
GLUTAMIC ACID	UAG
GLUTAMINE [PREDICTED]	UCG
GLYCINE	UGG
HISTIDINE	UAC
ISOLEUCINE	UUA
LEUCINE	UUC, UUG, UUA
LYSINE	UAA
METHIONINE	UAG
PROLINE	UCC
SERINE	UUC
THREONINE	UAC, UCC
TRYPTOPHAN	UGG
TYROSINE	UUA
VALINE	UUG

GENETIC CODE shows the sequence of bases in ribonucleic acid (RNA) that identifies each of the 20 amino acids commonly found in proteins. U signifies the base uracil; A, adenine; C, cytosine; G, guanine. The code shown is that worked out by Severo Ochoa and his associates at the New York University School of Medicine. It differs slightly from the code proposed by Marshall W. Nirenberg and J. Heinrich Matthaei of the National Institute of Arthritis and Metabolic Diseases. The sequence in each triplet is not yet known, and there may be other code groups that do not contain uracil.

sequence designating one amino acid. There is no special "punctuation" separating the triplets, as some workers had proposed. If the starting point is displaced by one base, the triplets are grouped incorrectly and yield an incorrect sequence of amino acids in the resultant protein, or perhaps yield no protein at all.

4. It is likely that each type of amino acid can be coded by two or more base triplets. Such a code is described as degenerate. Degeneracy is inferred because four bases taken in groups of three are sufficient to make 64 different code words ($4 \times 4 \times 4$), and only 20 are needed to designate the common amino acids.

Crick and his co-workers reached these conclusions by carefully mapping mutations in a single gene, known as the B cistron, in the bacterial virus T4 [see "The Fine Structure of the Gene," by Seymour Benzer; SCIENTIFIC AMERICAN, January]. Perhaps the most striking finding, that the code is read from a fixed starting point, was deduced from observations such as the following. If the gene is made inactive by a mutation that *adds* a single base, activity can be restored by a mutation that *deletes* a single base—and not the same base but merely one near the one added. Evidently the deletion restores the "reading frame" to proper triplets, whereas the addition of a single frame has caused the frame to be displaced everywhere to the right or left (depending on the direction of reading) of the point where the addition occurred. The triplets between the added base and the deleted base will still differ from those in a standard (a "wild," or nonmutated) gene, but if only a few triplets are involved, the protein produced will often show some activity even if it contains a few wrong amino acids.

The evidence that the reading frame, or coding ratio, is indeed a triplet and not some other number rests on the observation that a mutant gene containing three extra bases at different nearby sites is active, or partially active. On the other hand, a mutant with only two extra bases is not active. Evidently, therefore, a minimum of three bases is needed to restore the reading frame.

Continuous Masers (Continued)

Two new types of optical maser, in which a solid crystal is made to emit a continuous, coherent beam of light, have been built recently by workers at the Bell Telephone Laboratories. One, announced at the December meeting of the American Physical Society in Los Angeles, emits infrared radiation; the other, reported at the society's New York meeting in January, produces visible red light. In both the output is so far only a few thousandths of a watt. The input power of the "pumping" light that excites the emission is about 900 watts—less than one-thousandth of the power required, only about a year ago, to produce brief pulses of radiation in the first optical masers.

In the infrared device the crystal is made of calcium tungstate containing small amounts of neodymium. It is placed at one focus of an elliptical reflector, with the pumping light at the other focus. The emitter of the second maser is a ruby cylinder grown together as a single crystal with flaring, trumpet-shaped sapphire. Pumping light from a mercury lamp is focused by mirrors on the large end of the sapphire, which funnels it into the ruby, concentrating it sixfold. The light is then reflected down and back through the ruby, thereby doubling its effectiveness. By these means the pumping efficiency is increased many times beyond that of previous masers.

The new devices follow by a few months the first continuously operating optical maser, also developed at Bell Laboratories. That one employed a gas as the active material and produced about the same amount of power as do these first solid-state masers. In time, however, it should be possible to extract much more optical power from solids than from gases.

More Cold Viruses

The isolation of at least six immunologically distinct viruses from patients with coryza (the feverless, runny-nose syndrome more familiarly known as the common cold) has been announced by each of two research teams. Barring duplications, this would bring to a dozen and a half the number of different germs implicated in the disease since the first successful tissue culture of a cold virus three years ago by Christopher Howard Andrewes and his colleagues in England.

The new isolations were carried out at the National Institutes of Health and the Merck Institute for Therapeutic Research. There may be duplication between the two groups of strains, as well as with those found by the Andrewes team, although the Andrewes viruses—which have also been found to fall into six

Teatime at ten miles a minute

Thirty years ago, Jimmy Doolittle pushed his Pratt & Whitney Aircraft Wasp-powered Gee Bee racer to 294.38 mph. He was then the world's fastest man.

Today, grandmothers regularly fly twice as fast. So do babies, businessmen, vacationers, statesmen—and grandfathers, too.  Traveling in comfortable jetliners powered by Pratt & Whitney Aircraft engines, more than one million passengers every month conquer time and distance at ten miles a minute.  Now, New York and Chicago are a catnap apart and the Atlantic Ocean is five hours wide.

United Aircraft Corporation has traditionally paced the swift science of flight. Pratt & Whitney Aircraft jet engines power a majority of the world's jetliners and front-line U.S. military aircraft. They fly more than 20,000 hours daily . . . for 34 airlines . . . in 79 countries . . . on seven continents. 

Jet engines are only one example of the expanding product spectrum at United Aircraft. This pioneering corporation serves industry, commerce and defense with unmatched research capability and the multiple skills of 60,000 people. United Aircraft is a significant and growing force in power, propulsion, nuclear energy, electronics, vertical flight, navigation, and controls.

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groups—differ in two important respects from the U.S. viruses. The English viruses multiply poorly in tissue cultures kept at normal body temperature and normal acidity; they require a slightly cooler and slightly more acid medium. In any event all three groups are distinct from the assortment of adenoviruses and other recently discovered viruses that have been found responsible for much respiratory illness in children.

Right Red Shift

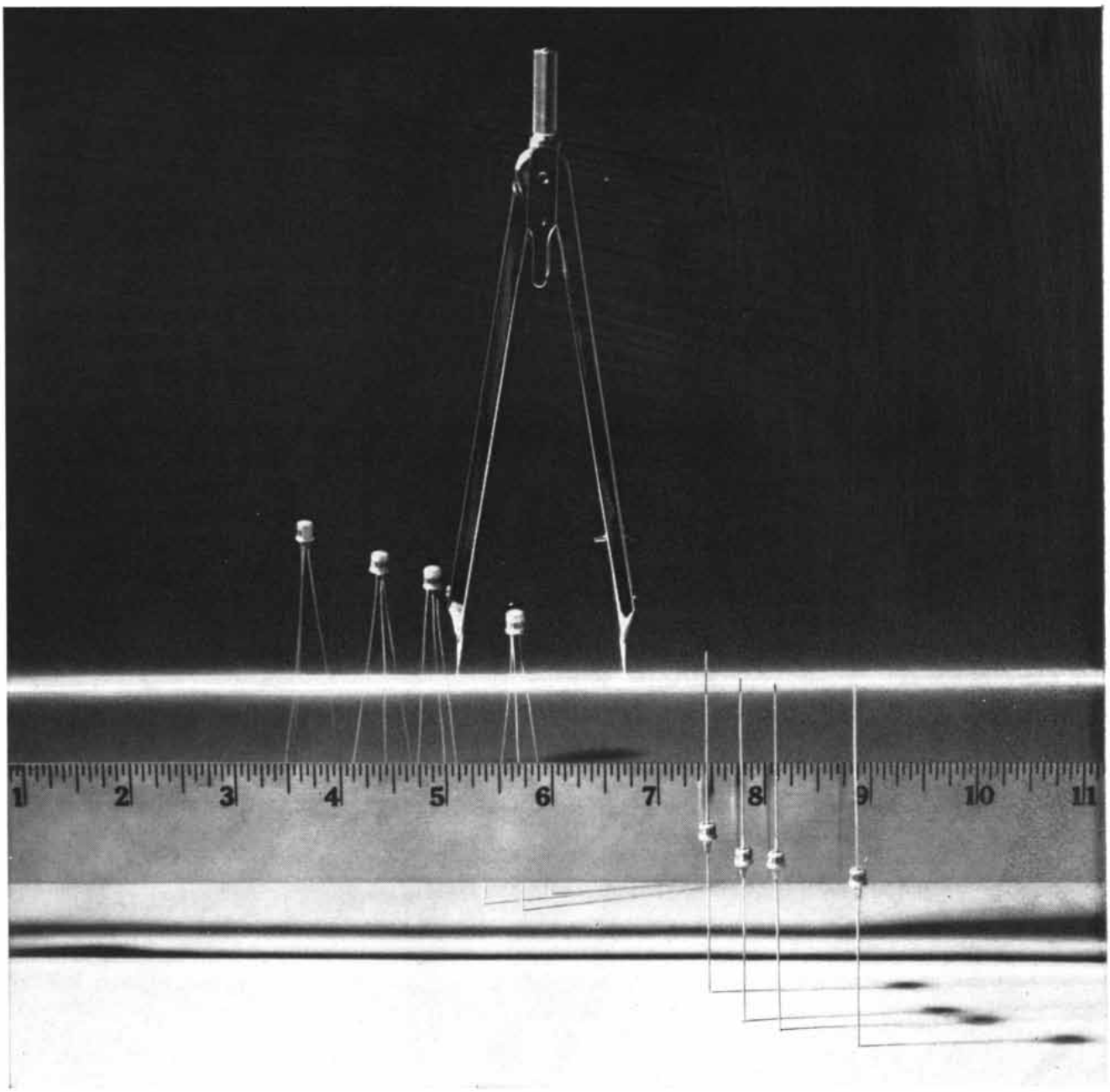
A recent paper by two French astronomers has apparently laid to rest a skeleton that has been rattling in the closet of physics for more than 40 years. In a measurement of unprecedented accuracy they have found a gravitational red shift in light from the sun almost exactly equal to that predicted by the general theory of relativity.

The prediction is a consequence of Albert Einstein's principle of equivalence, which states that the effects of accelerated motion are indistinguishable from those of a gravitational field. When it is applied to light and other electromagnetic radiations, the principle implies that the radiation will lose energy in moving outward from a massive body. According to quantum theory a loss of energy means a drop in frequency and a corresponding increase in wavelength. In the visible portion of the spectrum this would manifest itself as a shift toward the red.

The amount of the expected shift is minute. At the time that Einstein proposed it, and indeed for about 40 years thereafter, the calculated red shift that would be produced by the earth's gravitational field was hopelessly far below the limits of detectability, let alone measurement. In the more massive sun (and other stars), however, the predicted effect was big enough to measure. Turning their spectrographs on the sun, astronomers did find some red shift in the wavelength of absorption lines, but the amount was far less than that called for by the theory. Many times in the decades following 1920 the measurement was repeated on the sun and other stars, always with unsatisfactory results. Some observations agreed rather closely with theory, but it became clear that none of them was satisfactorily accurate.

A couple of years ago, with the discovery of the Mössbauer effect, the inability to confirm the red shift astronomically became less embarrassing. It was now possible to produce and meas-

TESTING. Western Electric must often devise sophisticated testing techniques to verify the high quality of communications products it makes for the Bell Telephone System and the U. S. Government. Problem in point: measuring switching times of transistors and diodes that operate in fractions of a nanosecond—the time it takes light to travel one foot. Solution: direct-reading test sets that use as a standard the propagation velocity of coaxial cable, time-referenced to the speed of light. As the result of a joint development with Bell Telephone Laboratories, Western Electric designed these sets that accurately record switching time variations of one light inch. They provide greater accuracy, repeatability, and ease of operation on the production line than ever before possible. Another way Western Electric continues to assure ever-better communications products for the Government and the Bell Telephone System. **WESTERN ELECTRIC**



ure gamma rays of extremely sharp frequency (and wavelength) and with them to confirm the red shift in terrestrial experiments [see "The Mössbauer Effect," by Sergio De Benedetti; SCIENTIFIC AMERICAN, April, 1960]. Nevertheless, the astronomical failure continued to nag at the conscience of physics.

In the new measurements J. E. Blamont and F. Roddier of the Meudon Observatory in France have determined the red shift of the absorption line of strontium. Instead of spreading the light into a spectrum and photographing it, they use the direct solar rays to excite a secondary emission in an atomic strontium beam. Describing their experiment in *Physical Review Letters,* they point out that "in this experiment atoms are used as a clock both on the sun and the earth. This removes errors made in wavelength calibration."

Light from the center of the sun exhibited a shift of about .009 angstrom unit plus or minus .001 angstrom unit. The theoretical value is .00976. At the edge of the disk Blamont and Roddier measured a shift of .012 angstrom unit. They attribute the difference to a "pressure red shift" of .0024 angstrom unit, which had been predicted by the astrophysicist E. Lindholm.

Self-reproducing Chloroplasts

Evidence is accumulating that chloroplasts, the chlorophyll-containing bodies in the cells of green plants, may lead a "life" of their own. It now appears that these bodies both contain and manufacture deoxyribonucleic acid (DNA), the material involved in the self-duplication of living cells and normally found only in the cell nucleus.

As long as 50 years ago it had been suggested that chloroplasts are not an indigenous part of the green-plant cell in spite of their essential role in photosynthesis. Instead they may be "infectious" particles that entered the plant cell early in the evolution of life and set up a symbiotic relationship with it, supplying energy in return for compounds they were unable to produce for themselves.

Originally this idea rested primarily on observed peculiarities in the multiplication and behavior of chloroplasts. The discovery of chlorophyll DNA lends it further support. The presence of DNA was established some years ago with the aid of a DNA-specific stain. Now two groups of investigators at the University of California—C. Ralph Stocking and Ernest M. Gifford at the Davis campus

THE PHANTOM II is the fastest fighter in the world. Flying deep in the region of aerodynamic heating known as the "thermal thicket" the Phantom II set a new world straightaway speed record of 1606.3 mph.

An operational fighter, the Phantom II set the new record without rocket assistance. Powered by two GE-J79 engines, the Phantom II reached peak speeds in excess of 1650 mph on the 16-kilometer course.

In combat, such speeds are required only for short periods of time. At 26 miles a minute, the Phantom II can cover vast distances before the oven-like heat can damage its surface. It has the speed to catch invaders . . . it has the speed to deliver an attack almost before radar can find it . . . and it has the speed to get away. At 26 miles a minute, it takes but 46 seconds to cross the English Channel. At 1600 miles an hour, it's less than eight minutes from New York to Boston, four minutes from Detroit to Cleveland.

The performance of the McDonnell Phantom II is matched by its armament versatility. The Phantom II can carry Sparrow III and Sidewinder missiles for air defense or air superiority missions. It can carry multi-ton loads of conventional bombs and napalm for troop support missions. It can carry nuclear stores for long range strategic attack.

. . . at 1600 mph, the Sky is an Oven

Record Flights of the Phantom II:

Altitude	98,557 feet
100 kilometer closed course	1390 mph
500 kilometer closed course	1216 mph
Los Angeles to New York	170 minutes
3 kilometer low altitude	902 mph
16 kilometer straightaway	1606.3 mph

MCDONNELL

Phantom II Fighter and Attack Aircraft • Mercury, Asset and Aeroballistic Spacecraft • Talos and Typhon Missile Airframes and Engines • Quail Decoy Missiles • Rotorcraft • Electronic Systems • Automation

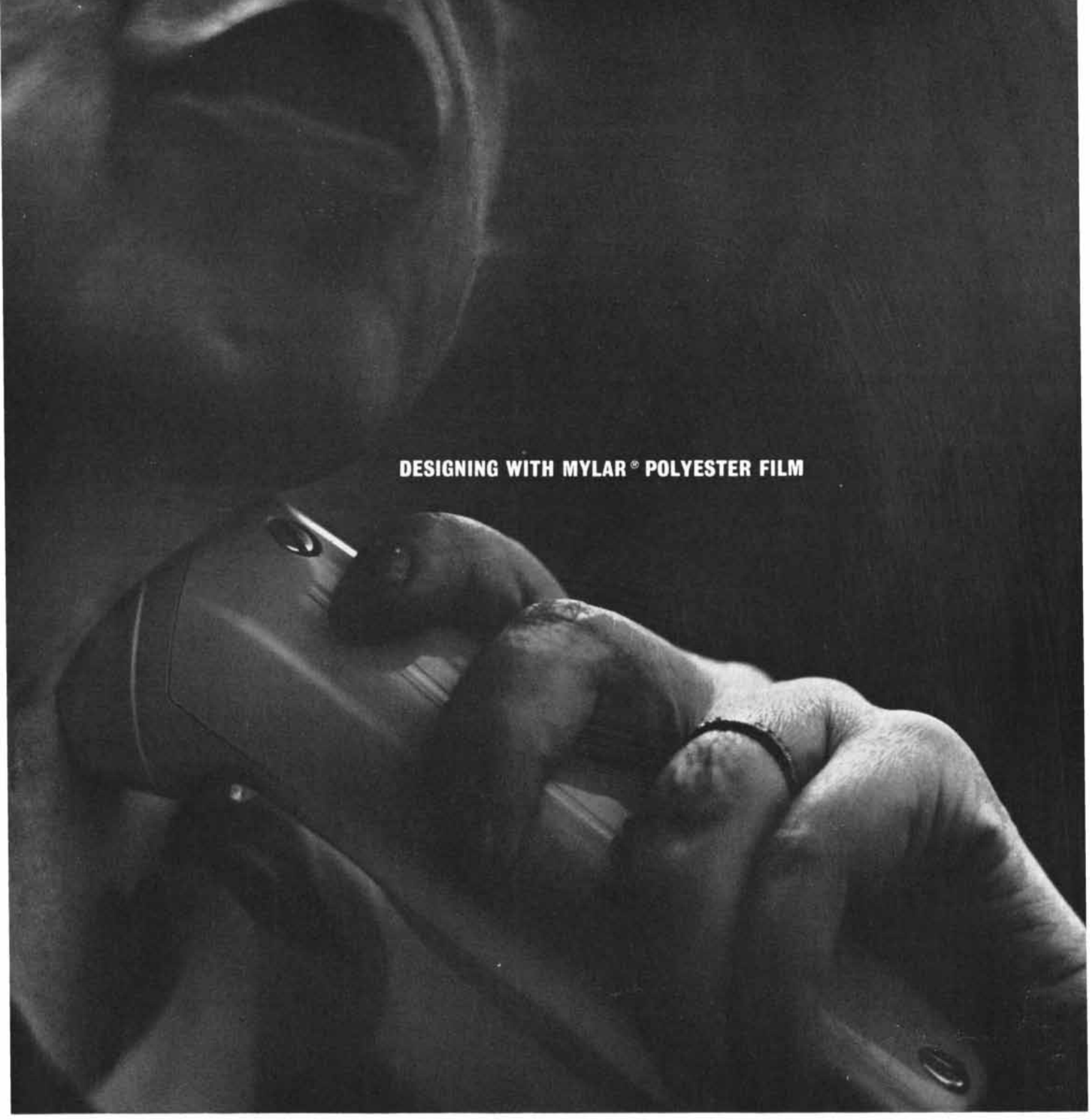
MCDONNELL AIRCRAFT • ST. LOUIS

and Stanley Scher and Lynn Sagan in the Space Sciences Laboratory at Berkeley—have found that chloroplasts in green algae and in the flagellate *Euglena* have the ability, essential to self-replication, to make new DNA. Using radioactive tracers, they have shown that chloroplasts take up and incorporate thymine. This is one of the four constituent bases that make up DNA and the only one that does not also form part of ribonucleic acid (RNA). The rate of uptake is modest—only a few per cent of that in the nucleus of the cell—but it is enough to suggest the existence of a separate hereditary apparatus in the chloroplast.

Tornadoes to Order

A French meteorologist has found a way to create artificial tornadoes. Jean Dessens of the University of Clermont made the discovery while trying to manufacture cumulus clouds. One day last June he set up an apparatus for generating a warm air column on a plateau in the Pyrenees Mountains of southwestern France. Called the Meteotron, the apparatus consisted of an array of 100 oil burners spaced over a square measuring 125 meters on a side, with pumps capable of feeding a ton of fuel oil per minute. The burners were adjusted for incomplete combustion of the fuel in order to generate smoke that would mark out the rising column of warm air and, hopefully, trace the evolution of a cumulus cloud. Nothing unusual was noted during the experiment itself; however, photographs taken from a distance of 2½ miles a few minutes after the burners were lighted showed a distinct tornado spout connecting the smoke column to the ground.

In subsequent trials, Dessens reports in *Nature*, "whirls and even incipient tornadoes were very often observed." But the most spectacular observations were made on a fair day at the end of August, when, as indicated by the behavior of the smoke column, the atmosphere was unstable up to an altitude of about 6,000 feet. An array of 48 burners produced a whirlwind so strong that it bent the burner flames at an angle of 45 degrees and blew three burners out. A bright tube also appeared along the whirlwind axis, and, about 30 seconds after the burners were extinguished, a "white twist" 300 feet in height was seen extending from the ground up to the base of the smoke cloud. Dessens is continuing the experiments with equipment designed specially to generate tornadoes.



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ULTRAHIGH VACUUM

In 1950 the limit of man-made vacuum appeared to be a pressure equivalent to 10^{-8} millimeter of mercury. A breakthrough in technique now provides pressures four orders of magnitude lower

by H. A. Steinherz and P. A. Redhead

The prefixes "super-" and "ultra-" are rather freely used in scientific literature these days. These superlatives may prove embarrassing when it comes time to describe the next round of advances, but they do reflect an explosive rate of progress that has carried many techniques beyond what seemed to be the attainable limits only a short time ago.

The history of ultrahigh vacuum, a good case in point, goes back to 1950. Before that year high-vacuum practitioners had been improving their pumps, valves, seals and other components and had been reaching lower and lower pressures. In the middle 1940's they seemed to have reached a dead end. Using the best pumps and the most exquisite care in the design and operation of the systems, they could reach pressures approaching a hundred-millionth of a torr. (The torr, named for the 17th-century vacuum pioneer Evangelista Torricelli and now the standard unit in vacuum technology, is defined as the pressure necessary to support a column of mercury one millimeter high.) Apparently further refinements availed nothing. The gauges still indicated 10^{-8} torr. It was generally supposed that the pumps must somehow fail at this pressure. (The extremely small pressures with which this article deals are most conveniently expressed in negative powers of 10. The fraction 1/10 is written 10^{-1}, 1/100 as 10^{-2} and so on. Thus 10^{-8} is one hundred-millionth of a torr.)

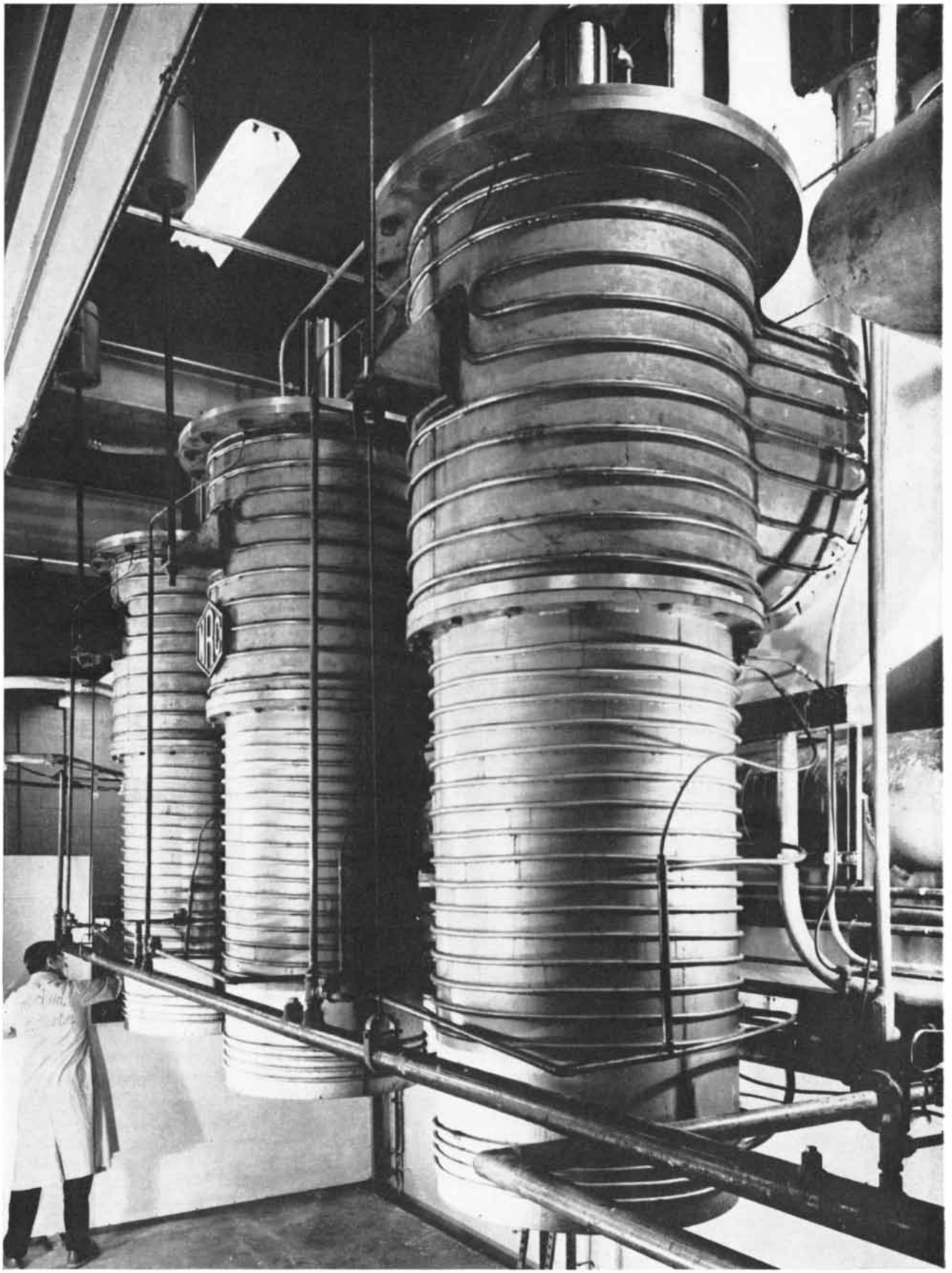
It is worth pausing a moment to appreciate the achievement that a pressure of 10^{-8} torr represents. It is about one hundred-billionth the pressure of the atmosphere at sea level, which means that only one of every hundred billion air molecules originally present in the vacuum chamber is left after pumping. At a pressure of one atmosphere each molecule travels, on the average, a few millionths of a centimeter before bumping into another molecule. At 10^{-8} torr, if it were not for the walls of the vacuum chamber, a typical molecule would travel almost 500,000 centimeters—some three miles—before encountering another. The pressure exerted by air at one atmosphere on a container (or on the mercury column of a pressure gauge) is the result of 3×10^{23} molecular impacts against each square centimeter of the container walls each second. At 10^{-8} torr the number of impacts is reduced, also by a factor of one hundred billion, to 3.8×10^{12} per square centimeter per second. This is still a lot of impacts, but not enough to hold up a column of mercury even one atom high. Obviously the definition of the torr given above no longer has any operational significance. The torr is nonetheless used to define these extremely low pressures, with the tacit understanding that it can be redefined in terms of a meaningful property such as the rate of impacts against a container wall, or the number of molecules per cubic centimeter (molecular density).

In 1947 Wayne B. Nottingham of the Massachusetts Institute of Technology suggested that the barrier at 10^{-8} torr was an illusion, caused by a failure in measurement rather than in pumping. The only instrument generally available that is capable of measuring pressures below about 10^{-4} torr is the ion gauge. The standard device in use during the 1940's consisted of a hot-wire cathode surrounded by a positively charged grid, which is in turn enclosed in an ion-collecting shell. The whole arrangement is enclosed in an envelope that is connected to the vacuum chamber, so that the gauge is in effect a part of the chamber. Electrons emitted from the central cathode move rapidly toward the grid. In the course of their journey some of them collide with molecules of the gas to be measured, knocking electrons out of its molecules and producing positive ions. All the electrons are eventually collected on the grid. The positive ions move to the negatively charged collector, each one causing a tiny pulse of current to flow in the collector circuit. The number of ions produced depends on the density of the gas (that is, on the number of molecules per cubic centimeter), and so the collector current is an index to the molecular density.

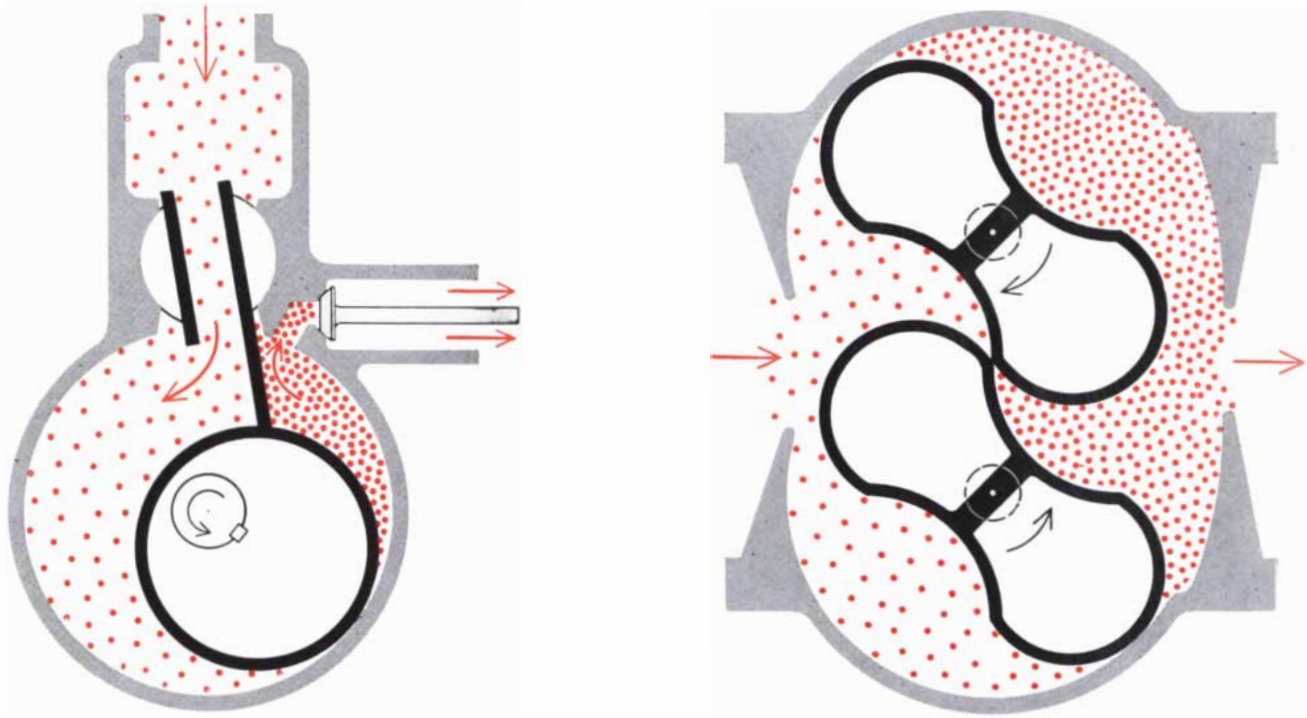
Analyzing the operation of the ion gauge, Nottingham realized that there must be an additional process at work in it. Electrons bombarding the grid produce low-energy X rays. Some of this radiation would strike the ion collector and release electrons from its surface by means of the familiar photoelectric effect. So far as the current meter in the external circuit is concerned, the departure of a negative electron from the collector has exactly the same effect as the arrival of a positive ion. In short, the meter would register some current even if there were no gas whatever in the gauge and therefore no ions. Nottingham's calculations showed that this irreducible photoelectric current corresponded to a pressure of about 10^{-8} torr.

The Bayard-Alpert Gauge

A couple of years later Robert T. Bayard and Daniel Alpert, then at the Westinghouse Research Laboratories, hit on a simple modification of the ion gauge that both proved the correctness of Nottingham's analysis and greatly extended the limits of operation of the instrument. Essentially they switched the positions of the cathode and the ion



LARGE OIL DIFFUSION PUMPS are located in Space Environments Laboratory of Fairchild Camera and Instrument Corporation's Defense Products Division at Syosset, N.Y. The three pumps, each 32 inches in diameter, are teamed with three others to attain 10^{-8} torr (equivalent to a 300-mile altitude) in a 2,825-cubic-foot chamber in which space vehicles and sensors are to be tested.



MECHANICAL PUMPS are used in the first stage of evacuation. The rotary type (*left*) depends on the action of an eccentric rotating piston to sweep gas out of a chamber. Blowers (*right*) contain two tightly fitted counterrotating lobes that trap and expel molecules.

collector. In the Bayard-Alpert gauge the cathode consists of a heated wire outside the grid, and the collector is a thin wire running down the axis of the instrument [*see illustration at top left on page 84*]. Carrying a negative charge, the collector still picks up most of the ions formed in the gas. But because of its greatly reduced surface area it intercepts far less X radiation than a cylindrical plate does and therefore produces a much smaller photoelectric current. Bayard and Alpert showed that the residual current is equivalent to a pressure of about 10^{-11} torr.

With the new gauge Alpert was able in 1950 to break into the range of ultrahigh vacuum, below 10^{-8} torr. In fact, the instrument played a doubly crucial role. One of the difficulties with ion gauges had always been that they acted to change the very property they were supposed to measure. The reason is that the gas ions driven to the collector are trapped; hence they are removed from the vacuum chamber and the pressure drops. In other words, the ion gauge is also a pump.

Alpert proceeded to capitalize on the drawback. He pumped down a small glass chamber to almost 10^{-8} torr by conventional means, and sealed off the chamber with a newly designed all-metal valve that required no organic sealing compound. (At these pressures conventional sealing compounds give rise to large amounts of gas.) Then he simply let the ion gauge continue to operate. Soon it was registering a pressure of 5×10^{-10} torr. Beyond this point the pressure would not go, although in principle the Bayard-Alpert gauge should have been capable of producing and measuring a pressure 10 times lower. Alpert then built a special type of mass spectrometer (which will be discussed later) to measure the pressures due to the various gases in the vacuum chamber. He found that the pressure limit in his system was set by the diffusion of helium atoms in the air through the glass walls of the chamber.

This work is as clear-cut an example of a scientific first as is ever likely to turn up. Yet, typically, once Alpert showed how to measure pressures in the ultrahigh-vacuum region it became clear that others had entered it before him. The new gauge demonstrated what some investigators had long suspected, that the diffusion pumps used in producing high vacuums could themselves penetrate the "barrier" at 10^{-8} torr. A review of the results of earlier work indicated that pressures not far from 10^{-9} torr had probably been attained as early as 1931.

Nevertheless, the opening of the age of ultrahigh vacuum must be dated from Alpert's remarkable experiments. After they had been published a growing number of workers entered the field, contributing further improvements to equipment and technique. Today a pressure of 10^{-12} torr is attainable, and still lower pressures are clearly in prospect. At 10^{-12} torr the molecular density is down to 33,000 molecules per cubic centimeter and the mean free path of a nitrogen molecule is about 50,000 kilometers, or 30,000 miles, long.

The Uses of Ultrahigh Vacuum

Before discussing the tools and methods of ultrahigh-vacuum technology, it seems appropriate to ask why they were developed. It is likely that sheer curiosity and the urge to explore would have produced them eventually. But there were far more practical lures, in both fundamental and applied research, to attract men and money to the task.

The original impetus toward ultrahigh vacuum came from the requirements of experimenters studying the physics and chemistry of solid surfaces. Most of the properties of such surfaces can be studied only on surfaces that have been cleaned of adsorbed gases and will stay clean long enough for the appropriate measurements to be made. Metals and semiconductors can be cleaned on an atomic scale by heating them in a vacuum or by spraying their surfaces with a low-energy discharge of an inert gas. How long the pristine surface lasts then depends on the rate at which it is bombarded by adsorbable molecules from the surrounding gas. At a pressure of 10^{-6} torr, considered a good vacuum only a few years ago, a layer of gas one

molecule thick will form on a metal surface in about one second. If the surface has been cleaned by heating in a vacuum of 10^{-6} torr, it is usually completely covered before the sample has cooled to its initial temperature, and before many of the desired measurements can be carried out. At 10^{-9} torr the "monolayer time" increases to about 20 minutes, and it becomes possible to observe the clean surface for a reasonable length of time.

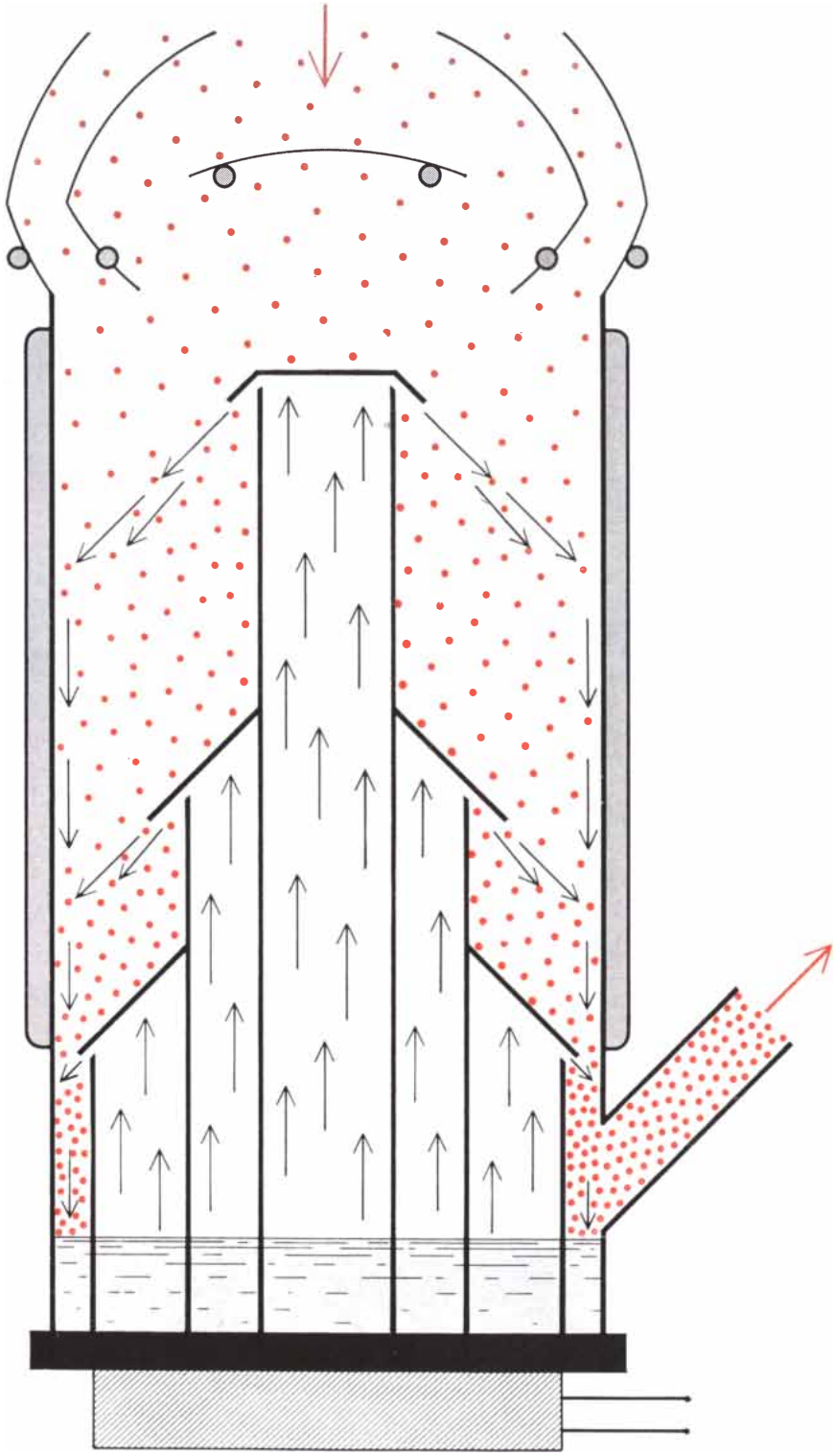
A remarkably wide variety of the properties of a material are affected by gases adsorbed on its surface. One obvious example is the force of friction. Indeed, the true friction between metallic surfaces has so far been measured for only a few metals. The standard handbook figures really refer to surfaces lubricated by adsorbed gas layers. Again, the emission of electrons from a solid surface (by thermionic emission, photoelectric emission or other processes) is sensitive to surface contamination, and ultrahigh-vacuum techniques are now being widely used to study the phenomenon. Some electrical properties of semiconductors are also strongly affected by adsorbed gas. Finally, the process of adsorption itself is more amenable to study when it can be observed in slow motion, so to speak, in an ultrahigh-vacuum chamber.

In any experiment involving gases of high purity at low pressures, ultrahigh-vacuum techniques are indispensable. For example, if it is required to maintain a purity of one part per million in a gas sample at a pressure of 10^{-3} torr, the vacuum chamber must be evacuated to less than 10^{-9} torr before the sample is introduced. If the experiment involves an electrical discharge, the difficulties are compounded. When radiation or gas ions from the discharge strike the vacuum chamber, they release contaminating gases from the walls.

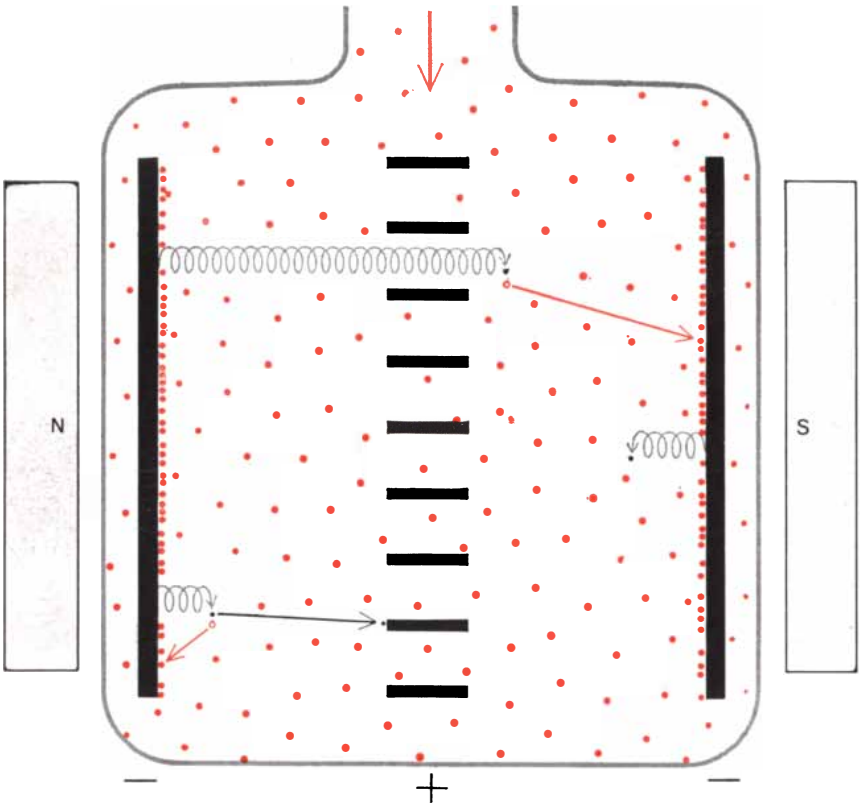
Maintaining clean surfaces is essential not only in laboratory studies but also in manufacturing many of the new miniaturized solid-state devices. These are made by depositing extremely thin layers of different materials, one over another on a base plate. The composition and dimensions of the layers must be precisely controlled, which is possible only under ultrahigh-vacuum conditions.

Conventional vacuum-tube electronics furnished one of the major incentives for the development of high-vacuum technology. With a few exceptions normal vacuum techniques are still adequate for tubes. In any vacuum tube, however, residual gases produce a number of undesirable effects, including increased noise, increased grid current and damage to the cathode through bombardment by positive ions. When the standards of performance are exacting, as in low-noise or high-power vacuum tubes, the pressure in the tube envelope must be reduced to the ultrahigh-vacuum range. High-power klystron tubes, for example, require a vacuum of better than 10^{-9} torr.

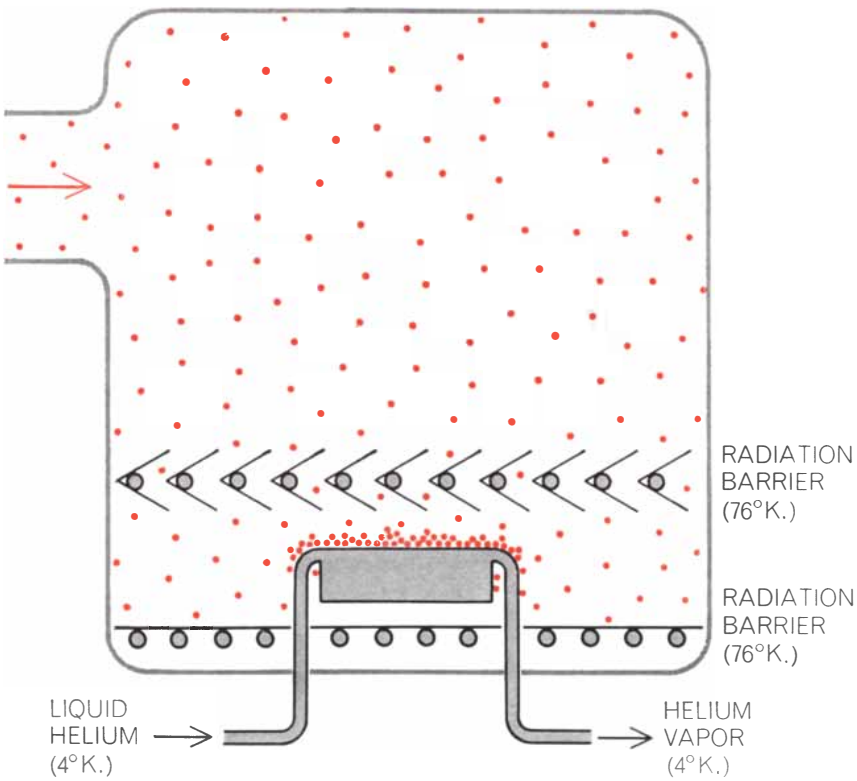
A new class of electron tube, still under development, obtains its current through the "field emission" of electrons due to high electric fields at a fine, unheated metal point. Tube failure through



DIFFUSION PUMP is the work horse of high vacuum. A liquid, usually oil or mercury, is vaporized by a heater at the bottom. The vapor rises and is deflected downward (*black arrows*) as a high-speed jet that entrains gas molecules (*colored dots*) diffusing out of the vessel above and carries them out of the pump. Back-diffusion of pumping vapor into the chamber is inhibited by baffles, cooled by coils (*gray circles*), on which the vapor freezes.



SPUTTER ION PUMP works by ionizing gas molecules and removing them from the chamber (*top*) to be evacuated. Electrons emitted by the cathode plates are accelerated (in spirals because of the magnetic field) by the anode. When they strike gas molecules, they create positive ions (*open colored circles*). These are attracted to the negative collector plates, from which fresh titanium metal is "sputtered" to provide clean pumping surfaces.



CRYOGENIC PUMP is another device that immobilizes gas molecules and thus removes them from a system. It does so by condensing the molecules on a surface cooled by liquid helium. The V-shaped baffles prevent heat radiation downward but allow molecules to pass.

filament breakage is thereby avoided. To obtain stable emission requires extremely low pressures. W. P. Dyke at the Linfield Research Institute in Oregon has built tubes that maintain stable emission for thousands of hours but only at a pressure of 10^{-12} torr. To maintain this vacuum the tube envelope must be made of a special aluminosilicate glass that has a low permeability to the helium in the atmosphere.

In all the cases mentioned so far the amount of space that must be evacuated is not very large—in the cubic centimeter range. There are two major applications in which the volume requirements are considerably greater.

One of them is in the machines with which physicists seek to solve the problem of how to control the release of power from the thermonuclear reactions of the light isotopes deuterium and tritium. An important obstacle to the achievement of thermonuclear power is the loss of energy by radiation from the hot gas, or plasma. Any contamination of the gas by the atoms of heavier elements increases the loss enormously, since these atoms radiate much more strongly than lighter ones do. When one of the early experimental machines was operated after evacuating it to 10^{-6} torr, the lowest pressure then attainable, the radiation loss was so great that the plasma temperature reached only a tenth of the calculated value. To reduce the loss to acceptable levels requires pressures in the ultrahigh-vacuum range. Recent improvements in technique have made it possible to maintain pressures in the range of 10^{-10} torr, where contamination is no longer a major problem. If practical thermonuclear power is ever achieved, the reactors will have to be very large. From the viewpoint of the vacuum engineer even today's experimental devices are big enough. For example, the evacuated volume in the Model C "stellarator" at Princeton University is about half a cubic meter. Not only must this chamber be pumped down to 10^{-10} torr before the plasma is introduced but also the pressure of the contaminants must be maintained at this value as impurities are released from the walls of the chamber by the action of the high-energy discharge.

The Simulation of Space

The most insistent, as well as the most stringent, demands on ultrahigh-vacuum technology come from the space-exploration program. At 450 miles above the surface of the earth the pressure of the

atmosphere is only 10^{-9} torr, and at 1,200 miles it falls to about 10^{-11} torr, approaching the limit now generally attainable in the laboratory. In interplanetary space the pressure is estimated to be on the order of 10^{-16} torr. This corresponds to a density of about four molecules per cubic centimeter.

Under these ultrahigh (and ultraultrahigh) vacuum conditions materials may behave in unexpected ways, and physical and chemical processes may be radically altered. For example, graphite, an excellent lubricant at atmospheric pressure, becomes an abrasive below 10^{-6} torr. Heat transfer, fluid flow, dielectric behavior and other phenomena change drastically as pressure is decreased.

Not all the changes are necessarily harmful. The resistance of metals to certain types of fatigue increases greatly at low pressure. A strip that will break after a few flexings under ordinary conditions can be bent back and forth for hours in an ultrahigh-vacuum chamber. It appears that in an ultrahigh vacuum tiny cracks that form at each bending reweld themselves when the strip is bent the other way. In air at atmospheric pressure the cracks are covered with an oxide coating as soon as they open. The metal cannot join together again, and as a result the cracks grow larger each time the piece is bent.

To test equipment designed for space vehicles, simulation chambers have been built at a number of laboratories. Small or moderate-sized enclosures that can be evacuated to the lowest pressures now attainable suffice for examining fundamental processes and the properties of materials. But to check the performance of complete components requires chambers of enormous size. The biggest ones go up to some 1,000 cubic meters. Even these huge spaces are now maintained at pressures near 10^{-8} torr.

Producing the Ultrahigh Vacuum

Ultrahigh-vacuum workers face two essential problems: (1) to produce and maintain pressures below 10^{-8} torr and (2) to measure the pressure they have achieved. So far as the first problem is concerned the solution in every case represents a balance between the capacity of the pump and the system gas load: the rate at which gas continuously enters the vacuum chamber from the various parts of the system (including the pump).

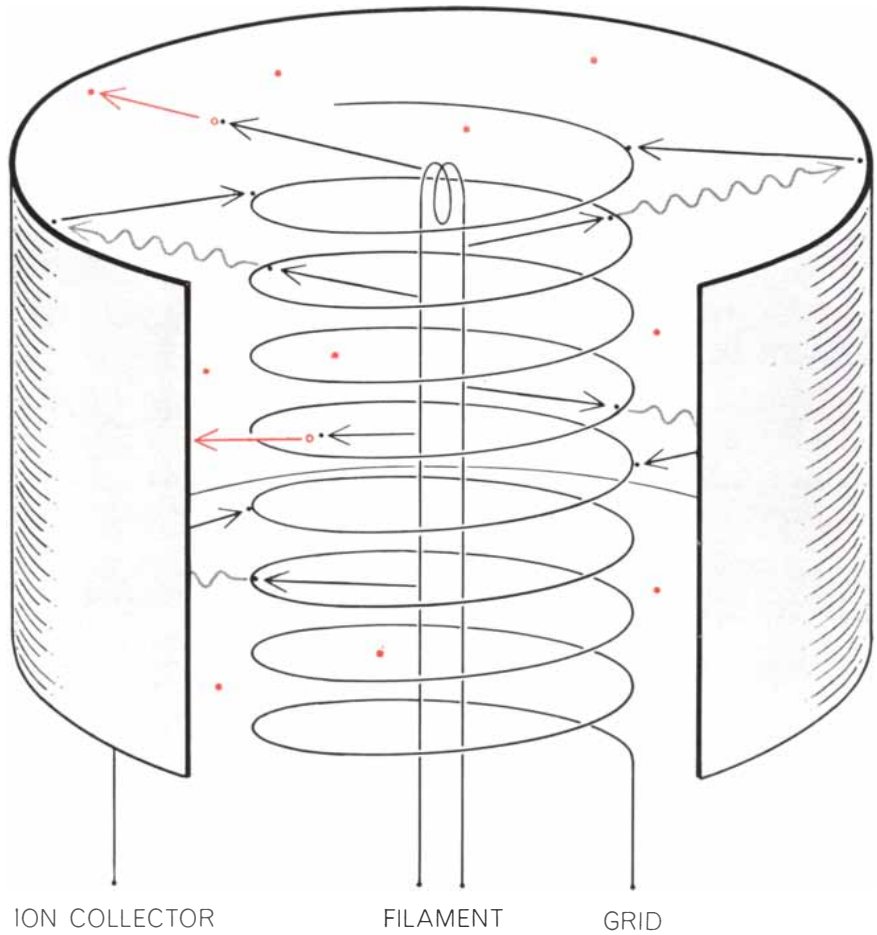
Each part contributes its share, which the vacuum engineer seeks to minimize. Following Alpert's lead, the valves in ultrahigh-vacuum systems are made of metal and only low-vapor-pressure sealing compounds are used.

In small systems where the experimenter wants to observe what is going on inside or to be able to change his setup easily, the ultrahigh-vacuum chamber and its connecting tubing are still made of glass [*see painting on the cover*]. The penetration of atmospheric helium through the glass is offset by a pump of sufficiently high capacity. Moreover, as has been mentioned, the composition of the glass itself can be altered to reduce its permeability.

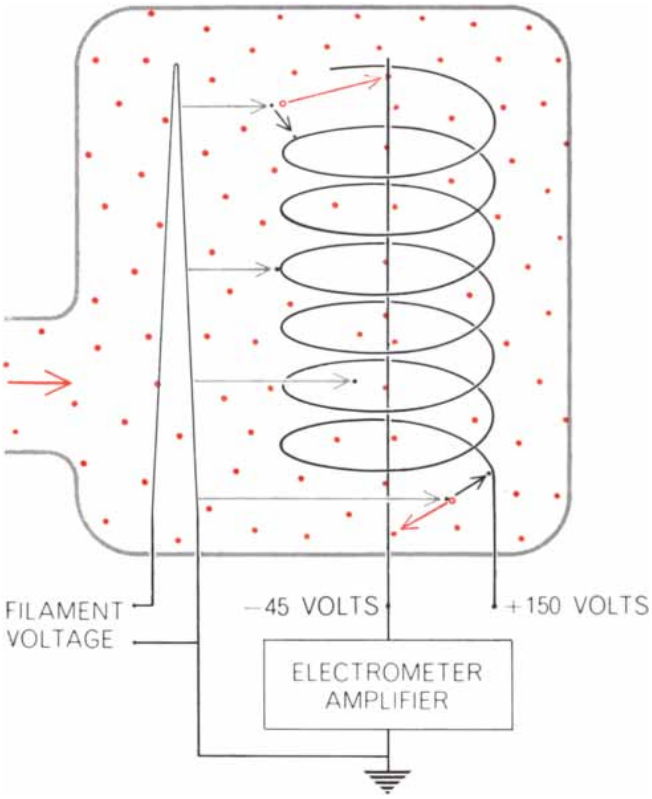
All large ultrahigh-vacuum systems, and nowadays many small ones, are built of metal, usually stainless steel. In the early days (10 years ago) designers had to weld or braze all joints to avoid excessive leakage. This equipment was hard to modify, and even introducing experimental samples into the chamber was awkward. With the recent development of improved metal gaskets and of certain elastomers such as Viton, which vaporizes very slowly even in an ultrahigh vacuum, bolted joints have become practical and metal vacuum systems are much more flexible.

Whatever the system is made of, all its parts must be able to withstand baking for hours at a temperature of several hundred degrees centigrade to drive off gas adsorbed on the surfaces and absorbed within the solid materials. Without this preparation the gas would steadily evolve into the chamber as pumping started and the pressure began to drop. To reach an ultrahigh vacuum would take an inordinately long time.

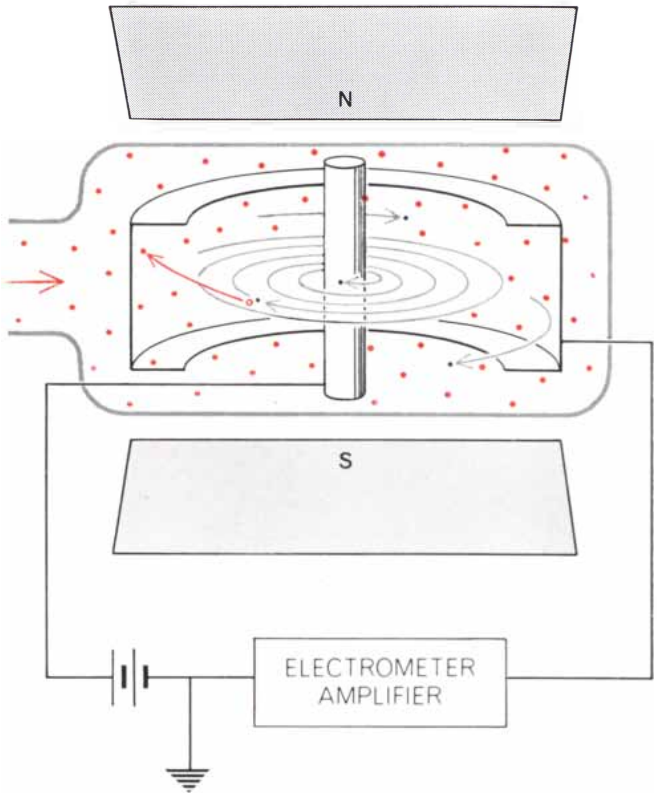
Even after the most careful preparation, desorption from the walls of the system constitutes a major source of the residual gas that keeps dribbling into an ultrahigh-vacuum system. An idea of the dimensions of the problem is provided by a typical small stainless steel system with walls one millimeter thick and a surface area of 100 square centi-



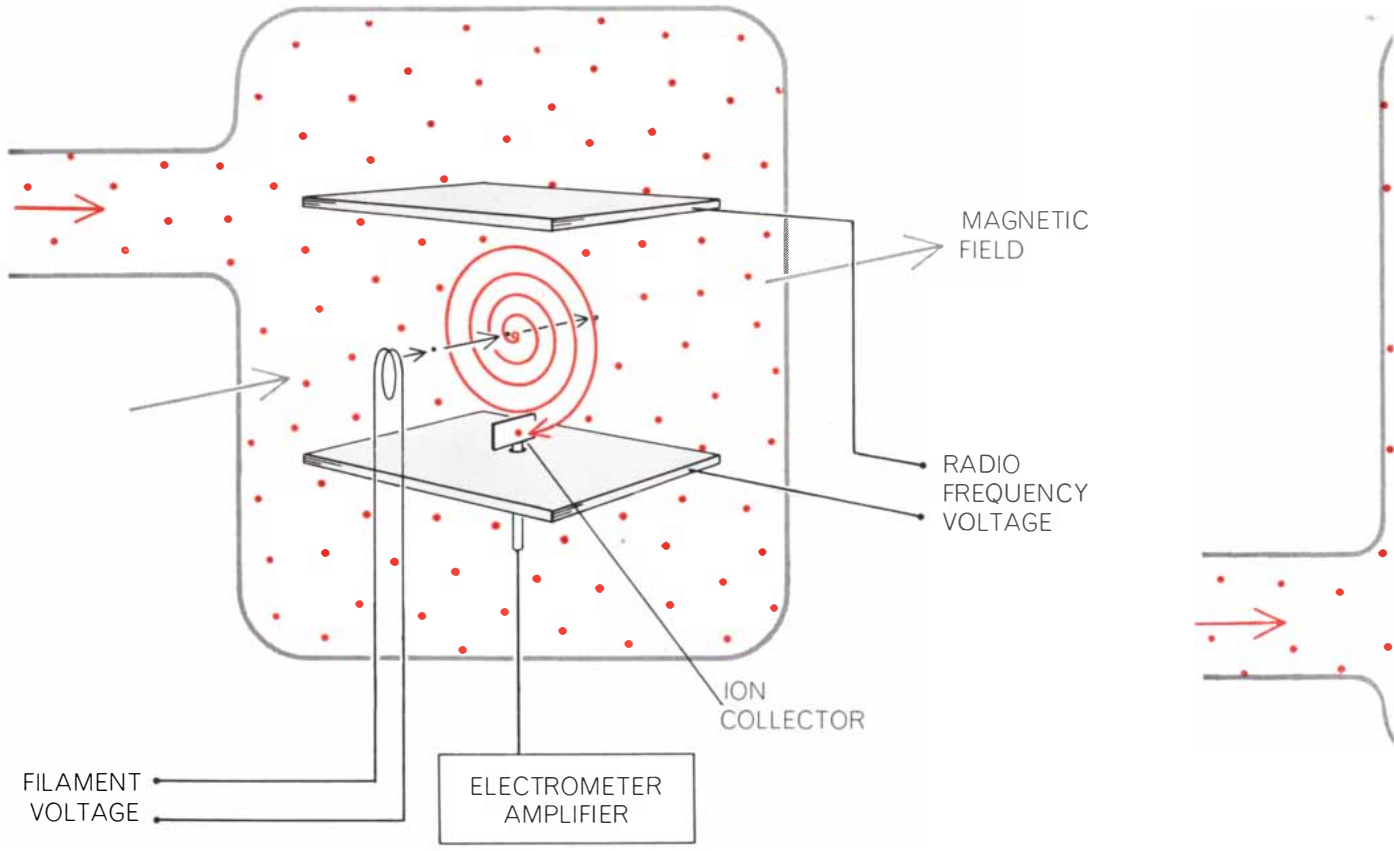
X-RAY PROBLEM made it impossible for early ion gauges to register below 10^{-8} torr. Electrons from the filament created positive ions (*colored circles*) that struck the collector and were counted. But electrons reaching the grid produced X rays (*wavy arrows*). When the X rays struck the large-area collector, they liberated electrons, causing a photoelectric current that could not be distinguished from the current resulting from ion impact.



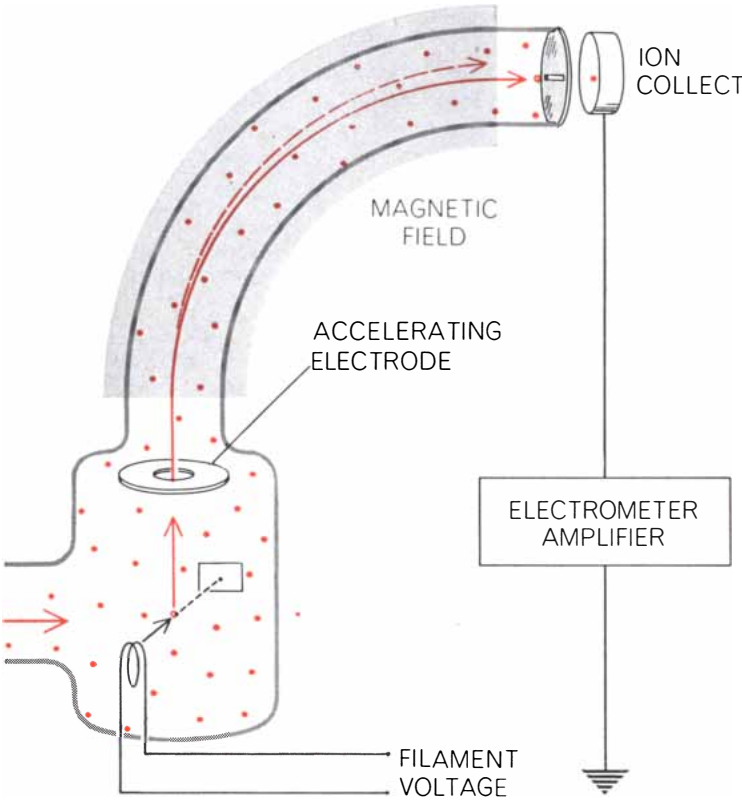
BAYARD-ALPERT GAUGE avoided the X-ray problem by putting the heated-filament cathode outside the grid and making the collector a thin axial wire. The negatively charged collector still gathers positive ions, but because of its small area it intercepts fewer X rays and therefore emits a smaller photoelectric current.



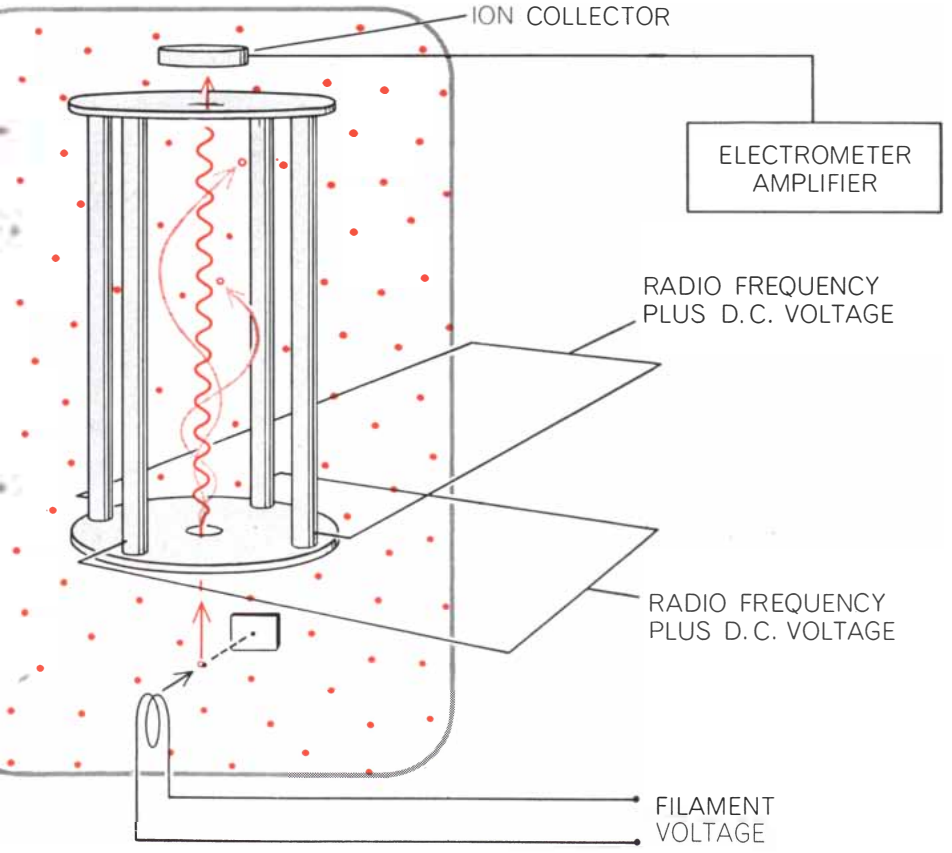
INVERTED MAGNETRON, a cold-cathode gauge, produces electrons by applying a high voltage to unheated electrodes. In such a gauge X rays are proportional to pressure, so no spurious current is produced. Electrons spiraling in toward the central electrode ionize gas molecules, which are collected on the curved cathode.



OTHER MASS SPECTROMETERS are diagramed. In the Omegatron (*left*) a radio-frequency voltage is varied to whirl positive ions of different masses into spirals that strike the collector. In the massen filter (*right*) the ion beam is accelerated along the axis of



MASS SPECTROMETER can measure the partial pressure of individual gases instead of just total pressure. In this gauge, a modification of a standard spectrometer, gas molecules are ionized by an electron gun (*bottom*) and then accelerated through a magnetic field. By varying the magnetic or electric field one can direct ions of different masses through the slit to strike the collector and so measure the density of one constituent gas at a time.



four rods carrying both direct-current and radio-frequency voltages. At each particular voltage ions of only one mass spiral up the axis to the collector; the others hit the rods.

meters. With good technique, the rate of evolution can be reduced to about 10^{-10} torr-liter per second. (This is a rate that would raise the pressure of an absolutely empty one-liter chamber to 10^{-10} torr in one second.) Inflow through microscopic leaks in valves and joints would contribute the same amount of gas. Permeation of helium through the walls would add only about a hundredth as much; in metal systems this permeation is negligible. A small laboratory ultrahigh-vacuum pump, with a capacity of 10 liters (a little more than 10 quarts) per second, can maintain this chamber at 2×10^{-11} torr. (The rating of a pump must be referred to the pressure range in which it operates. Working at 2×10^{-11} torr, the pump in the above example can remove in one second the number of gas molecules that a 10-liter chamber contains at 2×10^{-11} torr.)

In principle the same figures should hold for larger systems so long as the pumping rate increases proportionately with the wall surface. Space-simulation chambers often have areas of a million square centimeters or even more. Typically their pumping systems are rated at 100,000 liters per second. With the area multiplied 10,000 times and the pumping speed increased by the same factor, a pressure of 2×10^{-11} torr should still be attainable. In practice, however, unavoidable leaks at the many large gaskets and seals have limited the pressure in the big chambers to about 10^{-8} torr.

The Pumps

The evacuation of any chamber, regardless of size or eventual pressure, begins with mechanical pumping. The pump is almost always the familiar rotary type, in which gas is swept out by an eccentric rotating piston [*see illustration at left on page 80*]. Sometimes, particularly in large systems, the rotary pumps are joined in series with blowers, which remove gas by the action of two counter-rotating lobes [*see illustration at right on page 80*]. Mechanical pumps bring the chamber down to about a thousandth of a torr. Then the ultrahigh-vacuum pumps take over.

Today diffusion pumps are the work horses of high vacuum, as they have been since their invention 40 years ago. Improvements have now extended their usefulness through the whole of the present ultrahigh-vacuum range.

The only moving part in a diffusion pump is a high-speed jet of oil vapor or some other vapor, directed away from the opening of the vacuum chamber

[*see illustration on page 81*]. Gas diffusing out of the chamber is entrained in the jet and swept along with it out of the pump. The device is simple and fast and can be made as big or as small as is desired. Its major drawback—the factor that eventually limits the pressure it can reach—is the diffusion of vapor from the pumping fluid back into the vacuum chamber.

In the past few years the limit has been pushed back through a number of technical advances. Pump jets have been redesigned to allow higher boiler pressures and to reduce migration of the fluid into the vacuum chamber. New pump oils are available, consisting of polyphenyl ethers or liquid silicones, that have vapor pressures of less than 10^{-9} torr at room temperature, 10 to 100 times lower than those of the best oils available five years ago.

No matter how low the volatility of the fluid is, some of it is bound to back up in the pump. A good part of the contaminant, however, can be kept out of the vacuum chamber with baffles. The most common arrangement consists of a series of vanes, placed at the entrance to the chamber and cooled to the temperature of liquid nitrogen, on which the oil vapor freezes. Recently "molecular sieve" materials such as zeolite have demonstrated effective baffling action. With the help of zeolite filters operating at room temperature, diffusion-pumped systems have been held at 10^{-10} torr for more than 100 days. Refrigerating the zeolite extends its useful life even further and appears to eliminate oil contamination completely.

The decomposition of the pumping fluids has limited oil diffusion pumps to about 10^{-10} torr. Better results have been achieved by replacing oil with mercury. Small mercury diffusion pumps have now reached all the way down to 10^{-12} torr.

In spite of the many advantages of the diffusion pump, it is often replaced in small laboratory systems by the ion pump. Basically this device operates in the same way as the gauge that Alpert used to attain the first certified ultrahigh vacuum: ions, produced by electrons bombarding the gas molecules, are driven by an electric field to a collector, where they are adsorbed. Note that the ion pump works on a quite different principle from that of the diffusion pump. Instead of taking gas entirely out of the system, ion pumps immobilize it within the system. Herein lies one of their weaknesses: low capacity due to the saturation of the collecting surface.

Alpert's gauge had a capacity of only a small fraction of a liter per second. By designing the device primarily for pumping, the speed can be increased to many liters per second [*see top illustration on page 82*]. Containing no foreign pumping fluid, the ion pump contributes far less contamination than the best of the diffusion pumps. It is therefore better suited to operate unattended for long periods.

When the action of an ion pump is analyzed, it turns out to depend on two different processes. Some of the ions reaching the collecting surface are held there by adsorption. Others, however, react chemically with the collector material, forming stable compounds. Chemically active gases are pumped by both mechanisms; inert gases, only by the former. In most ion pumps the collector is made of titanium. The steady hail of ions "sputters" the surface, continuously providing fresh layers of clean titanium metal with which the chemically active gases combine.

All ion pumps suffer to some extent from the same pair of defects. First, they pump chemically active gases much faster than they do inert gases. Second, they re-emit a small fraction of the gas

	ATMOSPHERIC PRESSURE	BEGINNING OF HIGH-VACUUM REGION	BEGINNING OF VERY-HIGH-VACUUM REGION	BEGINNING OF ULTRAHIGH-VACUUM REGION	
PRESSURE (TORR)	760	10^{-3}	10^{-6}	10^{-8}	10^{-9}
NUMBER OF MOLECULES PER SECOND BOMBARDING EACH SQUARE CENTIMETER OF CONTAINER WALLS	3×10^{23}	4×10^{17}	4×10^{14}	4×10^{12}	4×10^{11}
MEAN FREE PATH OF ONE MOLECULE BETWEEN COLLISIONS WITH OTHER MOLECULES (CENTIMETERS)	6.5×10^{-6}	5	5×10^{2}	5×10^{5}	5×10^{6}
NUMBER OF MOLECULES PER CUBIC CENTIMETER	2×10^{19}	3×10^{13}	3×10^{10}	3×10^{8}	3×10^{7}
TYPE OF PUMPS USED	MECHANICAL: ROTARY AND BLOWER		DIFFUSION ION CRYOGENIC		

CHARACTERISTICS OF VACUUMS are charted, beginning with atmospheric pressure and extending to the currently practical laboratory limit. Values are given approximately, in orders of magnitude. Since "pressure" as such cannot be measured in extremely

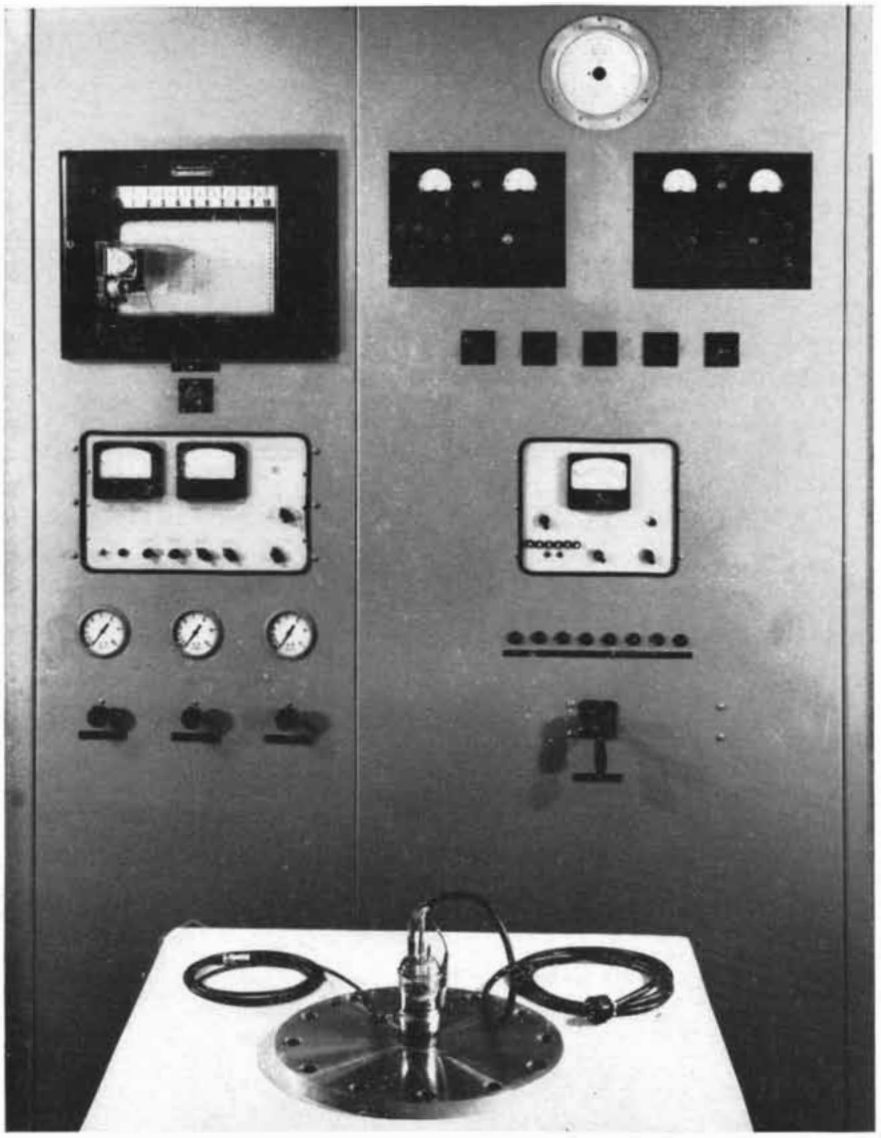
previously pumped. The re-emitted gas acts as an additional source in the vacuum system. Moreover, if one gas is pumped initially and then a second gas is introduced, the pump will remove the second while re-emitting the first. New designs have considerably reduced the size of this effect.

The Cryogenic Pump

Another type of immobilization device now coming into prominence is the cryogenic pump. It removes gas simply by condensation on a very cold surface [*see bottom illustration on page 82*]. Cryogenic pumps can be used in any position, and their speed is not restricted by connecting tubing. These advantages make them particularly valuable for large space-simulation chambers.

When a surface is cooled to the boiling point of helium (4.2 degrees centigrade above absolute zero), all gases are adsorbed, including helium. Pressures of about 10^{-13} torr have already been obtained in small glass systems by partially immersing them in liquid helium. From a study of the adsorption process J. P. Hobson of the National Research Council of Canada has estimated that a half-liter glass sphere evacuated to a

high vacuums, density is measured in terms of the other characteristics shown here.



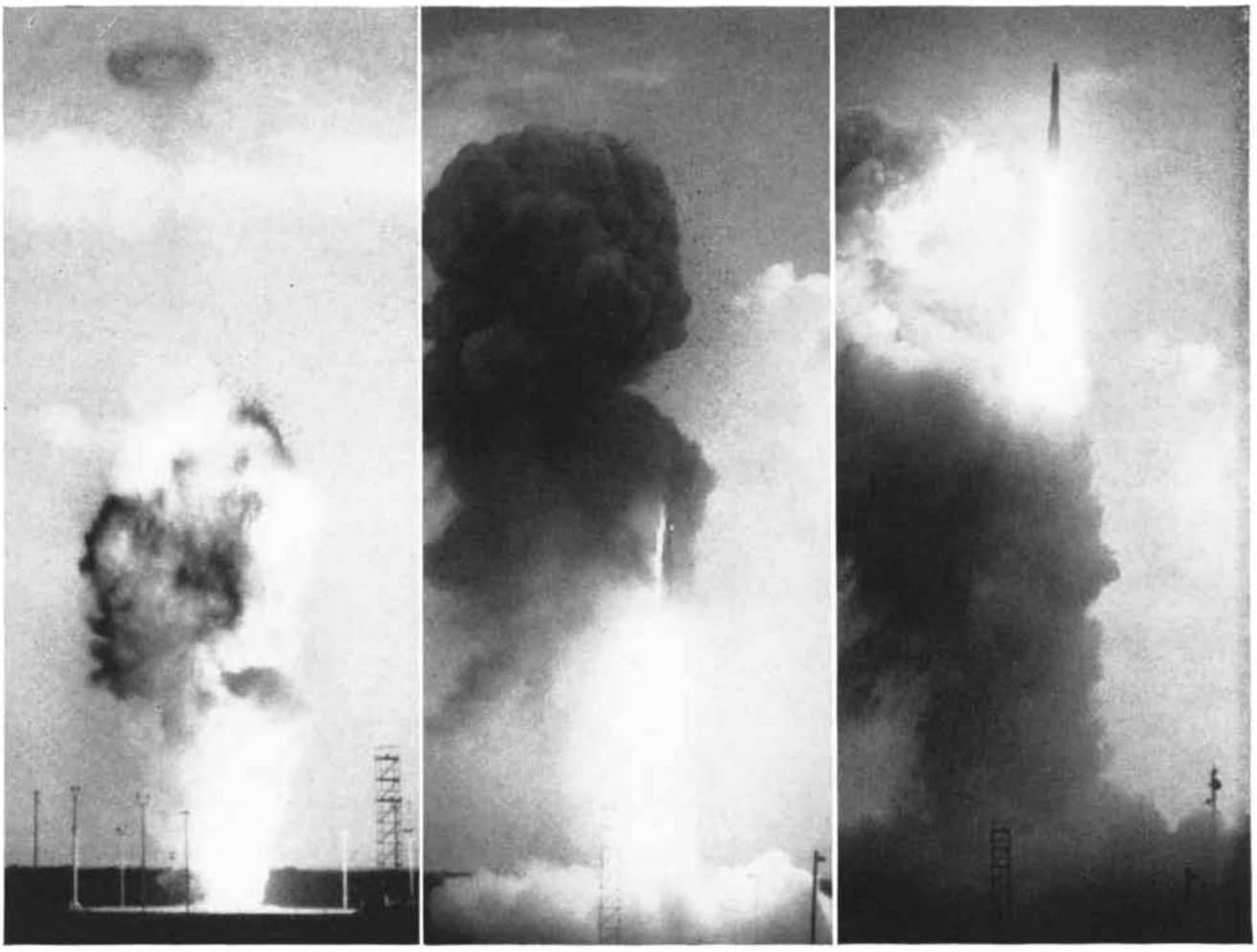
CONTROL PANEL (*top*) for pumps shown on page 79 includes a recorder (*left*) for ultrahigh vacuums and gauges (*right*) for earlier stages and subsidiary pumping systems. On the table in front is the Bayard-Alpert-type gauge to be installed in the chamber. In the close-up of the gauge (*bottom*) the transverse element is the ion collector, the fine spiral wire is the grid and the heavier diagonal wires are the filaments that supply electrons.

pressure of 5×10^{-10} torr by normal methods and then completely immersed in liquid helium should reach about 10^{-30} torr. For better or worse there is no pressure gauge capable of checking this pressure. The calculations indicate, however, that it should be possible, at least in small systems, to produce pressures in the laboratory as low as those thought to exist in interplanetary space.

At the moment, then, pumping has outstripped measurement. But the gauge too has been improved a great deal beyond where Bayard and Alpert left it. Their hot-wire design becomes more effective when the gauge is placed between the poles of a strong magnet. Instead of moving in straight lines the electrons are forced into spirals, which increases their length of travel and therefore their chance of ionizing gas molecules. Changes in the shape and placement of electrodes have further reduced the X-ray current. Nevertheless, the best heated-filament gauges now generally available are only slightly better than the Bayard-Alpert type: their lower limit is about 10^{-10} torr, as opposed to 5×10^{-10}. Recently James M. Lafferty of the General Electric Research Laboratory has built a hot-wire gauge with a magnetic field, capable of measuring pressures as low as 4×10^{-14} torr. Attached to an electron multiplier, its range has been extended even further.

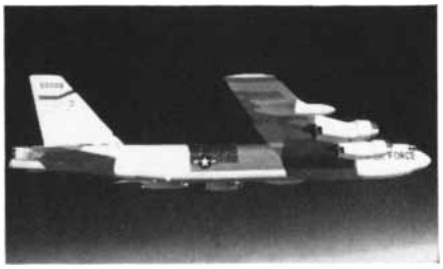
Measurements at 10^{-10} torr and below can now be made with cold-cathode gauges, in which ionizing electrons are produced by applying a high voltage to a pair of unheated electrodes [*see illustration at top right on page 84*]. Lacking a separate grid, the cold-cathode gauge generates no spurious X-ray current. One version of the instrument developed by one of the authors (Redhead) can measure pressures as low as 10^{-12} torr.

The sensitivity of most ultrahigh-vacuum gauges depends on the composition of the gas being measured. In turn, the mixture of molecular species making up the residual gas in an ultrahigh-vacuum system depends largely on the system involved and the pumping methods. For example, a small glass apparatus exhausted with an ion pump contains chiefly helium from diffusion through the walls. On the other hand, hydrogen and hydrocarbons constitute most of the gas in a metal chamber evacuated by an oil diffusion pump. For many purposes it is more important to know the partial pressure of a particular gas or group of gases than the total pressure. What is needed is a mass spectrometer rather than a total-pressure gauge. Moreover, at very low pressures—below 10^{-12} torr—total-



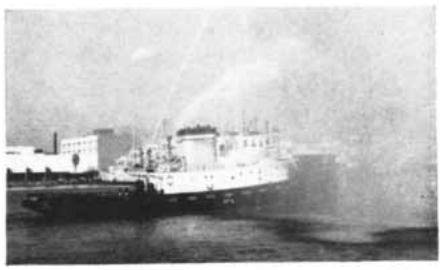
SILO FIRING. Sequence photos show America's first solid-fuel intercontinental ballistic missile, Minuteman, blasting out of underground silo at Cape Canaveral, Florida. This U. S. Air Force missile, described as an "economical breakthrough" in terms of procurement and maintenance costs, is simple, compact, quick-firing. Minuteman missiles will be stored underground at sites hardened against nuclear attack. Boeing is weapon system integrator, responsible for Minuteman assembly, test, launch control and ground support. The Minuteman ICBM weapon system will be operational later this year, a year ahead of original schedule.

Capability has many faces at Boeing



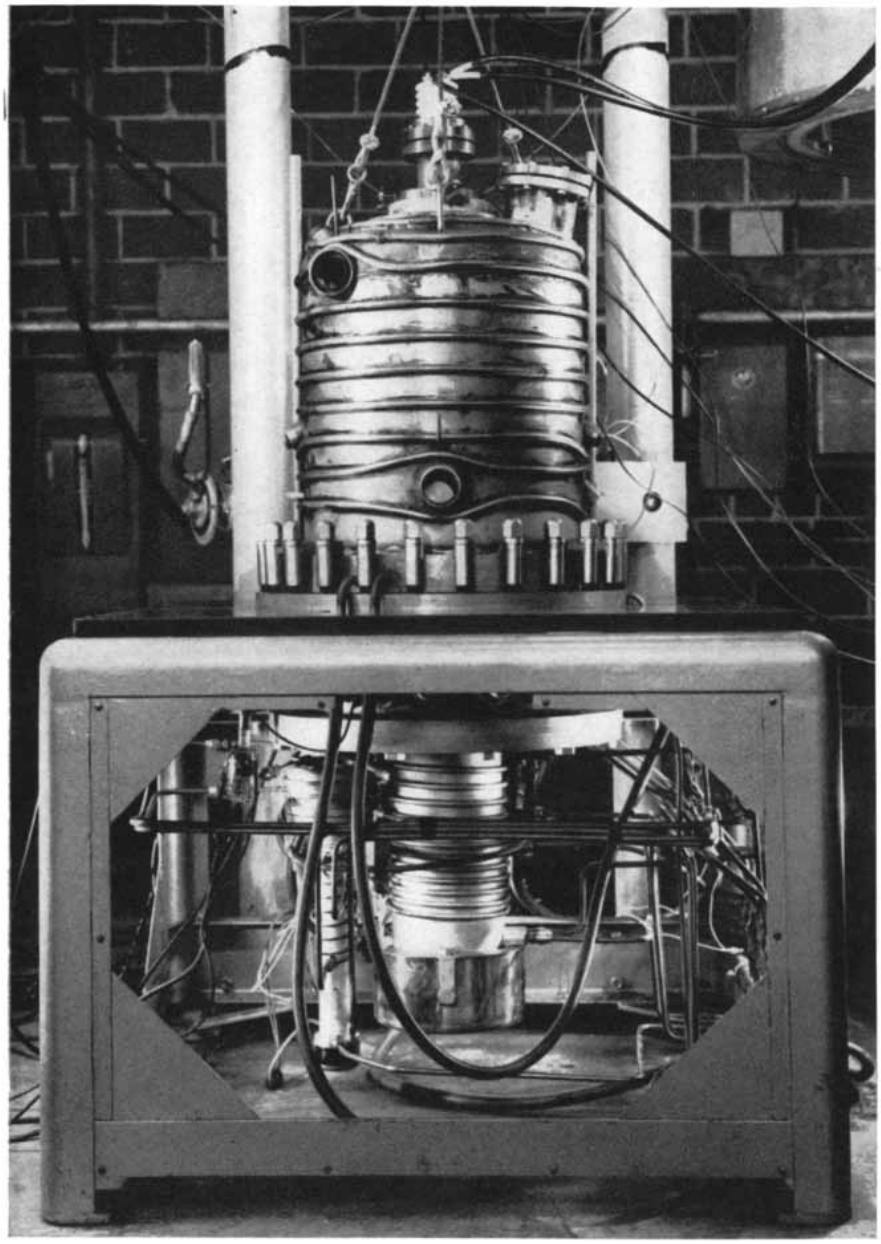
DISTANCE CHAMP. A Boeing B-52H missile bomber set new world distance record, flying 12,519 miles from Okinawa to Spain, non-stop, without refueling. This Strategic Air Command flight demonstrated the global reach of the missile launching Boeing B-52s.

CLEAN ROOM. In super-clean room, Boeing technician inspects magnified circuit card detail. More than 4000 Boeing people are in electronics engineering and manufacturing activities.



WATER, WATER. New U. S. Army tug-fireboat uses two Boeing gas turbine engines to drive two pumps, each handling 2000 gallons of water a minute. Turbines weigh 335 pounds each, deliver 270 hp. Tough, tested Boeing turbines also power U. S. Navy minesweeping launches, generators, and personnel boats.

BOEING



ULTRAHIGH-VACUUM SYSTEM made by NRC Equipment Corporation of Newton, Mass., is tested. Oil diffusion pumps (*bottom*) evacuate the chamber on the table to 10^{-9} torr. A furnace (*visible at top right*) swings over the chamber to bake it before experiments.

pressure gauges are scarcely less complex than mass spectrometers. Except in a few special cases, total-pressure ionization gauges have little to recommend them in apparatus designed for pressures below 10^{-12} torr.

Mass spectrometers, although they come in a wide variety of forms, all work in fundamentally the same way: the gas to be measured is ionized and the resulting positive ions are made to move at high speed through a magnetic, electric or combined field. Ions with different masses (but the same charge) follow different paths and are thereby distinguished from one another. The current produced by ions that have traced a particular path is an index of the number of gas molecules of a particular mass.

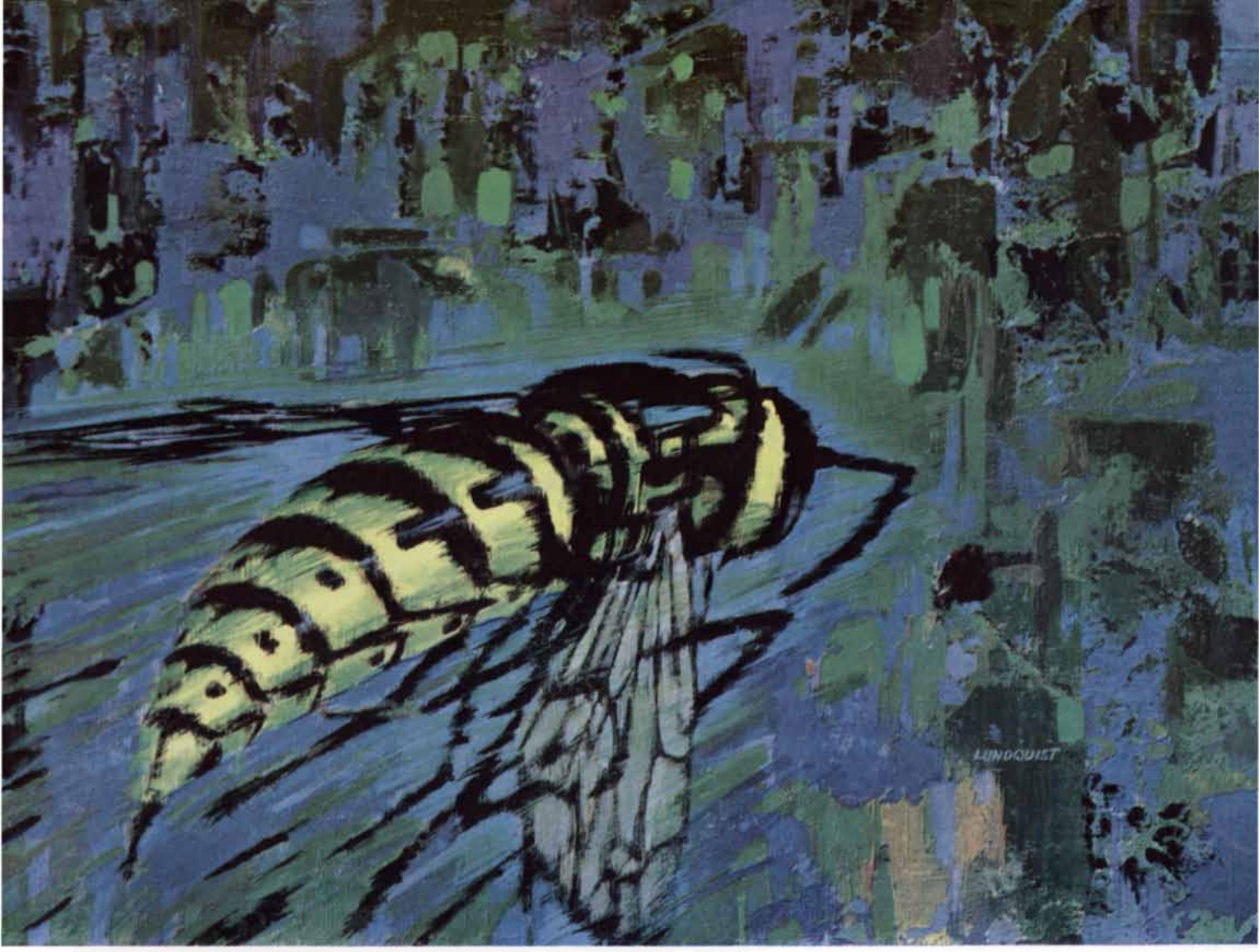
Spectrometers intended for ultrahigh-vacuum work must meet far stricter requirements than are demanded of ordinary analytical instruments. For one thing, they must be extremely sensitive; for another, their operation must not change the composition of the gas in the chamber. This means that they must withstand the preparatory high-temperature baking to which all ultrahigh-vacuum components are subjected.

A number of quite different designs that satisfy the requirements of ultrahigh vacuum are now available. One, developed by W. D. Davis and Thomas A. Vanderslice of the General Electric Research Laboratory, is a modification of a conventional 90-degree sector instrument, in which the ion path is bent through a right angle [*see top illustration on page 85*]. By varying the magnetic field, ions of different mass are directed at the collecting plate, and the corresponding current is measured with the help of an electron multiplier. The instrument can measure partial pressures as low as 10^{-14} torr and can distinguish ions differing in mass by 1 per cent.

Another popular form of spectrometer is the Omegatron, which works like a cyclotron [*see bottom illustration on page 84*]. A radio-frequency field applied at right angles to the magnetic field whirls the ions in curved paths. At each value of the frequency, molecules of a particular mass will follow a smooth spiral to the collector plate, whereas others will be diverted. The Omegatron has a lower limit of about 10^{-11} torr. Because of the shape of the instrument and the strong magnetic field that it requires, the addition of an electron multiplier to extend its range is most difficult.

A device called the massen filter, originally proposed by W. Paul of the University of Bonn in Germany, employs another arrangement of radio-frequency electrodes. It consists of four parallel, equally spaced circular rods carrying both direct-current and radio-frequency voltages [*see bottom illustration on page 85*]. The ion beam is shot down the axis of this structure. For a particular value of the voltages, ions of one mass have a stable path, oscillating closely around the axis and striking the collector plate at the far end. Ions of different masses follow trajectories that make them strike the rods. Changing the voltages changes the mass of the ions collected. With electrodes 25 centimeters long it has been possible to distinguish ions differing in mass by 1 per cent. The addition of an electron multiplier to the massen filter is relatively simple, and the combination has measured partial pressures down to 10^{-15} torr.

For the past few years ultrahigh-vacuum workers have been consolidating their position at about 10^{-12} torr. Today this pressure is obtained and measured consistently, whereas a few years ago it could be reached only by heroic efforts. Now a new cycle is beginning. Present developments in the design of gauges promise to carry them into the range of 10^{-18} torr total pressure. Improvement in pumping can be expected to follow. In fact, as has been indicated, cryogenic techniques may already be capable of producing pressures as low as those in interplanetary space.



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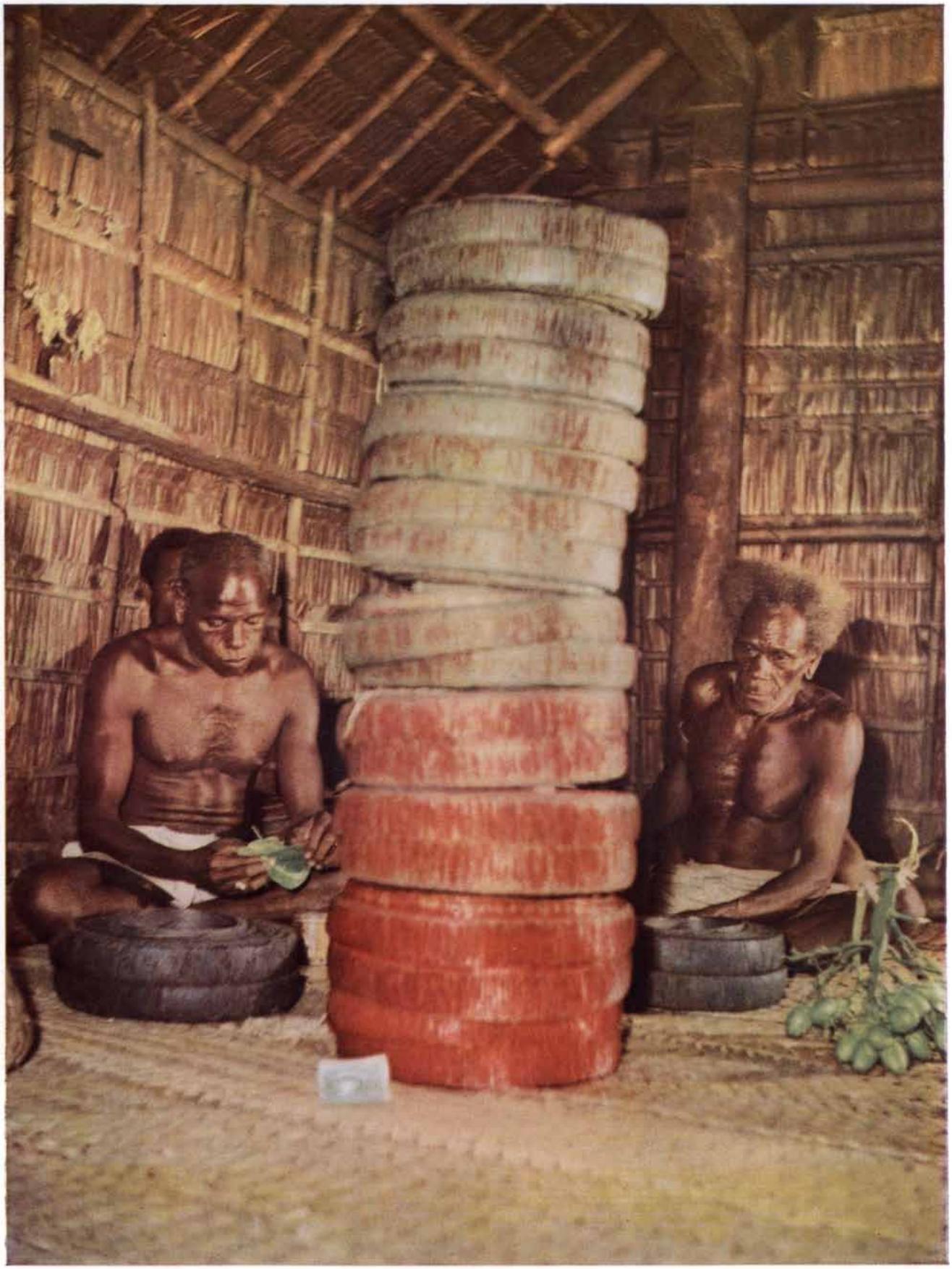


FEATHER-MONEY BRIDE PRICE is negotiated by the bride's father (*left*) and a relative. They have accepted nine of the ten required pieces, which are stacked between them. In bargaining over the tenth and least valuable, the bride's father has rejected the two pieces flanking the stack. He had earlier demanded Australian currency (*foreground*) to supplement the bottom piece, which he considered not quite up to standard. This photograph and the others that illustrate the article were made by the author.

RED-FEATHER MONEY

This primitive currency fashioned from feathers, tree sap and fibers is the basis of a complex monetary and trading system in the Santa Cruz Islands of the southwest Pacific

by William Davenport

One of the most exotic kinds of money in the world today is a belt two inches wide and 30 feet long made of glue, fibers and feathers, particularly the downy red feathers plucked from the breast, head and back of a tropical forest bird. The red-feather currency of the Santa Cruz Islands of the southwest Pacific nonetheless fits the most rigorous definition of the term "money." It serves as a means of accumulating wealth and as a universal medium of exchange in the highly diversified commerce that flows among these islands. The currency itself is fully interchangeable, each belt having a precisely negotiable value in terms of other belts. Against the recent invasion of the Australian pound, moreover, the red-feather money has kept its integrity. It is still the only acceptable specie for the purchase of brides, fine pigs and certain forms of labor.

This improbable currency demonstrates that the use of money is not an economic sophistication limited to high civilizations. Many, but by no means all, primitive peoples have devised moneys of their own. Although the forms of the currencies are as diverse as any of man's inventions—running the gamut of animal, vegetable and mineral matter in the live, raw and processed states—the maintenance of these so-called primitive monetary systems requires the balancing of the same equation of supply and demand that confronts the U.S. Treasury and the Federal Reserve System.

If a currency is to serve as a common denominator of value, its value in turn must be carefully regulated. This is one of the most delicate operations in the management of a modern state. It involves adjustment of the demand for as well as supply of money, achieved by control over both the flow and the production of the currency. To a certain extent, especially for purposes of international exchange, the Western capitalist economies still refer their currencies to the value of gold on the world market. But in the main it is the scope of the modern state's authority and the extent of its jurisdiction that effectively fix the value of its currency.

Lacking the power to regulate demand (by such devices as manipulation of the interest rate), primitive societies must rely on measures that control the supply of currency against the demand in their completely free markets. Frequently the supply is limited by natural or social circumstances beyond the control of its users, much as the scarcity of gold or silver once set the value of the dollar or the pound. Often, however, the nature of the currency is such that the society could "mint" it without limit. Scarcity is then maintained by some convention that, through consumption, destruction or deterioration, renders the currency valueless and withdraws it from circulation.

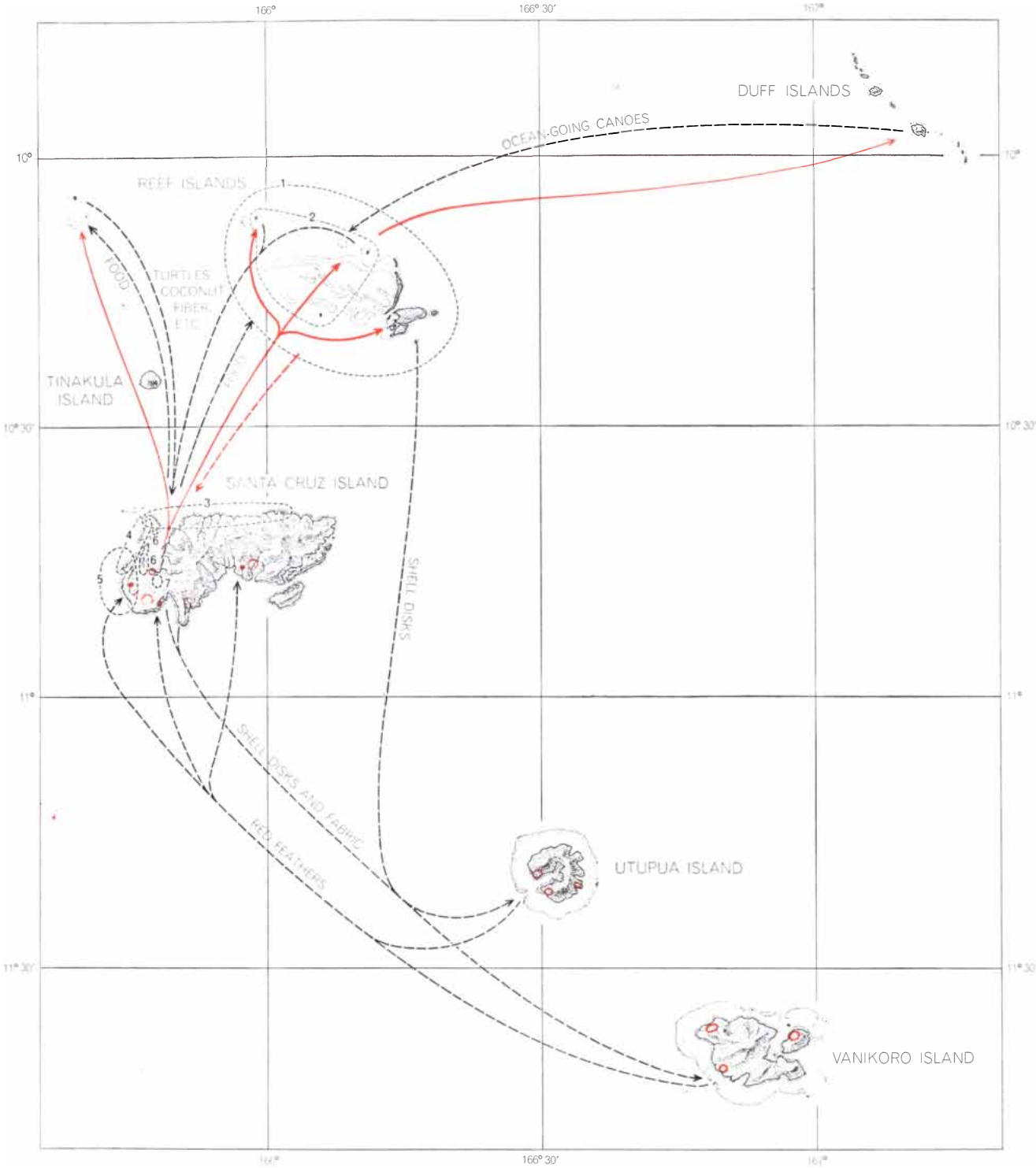
The red-feather currency system shows both principles in operation. The supply of new money is regulated by the availability of the red feathers and by the output of the hunters and artisans who make the money; old currency goes out of circulation because it loses value as its color fades. Produced by the natives of Santa Cruz Island itself, the red-feather currency circulates throughout most of the islands in the group. In these islands, where the indigenous political organization has never extended beyond a single village, it functions as international currency, the common medium of exchange among peoples who speak different languages and live in contrasting ecological settings.

The Santa Cruz Islands, part of the British Solomon Islands Protectorate, are scattered over some 15,000 square miles of the Pacific Ocean just north of the New Hebrides Islands. Santa Cruz, a volcanic island, is the largest in the group as well as its financial center. About 25 miles to the north is a chain of small coral islets called the Reef Islands, and midway between these and Santa Cruz is Tinakula, a volcano too spectacularly active for human settlement. The Duff Islands, 60 miles northeast of the Reefs, are remnant peaks of a narrow volcanic ridge. The only other large islands of the group are Utupua and Vanikoro, respectively some 40 and 60 miles south of Santa Cruz.

Partly as the result of a long history of inhospitality to visiting mariners and missionaries, the islands were left pretty much to themselves even through the first two decades of this century, when colonial powers were asserting dominion over other islands in the Pacific. It was not until 1923 that the British assumed direct administration of the islands, which they had claimed since 1899, and only since World War II has the Santa Cruz group actually been drawn into the current of world affairs. Today some 7,000 people inhabit the islands, most of them concentrated along the north coast of Santa Cruz and in the eastern Reef Islands. The people of the Duffs and the western Reefs speak a Polynesian language and are racially similar to the Polynesians of the central Pacific islands. The darker Melanesians of the eastern Reefs and Santa Cruz itself speak four local languages that constitute an independent language family. Melanesians also live on Utupua and Vanikoro, but their three languages belong to the large Malayo-Polynesian family. The cultures of Santa Cruz and the islands north of it are similar in spite of language and racial differences, and it is through this area that the red-

feather money circulates. Utupua and Vanikoro have different cultures and do not use feather currency, although their economy is closely linked to that of the red-feather islands.

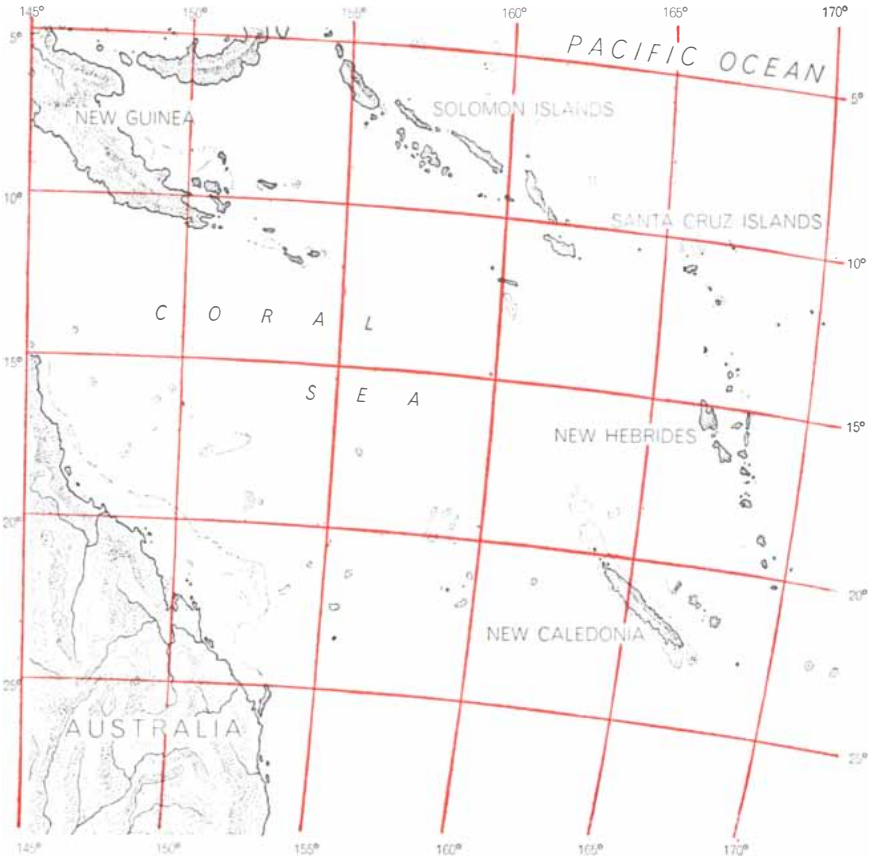
Diversity and specialization, necessitated in part by differences in geology and geography, characterize the economies of the islands. Santa Cruz, where there is plenty of arable land, exports taro root and yams, the staple vegetables of these people, to the Reef Islands, where the sandy soil will not grow good root crops. The natives of certain islands and districts with particular types of reef offshore, with lagoons or with easy access to the deep sea are exporters of fish; pigs are bred in sandy areas where coconuts for feeding are plentiful, and several kinds of arboriculture are associated with the rainfall and forest cover peculiar to other areas. But specialization goes beyond ecology. Such arts as the raising and training of hunting dogs,



ECONOMIC MAP of the Santa Cruz group shows the specialized areas of origin of some of the major agricultural and manufactured products and the complex trade pattern made feasible by the red-feather monetary system. Feather money, which is made only in

canoe building, weaving, the manufacturing of bark cloth, tools and ornaments—and currency making—are indigenous to one or another small island or to one village on an island. Each of these specialized industries and crafts is regarded by its practitioners as a right inherited in the family line, and only individuals in the proper line of succession may manufacture currency, go shark fishing, build canoes or follow any other trade.

This primitive division of labor requires in many instances that raw or semiprocessed materials be brought from one district or island to another, where the goods are finished for local consumption or for export. In the busy commerce of the interisland economy goods are rarely bartered. They are sold for currency: feather money or, increasingly, Australian currency. For all who participate the motivation of this trade goes beyond the exchange of necessities and native luxuries; the islanders buy and sell for the express purpose of making money. The accumulation of money is the way to prestige. But since the currency itself is perishable, prestige finds its tangible expression in spending as well as in accumulation, above all in helping to buy brides for members of one's family and friends and in giving feasts. Prestige won in these ways is the source of political power and authority.



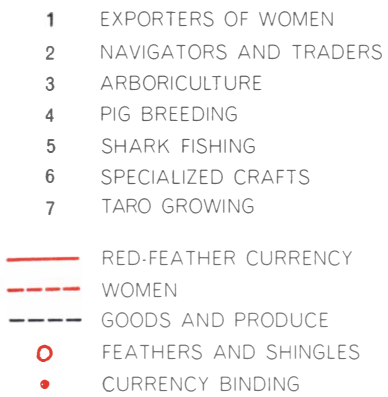
SANTA CRUZ ISLANDS are a part of the British Solomon Islands Protectorate in the southwest Pacific. They were largely untouched by outside influences until after World War II.

The red-feather currency is made only on Santa Cruz Island. It is made on contract for a specific purchaser, who negotiates individually with the three different hereditary specialists whose combined skills are required for its manufacture. The first specialist snares the little jungle bird whose down supplies the red color of the money. The second makes individual platelets of pigeon feathers and decorates each with a band of the red down. The third assembles the platelets by binding them on two cords to form a belt.

The bird on which the entire system depends is a small scarlet-colored honey eater (*Myzomela cardinalis*) of the rain forest. The bird snarer makes portable perches covered with the sticky latex of a forest tree and fastens at the top of each either a live decoy of the species or a flower that the honey eater likes. Hanging a number of these perches in adjacent trees, he shields himself behind a blind of betel palm leaves and attracts birds into the area by chirping with a whistle made from a tree bud. Investigating the flower or the decoy, the honey eaters approach the sticky perch and are caught by their wings or feet. The bird snarer plucks the red down from the birds' breasts, heads and backs; he does not deliberately kill them in the process, but they usually die as a result. In the half-shell of a coconut he packs tightly the down of 10 birds, and this is the basic unit in which he deals.

The platelet maker usually secures his own pigeon feathers, shooting the gray Pacific pigeon (*Ducula pacifica*) with bow and arrow. With a mucilage made from the sap of the paper mulberry (*Broussonetia papyrifera*), he glues the feathers together into the flexible platelet. The flat surface of a wooden platen, usually about 2¼ by 1¼ inches, serves as a gauge for fashioning each platelet in the proper size. Using the same glue, the craftsman tacks a half-inch band of red down from the honey eaters along one edge of the gray platelet. A piece of currency requires about 1,500 platelets, overlapped like shingles to expose only the band of red feathers. Since one 10-bird packet of down is enough for 50 platelets, about 300 honey eaters are required for a standard piece of new currency.

The platelets are passed on to the currency binder, who collects and prepares the other necessary materials: long-staple fibers from the bark of a rainforest tree (*Gnetum gnemon*), colored seeds for decoration and pieces of turtle shell. He stretches two three-ply fiber cords from a large stump to a springy sapling set in the ground about five feet away, and he spaces the cords about



certain districts of Santa Cruz Island, circulates there and in the Reefs and Duffs.

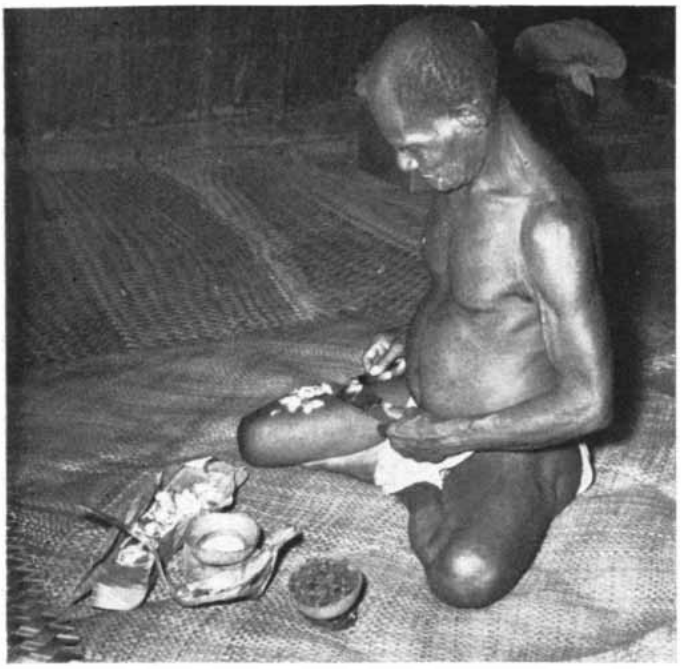
BIRD SNARER crouches by his decoy-baited perch and whistles to attract honey eaters, which are trapped by latex on the perch.

STRING OF LIVE BIRDS is brought back to the village. The red down will be plucked and then passed on to the platelet maker.

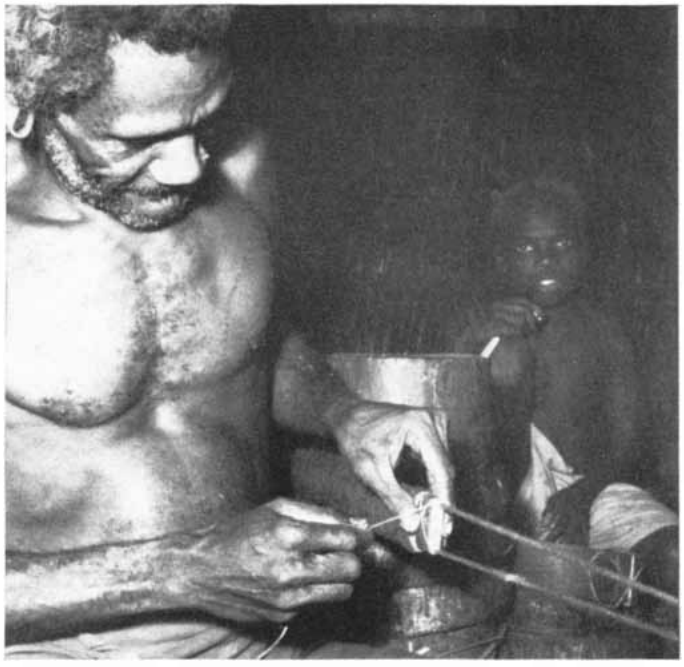
two inches apart by means of a notched spacer made from the wing bone of a fruit bat. The spacer marks the center of the belt of currency. Over it a special platelet, with a band of red in the middle instead of along one edge, is placed and bound to the cords. Working outward from the center, first toward one end and then toward the other, this craftsman proceeds to place and wrap the feather shingles one at a time. He maintains the proper distance between the cords with a sliding bat-bone spacer that he moves a quarter of an inch for each platelet [*see illustrations on page 100*]. When he has bound 750 platelets toward each end, he brings the foundation cords together, sheathes them with turtle shell and plaits them into a triangular end piece into which he works a hallmark design of his own. Finally the cords, braided together, are fastened to a bark ring. The completed belt of currency is rolled up from the ends toward

EXCHANGING CURRENCY in the men's clubhouse, the man at the left is selling the piece in the center for the two that flank it.

EXAMINING CURRENCY offered in a bride price, the bride's family considers whether it is up to standard for its denomination.



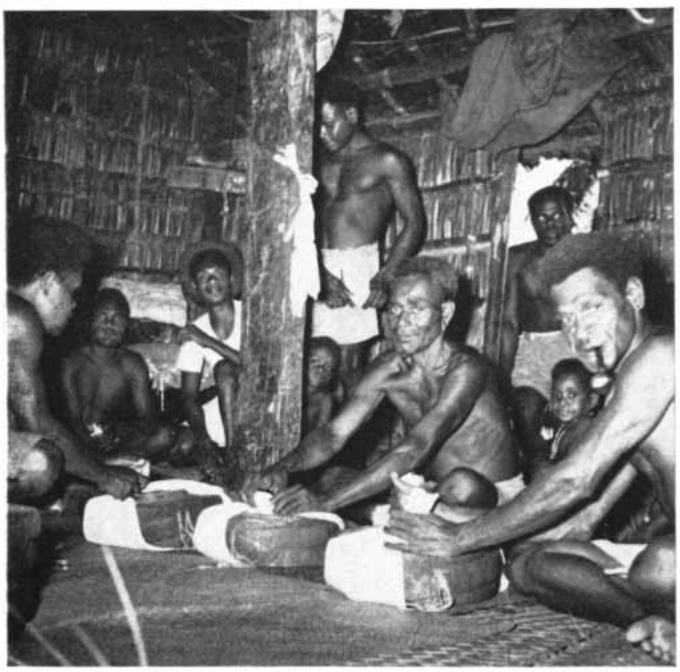
PLATELET MAKER, with pigeon feathers, glue and red down before him, fashions the individual platelets on a hand-held platen.



CURRENCY BINDER assembles the platelets, binding them with fibers to a cord foundation (*see also illustrations on next page*).

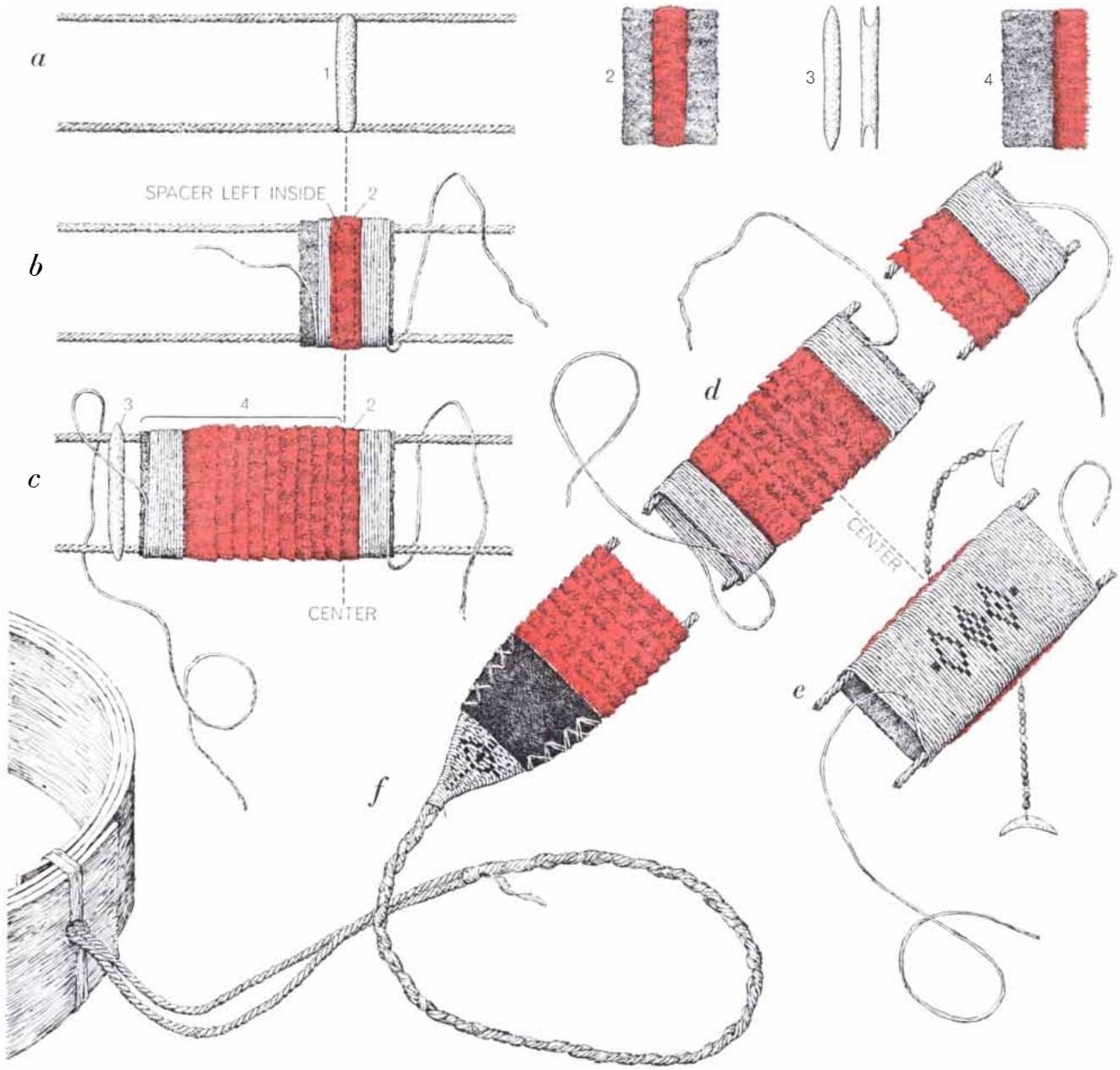
the center like a scroll, the shingling of the feathered surface resembling the scales of a snake when its spine is flexed.

All three of the skills involved in the manufacturing of feather money are believed to have been given to mortals by munificent spirits who still inhabit the island, keeping a watchful eye on the work of their protégés. None of the tasks requires exceptional skill or a lengthy apprenticeship, but the craftsman depends on secret incantations and talismans to keep in close communion with the spirits. The right to pursue a currency-making skill comes with the inheritance of these magic secrets; no unauthorized person will risk the anger of the spirits by making his own currency. Many of the islands' other specialties have their own supernatural trappings, which reinforce the restrictions imposed by heredity. No specialty is regarded as superior to any other and none, not even currency making, is likely

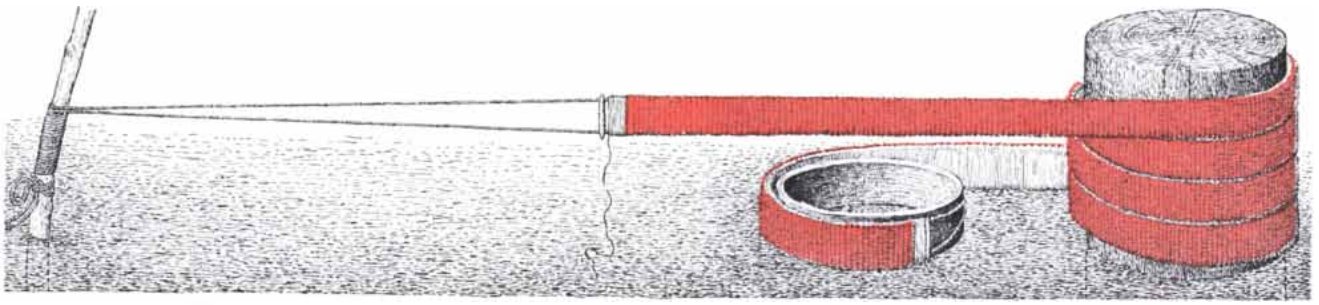


PREPARING BRIDE PRICE for delivery, the groom's family wraps each piece that has been selected in a new piece of cloth.

DELIVERING BRIDE PRICE, women parade from the groom's village to the bride's, showing off the feather currency along the way.



BINDER'S MATERIALS include (*a*) two fiber foundation cords with a bone spacer marking the center (*1*), a center platelet with red down in the middle (*2*), a movable spacer (*3*) and platelets with down along one edge (*4*). After placing the center platelet (*b*), the binder overlaps the others (*c*) one by one like shingles, maintaining the proper width with the movable spacer. He works outward from the center (*d*), which is marked with a woven design and pearl-shell pendants (*e*). At each end (*f*) he sheathes the belt with turtle shell, plaits in his hallmark, braids the two cords and attaches them to the bark cores on which the currency is wound.



FOUNDATION CORDS are stretched tightly from a tree stump to a springy sapling. The binder works on a short segment, then unties the belt and reverses it to work in the opposite direction. Each overlapping platelet covers the binding of the preceding one.

to be more lucrative than another. The specialists plying each trade compete with one another, and the hereditary lines in each occupation are sufficiently numerous and dispersed so that no individual or small group can easily obtain a monopoly or control over the market.

Feather currency has absolutely no other use than as a medium of exchange, a standard of value and a store of wealth. It is not worn or displayed. In other words, it has no inherent usefulness; it is a true money. Yet it is produced and circulated in a free market, controlled only by supply and demand and by the principle of devaluation over time. Inflation is avoided, in spite of the constant issuance of new money, by the depreciation and withdrawal from circulation of old money.

The size and richness of color of a new piece of currency determine its original value. These two criteria are reducible to the number of birds and the amount of labor that go into its manufacture. In addition to the down of 300 birds, the average piece embodies 500 or 600 man-hours of work by the three specialists. But the width and sometimes the length of a belt can vary. And the red hue can be more or less saturated depending on how much down was used or the extent to which the less admired orange feathers were discarded.

Depreciation comes with time from damage by vermin and molds as well as from the wear and tear of handling. Great care is taken to protect the currency. The double coils are wrapped tightly, first in a dried fan-palm leaf and then in many layers of bark cloth. Looking more like a bundle of rags than something of value, the coils are stored on a shelf under which the household fire is kept smoldering. The heat inhibits molds, the smoke keeps insects and other vermin away and the wrappings protect the money from smoke damage. In spite of these precautions, each piece of currency eventually deteriorates. When the last bit of color disappears, the belt is discarded.

The value of most currencies is referred ultimately to some standard; in the Santa Cruz Islands the standard is the unseemly combination of pigs and marriage payments. The minimum payment made to the bride's family by the groom's kin at marriage—the bride price—always consists of 10 units of currency graduated in value from a new or nearly perfect No. 1 ("bottom") piece to a No. 10 ("top") piece, which is just above the threshold of no value. The

negotiation of a bride price calls for a session of formalized bargaining, involving the close examination of each coil of currency. Everyone concerned has a clear idea of the range of quality appropriate to each of the 10 units. Thus the bride price supplies not only a basic standard for the value of feather money but also a scale of ideal images in terms of which the "denomination" of any piece of currency can be expressed.

The progression is not arithmetic but geometric: each piece is worth twice as much as the one below it on the scale. If a "top" piece is given an arbitrary value of one, then a No. 6 piece is worth 16 and a "bottom" piece is worth 512. These values are not explicit. No one says that a piece is "worth 128" but all understand that an ideal No. 6 belt has a par value of two No. 7 belts. In the terminology of the pig standard, the pieces from No. 1 to No. 5 are called "porkers," because a pig suitable for a feast can be bought with currencies in this range; pieces from No. 6 to No. 10 are called "sucklings," because they will buy only pigs too small to be eaten. Except for the negotiation of bride prices, there is remarkably little haggling over the price of any purchase. The buyer of a pig or canoe or taro roots offers what he considers a fair amount of currency, and the seller accepts. If the seller feels he has been underpaid, he can seriously damage the buyer's reputation by gossiping about the transaction and refusing to deal with him again.

As in the purchase of a bride, certain other purchases must be made with specified pieces of high value. The seller has no obligation to "make change," so currency is exchanged ahead of time. This can be done by anyone, but some men who are particularly adept at money changing specialize in it and make a profit. These transactions take place before an informal gathering of witnesses in the men's clubhouse of a village, where the pieces of currency are draped over a horizontal bar for close comparison. Regardless of who has initiated the deal, the piece of greatest value (the "high piece") is hung over the center of the bar. Alongside it (and always in the direction of the Nembo River, a spring-fed stream symbolically associated with the currency spirits) is hung the "base piece," the most valuable of the belts to be exchanged for the high piece. On the other side is hung the "crown piece," the piece that makes up the difference in value between the base piece and the high piece. Values are matched in terms of the 10-point scale. For example, if the high piece is an average No. 6 and the base piece is a fine No. 7, a middling No. 7 may suffice as a crown.

In this manner the par value of the high piece is agreed on. But the price at which it now actually sells is something else again. Because high-value currency is scarcer than low-value currency, the owner of the high piece is a seller in a seller's market. The buyer (the owner of the base and crown pieces) must offer additional currency. It is not only that the high piece is newer; there are fewer new pieces in circulation. Hence market value is correlated to scarcity. The greater the par value of the high piece, the greater the spread between this value and the market price. (It is as though a $10 bill were worth a little more than two fives and a $20 bill worth more than two tens by a still larger margin.) It is the difficulty and expense of obtaining high-value pieces on the exchange market that ultimately leads a man to contract with the three currency specialists for a new piece.

Since all the feather currency originates on Santa Cruz Island, it must flow continually from its source to the Reef and Duff islands, where it is not manufactured. To maintain this one-way flow of currency the Reef Islanders have traditionally exported some of their women to Santa Cruz. Today the women go only as wives but once some went as concubines. Concubines were clearly distinguished from wives: they were shared by a group of men; they did no gardening or other domestic chores; having no dwelling of their own, they lived in the men's clubhouse. On the other hand, a concubine's possessors

OCEAN-GOING CANOE, made in the Duff Islands and manned by Reef Islanders, sets out from Santa Cruz on a trading voyage. Cargo is stored in the hull and in the thatched cabin.

could purvey her services as a prostitute, sell her outright or even kill her without fear of retaliation. None of these things could be done with wives. But since the purchase price of a concubine was 10 times higher than a bride price, selling a girl into concubinage had its attractions for many Reef Island families. The British Government has forbidden the practice, but Reef Island women still go south as wives. Their bride prices are the main source of currency for their home islands. An imported wife brings extra prestige to a Santa Cruz man, and bride prices for Reef women run about twice as high as they do for domestic wives.

The Duff Islanders get their feather currency not by selling women but by building large sailing canoes that carry on interisland traffic in passengers and cargo. The men of the Duffs do not engage in that traffic themselves; they sell the canoes for feather currency to the people of a few of the western Reef Islands, who in turn specialize in voyaging and trading throughout the islands. These mariners sail even to the southern islands of Utupua and Vanikoro in search of trade. The two islands are outside the feather-currency area, but their people until recently depended on the canoes to bring them the shell disks and lengths of woven cloth they used as currency. For these precious items they traded, at fixed rates, packets of red honey eater feathers, and these were resold on Santa Cruz to the makers of feather currency. In this manner the two different money systems became interlocked and interdependent, and the economies of north and south remain so today, even though there is no longer any traffic in currency materials.

Since the end of World War II the Santa Cruz monetary system has come under pressure from the world outside. More and more Australian money has flowed into the islands; it circulates along with the feather currency and is completely interchangeable with it. Today the rate of exchange is roughly one shilling for a piece of feather money of minimum value. This makes the par value of a No. 1 piece 512 shillings, or about 25 Australian pounds. Figured in terms of labor (at the prevailing net wage rate for unskilled labor in the central Solomons, where most Santa Cruz men work at some point in their lives), the value of a new piece of currency is roughly comparable: about 20 to 24 pounds.

Plantation wages have nearly trebled since 1945. The great increase in the

quantity of Australian money within the Santa Cruz group has caused a precipitate fall in its value in terms of local goods. Once a shilling bought 10 pounds of native tobacco; now it buys half a pound. During the same period, in an effort to increase copra production by channeling more islanders into plantation work, the colonial administration has taken steps that tend to depress interisland and intervillage trade in domestic products. Less feather currency is needed and less is being produced. At the moment there are only five men on Santa Cruz who bind currency, whereas a decade ago there were more than a dozen. Yet marriages go on as before, and men still refuse to marry off their daughters without receiving the traditional red-feather payment. Indeed, there is no area of the islands' economy in which confidence in the feather currency has been shaken. The craft and agricultural specialists still demand red-feather money for their best products.

With the value of feather currency rising as it becomes scarcer and that of Australian money dropping as it becomes more abundant, the market price of feather currency in Australian pounds has increased nearly 20 times in the past 15 years. Although it is recognized that 25 Australian pounds is the appropriate par value for a new piece of feather money, it takes considerably more than that to induce the currency specialists to turn one out. This is, to be sure, not true in the case of the bird snarers. As a result of the decreased production of feather money, the *Myzomela cardinalis* population has been increasing; the snarers can take birds more easily and in more accessible places and they would be willing to work for the old rates. But the labor involved in making platelets and binding new currency has not diminished. Like skilled artisans anywhere, the specialists in these processes prefer to charge more and work less. In pricing their labor they are mindful not only of today's high market but also of the fact that the value of their product in Australian money is likely to be even greater as time passes. As a result the production of feather currency has now fallen behind even the currently reduced demand. As the "bad" Australian money drives out the "good" red-feather currency in accordance with Gresham's law, a simple society in the South Seas is experiencing a monetary crisis familiar to many more sophisticated economies.

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CATARACTS

These opaque areas in the lens of the eye result from a derangement of the metabolism of the lens. They are treated by removing the lens, but recent studies suggest the possibility of nonsurgical treatment

by Sidney Lerman

The lens of the normal eye is a precisely formed but flexible structure containing about 65 per cent water and 35 per cent organic material, chiefly proteins in solution. The water content of the lens is actually somewhat smaller than that present in most body tissues, yet the lens has a transparency that comes within a few per cent of the crystal clarity of pure water. With the passing of the years the transparency of the lens tends to decline, and among elderly people the lens of the eye is frequently marred by opacities called cataracts.

Before describing how these opacities develop and how they can be removed, let me briefly review the role the lens plays in vision. We are able to see with high acuity because the eye is able to focus objects onto one small region in the center of the retina, called the *macula lutea* (the yellow spot). The macular area includes the fovea, a region only about .5 millimeter across, where the eye has its maximum resolving power. The macula is also responsible for color vision. The remainder of the retina provides peripheral vision of low resolution as well as night vision.

To focus light rays the eye is equipped with two lenslike elements that have the power to refract, or bend, light rays. The first is the cornea, which is comparatively immobile and whose refractive power remains essentially constant throughout life. The second element is the lens proper, which has the power to change shape, or accommodate, and thereby bring into sharp focus objects that are at various distances.

The refractive power of these two elements is expressed in diopters. One diopter is defined as the refractive power of a lens that has a focal length of one meter. Since the refracting elements of the eye are able to bring light to a focus within a distance of about 1.5 centimeters, their total refractive power is approximately 65 diopters. Of this total the cornea provides some 45 diopters and the lens, in its resting state, another 20 or so. The 65 diopters of the resting state are sufficient to focus objects that are relatively distant. The light rays from such objects are more or less parallel as they reach the eye [*see top illustration on page 112*]. When objects are closer than about 20 feet, the light rays that reach the eye diverge significantly, and to bring them to a focus it is necessary for the lens to increase its refractive power. The increase is achieved by muscles located in the ciliary body of the eye [*see illustration on opposite page*]. When these muscles contract, the tension on the suspensory ligaments holding the lens is decreased. As a result the front face of the inherently elastic lens bulges forward. This change in shape can increase the refractive power by more than 50 per cent above that of the resting state. The accommodative power of the lens, however, is closely tied to age and typically decreases from a maximum of about 14 diopters in children to only one or two diopters among people who are 40 or older. The decline is due chiefly to a loss of elasticity in the lens but in part to aging of the muscles that indirectly cause the forward bulging of the lens. For this reason most people over 40 find that they need glasses for reading or close work.

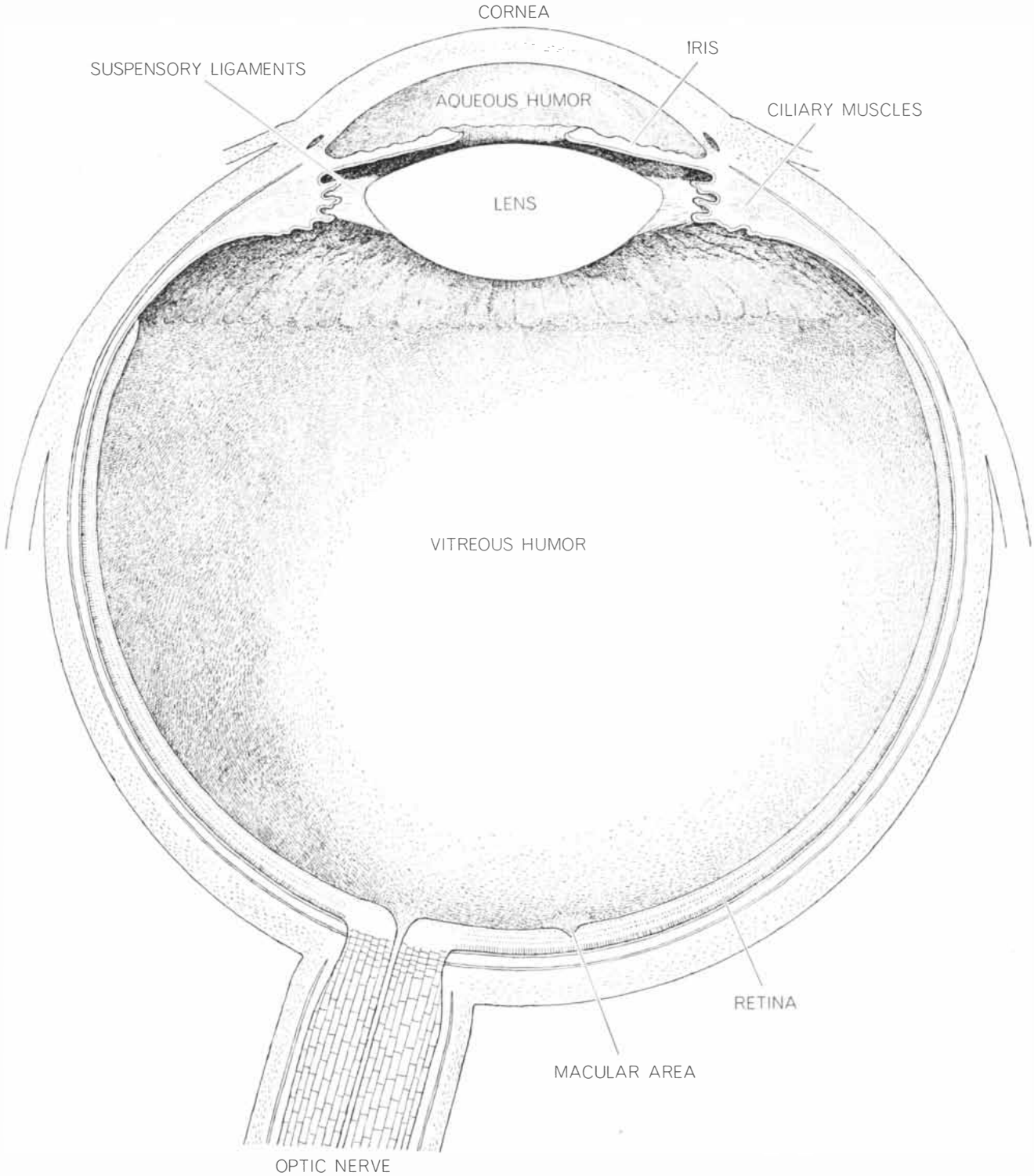
The lens of the eye is a unique structure. It has no blood supply and depends on a fluid called the aqueous humor, which lies between the lens and the cornea, to provide nutrients and remove waste products. Being transparent and directly observable, the lens is easily studied by means of a low-power binocular microscope called a slit lamp. Changes in the opacity of the lens and disease processes can be followed from their earliest stages.

The cells that produce the fibers that make up the lens originate in the epithelium at the front surface of the lens and under a capsule that encloses the whole lens. The epithelial cells are complete cells, containing nuclei and chromosomes. Those located along the equator of the lens multiply at the highest rate, and as they grow and divide they migrate toward the center of the lens. They stretch out, lose their nuclei and finally form the lens fibers. The net result of such growth is an onion-like arrangement of fibers, with the oldest in the center of the lens [*see illustration on page 108*].

By the time a person is 25 or 30 the lens develops a distinctly visible "core." The protein in the core is relatively insoluble compared with the protein in the cortical, or outer, parts of the lens. As a result the lens becomes less and less elastic as the core continues to grow. At 40 or so normal aging has produced the condition of presbyopia (farsightedness due to age). A person who has been myopic (nearsighted) as a child may find that the presbyopia has actually improved his vision. On the other hand, a person who is inclined to hyperopia (farsightedness) can expect to develop presbyopia at an earlier-than-average age. It was thought until recently that the deposition of insoluble protein in the lens was due simply to a degradation of one of the soluble lens proteins. Now there is evidence that the insoluble protein is actively, although slowly, synthesized by the lens as a specific product. There is also experimental evidence that glucose provides

energy for the metabolism of lens tissue by two biochemical pathways, and that there is a shift in the importance of the two pathways as the lens ages. In the lens, at least, the aging process seems to reflect a specific alteration in metabolism. It is too early to say whether or not the aging process observed in the lens can serve as a model for aging in other tissues and organs, but in any case the lens provides a simple and accessible structure for studying age and metabolism.

Cataracts are a frequent concomitant of aging. The word itself has a curious etymology. The earliest use of "cataract" in English was to describe either floodgates or a portcullis (a heavy iron gate), and it is this meaning that survives when the word is applied to the disease of the eye. The "gate" that descends on



SECTIONAL VIEW OF THE EYEBALL shows the position of the lens (where cataracts form) and other main structures. Both cornea and lens bend light rays and thus focus them on the retina, but only the lens can accommodate (i.e., change its focus). Contraction of ciliary muscles loosens the suspensory ligaments; this in turn enables the inherently elastic lens to assume a more spherical shape and thereby increases the degree to which it bends light rays. The macular area is the region of greatest visual acuity in the retina.

the eye can vary from a few small spots to an opaque area covering practically the whole lens and causing almost total blindness.

To describe the stage of development the clinician will characterize a cataract as incipient, immature or mature. Once it was thought wise to wait for a cataract to mature before removing the lens by surgery, but this is no longer true. Today the principal criterion for surgical removal of a cataractous lens is the amount of visual acuity the patient needs to go about his daily business. If a patient is a draftsman, for example, surgery will be recommended sooner than if his occupation is one in which vision is less critical. Much will still depend, of course, on the nature of the cataract. A large, centrally located opacity will seriously interfere with vision, whereas one of similar size located at the periphery of vision will not be so troublesome. Moreover, the nearer the opacity is to the rear of the lens, the more it will interfere with seeing.

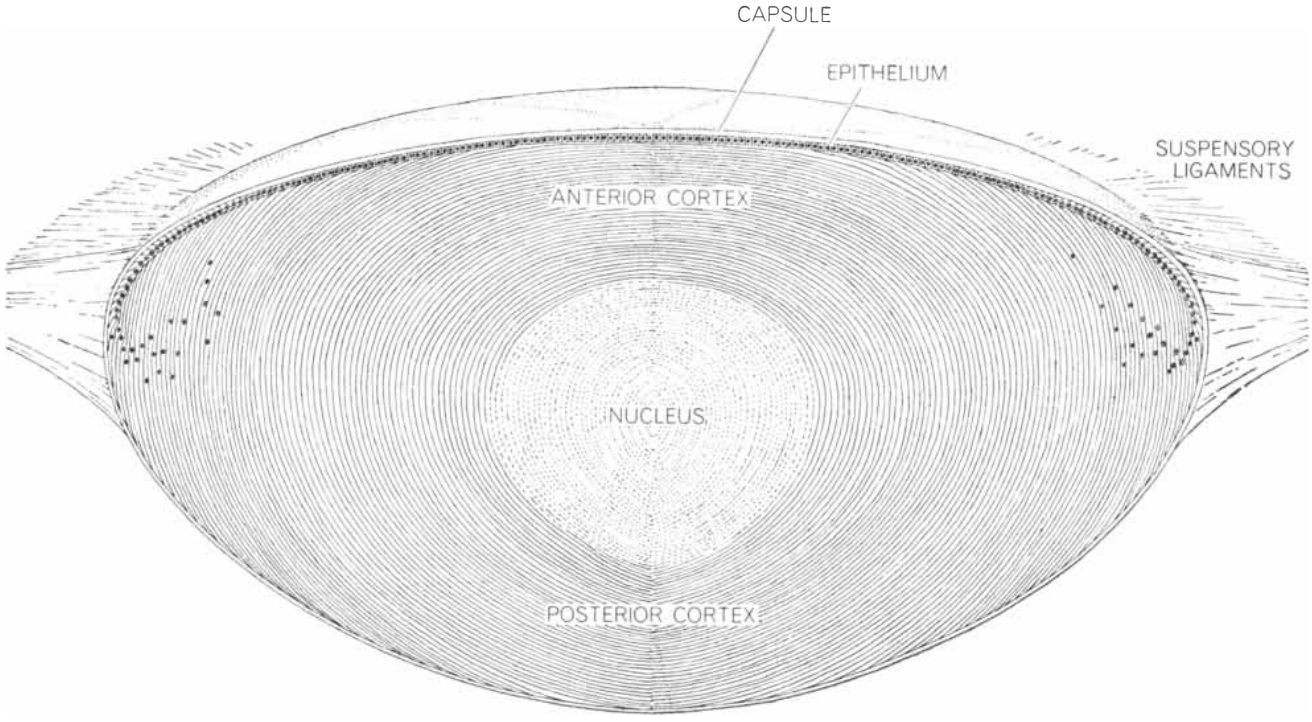
It is generally accepted that the "senile" cataract, the type of cataract associated with advanced years, is linked to the same aging process that builds up insoluble protein in the lens. In some people this process is accelerated and leads to the formation of cataracts. The material constituting the cataract, or opacity, represents a change in the physicochemical state of the normal lens protein. Just as graying of the hair or hardening of the arteries develops at different ages in different people, so cataracts appear at various ages, and many people live to 70, 80 or 90 without developing any serious amount of lens-clouding.

Perhaps the best example of the senile cataract is the nuclear cataract, which develops in the core, or nucleus, of the lens [*see illustration on page 110*]. During its development it is usually associated with a slow, progressive myopia, caused by changes in the refractive index of the lens. The change in index more than cancels the presbyopia expected from the concurrent loss of lens elasticity. It can be shown that the lens with a nuclear cataract often contains a higher concentration of insoluble protein than does an undiseased lens of the same age.

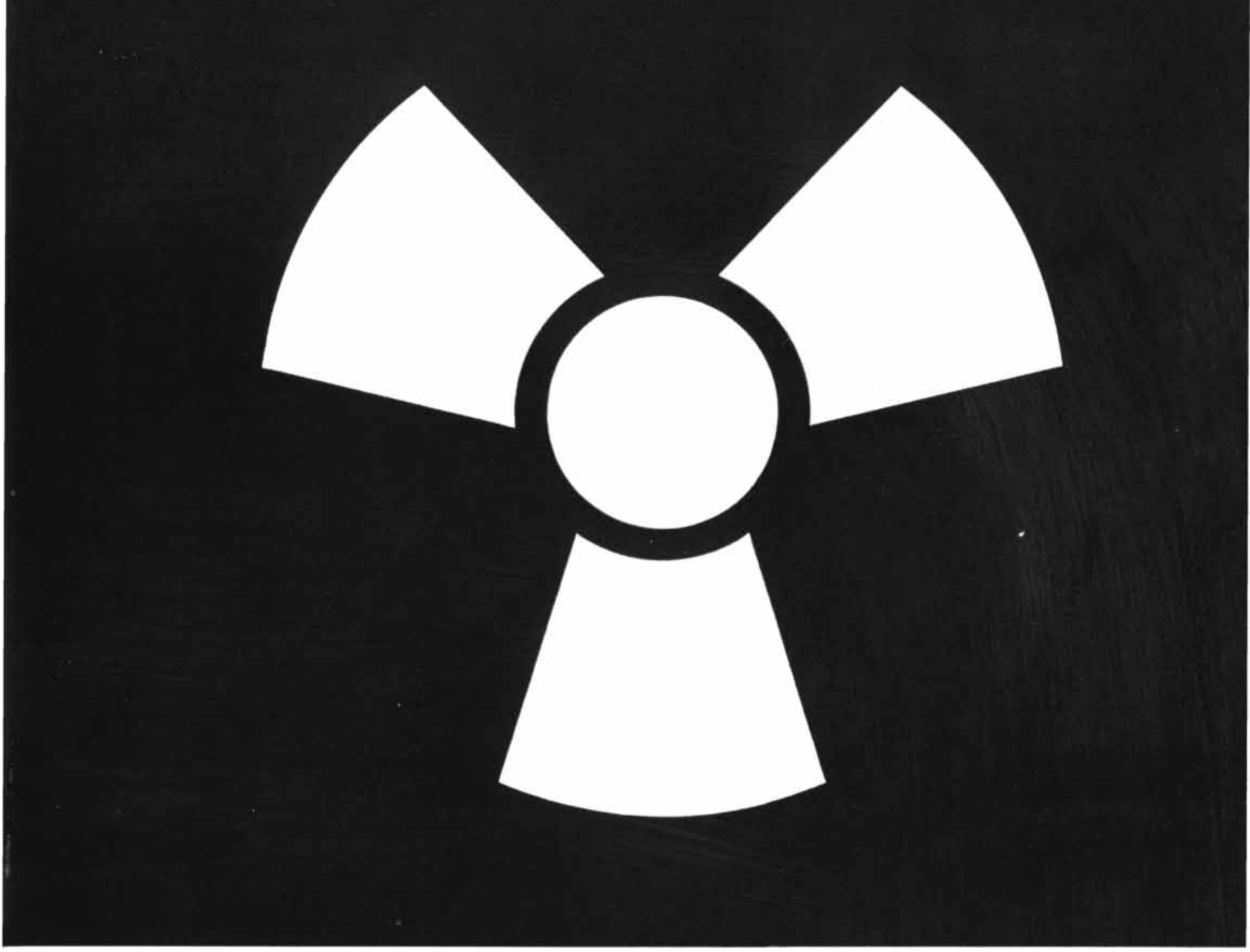
Another form of senile cataract is one in which the major degree of clouding develops in the cortex of the lens rather than in the nucleus. Since cortical changes are frequently seen in lenses of older individuals, this form of cataract is also believed to represent an acceleration of the normal aging process.

The surgical removal of a senile cataract is a fairly simple procedure. The operation is usually done under local anesthesia, and the average patient is up and about in a day or so. Numerous 90-year-old patients have taken the operation in stride. In a typical operation the surgeon gains access to the lens by making a semicircular incision just beyond the outer edge of the cornea, using the outer edge of the iris as a guide [*see drawing at top in illustration on page 114*]. Before extracting the lens he makes a small hole in the iris. Normally the aqueous humor, formed in the chamber behind the iris, flows into the chamber in front of the iris through the pupil. When the lens is removed, this passageway is often blocked by the bulging of the vitreous humor, the gelatinous fluid that fills the posterior two-thirds of the eyeball [*see drawing at bottom in illustration on page 114*]. Hence the need for a secondary passageway through the iris.

Before the lens itself can be removed, the ligaments that hold it in place must be broken. Once this was done by gentle pressure. Now surgeons often use the recently developed alpha-chymotrypsin,



CROSS SECTION OF LENS shows the onion-like layering of cells. The major germinative cells are located in the equatorial zone of the epithelium. These cells divide and grow in toward the nucleus; as they migrate they elongate, form lens fibers and lose their nuclei.



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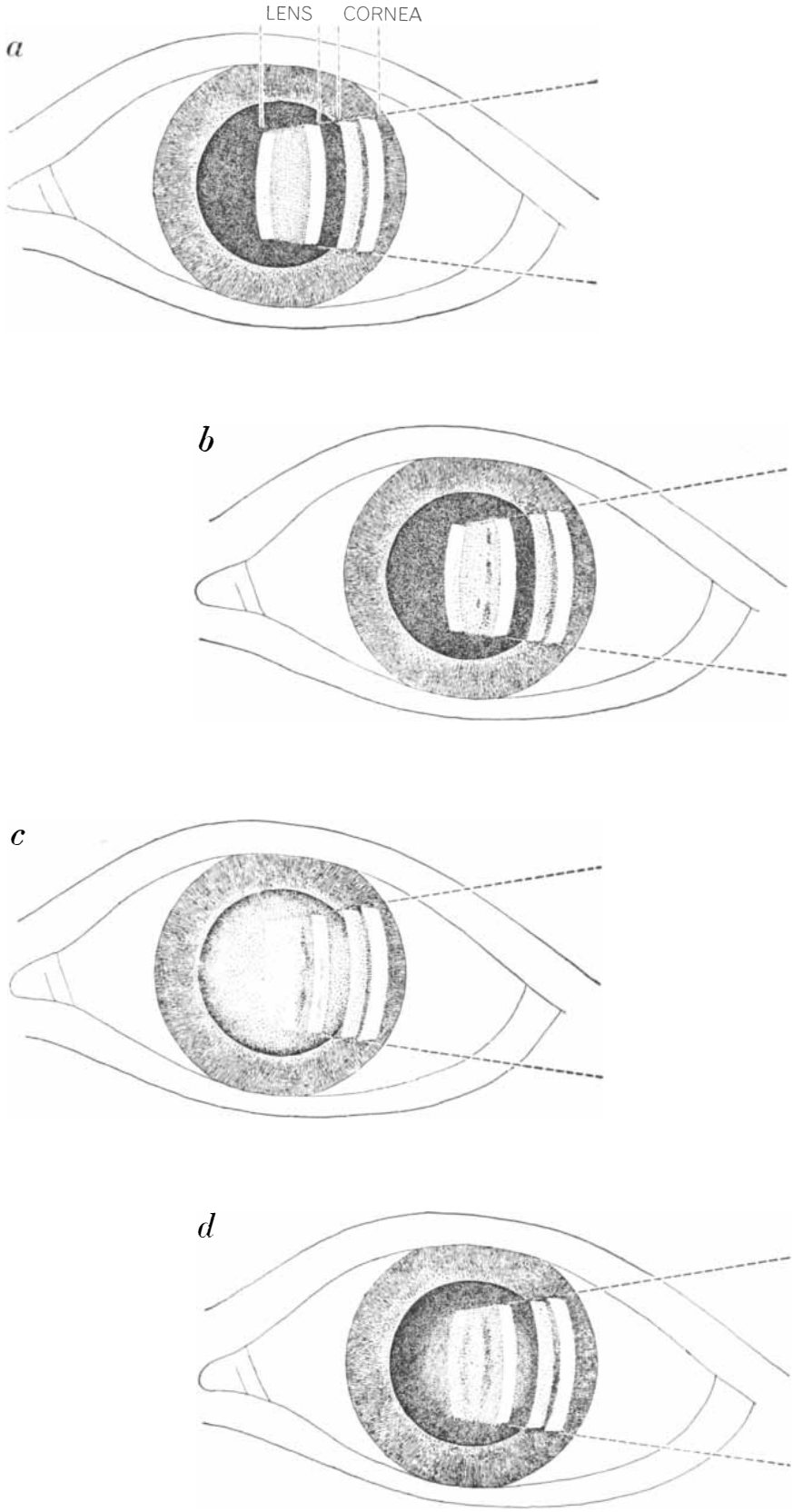
CATERPILLAR



LENS AND CATARACTS as seen through a slit lamp (a special type of low-power binocular microscope) are depicted. A beam of light (*bounded by dashed lines*) directed at an angle into the eye (*a*) illuminates thin, flat sections of the lens and cornea. The front and back surfaces of the lens appear more brightly illuminated. An incipient cortical cataract (*b*) may appear as a group of small, dark opacities near the front surface of the lens. A mature cortical cataract (*c*) obscures not only the lens but most of the pupil as well. A nuclear cataract (*d*) appears in the lens nucleus as an opacity having well-defined boundaries.

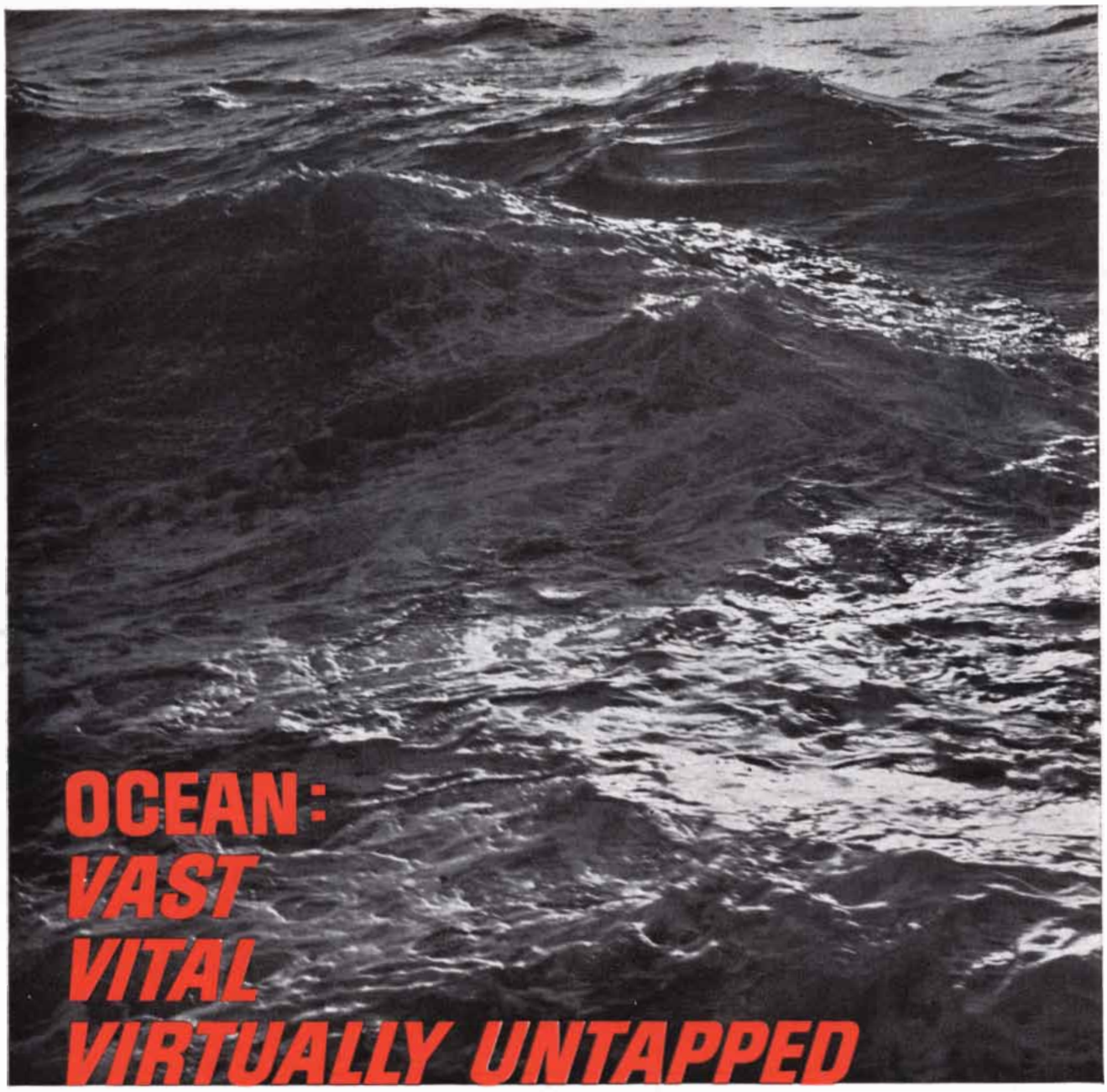
an enzyme that digests the ligaments. When the lens is free, it is carefully tumbled out of the eye. The incision in the cornea is then closed with sutures.

Four to six weeks after surgery the patient is fitted with permanent glasses. The lensless (aphakic) eye is very farsighted, and to provide adequate refraction the glasses must be quite strong (usually eight diopters or more). Furthermore, the new accessory lens, being located out in front of the eye, magnifies objects considerably. So long as the images produced by the two eyes do not differ in magnification by more than 10 per cent, the brain can usually fuse them successfully into a single image. Unfortunately a single aphakic correction (with the other eye uncorrected) will cause a great deal more than 10 per cent magnification on the corrected side; as a result the two images will not fuse. For this reason many ophthalmologists are reluctant to remove a single lens with a senile cataract, preferring to wait until a cataract develops in the second eye and justifies the removal of both lenses.

By using a contact lens, however, it is possible to correct the vision in a single aphakic eye without objectionable magnification of the image. This is because a contact lens can be placed directly on the cornea and is therefore much closer to the site of the original lens. The same result can be achieved by inserting a plastic lens directly into the eye to replace the one removed. The first plastic lens for this purpose was developed around 1940 by Frederick T. Ridley of Moorfields Eye Hospital in England. The artificial implants, however, present a number of problems and, in spite of much development, they are not altogether satisfactory.

The senile cataract is only one of many kinds of cataract. Some of the other kinds result from specific diseases, some from metabolic disorders, some from injury, some from X rays and other forms of radiation and some from causes as yet unknown. Radiation is a significant cataract hazard in laboratories and industries where workers are exposed to high-energy radiation of any kind, including both infrared and microwave radiation.

Probably the most troublesome of the nonsenile cataracts are those in the rather heterogeneous group classified as congenital. These include cataracts associated with basic defects in the developing embryo, cataracts associated with illness of mothers during pregnancy (for example, the occurrence of German



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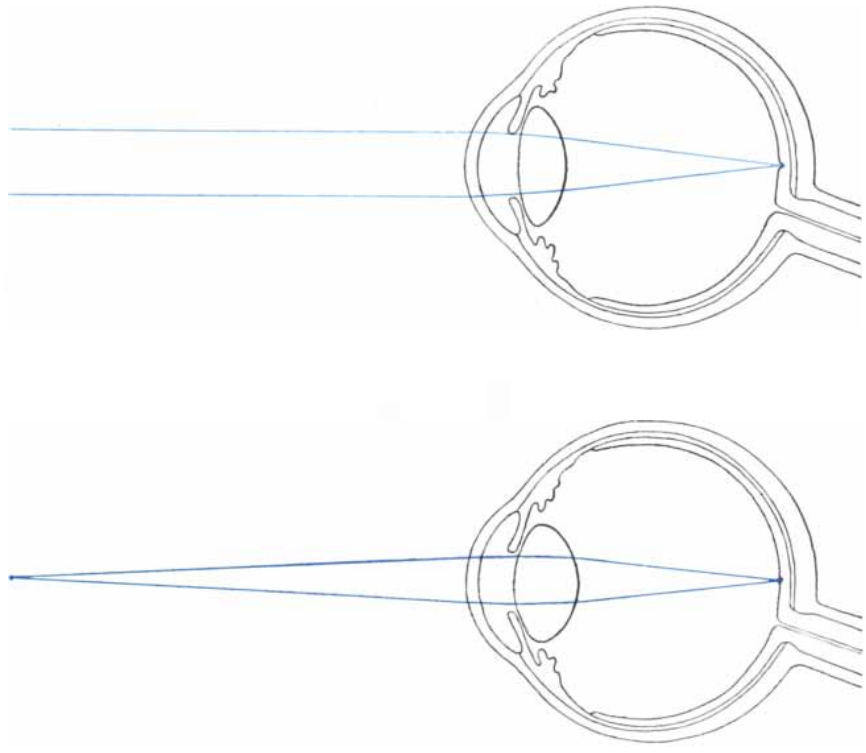
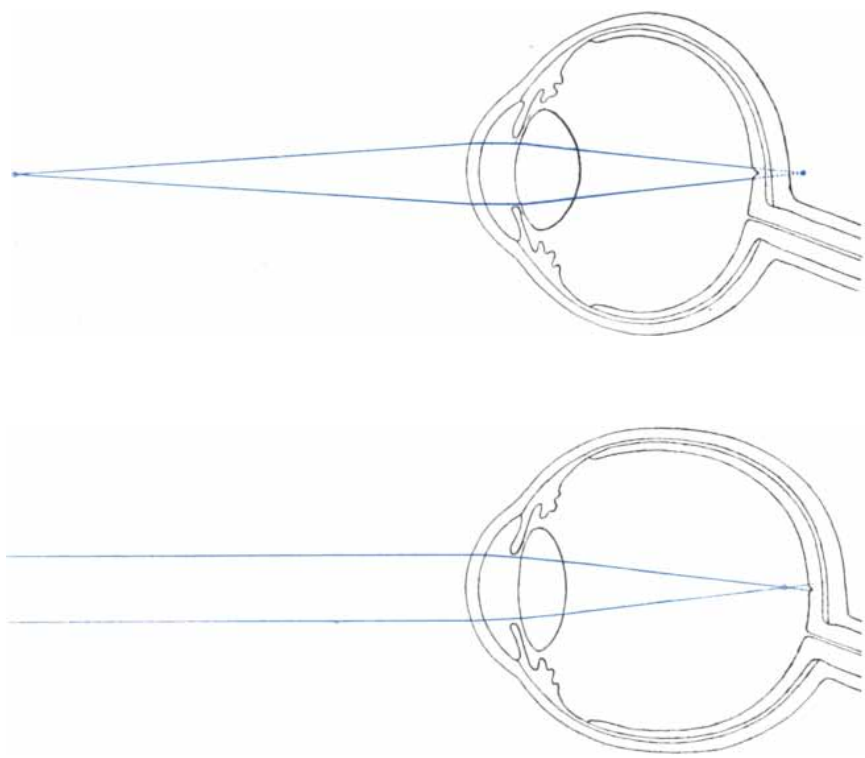


NORMAL FOCUSING of a distant object by the cornea and lens (*top*) does not require lens accommodation. Focusing of a near object (*bottom*) does; bulge in lens is exaggerated.



ABNORMAL FOCUSING results when a farsighted person is unable to accommodate for a near object (*top*). The image falls beyond the retina. When a nearsighted person tries to focus a distant object (*bottom*), just the reverse occurs: the image falls in front of the retina.

measles during the first three months of pregnancy) and cataracts associated with specific metabolic defects (such as congenital galactosemia). Congenital cataracts are particularly serious because many of the important reflexes associated with normal visual acuity and binocular vision are not fully developed until several months after birth. For example, a child born with dense cataracts in both eyes may never learn to fixate objects properly, and even if the cataracts are removed, he may always suffer from a condition known as searching nystagmus, a ceaseless jerky motion of the eyes.

Because the ligaments holding the lens are much stronger in the young eye than in the eye of the aging adult, a child's cataractous lens normally cannot be removed by the method used for a senile cataract. Instead the surgeon usually ruptures the lens capsule, removes what material he can and allows the remaining material to be dissolved and washed away by the aqueous humor. This procedure is feasible because the protein in a child's lens is almost completely water-soluble.

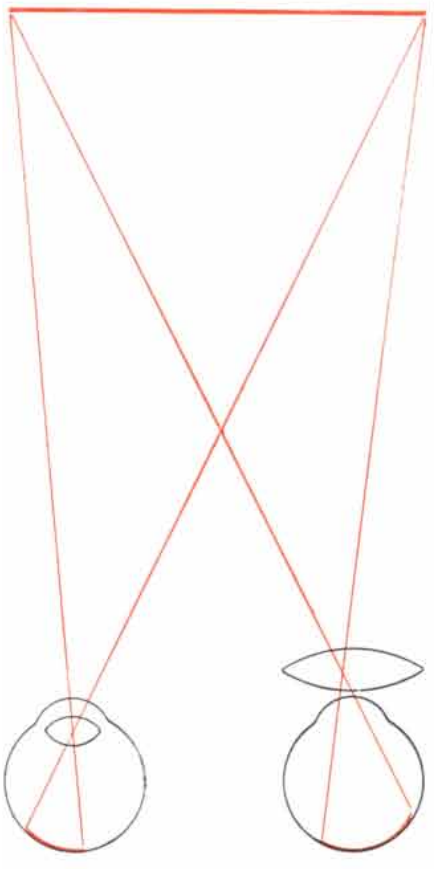
Two of the principal forms of metabolic cataract, those associated with diabetes and galactosemia, are notably open to study because they can easily be reproduced in experimental animals. It is now known that the galactosemic cataract is caused by a genetically controlled block in the formation of a single enzyme system. The enzyme is responsible for the proper utilization of galactose by the body. Since galactose constitutes half of the sugar present in milk, babies born with galactosemia may die unless milk is promptly eliminated from their diet. One symptom of this disease is the early appearance of a cataract, which results from an accumulation of galactose in the lens. When galactose is eliminated from the diet, the cataract does not form.

By contrast, diabetes is a much more puzzling disease than galactosemia in that its effects appear to be much more varied and far-reaching. Although an elevation in the level of sugar in the blood is a common symptom of diabetes, the disease probably involves a generalized derangement of many metabolic processes. The study of diabetic cataracts in animals may lead not only to a method for preventing the cataract itself but also to a better understanding of all aspects of the disease.

The white rat, which is an excellent experimental animal for the study of diabetes or galactosemia, is also useful

for observing cataracts produced by radiation. It is now known that the lens of the eye is one of the most sensitive of all body tissues or organs to ionizing radiation. The lens is easily damaged by electromagnetic radiation having a wavelength either shorter or longer than visible light. It is also damaged by electrons, neutrons and other forms of corpuscular radiation. It seems probable that the same sequence of biochemical events underlies most, if not all, forms of radiation cataract.

Preliminary results of animal experiments indicate that one aspect of radiation damage is an acceleration of the aging process. Biochemical studies suggest that radiation can produce harmful alterations in the giant molecule of deoxyribonucleic acid (DNA), responsible for the transmission of hereditary characteristics, and in the related molecule of ribonucleic acid (RNA), which plays a major role in the synthesis of all body proteins. Fairly large con-

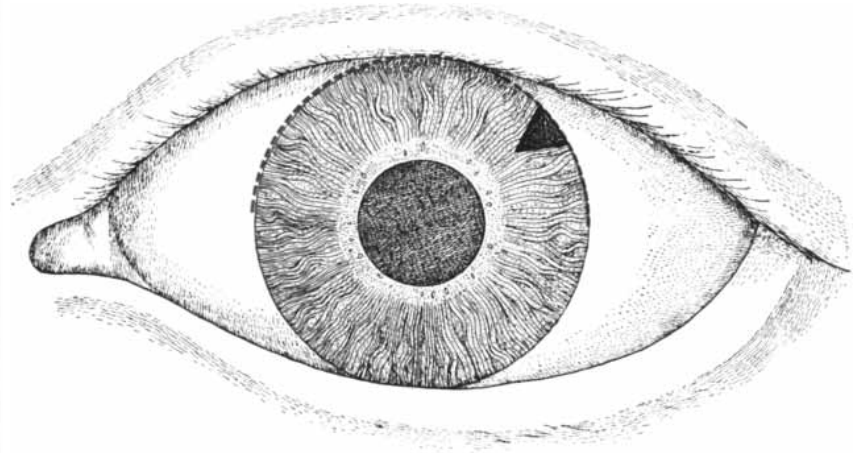


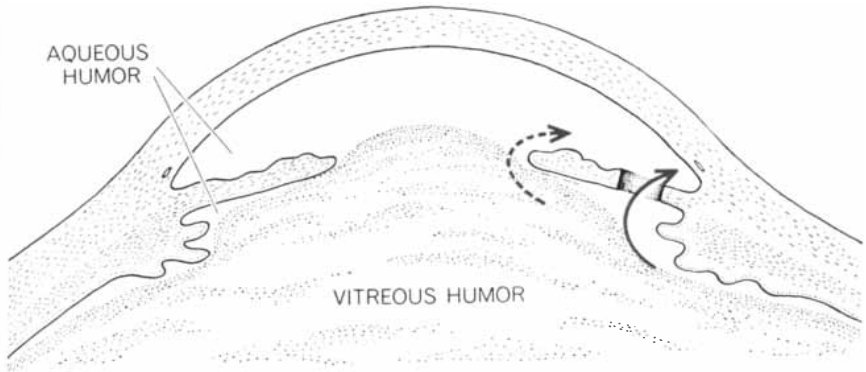
APHAKIC (LENSLESS) EYE equipped with an accessory lens (*right*) magnifies an object much more than does a normal eye (*left*). If the difference in size between the two retinal images is greater than 10 per cent, the brain cannot fuse the two images.

centrations of RNA are found to be associated with the albuminoid, or insoluble, protein in the lens. Results of experiments in our laboratory at Strong Memorial Hospital of the University of Rochester indicate that X rays alter the activity of this albuminoid RNA. Following radiation we find that amino acids, which are the building blocks of proteins, are incorporated at an increased rate in the albuminoid protein fraction of the lens. Since the concentration of this material in the lens is a good index of aging, these experiments suggest that one effect of ionizing radiation is to accelerate the aging process.

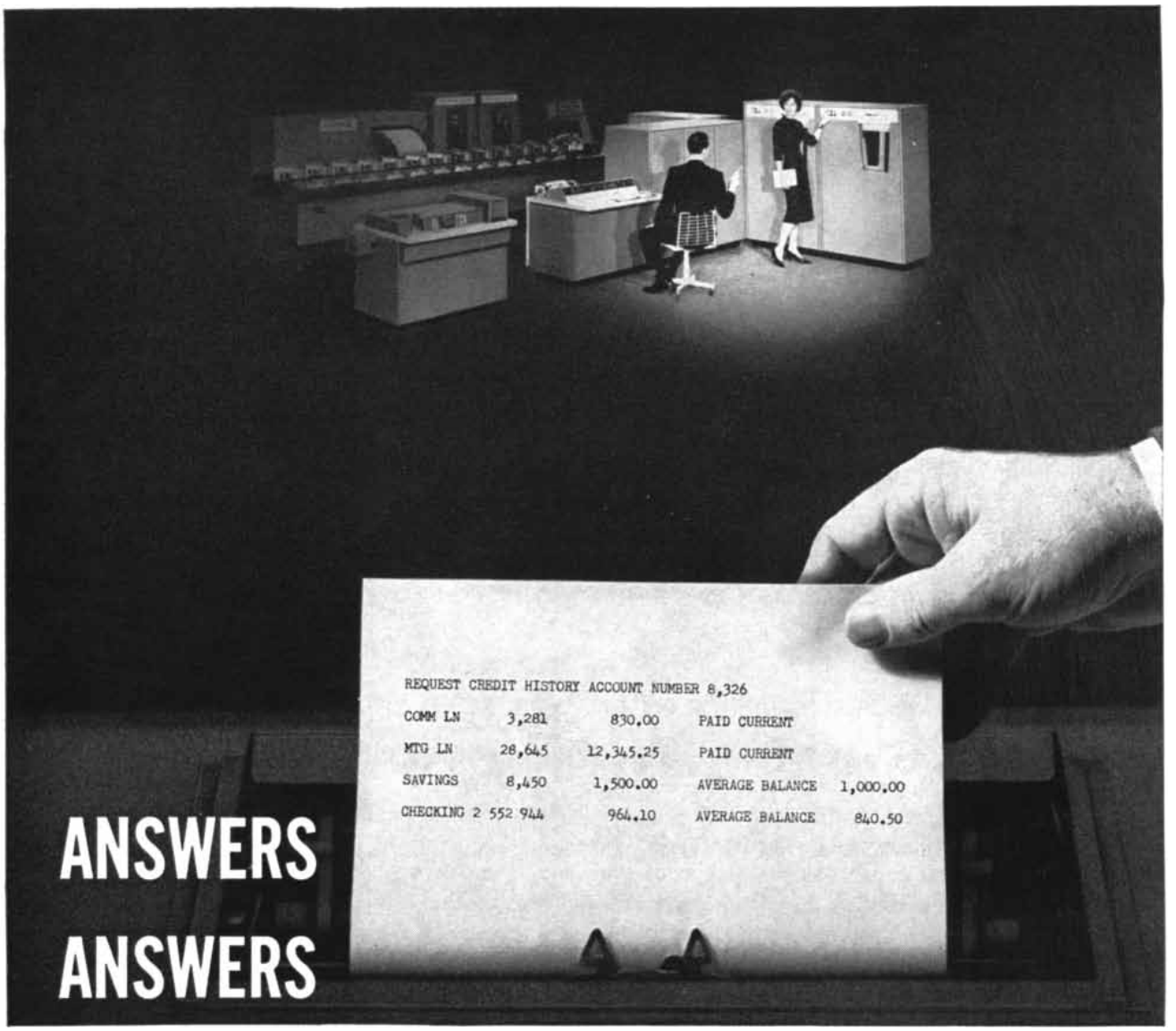
A recent observation by the Soviet investigator T. A. Sicharulidze may prove to be of value in studying some forms of cataract formation. He reported that he was able to obtain regeneration of an adult rabbit lens by removing most of the lens matter and transplanting a certain type of embryonic tissue into the lens. This method may prove to be very useful in studying the chemistry and physiology of the growing lens. Furthermore, most cataract-producing agents are much more effective in the rapidly growing lens; the method may therefore serve as a valuable laboratory tool for producing changes in the lens.

Out of such research one can expect that a medical therapy, probably preventive, will eventually be developed for the typical senile cataract and for certain other types of cataract as well. Until then the surgical removal of the cloudy lens remains a simple and effective procedure.





CATARACT OPERATION is performed by first making a semicircular incision near the edge of the cornea (*broken line in drawing at top*). Then a small hole is cut in the iris before the lens is removed. This provides an alternative path (*solid arrow in drawing at bottom*) for aqueous humor to flow into chamber in front of the iris. Normal path (*broken arrow*) is often blocked by tendency of vitreous humor to bulge forward into front chamber.



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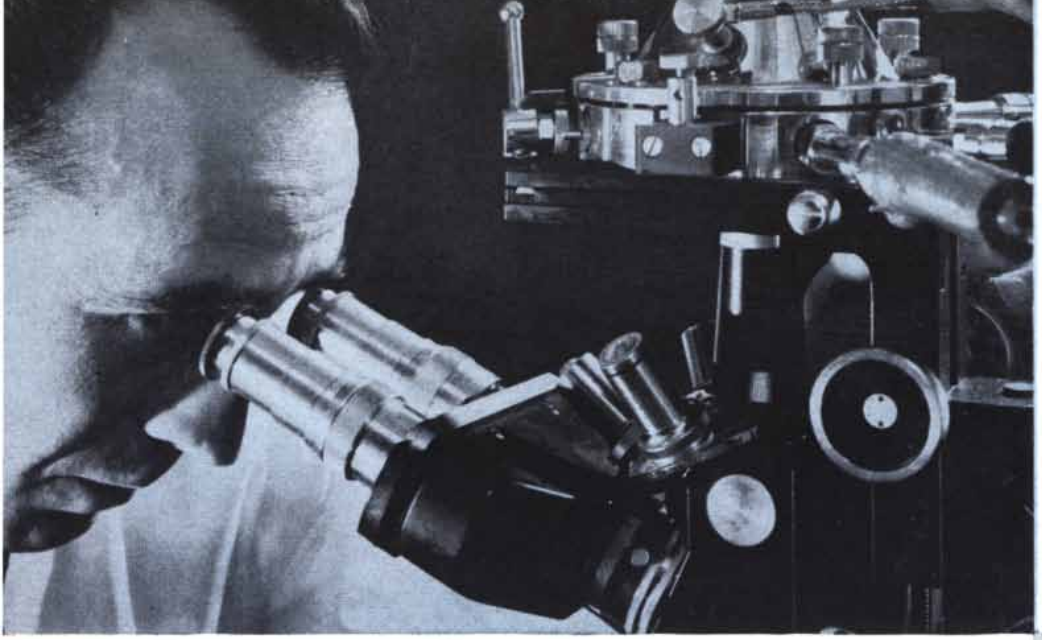

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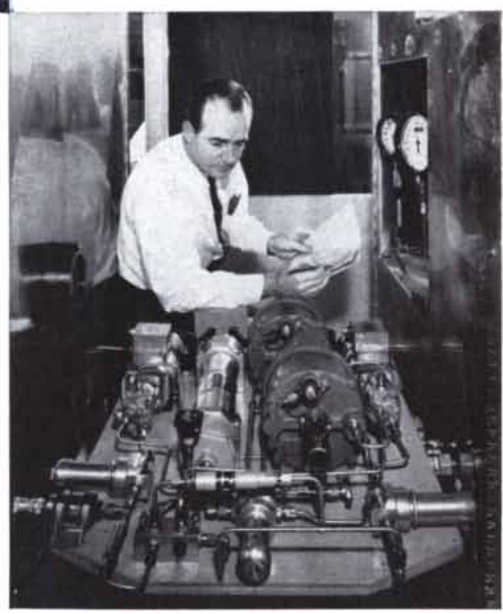

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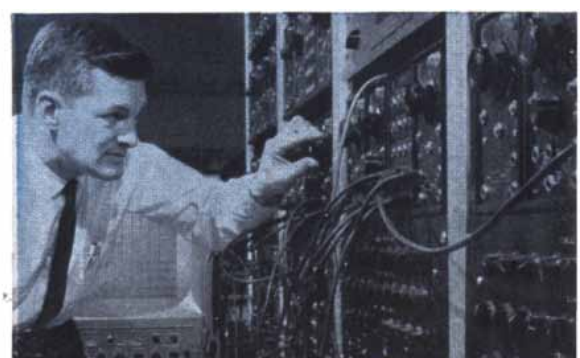

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The Smallest Living Cells

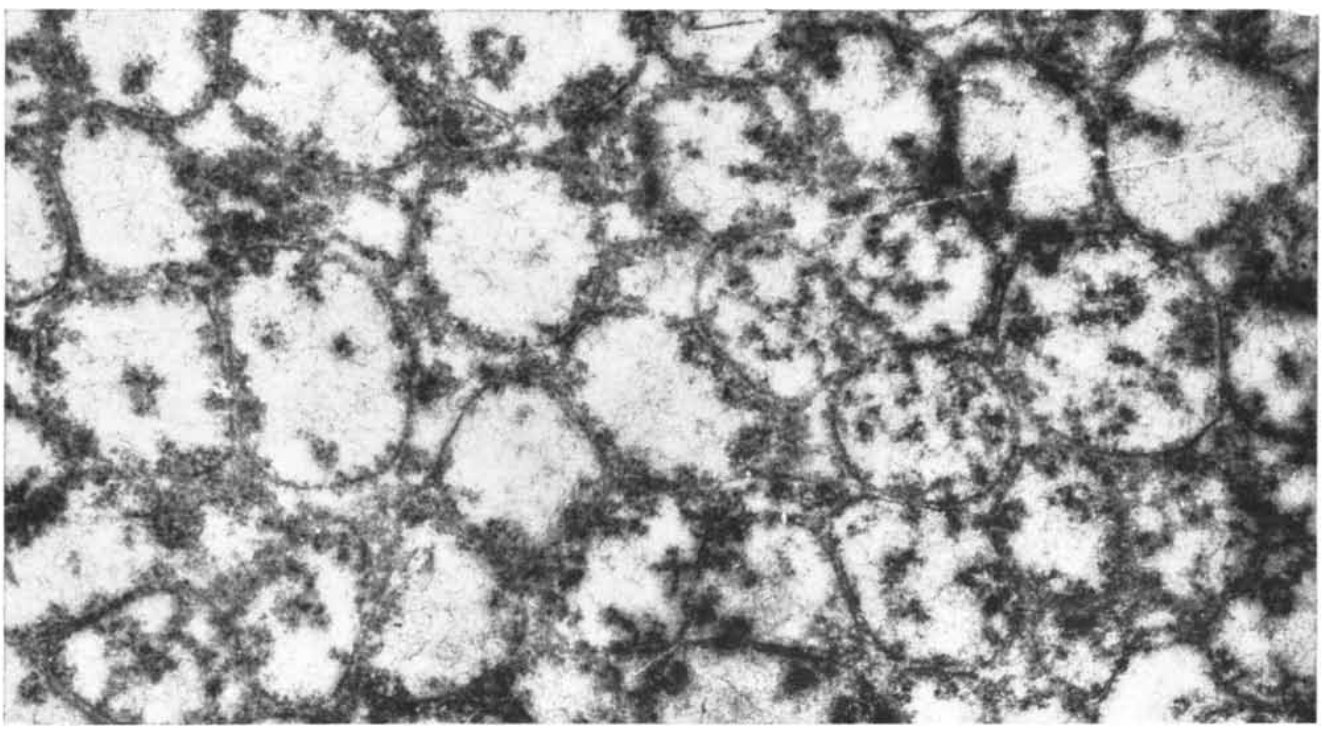
A microbe known as the pleuropneumonia-like organism gives rise to free-living cells smaller than some viruses. They suggest the question: What are the smallest dimensions compatible with life?

by Harold J. Morowitz and Mark E. Tourtellotte

What is the smallest free-living organism? The most likely candidate for this niche in the order of nature was discovered by Louis Pasteur when he recognized that bovine pleuropneumonia, a highly contagious disease of cattle, must be caused by a microbial agent. But Pasteur was unable to isolate the microbe: he could not grow it in nutrient broth nor could he see it under the microscope. Apparently it was too small to be seen.

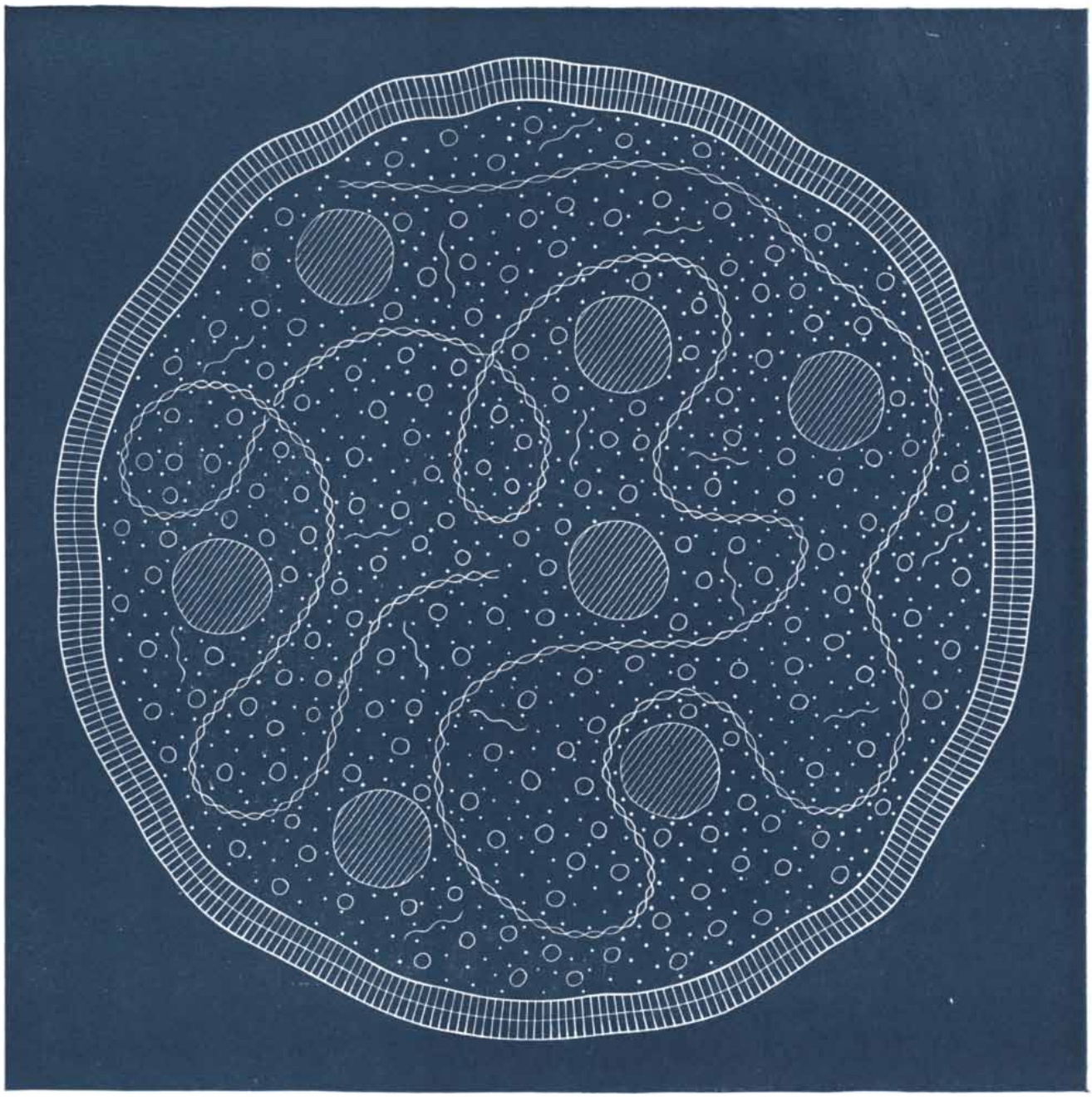
Then, in 1892, the Russian investigator D. Iwanowsky succeeded in demonstrating that certain infectious agents were so small that they could pass easily through the porcelain filters used to trap bacteria. The size of the microbes postulated by Pasteur was comparable to that of Iwanowsky's organisms, which were subsequently named viruses. All viruses, however, are parasites of the living cell. The pleuropneumonia agent, on the other hand, is not. In 1898 Pasteur's successors E. I. E. Nocard and P. P. E. Roux were able to grow the pleuropneumonia agent in a complex, but cell-free, medium. In this respect the agent seemed more like a bacterium than a virus. In 1931 W. J. Elford of the National Institute for Medical Research in London, who developed the first filters in which pore size could be precisely determined, showed that cultures of the pleuropneumonia agent contained viable particles only .125 to .150 micron (.0000125 to .000015 centimeter) in diameter. Thus the particles were smaller than many viruses. Yet, as subsequent investigations have shown, the particles fully satisfy the definition "free-living": they have the ability to take molecules out of a nonliving medium and to give rise to two or more replicas of themselves.

More than 30 strains of this tiny organism have now been isolated from soil and sewage, as contaminants from tissue cultures and from a number of animals,



CELLS OF PLEUROPNEUMONIA-LIKE ORGANISM, abbreviated PPLO, are seen in cross section in this electron micrograph made by Woutera van Iterson of the University of Amsterdam. The cells, which are enlarged 72,000 diameters, are not the smallest PPLO's that have been observed. Nevertheless, they are only about 50 per cent larger than the vaccinia virus. Unlike the virus, however, these cells and smaller PPLO's meet a biologist's criterion for life: they are able to grow and reproduce in a medium free of other cells.

including man. In veterinary medicine one or another of them has been identified as the cause of a respiratory disease in poultry, of a type of arthritis in swine and of an udder infection in sheep. Although a pleuropneumonia organism was implicated in cases of human urethritis (inflammation of the urethra), it was not until January of this year that one of them was positively identified as an agent of disease in man. Robert M. Chanock and Michael F. Barile of the National Institutes of Health and Leonard Hayflick of the Wistar Institute of Anatomy and Biology then published their finding that an organism called the Eaton agent, first isolated in 1944, is actually a member of the pleuropneumonia group and is the cause of a common type of pneumonia. Because these organisms pass through filters (like viruses) and grow in nonliving media (like bacteria) they are considered by some workers to be a bridge between these two large classes of organism, and because they show obvious differences from both bacteria and viruses they have been accorded the status of a separate and distinct order: *Mycoplasmatales*. Because of their similarity to the original pleuropneumonia

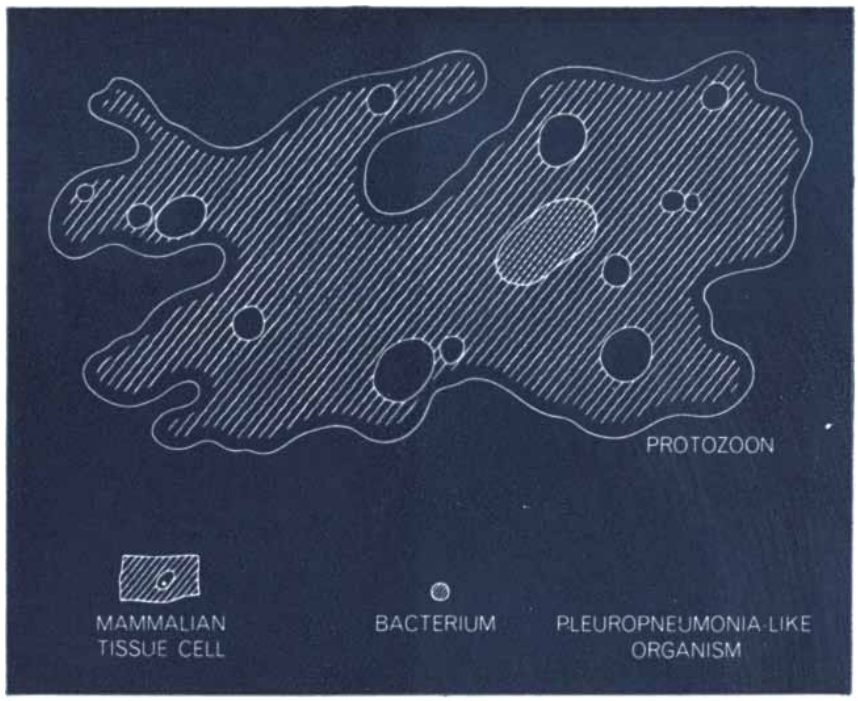


SCHEMATIC REPRESENTATION of a single cell of a PPLO is based on the authors' chemical analysis of *Mycoplasma gallisepticum*, which causes a respiratory disease in poultry. Deoxyribonucleic acid (DNA) and ribonucleic acid (RNA), found both in the ribosomes and in soluble particles, constitute 12 per cent of the total weight of the cell. The soluble proteins are similar to those in larger cells. The delicate cell membrane is composed of successive layers of protein, lipid, lipid and protein.

organism they are usually referred to as pleuropneumonia-like organisms, abbreviated to PPLO.

Although some very small bacteria are smaller than the larger PPLO, none is as small as the smaller PPLO: .1 micron (.00001 centimeter) in diameter. This is a tenth the size of the average bacterium; it is only a hundredth the size of a mammalian tissue cell and a thousandth the size of a protozoon such as an amoeba. But as the British mathematical biologist D'Arcy Wentworth Thompson observed some years ago, a major factor in any comparison of living things is mass, and mass varies as the cube of linear dimension. By such reckoning a protozoon is a billion times heavier than a PPLO. This vast gap in size gains vividness in the mind's eye from the reckoning that a laboratory rat is about a billion times heavier than a protozoon. A protozoon weighs .0000005 gram; a PPLO weighs a billionth as much: 5×10^{-16} gram.

In terms of linear dimensions the smallest PPLO is as close in size to an atom as it is to a 100-micron protozoon. A hydrogen atom measures one angstrom unit (.0001 micron) in diameter; a PPLO cell .1 micron in diameter is only 1,000 times larger. The existence of such a small cell raises intimate questions about the relationship of molecular physics to biology. Does a living system only a few orders of magnitude larger than atomic dimensions possess sufficient molecular equipment to carry on the full range of biochemical activity found in the life processes of larger cells? Or does the minuscule amount of molecular information it can carry compel it to operate in a simpler way? What biological or physical factors place a lower limit on the size of living cells?



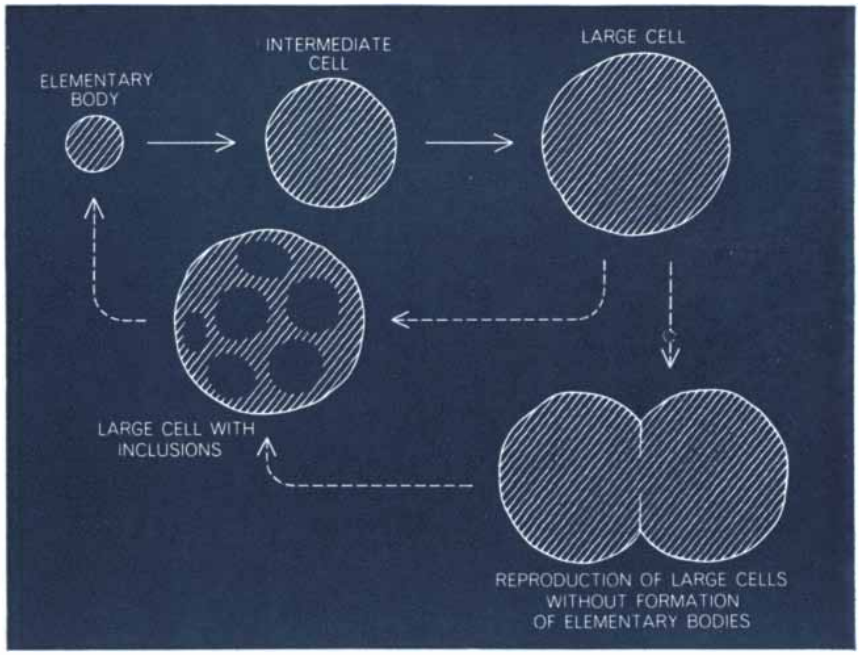
SIZES OF VARIOUS CELLS are compared. A protozoon, with a diameter of .01 centimeter, is 10 times bigger than a tissue cell, 100 times bigger than a bacterium and 1,000 times bigger than the smallest PPLO, with a diameter of .1 micron, or .00001 centimeter.

In our laboratory at Yale University we have cultured 10 distinct strains of PPLO, clearly distinguished from one another by their metabolic behavior and by the antibody responses they produce in rabbits. Our work so far has been concentrated primarily on two of these strains: *Mycoplasma laidlawii,* a strain that is normally free-living in nature, and *Mycoplasma gallisepticum,* which causes chronic respiratory disease in poultry. In the first, which contains the smallest cells we have thus far studied, we have been able to follow the life cycle. In the second we have been able to determine details of chemical composition and structure.

At many stages in its life cycle the individual PPLO cell is too small to be seen in the light microscope. In the electron microscope, however, we have been able to examine at least four different types of cell in *M. laidlawii.* One, called an elementary body, is a small sphere between .1 and .2 micron in diameter. A second is somewhat larger than this. A third is still larger: up to a full micron in diameter, about the size of a bacterium. A fourth type, which is of similar size, contains inclusions that are about the size of elementary bodies. In addition to observing the cell sizes directly, we measured them by forcing the cultures through filters with pores of various sizes and then examining in the electron microscope the material that had gone through the filters [*see illustration on page 124*]. To determine the size of the smallest PPLO cells we calibrated our filters by performing filtrations on two viruses of known size: the influenza virus, which is .08 to .1 micron in diameter, and the vaccinia virus, which is .22 by .26 micron in size. The smallest PPLO cells lie between these two; they are larger than the influenza virus but smaller than the vaccinia virus.

To separate the smallest cells of the strain from the others we had to employ the method of density-gradient centrifugation [*see bottom illustration on next two pages*]. This technique derives its effectiveness from the fact that cells as small as the PPLO vary in density as well as in size as they go through their life cycle. The density at each phase depends on the changing chemical composition of the cell and closely approximates the mean of the densities of its constituents. Salt solutions of different concentration are layered in a centrifuge tube, and the cell culture is added at the top. When the tube is inserted in the centrifuge and spun at high speed, cells of various sizes settle in the layer of salt solution that has a density equal to their own. Centrifuging a 72-hour culture of *M. laidlawii* in solutions that varied in density from 1.2 to 1.4 (the density of water is 1.0) revealed three bands. Examination of these bands in the electron microscope showed the bottom band contained large cells; the top band, elementary bodies; and the middle band, cells of intermediate size and large cells with inclusions.

Starting with elementary bodies thus isolated from a culture, we have been able to follow a culture of *M. laidlawii* through its life cycle. Our method is to sample the culture at periodic intervals and inspect the samples in the electron microscope. Young cultures—about 24 hours old—are primarily composed of large cells. Cultures about six days old, on the other hand, are predominantly elementary bodies. Samples

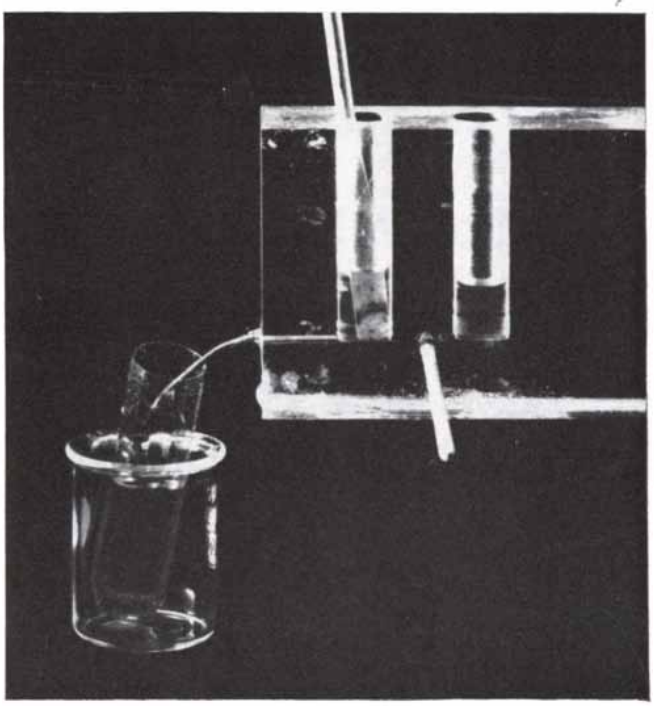


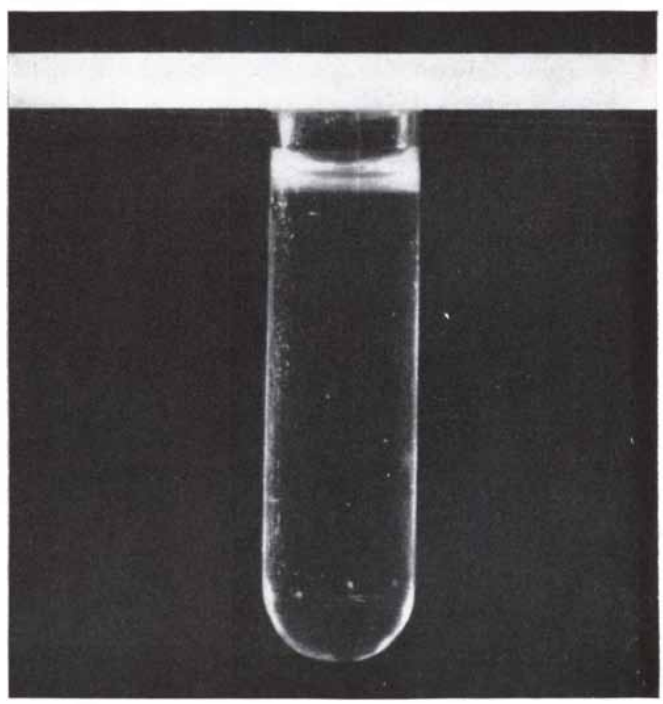
LIFE CYCLE of the PPLO *Mycoplasma laidlawii* is outlined. Elementary bodies grow to intermediate cells and then large ones. The large cells may divide, some developing inclusions released as elementary bodies, or may develop and release inclusions directly.

FOUR TYPES OF CELL in the PPLO *M. laidlawii* are seen in these electron micrographs. First micrograph (*far left*)

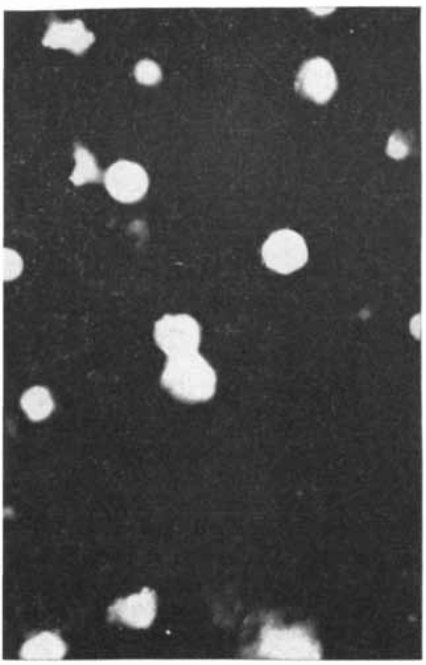
taken over the course of the five-day interval suggest that this strain has two methods of reproduction. In both cases the organism goes through a cycle in which elementary bodies are transformed first into intermediate cells, then into large cells and then back into elementary bodies again. Differences in composition between young and old cultures show, however, that the organism can probably adopt one of two courses once it has reached the large cell stage. In one cycle the large cells develop inclusions, which are apparently released as elementary bodies. In the second the large cells seem to reproduce by binary fission. Thereafter it appears that some of them form inclusions from which new elementary bodies are liberated. In either case the new elementary bodies begin the life cycle all over again.

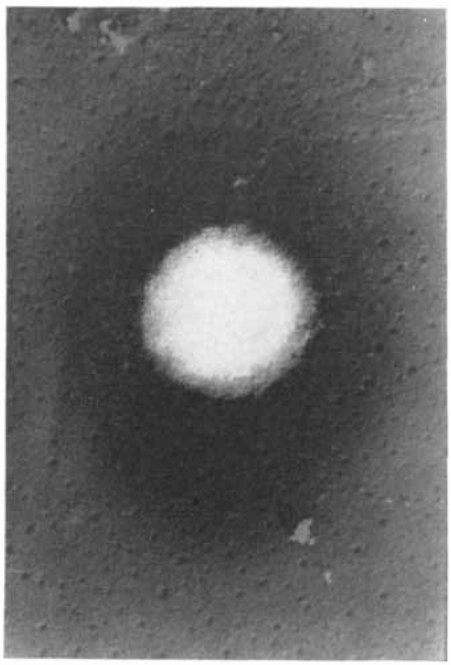
We have not so far been able to establish the mode of reproduction in *M. gallisepticum*. None of our cultures has





SEPARATION OF PPLO CELLS BY SIZE AND TYPE is achieved by density-gradient centrifugation. This method can be used because small cells have different densities at different times in their life cycle. In photograph at far left two densities of salt solution are layered in a centrifuge tube. In the second photograph a PPLO culture has been added at the top of the tube. In the third photograph the

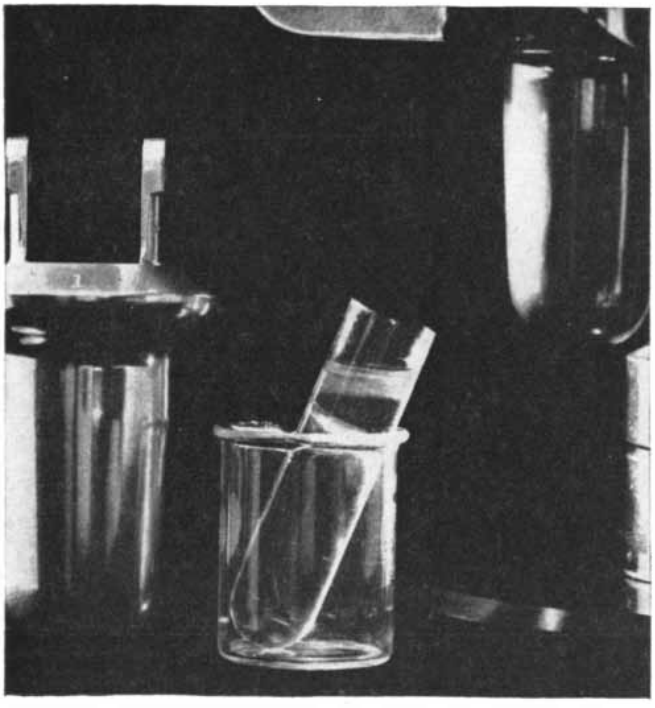


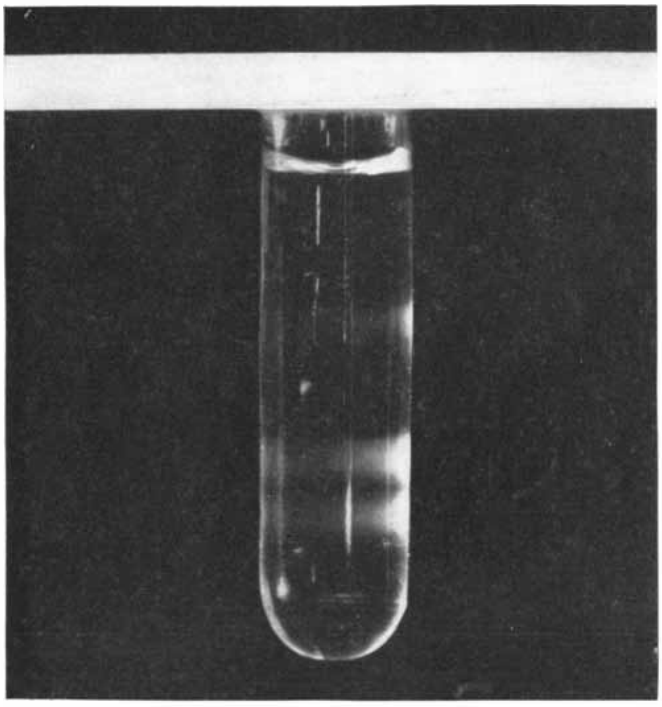


shows elementary bodies about .1 micron in diameter. The second shows intermediate cells. The third shows large cells about 1 micron in diameter, and fourth shows large cells that have developed inclusions. The inclusions may be released as elementary bodies to begin the life cycle again. All the micrographs, which enlarge the cells 17,750 diameters, were made by the authors.

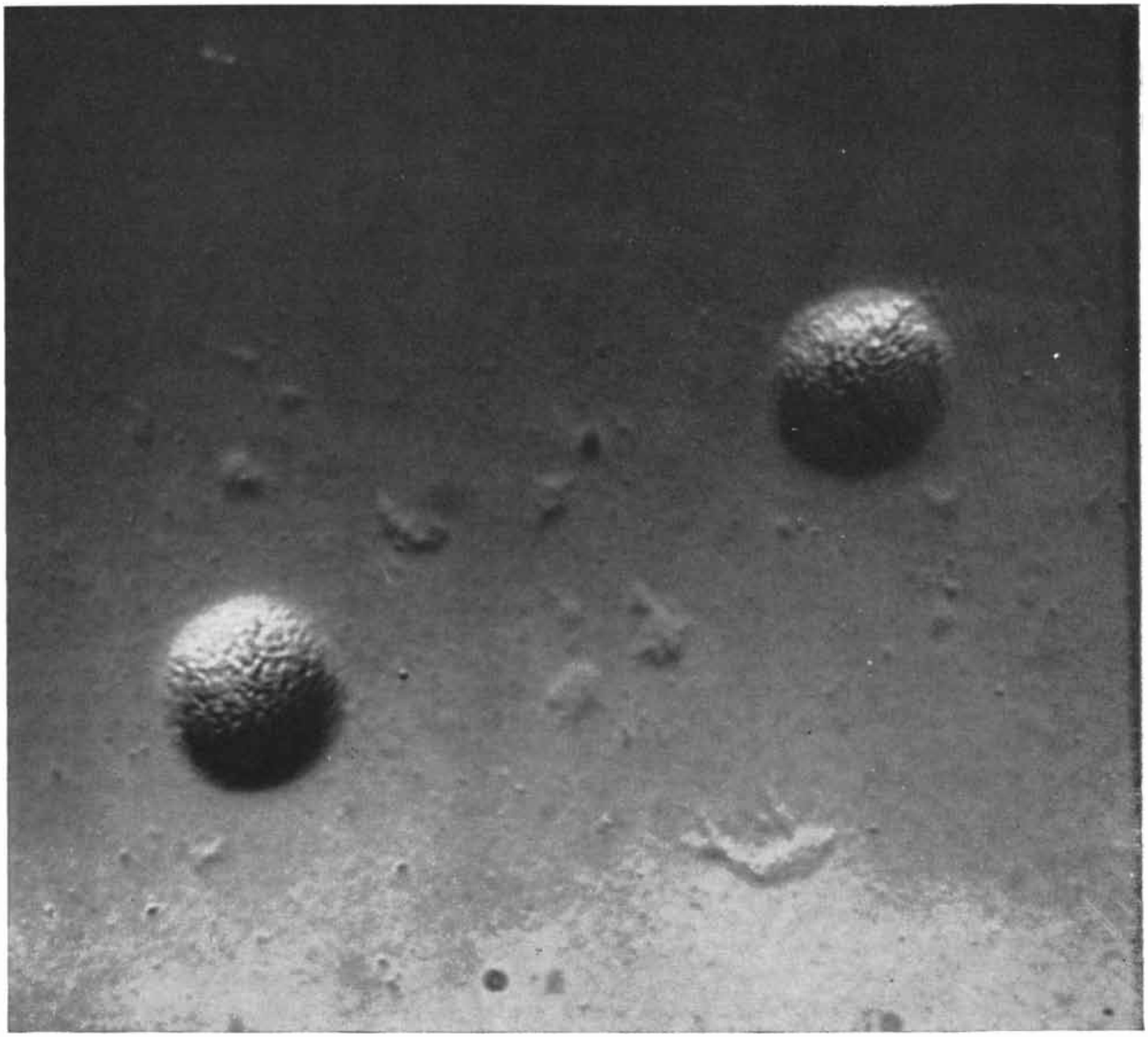
revealed either elementary bodies or large cells. All the cells we have seen appear uniformly spherical and all appear to be about .25 micron in diameter [*see illustration on page 118*]. Our work with *M. gallisepticum* has helped, however, to settle the question of whether or not these tiny organisms conduct the same biochemical processes as larger cells.

Chemical analysis shows that the *M. gallisepticum* cell has the full complement of molecular machinery. In the first place, the nonaqueous substance of the cell contains 4 per cent deoxyribonucleic acid (DNA) and 8 per cent ribonucleic acid (RNA). These large molecules have been identified in larger cells as the bearers of the genetic information that governs the synthesis of the other components of a cell. Moreover, we find that in the tiny cells the composition of these molecules, the so-called base ratios, falls within the normal range. The DNA ap-



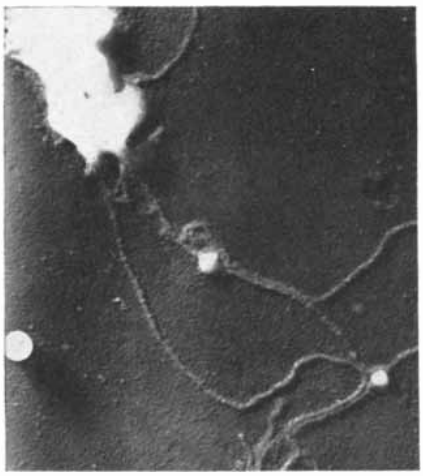


tube is ready to be placed in a container (*left*) and fastened to a rotor, part of which is seen at right. The rotor is then placed in a centrifuge. The last photograph shows the tube after centrifugation. The PPLO's have settled in three bands. The bottom band contains large cells; the middle band, intermediate cells and large cells with inclusions; the top band, elementary bodies.



COLONIES OF THE EATON AGENT, now known to be a PPLO, are seen at a magnification of 600 diameters in this light micrograph. Discovery that the Eaton agent causes a type of pneumonia in man is the first proof that a PPLO can produce human disease.

PPLO CELLS from a rat strain are contrasted in size with a .26-micron sphere. The large cell seen at the center contains inclusions.



FILAMENTS are observed in many strains of PPLO. The cells shown here are the same strain as those in micrograph at left.

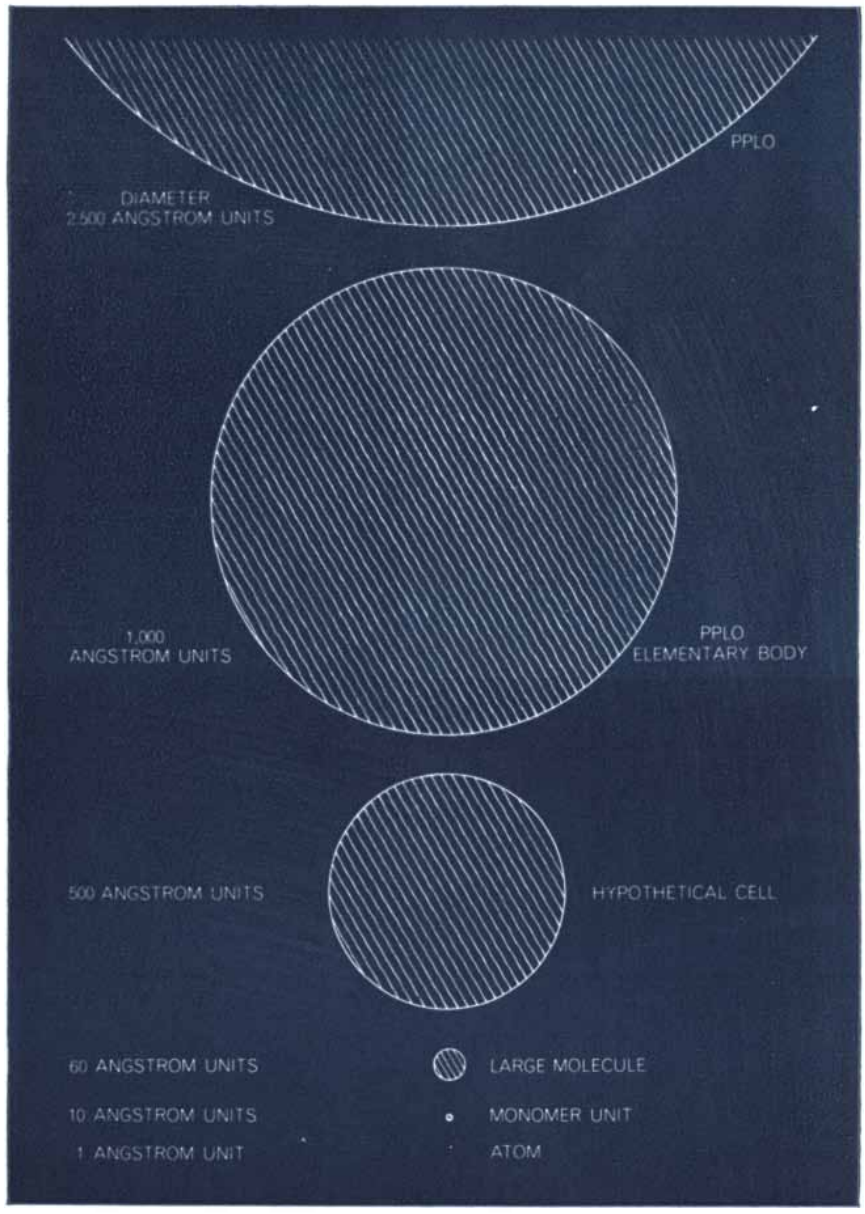
HUMAN PPLO is seen in this electron micrograph. All three micrographs, magnified 16,000 diameters, were made by the authors.

pears as the familiar double-stranded helix found in the chromosomes of larger cells, and most of the RNA appears to be in the form of particles resembling ribosomes, the organelles that are believed to conduct protein synthesis in larger cells. The soluble proteins in the cell seem to have the usual range of size and variety, and the amino acid units of which they are composed occur in the expected ratios.

In several respects this PPLO cell appears to resemble animal cells more than it does plant cells or bacteria. The composition of its fatty substances, including cholesterol and cholesterol esters as an essential element, is characteristic of animal cells. More important, it has no rigid cell wall but has instead a flexible membrane that, in other strains of PPLO, permits the cells to assume a great variety of shapes. In spite of its delicacy the PPLO membrane is able to fulfill the functions of a cell membrane. It effectively distinguishes the cell from its environment and it is firm enough to contain the cell's internal structures in a coherent way. Indirect measurement of its electrical properties shows that they fall within the normal range. At a sufficiently high magnification the membrane can be seen in the electron microscope. It measures about 100 angstrom units (.01 micron) in thickness, which is typical of many animal cells.

Thus far we have been able to demonstrate more than 40 different enzymatic functions in *M. gallisepticum*. These include the entire system of enzymes necessary for the metabolism of glucose to pyruvic acid, one of the processes by which cells extract energy from their nutrients. Therefore the evidence points to a considerable biochemical complexity in these organisms. In spite of their size they seem to compare in structure and function with other known cells.

The demonstration that these tiny cells are indeed free-living compels a further question: Can there be other cells, even smaller than the PPLO and as yet undiscovered, that possess the capabilities for growth and reproduction in a cell-free medium? The mere detection of such cells presents a challenge to the ingenuity and technical resources of the biologist. If the cells happen to be pathogens, they might be discovered by the diseases they produced. If they are harmless to other forms of life, they might put in a visible appearance by causing turbidity in a culture medium through mass growth, or they might



	NUMBER OF ATOMS IN DRY PORTION OF CELL	MOLECULAR WEIGHT OF DNA (DNA = 4 PER CENT OF CELL CONTENT)	NUMBER OF MONOMER UNITS (AMINO ACIDS AND NUCLEOTIDES)	NUMBER OF LARGE MOLECULES
PLEUROPNEUMONIA-LIKE ORGANISM (DIAMETER: 2,500 ANGSTROM UNITS)	187,500,000	45,000,000	9,375,000	18,750
PLEUROPNEUMONIA-LIKE ORGANISM ELEMENTARY BODY (DIAMETER: 1,000 ANGSTROM UNITS)	12,000,000	2,880,000	600,000	1,200
HYPOTHETICAL CELL (DIAMETER: 500 ANGSTROM UNITS)	1,500,000	360,000	75,000	150

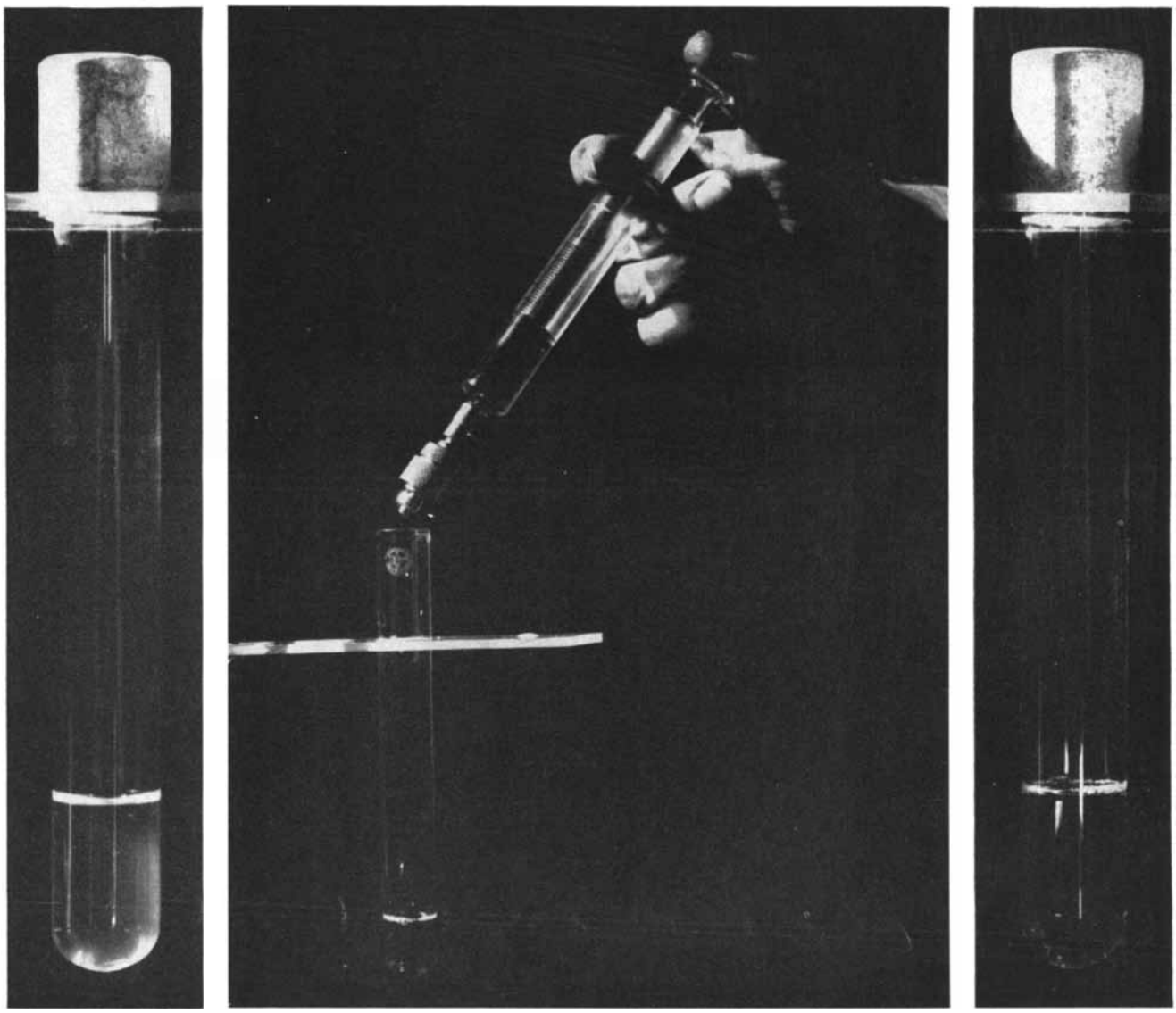
PPLO CELLS AND ATOMS can be shown on the same scale; a PPLO elementary body is only 1,000 times larger than a hydrogen atom. Table shows number of atoms, molecular weight of DNA, number of monomer units (the repeating units of a large molecule) and number of large molecules anticipated in PPLO cells and in smallest theoretical cell.

show up in electron microscope preparations. A very small cell, however, might escape detection by any of these methods. If the population it formed grew to a concentration of only 100,000 cells per cubic centimeter of the growth medium, the chances of finding it would be slight. There is no assurance that the proper growth medium could be found to culture such cells. It may well be, therefore, that the PPLO is not the smallest living cell.

Yet there are lower limits, in theory at least, to the size of a living organism. Biological considerations suggest one such limit. A cell must have a membrane, if only to provide coherence for its structure. Since all cell membranes so far studied appear to be on the order of 100 angstrom units (.01 micron) in thickness, it would seem that no cell could exist that had a diameter less than 200 to 300 angstrom units (.02 to .03 micron), or about a tenth the diameter of the *M. gallisepticum* cell. Biochemistry suggests that the smallest cell would have to be somewhat larger in size. The complexity of function necessary to growth and reproduction indicates that the minimal organism must be equipped to conduct at least 100 enzymatically catalyzed reactions. If each reaction were mediated by a single enzyme molecule, the molecules would require a sphere 400 angstrom units in diameter to encompass them and the raw materials on which they operate.

Biophysics suggests another limit to the smallest size. In his little book *What Is Life?* the physicist Erwin Schrödinger pointed out that a cell has to survive against the ceaseless internal deterioration caused by the random thermal motion of its constituent molecules. In a very small cell even small motions are large in proportion to the entire system, and small motions are statistically more likely to occur than large ones. With only one or at most a few molecules of each essential kind present in the smallest conceivable cell, the most minute dislocation might be enough to disable the cell.

The foregoing reasoning seems to set 500 angstrom units as the minimum diameter of a living cell. A cell of this size would have, in its nonaqueous substance, about 1.5 million atoms. Combined in groups of about 20 each, these atoms would form 75,000 amino acids and nucleotides, the building blocks from which the large molecules of the cell's metabolic and reproductive apparatus would be composed. Since these large molecules each incorporate about



FILTRATION of a PPLO culture requires filters calibrated for viruses. At left is a tube holding an unfiltered culture of PPLO's. In middle, PPLO culture is forced through a filter with .22-micron pores. Tube at right contains filtered PPLO elementary bodies.

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500 building blocks, the cell would have a complement of 150 large molecules. This purely theoretical cell would be delicate in the extreme, its ability to reproduce successfully always threatened by the random thermal motion of its constituents.

The smallest living organism actually observed—the .1-micron, or 1,000-angstrom, elementary body of *M. laidlawii*—is only twice this diameter. Its mass, of course, is eight times larger, and calculation from its observed density shows that it may contain 1,200 large molecules. This is a quite finite number, and since the organism grows to considerably larger size in the course of its reproductive cycle it cannot be said that 1,200 large molecules constitute its complete biochemical equipment. In the case of *M. gallisepticum*, however, we know that a diameter of .25 micron—only five times the theoretical lower limit—does encompass an autonomous metabolic and reproductive system. Our chemical analysis shows that the entire system is embodied in something less than 20,000 large molecules [*see chart on page 123*].

This is still an exceedingly small amount of material to sustain the complexity of biochemical function necessary to life. In fact, the portion of it allotted to the genetic function seems inadequate to the task. The 4 per cent of its dry substance that is DNA has a total molecular weight of 45 million. Since, according to current views of genetic coding, it takes an amount of DNA with a molecular weight of one million to encode the information for the synthesis of one enzyme molecule, *M. gallisepticum* would seem to contain enough genetic material to encode only a few enzymes beyond the 40 we have identified so far. That is far short of the 100 enzymes thought to be the minimum for cellular functions. It may be that the enzymes of very small cells are less specific and hence more versatile in their action than the enzymes of larger ones. On the other hand, it may prove necessary to re-examine prevailing ideas about the way information is encoded in the genetic material.

Questions of this kind suggest the principal challenge of very small cells. If they are indeed simpler than other cells, they can tell much about the basic mechanisms of cell function. If, on the other hand, they are functionally as complicated as other cells, they pose the fundamental question of how such functional complexity can be carried in such tiny pieces of genetic material.

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The Longest Electromagnetic Waves

Sensitive magnetometers commonly detect oscillations with a period of 100 seconds and a wavelength of 18,600,000 miles. The origin of these waves is unknown, but they promise to be useful in geophysics

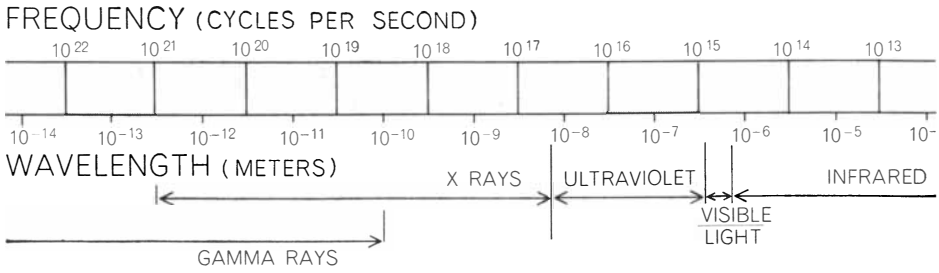
by James R. Heirtzler

As radio and its allied technologies have opened up one and then another band of the radio spectrum to exploitation over the past century, man has invariably discovered that nature was there before him. The signals broadcast by nature, usually labeled "interference" or "static" at first, have just as invariably been found to carry some important message—some clue to the workings of nature. At a wavelength of 21 centimeters, for example, the radiation from clouds of interstellar hydrogen has made it possible to map the principal structures of our galaxy. On the long side of the radio spectrum, where wavelengths are measured in kilometers, the "clicks" and "whistles" generated by lightning discharges help in the exploration of the earth's magnetic field. Recently geophysicists have discovered evidence that nature broadcasts on still longer wavelengths, out beyond the reach of radio technology. These waves have astronomical dimensions: some are 30 million kilometers (18,600,000 miles) long, and their upper limit is undefined. At present the mere detection of such waves presents the principal challenge to the investigator. But when the messages they carry are understood, they may tell a great deal about the electrodynamic interaction of the earth and the sun and provide a new way to look into the earth's interior.

Since the waves are much longer than the diameter of the earth itself, no earthly detector could "see" them in their entirety. The existence of the waves was first demonstrated indirectly by instruments that respond to the magnetic component of the waves. It was the celebrated equations of the great 19th-century physicist James Clerk Maxwell that first described the relationship between the electric and the magnetic components of electromagnetic waves. No matter what their length, electromagnetic waves are generated by the motion of electrically charged matter. In the simplest model the oscillation of an electron produces a wave in the surrounding electric field that travels outward in the plane of the oscillation. The same oscillation of the particle produces a complementary magnetic disturbance that travels outward in a plane that, at a distance greater than one wavelength from the source, is oriented at right angles to the plane of the electric component [*see top illustration on page 130*].

Each of these components of the electromagnetic wave is a vector quantity. In other words, a suitable probe—a voltmeter in the case of the electric component and a compass needle in the case of the magnetic component—will show that at any given point in time and space each exerts a force of a particular amplitude or strength in a particular direction. Although they can be observed independently of each other, neither the electric nor the magnetic component can exist without the other; in a sense the oscillation in the electric field generates the wave in the magnetic field, and the change in amplitude and direction in the magnetic field generates the corresponding change in the electric field. Because the electromagnetic wave travels with the universally constant speed of light (300,000 kilometers, or 186,000 miles, per second in a vacuum), the number of oscillations per second determines the length of the wave. If the observer could see the wave as he can a water wave, he could measure the wavelength directly. Actually he observes the wave as it passes a given point in space, and what he measures is the frequency of the oscillation or, if the wave is an exceedingly long wave, the period of the wave—the number of seconds required for a full oscillation. Having measured the frequency or period of oscillation he can calculate the wavelength; a wave with a period of one second, for example, will have a length of 300,000 kilometers.

The electromagnetic waves observed in nature depart, of course, in many ways from this ideal model. They usually have their origin in the random oscillation of huge numbers of particles; it is only when the mass motion of the particles is organized by special circum-



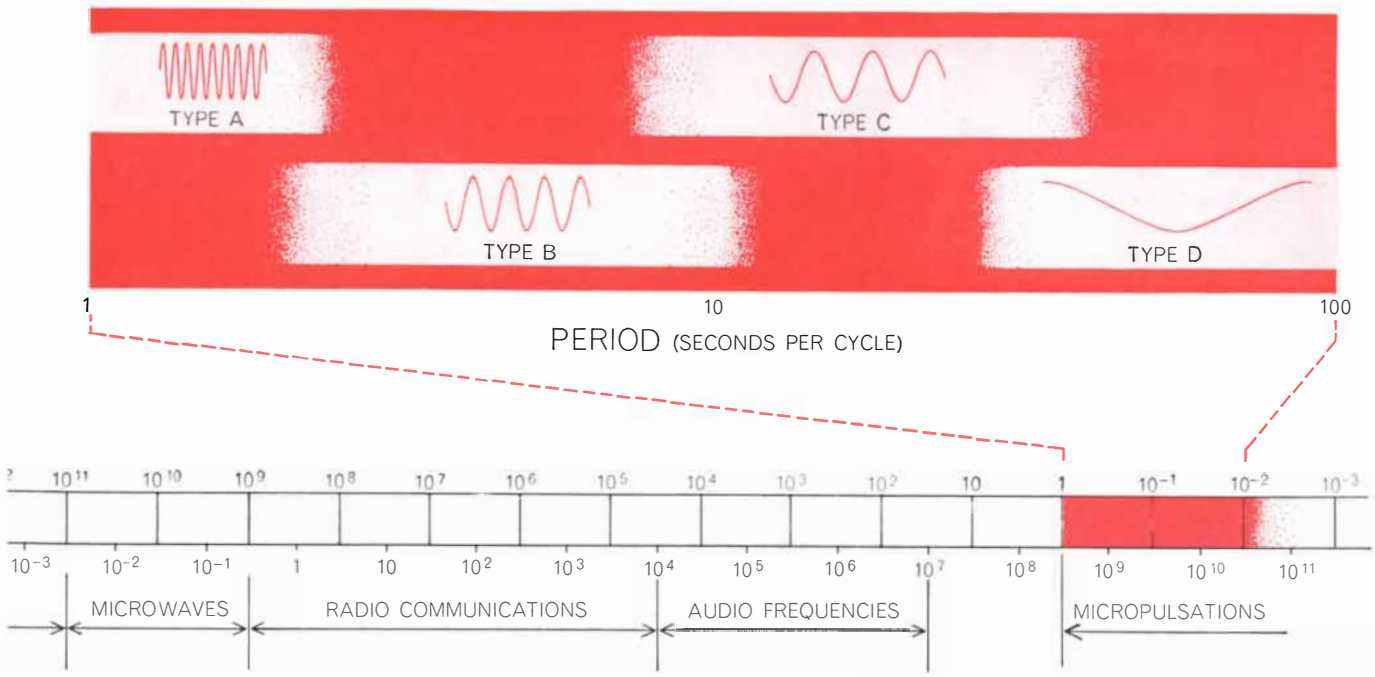
LONGEST WAVES, known as micropulsations, occur at right on this representation of the electromagnetic spectrum. Scale is logarithmic. The micropulsation region is enlarged to

stances that the radiation is so sharply polarized as to separate the planes of the electric and magnetic components. What is more, the waves are almost always modified by the medium through which they propagate. Depending on the electric or magnetic properties of the medium, the speed of propagation and hence the length of the wave may be changed, the amplitude may be reduced by dissipation of the wave's original energy and the angle between the electric and magnetic components of the wave may be skewed from the ideal 90 degrees. Ordinarily these effects can be neglected, but they are crucial to the ultimate determination of the origin of the newly discovered waves of long period and length and to the interpretation of the information they contain.

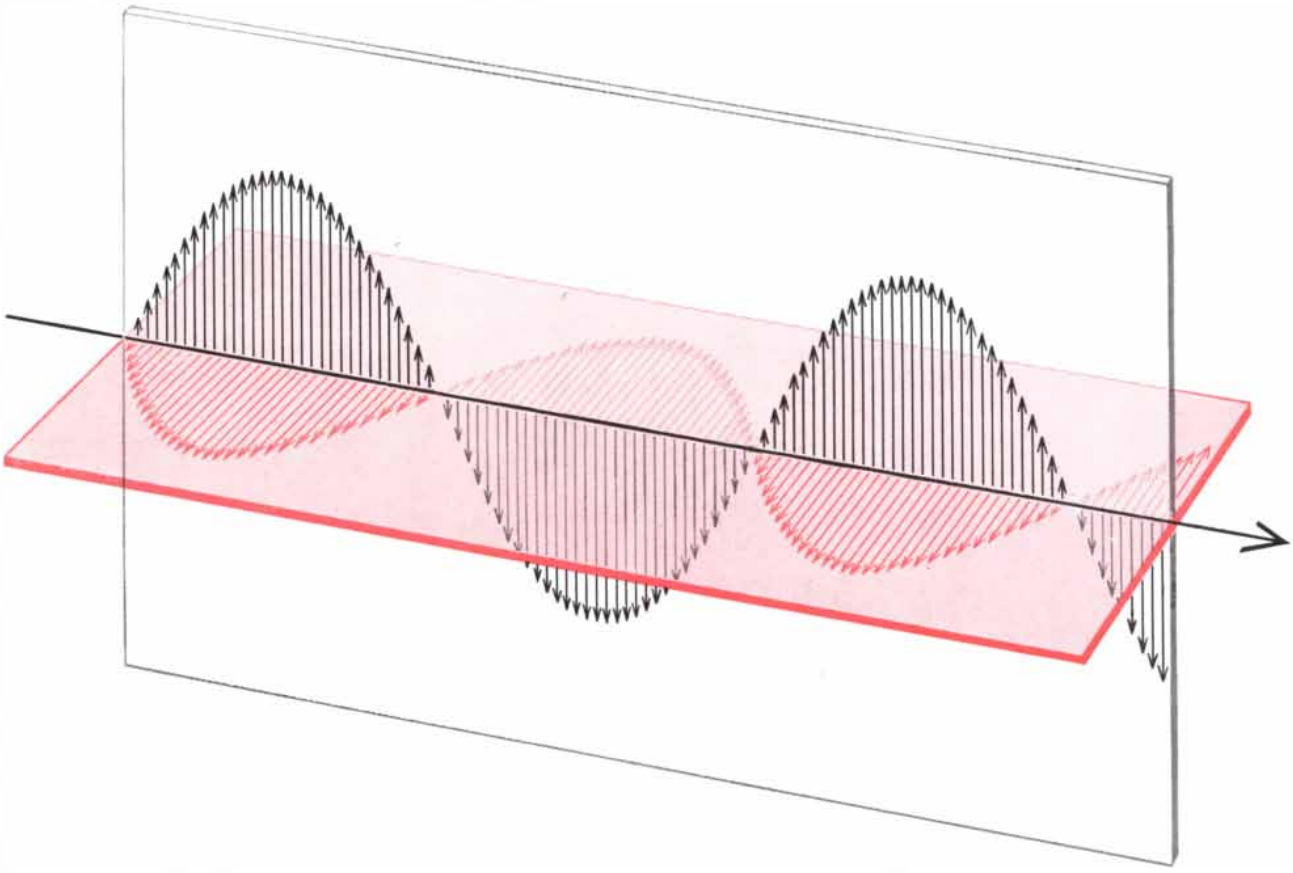
In spite of their astronomical dimensions these waves are called micropulsations because they have such tiny amplitude. They were first detected by the instruments set up to monitor variations in the earth's magnetic field. These instruments essentially consist of magnets suspended by fine fibers, and they are designed to record disturbances ranging in period from 30 seconds to a year or more. This is comparable to a radio receiver that would pick up standard broadcast waves at a million cycles per second, television signals at 100 million cycles per second and natural radiations from Jupiter at 1,000 million cycles per second, all at the same time. Probably not more than 1 per cent of the events recorded on such instruments is understood. In the midst of this profusion of waves the micropulsations show up as small fluctuations in disturbances of longer period. Because micropulsations with a period of 100 seconds are 1,000 times stronger than those with a period on the order of a second, the longer waves mask the shorter ones, and it is rare that the shorter waves stand out clearly on recordings made at standard magnetic observatories.

The study of electromagnetic waves with periods between one and 100 seconds has called for the development of a whole new class of instruments. They are not radio receivers in the usual sense of the term; they respond to the magnetic rather than the electric component of the wave. On the other hand, these instruments are sharply tuned, with their response confined to magnetic fluctuations that fall within a narrow range. They can be designed to measure either the change in the intensity of the magnetic field or both the intensity in a preferred direction and the rate of change of the field. Instruments of the first kind have been designed to employ the most sophisticated means for amplifying tiny forces; the latest is the optically pumped rubidium or helium magnetometer [see "Optical Pumping," by Arnold L. Bloom; SCIENTIFIC AMERICAN, October, 1960]. The instruments that respond to the change in the magnetic vector work by the principle of induction. They usually consist of a coil of wire wound around a special iron core, and they convert the change in the magnetic vector into a tiny but measurable voltage. Because they yield a smaller output in response to waves of higher amplitude and longer period, they give relatively greater prominence to the waves of shorter period.

All these instruments must be capable of measuring extremely small forces. Magnetic forces are commonly expressed in gauss; the amplitude of micropulsations is expressed in gammas: .00001 gauss. A child's horseshoe magnet may have a field strength of 1,000 gauss; the earth's magnetic field ranges from 70,000 gammas at the magnetic poles to 25,000 gammas at the magnetic equator; the amplitude of a 100-second wave may be only one gamma and that of a one-second wave .001 gamma. The induction instruments that give direction as well as strength are understandably sensitive to motion. In middle latitudes a directional detector can yield a false output of .001 gamma if it is rotated through an angle as small as .0000000003 degree! Earthquakes and



show the four types of wave found within it. Sine waves accompanying each type symbolize increasing wavelength from Type A through Type D. Instead of being measured in cycles per second, these longest waves are normally measured in seconds per cycle.

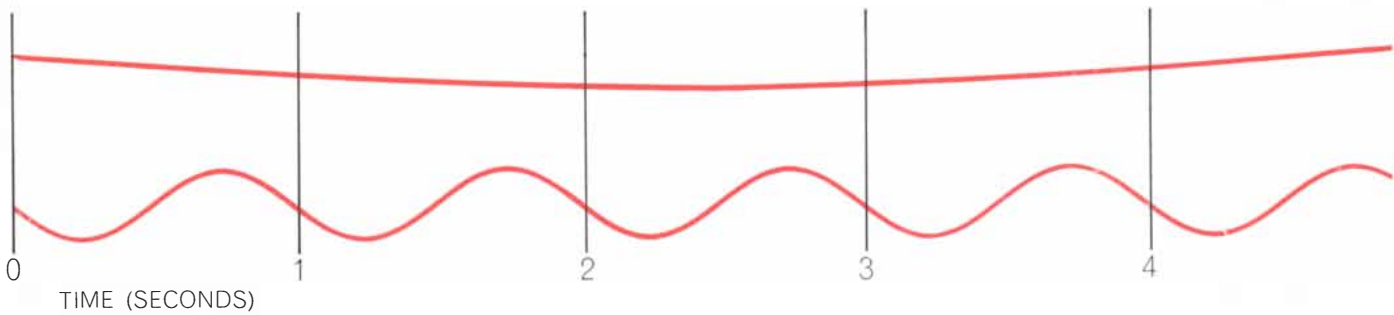


SIMPLEST ELECTROMAGNETIC WAVE consists of an electric field moving at right angles to a magnetic field. In this diagram the electric field is vertical (*black*), the magnetic field horizontal. Wave is propagating from left to right. The arrows that delineate the two fields represent vectors, which are changing cyclically in amplitude (strength) and in direction. This wave is "plane-polarized."

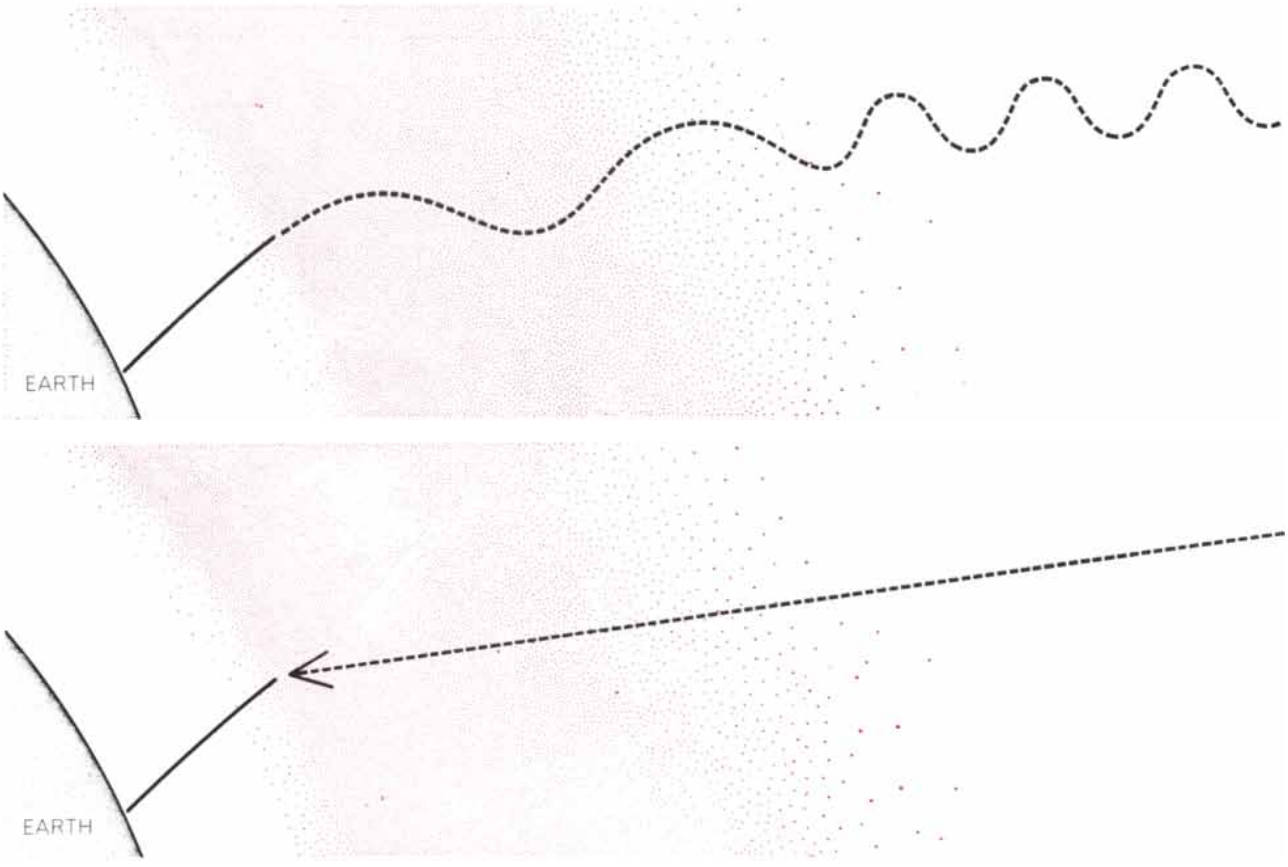
even everyday seismic motions can cause this much rotation. Consequently the detectors must be shock-mounted and in every other possible way insulated from vibration.

Several networks of widely separated stations equipped with instruments of this kind are now observing micropulsations in the Western Hemisphere, the polar regions, Australia and the U.S.S.R. In addition, several investigators are operating single stations. The lack of coordination in this fast-growing field is indicated by the fact that several of the networks overlap, use different instruments and conduct different programs of observation. Special committees of the International Union of Geodesy and Geophysics and of the American Geophysical Union are seeking to remedy this situation.

The most important conclusion indicated by investigations so far is that electromagnetic waves with periods of one to 100 seconds originate mostly, if not entirely, above the earth's surface. They apparently approach the earth from a vertical or nearly vertical direction. The vectors of the magnetic component, as shown by the induction instruments, tend to oscillate around an ellipse to a greater or lesser degree. The waves are therefore said to be elliptically polarized. In such polarization the vectors may be visualized as tracing out the pattern of a flattened corkscrew along the path of the wave [*see illustration on page 132*]. Some of the waves are almost plane-polarized, that is, the vectors move back



WAVES OF TWO PERIODS are represented here. The long wave may be thought of as having a period of 10 seconds: it takes 10 seconds for a whole cycle, or wave, to pass any given point. The shorter wave has a period of one second: a cycle passes a given point in



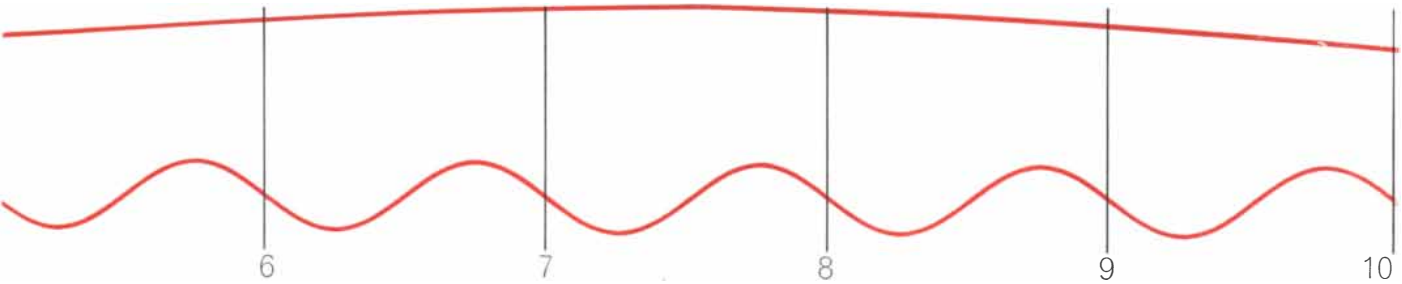
ORIGIN OF MICROPULSATIONS may be far out in earth's magnetic field or near the earth in the ionosphere. At top, wave generated far away by protons from the sun moves toward earth as a hydromagnetic wave, traverses ionosphere (*color*), changes to long electromagnetic wave (*solid line*) and strikes earth. At bottom, solar protons come in close, generating long wave in the ionosphere.

and forth in one plane. On the other hand, the few extremely long-period wave trains that have been recorded showed an almost circular polarization (the vectors traced out a helix). Polarization merits much more investigation because it can supply information about the source of the waves.

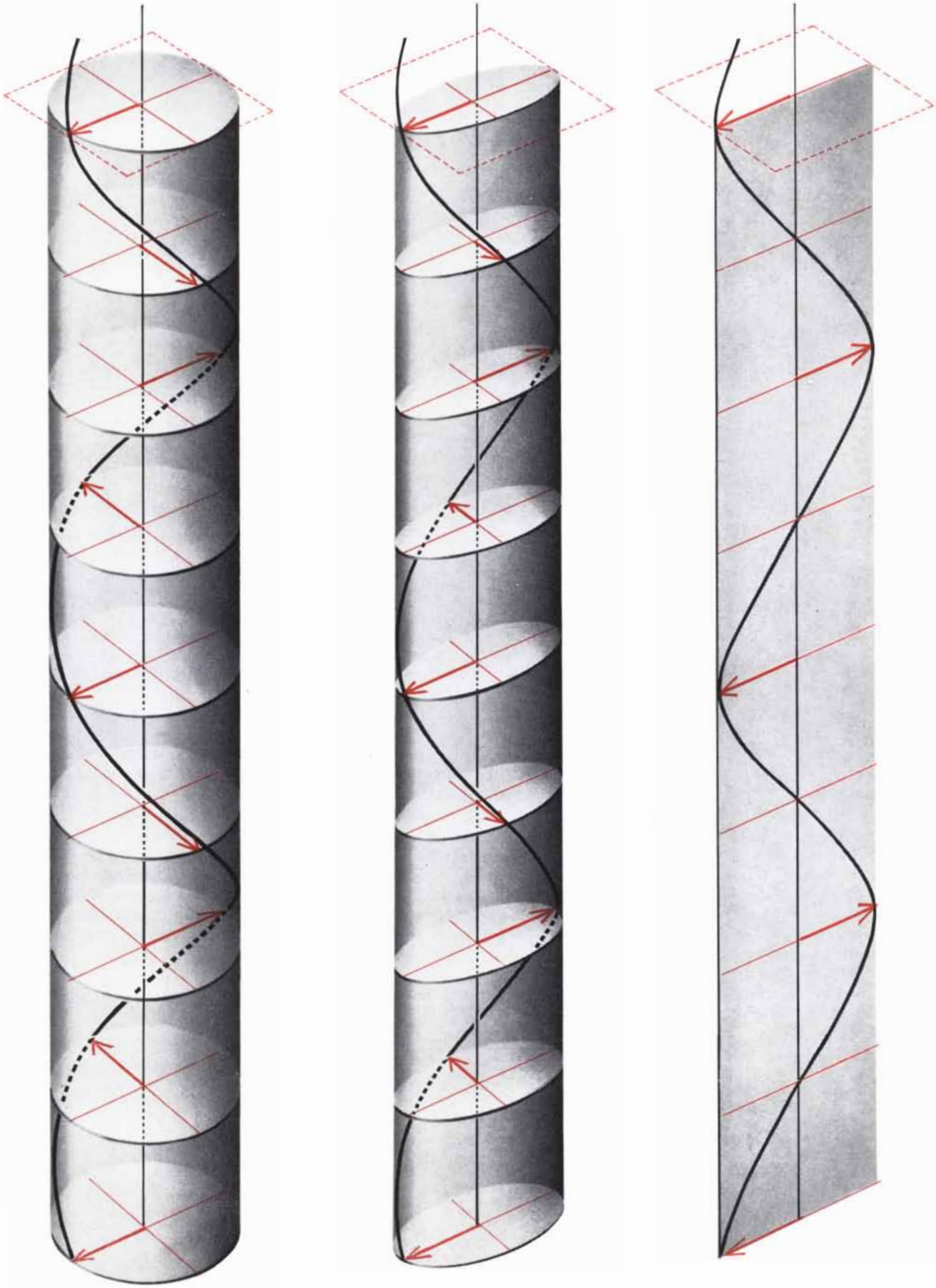
The waves are now classified in four bands, according to the time of day at which they are observed, their association with other events and, secondarily, their period and amplitude. One widely used classification, suggested by Hugo Benioff of the California Institute of Technology, has labeled them Types A, B, C and D. Since the limits of the bands are poorly defined, the bands overlap. Type A activity starts with a period slightly shorter than one second, and Type D extends to a period considerably longer than 100 seconds.

Trains of Type A waves, with periods up to two seconds, often persist for 24 to 48 hours. They can be distinguished from "bursts" of waves of similar and shorter period that attend lightning discharges. Often these wave trains appear to be superimposed on waves of longer period. Waves thus modulated are described as "pearly" because they resemble a string of pearls. The one detailed study of pearly waves made to date indicates that these shortest of the micropulsations display their greatest amplitude immediately after sunset and just before sunrise.

Type B waves, extending from about two seconds up to 10 seconds, may prove



one second; 10 cycles, or waves, occur in the 10-second period shown here. Assuming that these waves represent micropulsations traveling at the speed of light, each of the shorter waves would be 186,000 miles long and the long wave would be 1,860,000 miles long.



POLARIZATION OF WAVES can be circular (*left*), elliptical (*center*) or so elliptical that they become plane (*right*), depending on the kind of path traced by their vectors (*arrows*). Only magnetic-field vectors are shown. Waves are moving from top to bottom.

to have an origin different from that of Type A. They seem to occur frequently in periods of auroral activity. Since auroras appear on many nights during which the gross magnetic activity around the earth increases, Type B waves are probably related in some way to overall magnetic activity in the dark hemisphere of the earth.

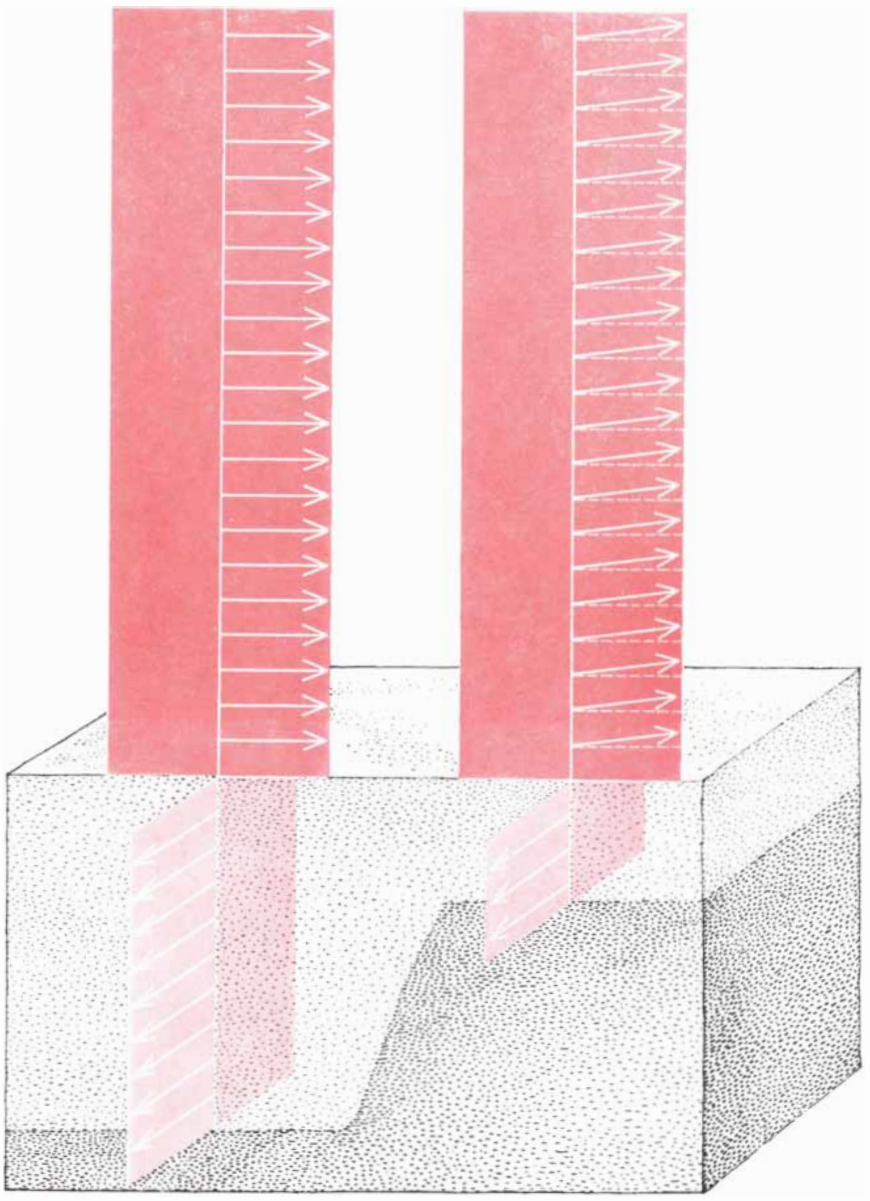
The Type C band, extending in period from eight to more than 40 seconds, has achieved the widest recognition. These waves are observed only on the sunlit side of the earth; they are called "daytime activity." It is apparently this family of waves that is most often found modulating the waves of Type A. If this is really the case, the pearly pattern should appear when the Type A and the Type C bands appear at about the same time, late in the evening and early in the morning. More observations are needed to check this idea.

The Type D band, extending to waves with a period of several hundred seconds and a wavelength of more than 1,000 million kilometers, may actually represent several kinds of activity. Often a Type D wave train consists of no more than a single cycle or pulse. Occasionally, however, long trains of these very long waves have been detected [*see bottom illustration on next page*].

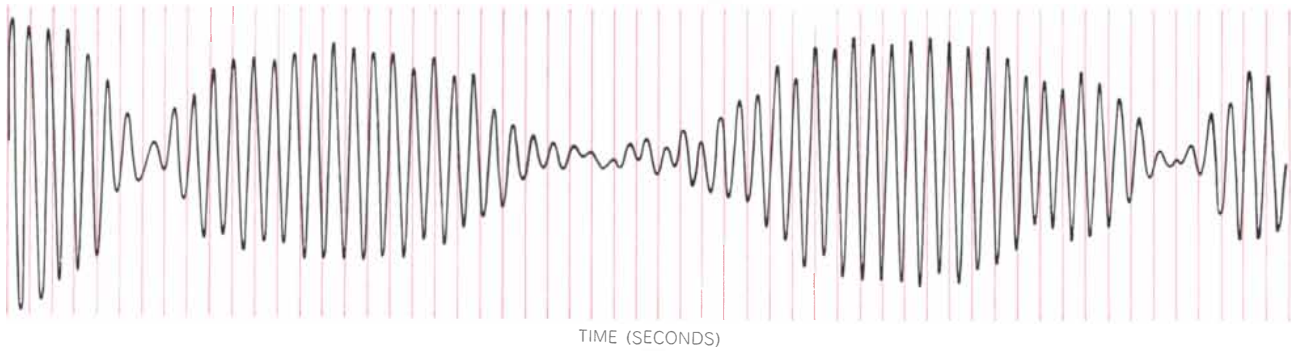
The bursts of activity thus recorded in this region of the electromagnetic spectrum are not nearly so well defined as are other natural events. Nor do they show any ready one-to-one correspondence with motions of material on earth. There are several types of mass motion with periods of the same order as these. Investigators at the outset tried to find correlations with elastic waves in the earth, with pressure fluctuations in the atmosphere and even with ocean waves —all to no avail. In the meantime, as the theorist exercises his imagination the experimentalist must continue his efforts to secure reliable and consistent observations.

Interference generated in the crust of the earth by the impinging long wave itself frequently confuses the record. Where the wave reaches the ground, the oscillating magnetic vector induces the flow of an electric current in the crust. Two electrodes planted in the ground can detect these currents, and geological surveyors often detect them. As yet few such observations have been correlated with measurements of the magnetic component of the incoming waves. Complications arise because the current induced in the earth generates a secondary magnetic field in the air that is picked up by the magnetometers along with the primary wave coming from above. In order to separate the two effects the observer should know just how well the earth in the area conducts electricity at various depths below the surface, because the conductivity determines both the amount of current and the strength and direction of the secondary magnetic wave.

In theory the micropulsations of longer wavelength should not be affected by the earth's crust. If the depth of penetra-

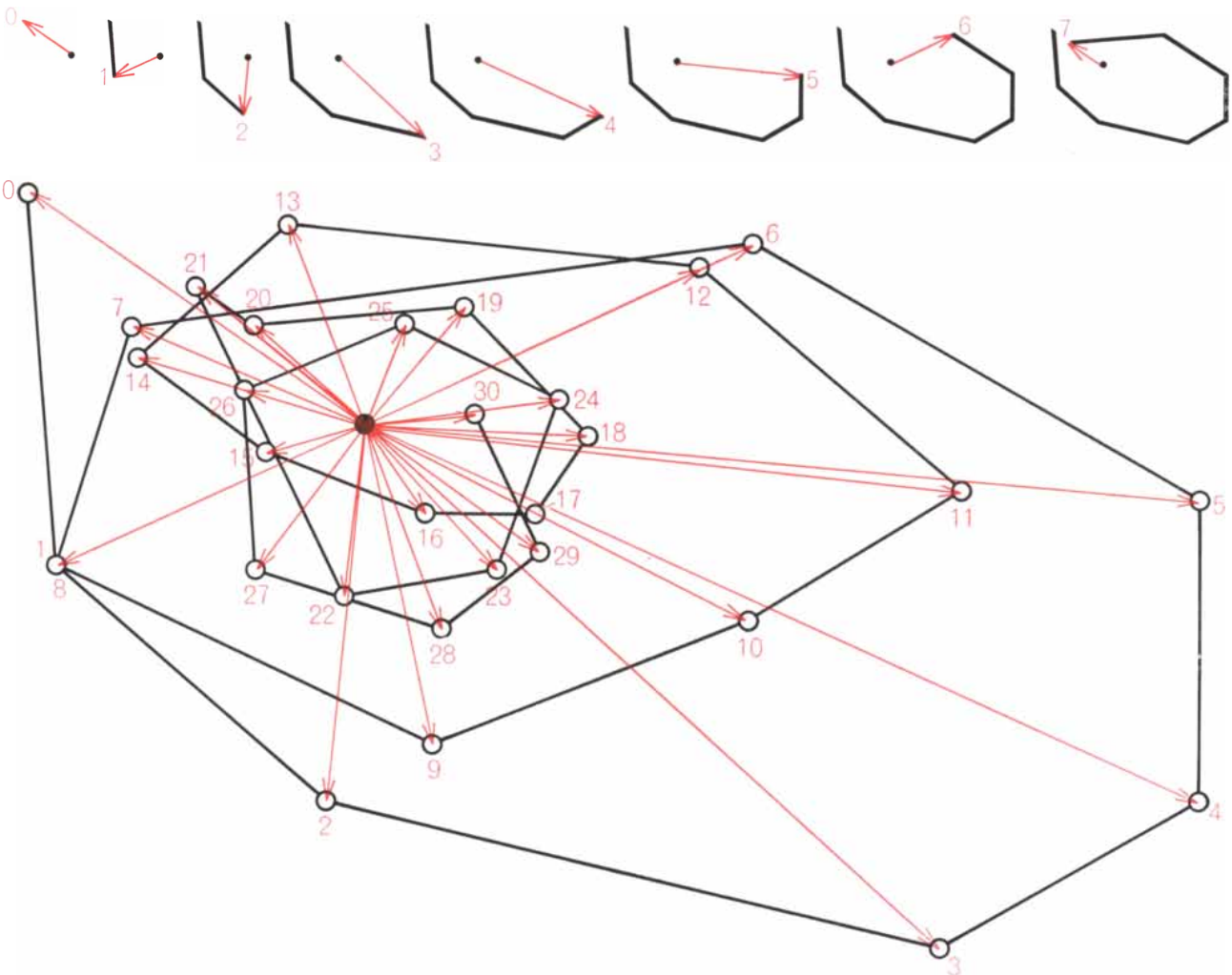


EFFECT OF LOCAL GEOLOGY on magnetic component of electromagnetic wave is shown in this highly schematic diagram. At left magnetic field strikes earth, creating electric current in earth at right angles to it. At right a local irregularity in rocks of earth's crust has electric conduction different from region of crust at left. This affects the electric currents. Electric currents in the earth generate secondary magnetic fields in the air. At right the secondary field has distorted the primary field, giving the vectors a "vertical component," represented here as a tilt in the arrows. The arrows, which are vectors, do not show any wave patterns because the distance represented here is minute in comparison with the extremely long waves. A change in the length of vectors on such a scale would be microscopic.



PEARLY PATTERN of micropulsations consists of shorter Type A waves, with a period of slightly less than one second, modulated by Type C waves with a period of about 20 seconds. It was recorded in Alberta in August, 1959, by investigators from the Pacific Naval Laboratories in Victoria, B.C. In this manifestation of micropulsations the Type A waves act rather like radio carrier waves.

tion of electromagnetic waves is defined as the point at which the electric intensity drops to 37 per cent of its value just below the surface, waves with a period of more than 100 seconds penetrate very deeply: 600 to 1,000 miles in regions of poor conductivity in which the wave cannot dissipate quickly. The continental crust is perhaps 30 miles thick and therefore makes up only a tiny fraction of all the material through which the long wave passes. The effects of the crust should be negligible. Because the structure of the earth's mantle (which lies below the crust) is thought to be quite uniform regardless of the shape of the crust over it, the secondary magnetic field generated by these long waves should be the same wherever the wave strikes, whether on mountains in Asia, on an island in the ocean or on ice at the North



TRAIN OF EXTREMELY LONG WAVES having a period of about six minutes and lasting for 30 minutes was recorded by Masahisa Sugiura of the University of Alaska. He calculated length or amplitude and directions of vectors (*arrows*) from magnetometer records. Sequence of eight small diagrams shows how he built up elliptical pattern of the wave from the length and directions of the vectors at the end of each minute. The University of Alaska is located in the auroral zone, where magnetic activity is intense.

Pole. Yet magnetometers separated by as little as 200 miles and tuned to the same incoming wave have produced significantly different records of intensity, vector and period. In Japan, where several magnetic observatories are located fairly close together, investigators are now trying to find out if the junction of the oceanic crust with the continental crust at the base of the islands causes this anomalous activity.

In the case of waves with periods of less than 100 seconds, which do not penetrate deeply, the local geology definitely affects the secondary earth currents. Here, however, observations square with theory. The measurements are modified in expected and explainable ways, provided the local geology is known. These local peculiarities show up plainly when each of two pairs of electrodes, placed along north-south and east-west lines respectively, are connected to a recording pen so that one pair of electrodes makes the pen move up and down and the other pair makes it move from side to side. The trace made over several hours during the passage of a wave train will be elliptical and will show a preferred orientation. A similar recording setup a few thousand yards away will trace an ellipse with its axis in a different direction if the rock layers have been fragmented by geological processes. Victor P. Hessler of the University of Alaska planted two pairs of electrodes in a large ice island north of Alaska and obtained a nearly circular pattern without a preferred axis. Since the ice island was in the deep ocean, "local geology" did not affect the waves.

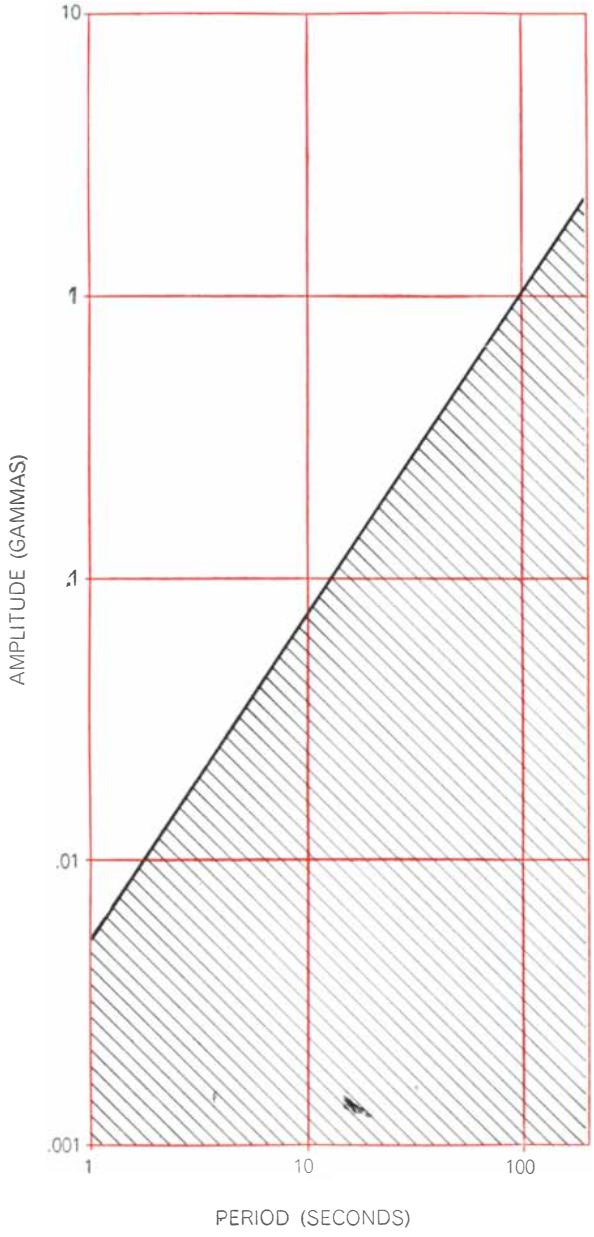
A great many questions would be cleared up if the original electric component of these long waves could be recorded in similar tracings. Unfortunately an instrument sensitive enough to detect the electric component will be "shorted out" by the weak electric conductivity of the air. If the angle between the electric and magnetic components could be measured, it would yield the distance to the source of the radiation. Provided that the source is located within one wavelength of the earth, as many investigators think it is, the angle would prove to be less than a right angle and the departure from 90 degrees would itself indicate the distance. This would solve the most important question concerning the waves, namely the question of their origin. It will probably be some time, however, before correlated electric and magnetic measurements can be made in the air. Until then it will be hard to compute where the waves come

from and how they originate. The answer to one question will probably provide the answer to the other.

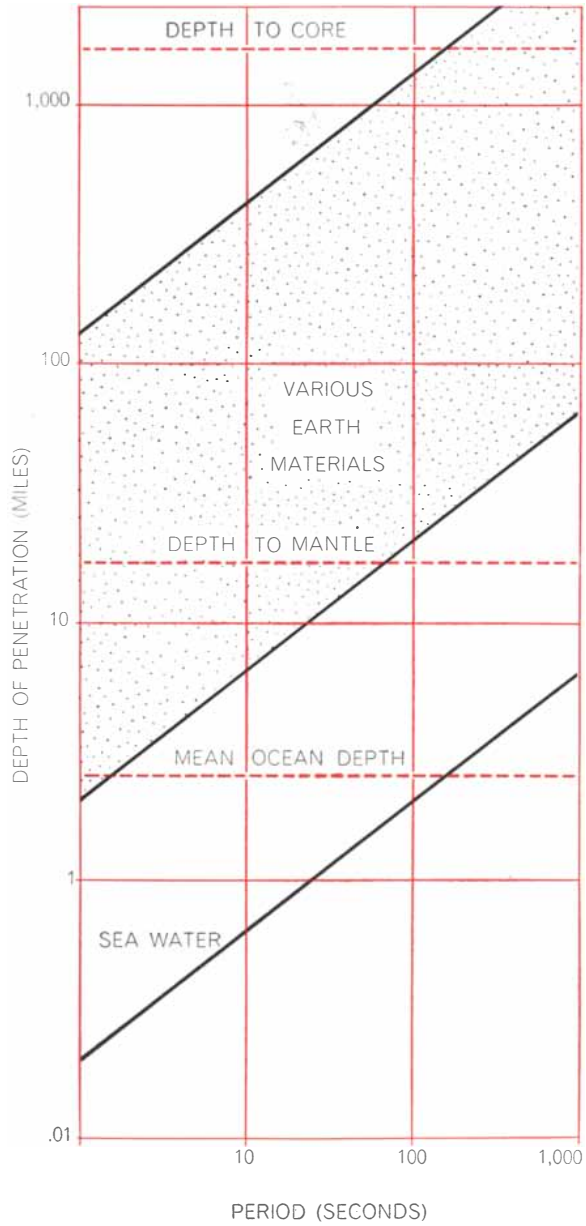
Some investigators would like to attribute at least some of the micropulsations to earth currents generated by the motion of material at the boundary of the earth's core or to seismic waves that produce earth currents. Others have suggested that a natural wave guide within the earth may be transmitting low-frequency electromagnetic activity from distant places. Such earth currents would generate electromagnetic waves in the air. But the observer can usually tell whether such waves are coming from above or below. So far the micropulsations detected in the air all seem to have been coming down.

That such long waves do occur in space is shown by measurements made by the *Pioneer I* space probe in 1958. It detected at a distance of 12.5 earth radii (about 50,000 miles) a wave train with a period of 10 seconds and an amplitude of 20 gammas. Unfortunately no effort was made to correlate this wave train with observations on the earth. The *Explorer X* satellite, sent aloft last March, carried a rubidium magnetometer to record rapid magnetic activity. But this satellite has failed to detect any pure wave trains that could be compared with long waves observed at ground level.

There are two dominant schools of thought on the origin of electromagnetic waves with periods longer than one second. Both hold that protons streaming



AMPLITUDES OF MICROPULSATIONS commonly recorded in middle latitudes of the earth are included in hatched area. The amplitudes observed in the auroral zones are usually considerably greater. Scales on both diagrams on this page are logarithmic.



DEPTH OF PENETRATION of micropulsations, defined as place where strength has dropped to 37 per cent of that just under the surface, is far greater for long-period waves. The depth to the earth's mantle indicated here is the depth under the continents.

out of the sun are ultimately responsible for the radiations. But they disagree on where the energy of the protons is converted to electromagnetic waves. One school believes that it happens in the ionosphere, and the other maintains that it happens above the ionosphere in the far reaches of the earth's magnetic field.

Advocates of the ionosphere idea drew support from the Argus project of 1958, which involved the detonation of two small nuclear bombs 300 miles above the South Atlantic. These explosions produced Type D waves that were recorded on many magnetometers in the U.S. and elsewhere. The speed at which these very long waves traveled—considerably less than the speed of light—places them in the category of hydromagnetic waves rather than that of true electromagnetic waves. Such waves are generated by the oscillation of a plasma—a gas composed of charged particles—and their behavior reflects the mass motion of the charged particles. The plasma in this case was the ionosphere, and it was mechanically as well as electrically disturbed by the explosion. Several months later studies of earth-current records made at the time of the tests showed that Type A waves had appeared all around the world at approximately the moment each explosion took place. The nearly instantaneous arrival of these waves still remains to be explained.

The satellite observations lend credibility to the theory of an origin in the outer reaches of the terrestrial magnetic field, at a distance of seven to 14 earth radii. Certainly in this region the solar particles press against the earth's magnetic field and bend its lines of force. Such deflection of the field could generate electromagnetic radiation of long period and wavelength.

If the waves do arise at this distance, a wave of full length never reaches the earth, in spite of the fact that long trains of waves are detected. The shortest micropulsation waves are 186,000 miles long, far more than the 56,000 miles represented by 14 earth radii. Micropulsations with a period of as little as 10 seconds have a far greater wavelength. The beginning of one of these waves would have been absorbed by the earth long before the end of the wave had left its point of origin. A detecting instrument, recording the cyclic changes in amplitude and direction that describe such a wave, draws a picture of a wave or even a train of waves that never actually existed.

MATHEMATICAL GAMES

How to build a game-learning machine and then teach it to play and to win

by Martin Gardner

I knew little of chess, but as only a few pieces were on the board, it was obvious that the game was near its close. . . . [Moxon's] face was ghastly white, and his eyes glittered like diamonds. Of his antagonist I had only a back view, but that was sufficient; I should not have cared to see his face.

The quotation is from Ambrose Bierce's classic robot story, "Moxon's Master" (reprinted in Groff Conklin's excellent science fiction anthology, *Thinking Machines*). The inventor Moxon has constructed a chess-playing robot. Moxon wins a game. The robot strangles him.

Bierce's story reflects a growing fear. Will computers someday get out of hand and develop a will of their own? Let it not be thought that this question is asked today only by those who do not understand computers. In recent years Norbert Wiener has been viewing with increasing apprehension the day when complex government decisions may be turned over to sophisticated game-theory machines. Before we know it, Wiener warns, the machines may shove us over the brink into a suicidal war.

The greatest threat of unpredictable behavior comes from the learning machines: computers that improve with experience. Such machines do not do what they have been told to do but what they have *learned* to do. They quickly reach a point at which the programmer no longer knows what sort of circuit his machine contains. Inside most of these computers are randomizing devices. If the device is based on the random decay of atoms in a sample radioactive material, the machine's behavior is not (most physicists believe) predictable even in principle.

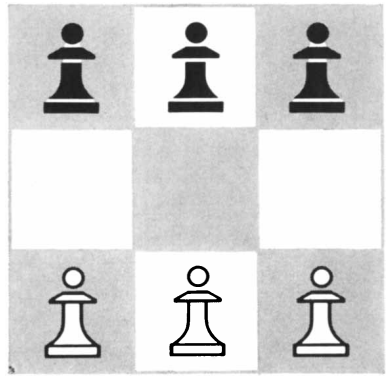
Much of the current research on learning machines has to do with computers that steadily improve their ability to play games. Some of the work is secret—war is a game. The first significant machine of this type was an IBM 704 computer programed by Arthur L. Samuel of the IBM research department at Poughkeepsie, N.Y. In 1959 Samuel set up the computer so that it not only played a fair game of checkers but also was capable of looking over its past games and modifying its strategy in the light of this experience. At first Samuel found it easy to beat his machine. Instead of strangling him, the machine improved rapidly, soon reaching the point at which it could clobber its inventor in every game. So far as I know no similar program has yet been designed for chess, although there have been several ingenious programs for nonlearning chess machines [see "Computer v. Chess-Player," by Alex Bernstein and Michael de V. Roberts; SCIENTIFIC AMERICAN, June, 1958].

Recently the Russian chess grand master Mikhail Botvinnik was quoted as saying that the day would come when a computer would play master chess. "This is of course nonsense," writes the American chess expert Edward Lasker in an article on chess machines in last fall's issue of a new magazine called *The American Chess Quarterly*. But it is Lasker who is talking nonsense. A chess computer has three enormous advantages over a human opponent: (1) It never makes a careless mistake; (2) it can analyze moves ahead at a speed much faster than a human player can; (3) it can improve its skill without limit. There is every reason to expect that a chess-learning machine, after playing thousands of games with experts, will someday develop the skill of a master. It is even possible to program a chess machine to play continuously and furiously against itself. Its speed would enable it to acquire in a short time an experience far beyond that of any human player.

It is not necessary for the reader who would like to experiment with game-learning machines to buy an IBM 704. It is only necessary to obtain a supply of empty matchboxes and colored beads. This method of building a simple learning machine is the happy invention of Donald Michie, a biologist at the University of Edinburgh. Writing on "Trial and Error" in *Penguin Science Survey 1961*, Vol. 2, Michie describes a ticktacktoe learning machine called MENACE (Matchbox Educable Naughts And Crosses Engine) that he constructed with 300 matchboxes.

MENACE is delightfully simple in operation. On each box is pasted a drawing of a possible ticktacktoe position. The machine always makes the first move, so only patterns that confront the machine on odd moves are required. Inside each box are small glass beads of various colors, each color indicating a possible machine play. A V-shaped cardboard fence is glued to the bottom of each box, so that when one shakes the box and tilts it, the beads roll into the V. Chance determines the color of the bead that rolls into the V's corner. First-move boxes contain four beads of each color, third-move boxes contain three beads of each color, fifth-move boxes have two beads of each color, seventh-move boxes have single beads of each color.

The robot's move is determined by shaking and tilting a box, opening the drawer and noting the color of the "apical" bead (the bead in the V's apex). Boxes involved in a game are left open until the game ends. If the machine wins, it is rewarded by adding three beads of the apical color to each open box. If the game is a draw, the reward is one bead per box. If the machine loses, it is punished by extracting the apical bead from each open box. This system of reward and punishment closely parallels the way in which animals and even humans are taught and disciplined. It is obvious that the more games MENACE plays, the more it will tend to adopt winning lines of play and shun losing lines. This makes it a legitimate learning machine, although of an extremely simple sort. It does not make (as does Samuel's checker machine) any self-analysis of past plays



The game of hexapawn

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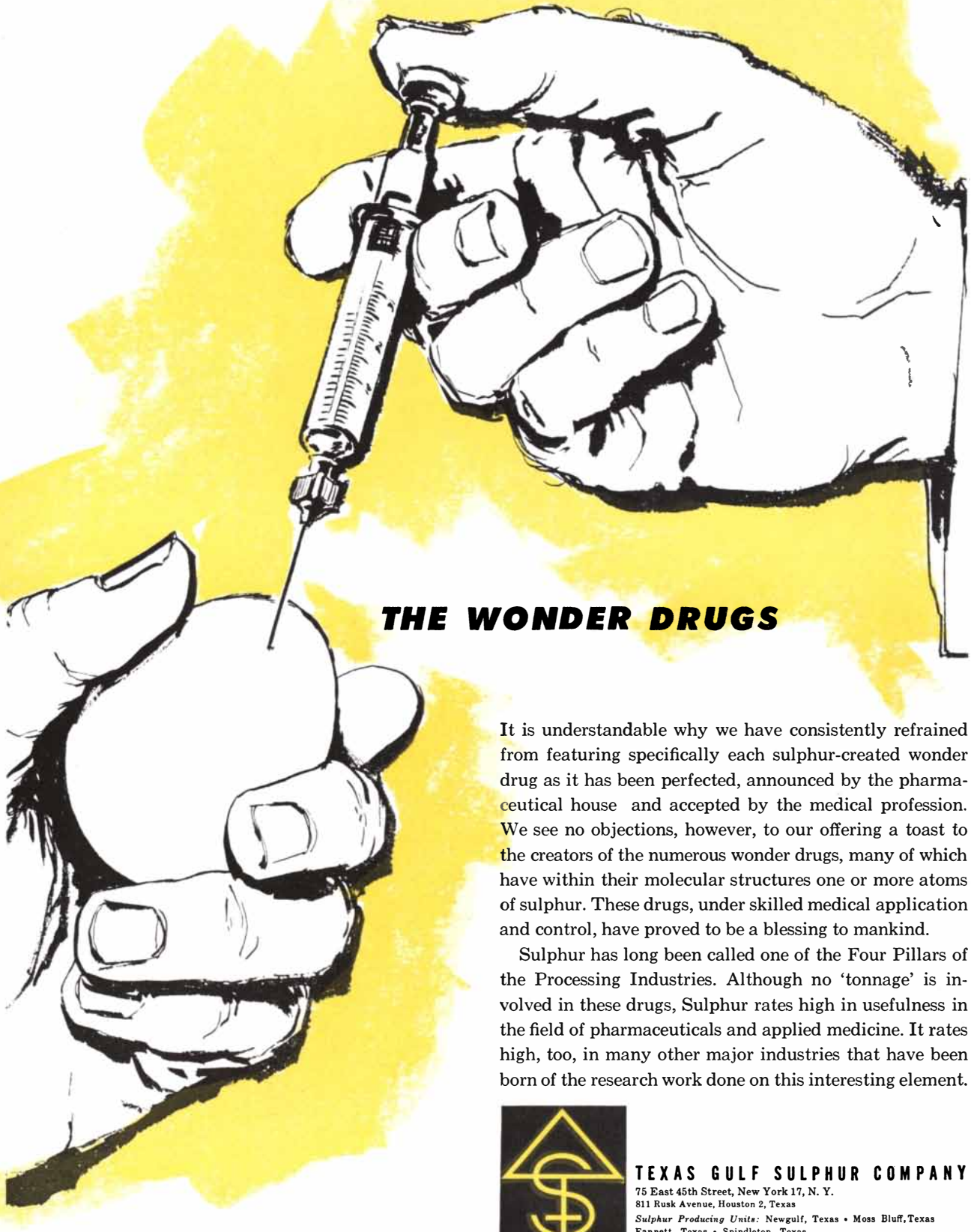

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that causes it to devise new strategies.

Michie's first tournament with MENACE consisted of 220 games over a two-day period. At first the machine was easily trounced. After 17 moves the machine had abandoned all openings except the corner opening. After the 20th game it was drawing consistently, so Michie began trying unsound variations in the hope of trapping it in a defeat. This paid off until the machine learned to cope with all such variations. When Michie withdrew from the contest after losing eight out of ten games, MENACE had become a master player.

Since few readers are likely to attempt building a learning machine that requires 300 matchboxes, I have designed hexapawn, a much simpler game that requires only 24 boxes. The game is easily analyzed—indeed, it is trivial—but the reader is urged *not* to analyze it. It is much more fun to build the machine, then learn to play the game while the machine is also learning.

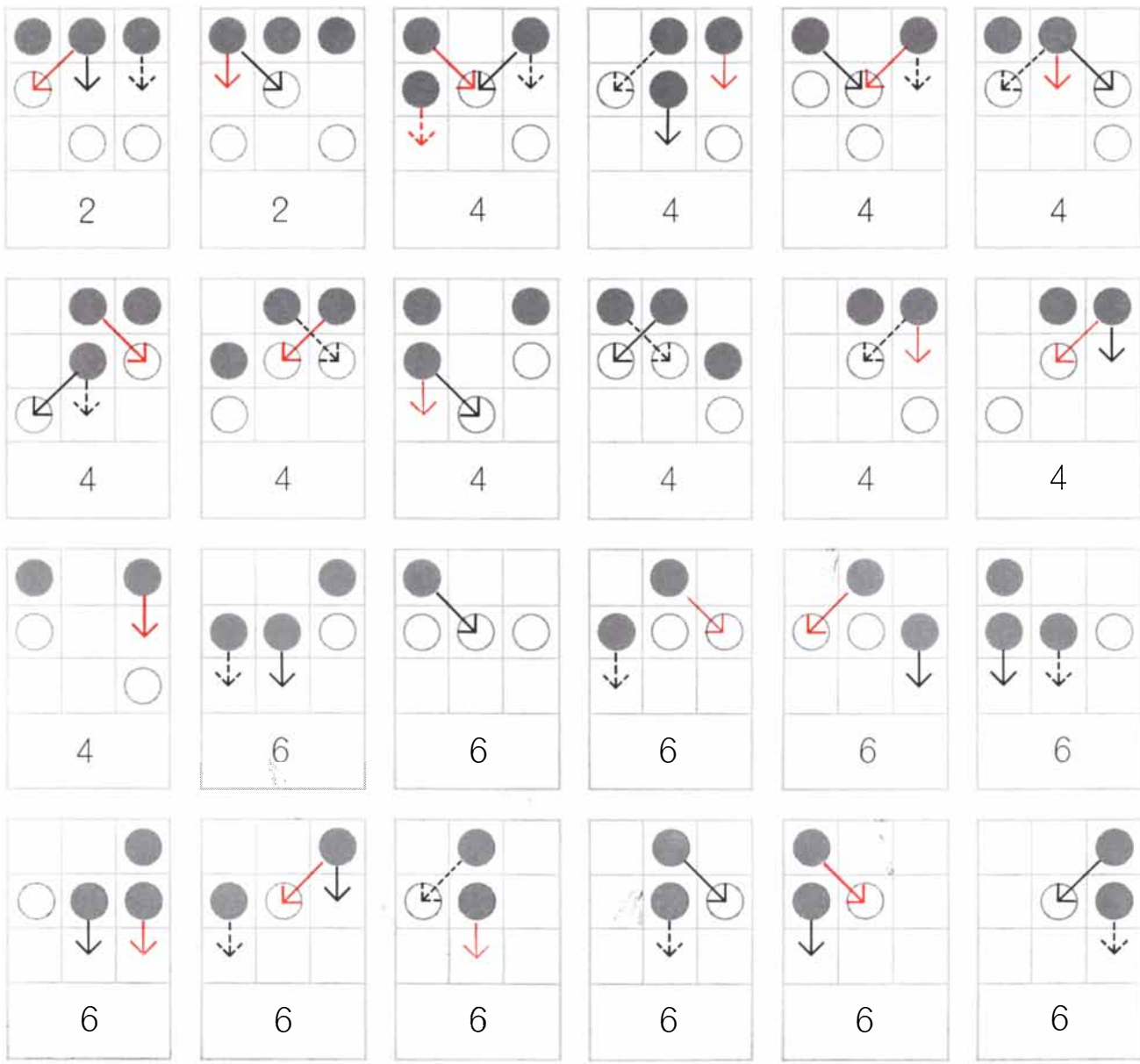
Hexapawn is played on a 3×3 board, with three chess pawns on each side as shown in the illustration on page 138. Dimes and pennies can be used instead of actual chess pieces. Only two types of move are allowed: (1) A pawn may advance straight forward one square to an empty square; (2) a pawn may capture an enemy pawn by moving one square diagonally, left or right, to a square occupied by the enemy. The captured piece is removed from the board. These are the same as pawn moves in chess, except that no double move, *en passant* capture or promotion of pawns is permitted.

The game is won in any one of three ways:

1. By advancing a pawn to the third row.
2. By capturing all enemy pieces.
3. By achieving a position in which the enemy cannot move.

Players alternate moves, moving one piece at a time. A draw clearly is impossible, but it is not immediately apparent whether the first or second player has the advantage.

To construct HER (Hexapawn Educable Robot) you need 24 empty matchboxes and a supply of colored beads. Small candies that come in different



Labels for HER matchboxes

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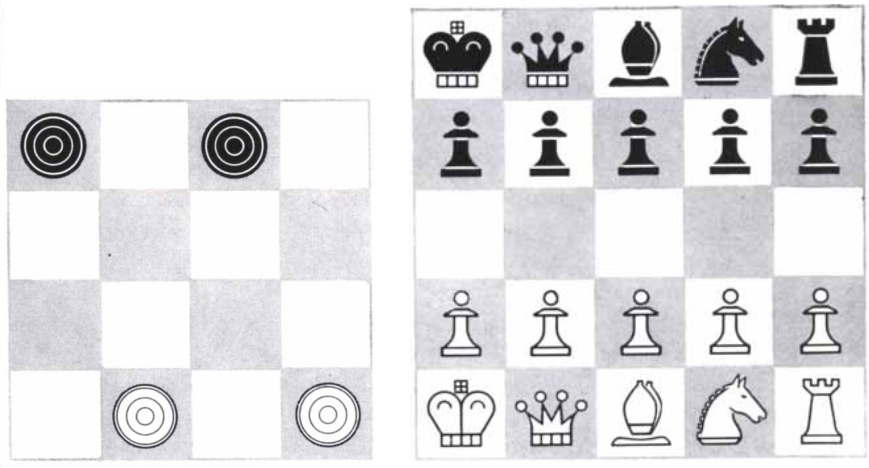
Learning curve for HER's first 50 games (downslant shows loss, upslant a win)

colors work nicely. (I used five five-cent boxes of jujubes.) Each matchbox bears one of the diagrams shown in the illustration on page 140. The robot always makes the second move. Patterns marked "2" represent the two positions open to HER on the second move. You have a choice between a center or an end opening, but only the left end is considered because an opening on the right would obviously lead to identical (although mirror-reflected) lines of play. Patterns marked "4" show the 11 positions that can confront HER on the fourth (its second) move. Patterns marked "6" are the 11 positions that can face HER on the sixth (its last) move.

Inside each box place a single bead to match the color of each arrow on the pattern. The robot is now ready for play. Every legal move is represented by an arrow; the robot can therefore make all possible moves and only legal moves. The robot has no strategy. In fact, it is an idiot.

The teaching procedure is as follows. Make your first move. Pick up the matchbox that shows the position on the board.



Matchbox machine can be built for simplified checkers (left) *but not for chess* (right)

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A factual statement on career opportunities for scientists and engineers from James E. Webb, head of NASA

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James E. Webb

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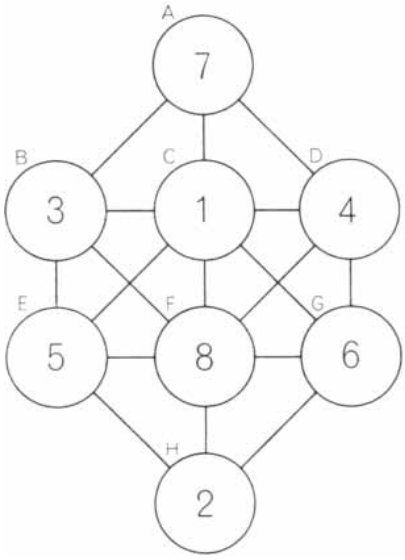


Solution to last month's Problem 1

Shake the matchbox, close your eyes, open the drawer, remove one bead. Close the drawer, put down the box, place the bead on top of the box. Open your eyes, note the color of the bead, find the matching arrow and move accordingly. Now it is your turn to move again. Continue this procedure until the game ends. If the robot wins, replace all the beads and play again. If it loses, punish it by confiscating only the bead that represents its *last* move. Replace the other beads and play again. If you should find an empty box (this rarely happens), it means the machine has no move that is not fatal and it resigns. In this case confiscate the bead of the preceding move.

Keep a record of wins and losses so you can chart the first 50 games. The top illustration on page 142 shows the results of a typical 50-game tournament. After 36 games (including 11 defeats for the robot) it has learned to play a perfect game. The system of punishment is designed to minimize the time required to learn a perfect game, but the time varies with the skill of the machine's opponent. The better the opponent, the faster the machine learns.

The robot can be designed in other ways. For example, if the intent is to maximize the number of games that the machine wins in a tournament of, say, 25 games, it may be best to reward (as well as punish) by adding a bead of the proper color to each box when the machine wins. Bad moves would not be eliminated so rapidly, but it would be less inclined to make the bad moves. An interesting project would be to construct a second robot, HIM (Hexapawn Instructable Matchboxes), designed with a different system of reward and punishment but equally incompetent at the the start of a tournament. Both machines would have to be enlarged so they could make either first or second moves. A tournament could then be played between HIM and HER, alternating the first move, to see which machine would win the most games out of 50.

Similar robots are easily built for other games. Stuart C. Hight, director of research studies at the Bell Telephone Laboratories in Whippany, N.J., recently built a matchbox learning machine called NIMBLE (Nim Box Logic Engine) for playing nim with three piles of three counters each. The robot plays either first or second and is rewarded or punished after each game. NIMBLE required only 18 matchboxes and played almost perfectly after about 30 games.

By reducing the size of the board the complexity of many familiar games can be minimized until they are within the scope of a matchbox robot. The game of go, for example, can be played on the intersections of a 2 × 2 checkerboard. The smallest nontrivial board for checkers is shown at the left in the bottom illustration on page 142. It should not be difficult to build a matchbox machine that would learn to play it. Readers disinclined to do this may enjoy analyzing the game. Does either side have a sure win or will two perfect players draw? (The answer will be given next month.)

When chess is reduced to the smallest board on which all legal moves are still possible, as shown at the right in the bottom illustration on page 142, the complexity is still far beyond the capacity of a matchbox machine. In fact, I have found it impossible to determine which player, if either, has the advantage. The game is recommended for computer experts who wish to program a simplified chess-learning machine and for all chess players who like to sneak in a quick game during a coffee break.

The answers to last month's collection of short problems are given below:

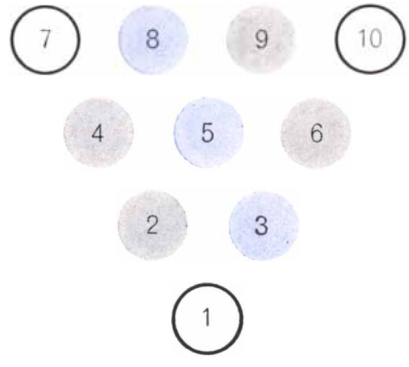
1.

If the numbers from 1 to 8 are placed in the circles as shown in the illustration at the top of this page, no number will be connected by a line to a number immediately above or below it in serial order. The solution (including its upside-down and mirror-image forms) is unique.

L. Vosburgh Lyons, who gave me this puzzle, solved it as follows. In the series 1, 2, 3, 4, 5, 6, 7, 8 each digit has two neighboring numbers except 1 and 8. In the diagram, circle C is connected to every circle except H. Therefore if C contains any number in the set 2, 3, 4, 5, 6, 7, only circle H will remain to accommodate *both* neighbors of whatever number goes in C. This is impossible, so C must contain 1 or 8. The same argument ap-

GAMES	1	2	3	4	5	6	7	8	9
SERVER	R	M	R	M	R	M	R	M	R
WINNER	R	M	R	M	R	M	M	M	M
GAMES WITH SERVICE	X	X	X	X	X	X		X	
GAMES V. SERVICE							X		X

Chart for Problem 3



Impossibility proof for Problem 4

plies to circle F. Because of the pattern's symmetry, it does not matter whether 1 goes in C or F, so let us place it in C. Circle H is the only circle available for 2. Similarly, with 8 in circle F, only circle A is available for 7. The remaining four numbers are now easily placed.

2.

The problem of the lady or the tiger is merely a dressed-up version of a famous ball-and-urn problem analyzed by the great French mathematician Pierre Simon de Laplace (see James R. Newman's *The World of Mathematics*, Vol. 2, page 1332). The answer is that the young man on his third choice of a door has a probability of 9/10 that he will choose the lady. The pair of doors concealing two tigers is eliminated by his first choice of a lady, which leaves 10 equally probable possibilities for the entire series of three choices.

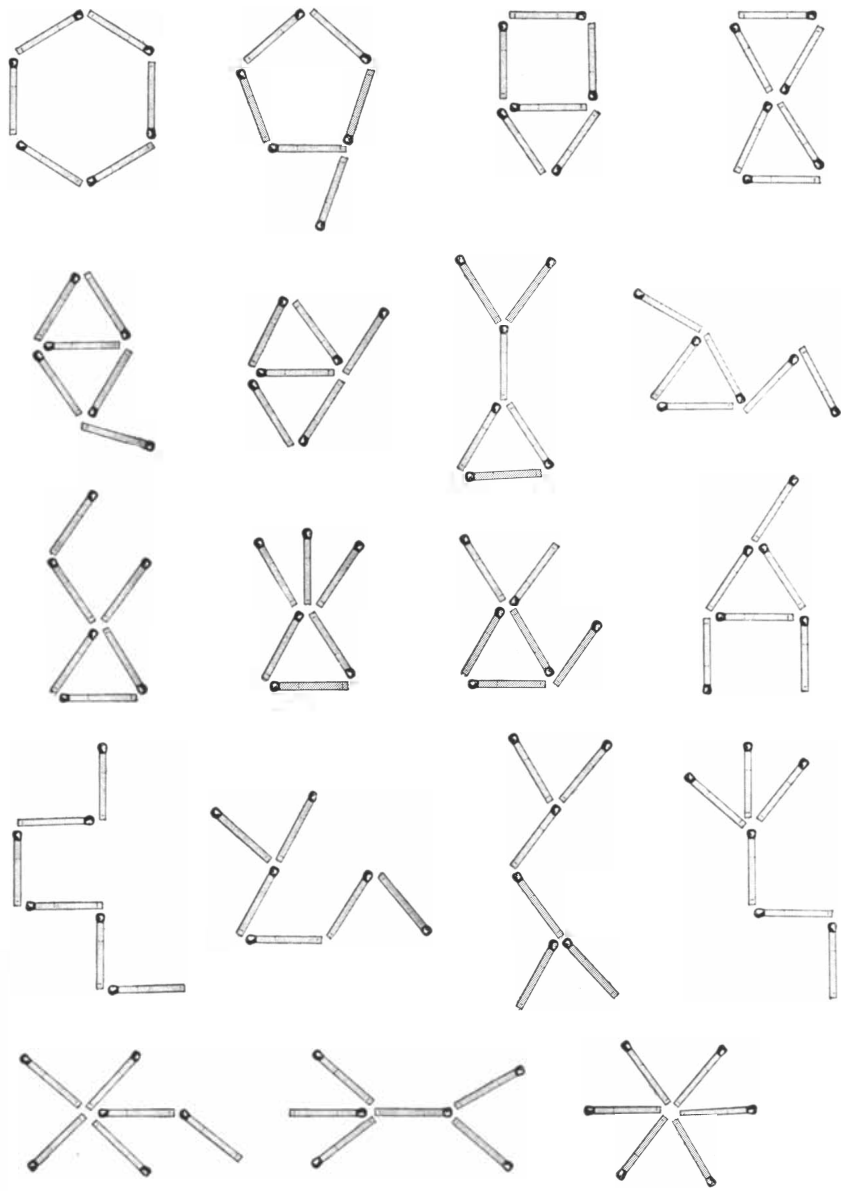
If the doors conceal two ladies:

Lady 1 — Lady 1 — Lady 1
Lady 1 — Lady 1 — Lady 2
Lady 1 — Lady 2 — Lady 1
Lady 1 — Lady 2 — Lady 2
Lady 2 — Lady 1 — Lady 1
Lady 2 — Lady 1 — Lady 2
Lady 2 — Lady 2 — Lady 1
Lady 2 — Lady 2 — Lady 2

If the doors conceal a lady and a tiger:

Lady 3 — Lady 3 — Lady 3
Lady 3 — Lady 3 — Tiger

Of the 10 possibilities in the prob-



Solution to Problem 5

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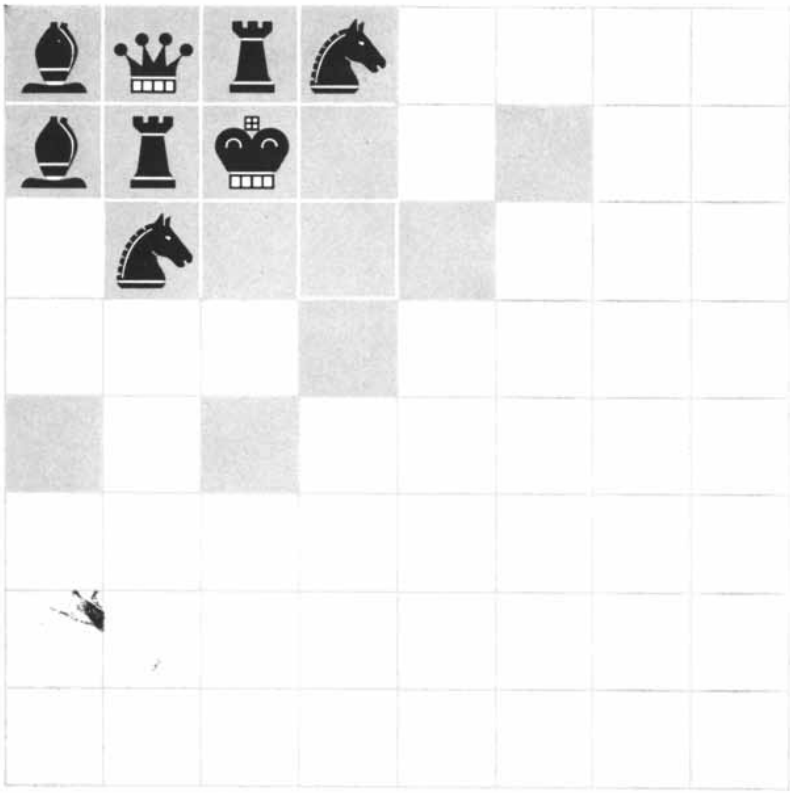
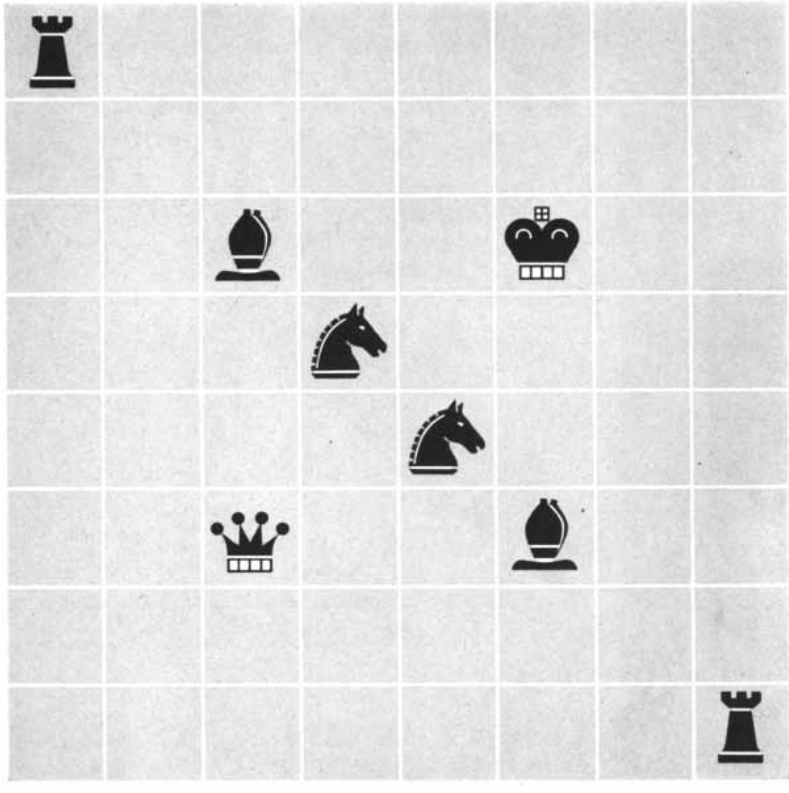


Solution to minimum attack problem



Solution to maximum attack problem with bishops on same color

lem's "sample space," only one ends with a fatal final choice. The probability of the man's survival is therefore 9/10.

3.

Miranda served first. One way to prove it follows:

Tennis players alternate in serving. Assume that Rosemary served first. The set included nine games so she must also have served last. Since Miranda won the set, she must have won the last game. We are told that Miranda won six games to Rosemary's three games and that five games went against service. Of the eight games that remain, therefore, five were won by Miranda, three by Rosemary.

Consider the three that Rosemary won. There are four possibilities:

A. Rosemary served all three.
B. Rosemary served two.
C. Rosemary served one.
D. Rosemary served none.

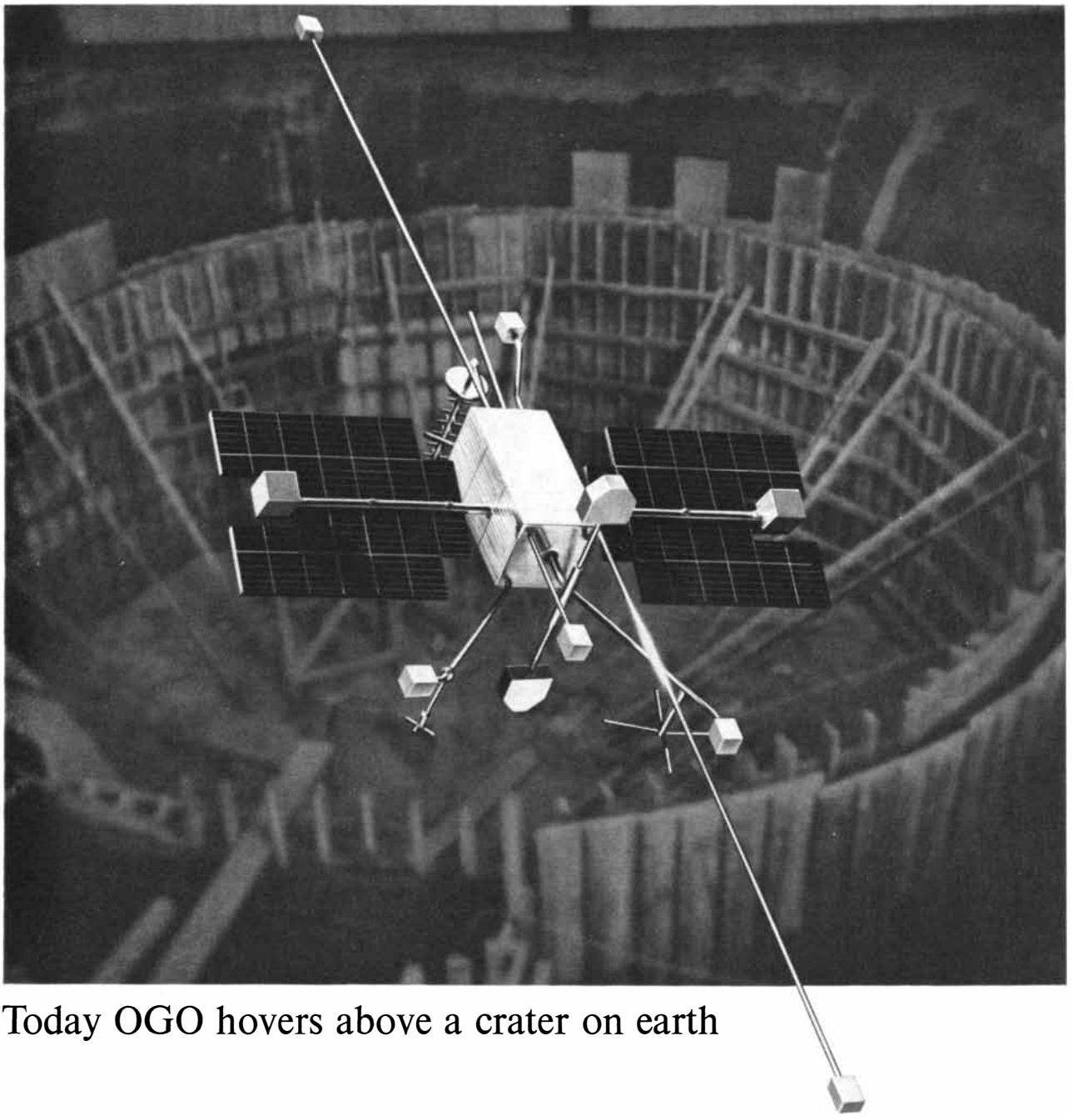
The illustration at the bottom left on page 144 is a chart of the first possibility. Three *R*'s are placed in the third row beneath any three *R*'s in the second row. The remaining blanks of the third row must be filled by *M*'s. This shows only two games won against service; therefore possibility A is eliminated. Similar charts eliminate B (four games against service), C (six games against service) and D (eight games against service). This exhausts the four possibilities, proving that Rosemary could not have served first.

It remains to be seen if the assumption that Miranda served first is consistent with the known facts. By drawing a new chart and following the previous procedure it will be found that all data can be accounted for on the assumption that Miranda served first and that Rosemary served one of her three winning games.

4.

It is not possible to mix bowling pins of two different colors and set up a triangular formation of 10 pins in such a way that no three pins of the same color mark the corners of an equilateral triangle. There are many ways to prove this. The following is typical:

Assume that the two colors are red and black and that the 5 pin [*see illustration at bottom right on page 144*] is red. Pins 4, 9, 3 form an equilateral triangle, so at least one of these pins must be red. It does not matter which we make red, because of the figure's symmetry, so let us make it the 3 pin. Pins 2 and 6 must therefore be black. Pins 2, 6, 8 form



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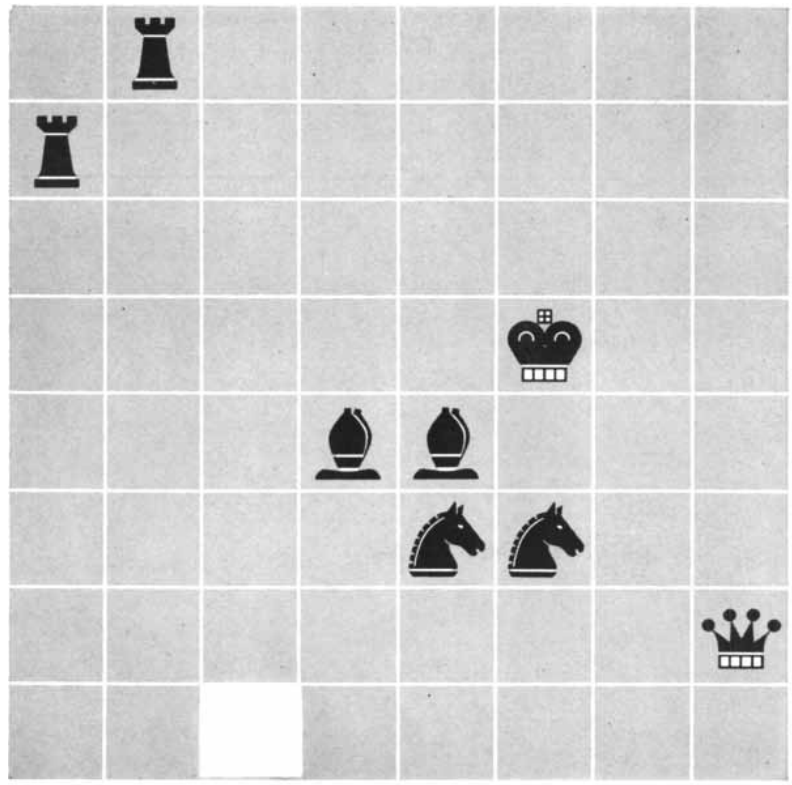

Solution to maximum attack problem with bishops on different colors

a triangle, forcing us to make 8 a red pin. This in turn makes the 4 and 9 pins black. Pin 10 cannot be black, for this would form a black triangle with 6 and 9, nor can it be red, because this would form a red triangle with 3 and 8. Therefore pin 5, with which we started, cannot be red. Of course, the same argument will show that it cannot be black.

5.

Nineteen topologically distinct networks can be made with six matches, placing them on a plane so that no matches overlap and the matches touch only at their ends. The 19 networks are shown in the illustration on page 146.

6.

The top illustration on page 148 shows how eight chess pieces of one color can be placed on the board so that only 16 squares are under attack. The queen and the bishop in the corner can be switched to provide a 16-square minimum with bishops on the same color. This is believed to be the minimum regardless of how the bishops are placed.

The bottom illustration on page 148 shows one way to place the eight pieces so that all 64 squares are under attack, obviously the maximum. If the bishops are not permitted on the same color, however, 63 squares is believed to be the maximum. There are many solutions, one of which is shown in the illustration above. The maximum attack problem was first proposed in 1849. With bishops on opposite colors, 83 basically different solutions have been proved possible. The single unattacked square may be in any position except the corner of the board. I am indebted to Edward Early of Stamford, Conn., for having called this problem to my attention.

7.

To find the mileage covered by the Smiths on their trip from Connecticut to

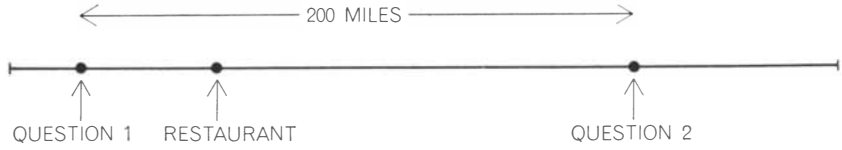

Chart for Problem 7

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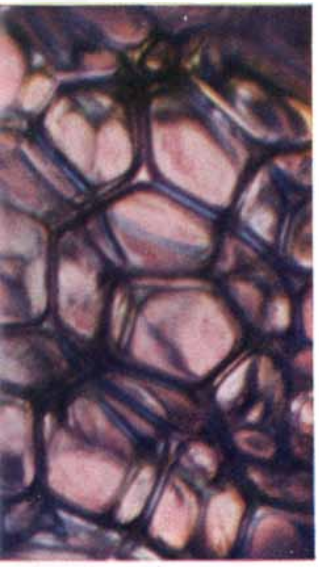
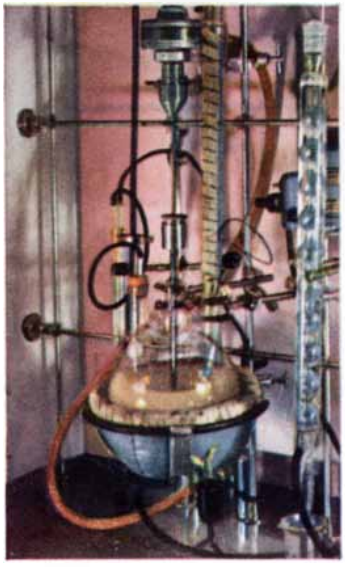
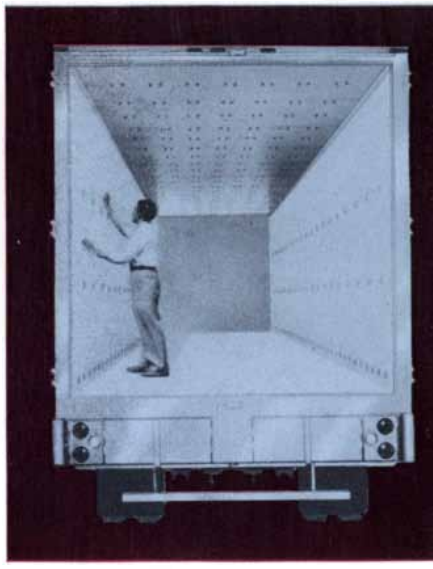


1 Under 50X magnification, rigid Glidfoam shows myriad of individual fully sealed airtight cells which give this moisture-resistant plastic its low density of only 2.0 lbs./cu. ft.



2 Glidden chemists formulate custom recipes of resin, catalysts, blowing agents, and surfactants to meet the specific flow and foaming requirements of each Glidden application . . . reefer bodies, pallatized containers and commercial freezers.

3 This transparent mold, simulating double-wall trailer construction, shows how Glidfoam, pumped as a two-component liquid, solidifies into a homogeneous bubble-filled rigid foam of uniform density with no shrinkage at successive pour "knit lines."



4 On a reefer-trailer production line, the temporary form has been removed from the trailer interior for final inspection of the poured Glidfoam after setting. Note that Glidfoam is a sturdy, self-supporting, continuous, thermal barrier that cannot vibrate down and leave uninsulated heat paths at the trailer roof-line.

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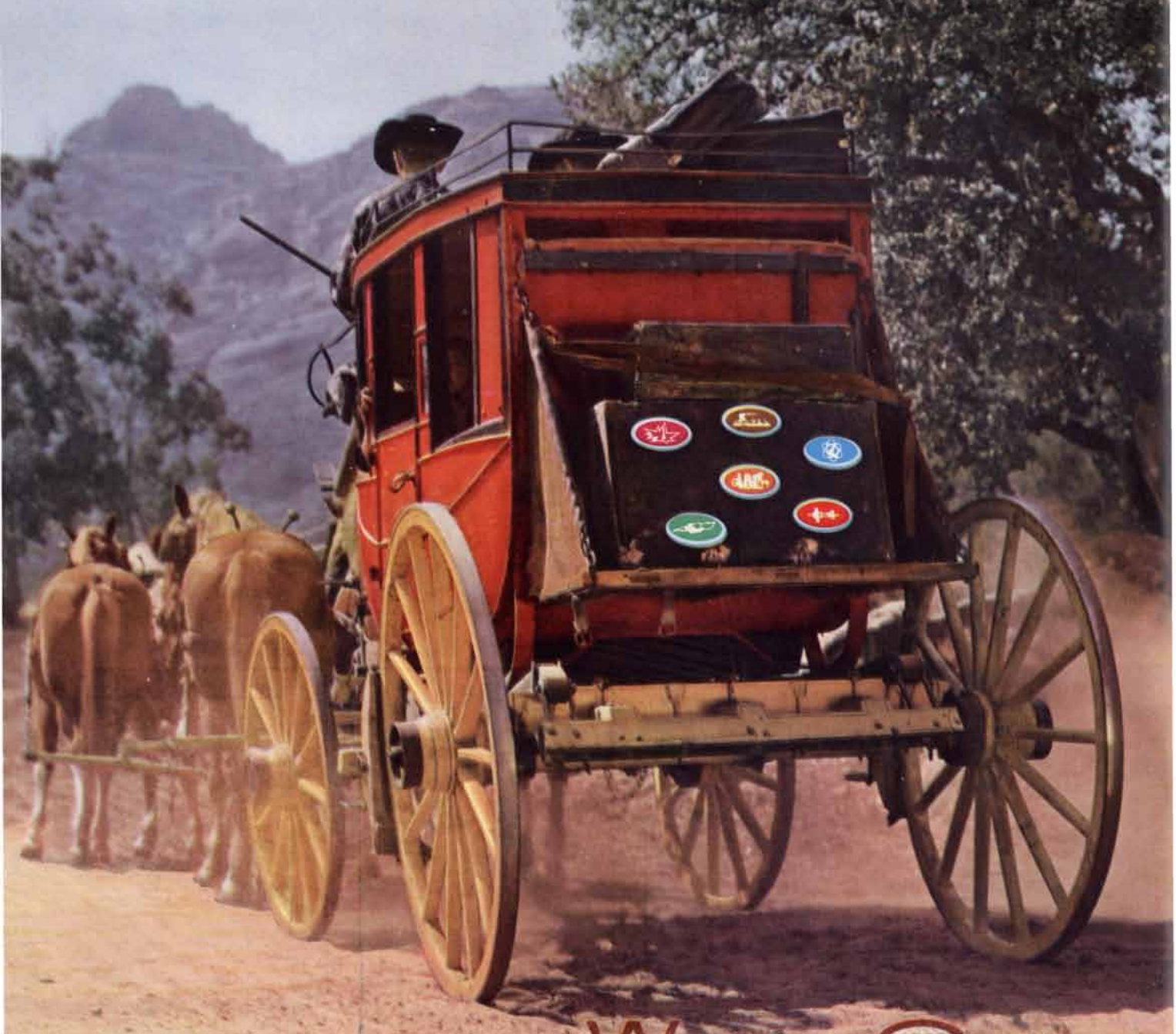

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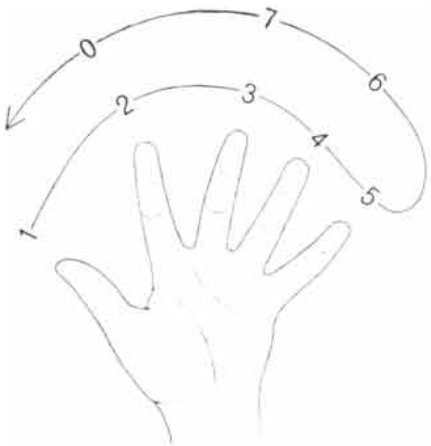
Pennsylvania, the various times of day that are given are irrelevant, since Smith drove at varying speeds. At two points along the way Mrs. Smith asked a question. Smith's answers indicate that the distance from the first point to Patricia Murphy's Candlelight Restaurant is two-thirds of the distance from the start of the trip to the restaurant, and the distance from the restaurant to the second point is two-thirds of the distance from the restaurant to the end of the trip. It is obvious, therefore, that the distance from point to point (which we are told is 200 miles) is two-thirds of the total distance. This makes the total distance 300 miles. The bottom illustration on page 150 should make it all clear.

8.

When the mathematician's little girl counted to 1,962 on her fingers, counting back and forth in the manner described, the count ended on her index finger. The fingers are counted in repetitions of a cycle of eight counts as shown in the illustration below. It is a simple matter to apply the concept of numerical congruence, modulo 8, in order to calculate where the count will fall for any given number. We have only to divide the number by 8, note the remainder, then check to see which finger is so labeled. The number 1,962 divided by 8 has a remainder of 2, so the count falls on the index finger.

In mentally dividing 1,962 by 8 the mathematician recalled the rule that any number is evenly divisible by 8 if its last three digits are evenly divisible by 8, so he had only to divide 962 by 8 to determine the remainder.



How fingers are labeled for Problem 8

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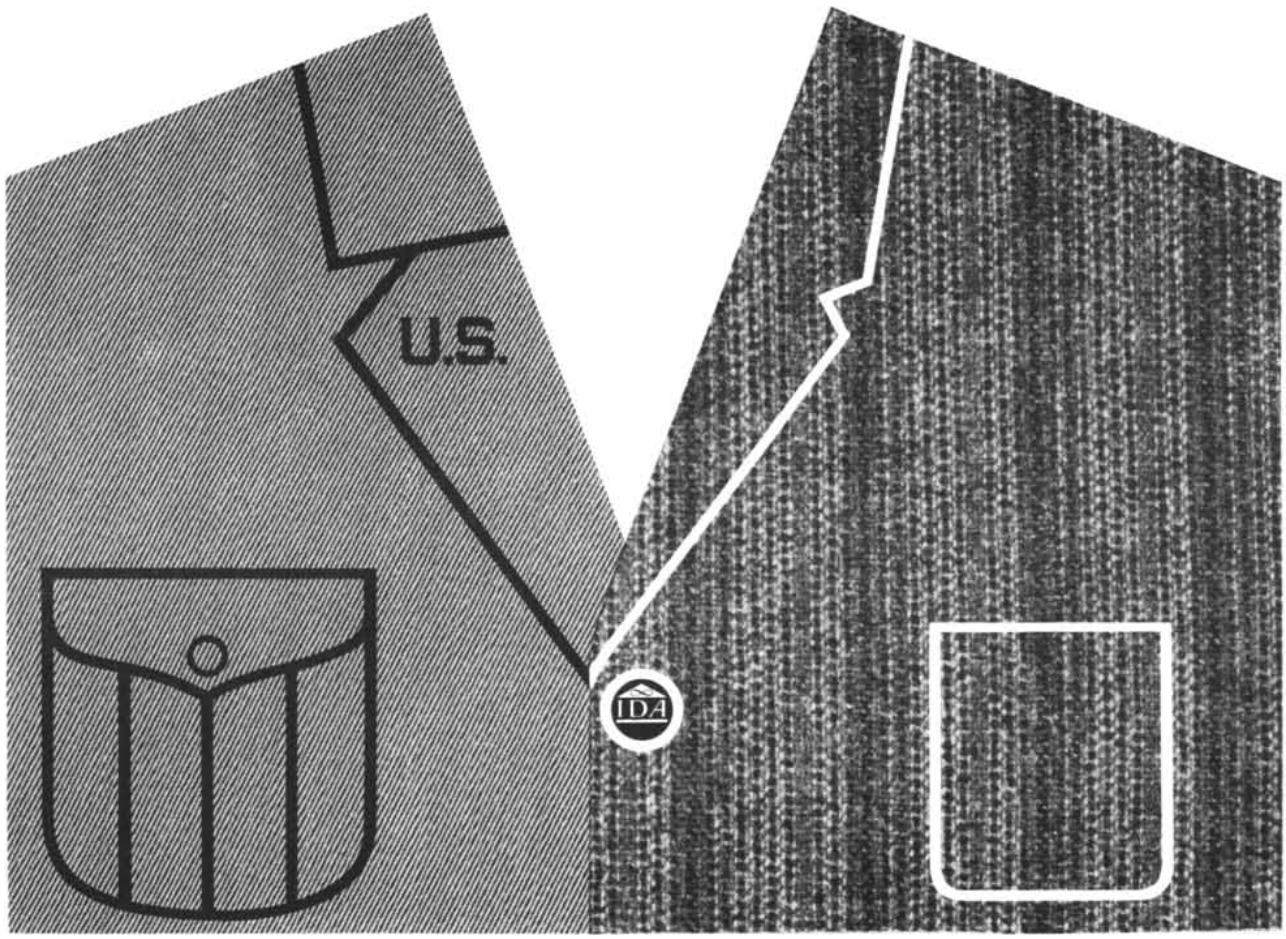


THE AMATEUR SCIENTIST

Growing crystals in silica gel mimics natural mineralization

Conducted by C. L. Stong

You can't make a mineral in the laboratory, no matter how hard you try. By definition, minerals are chemical elements and compounds that occur naturally as products of inorganic processes. On the other hand, several techniques have been devised for making reproductions of minerals that easily match and even surpass the natural products in perfection of substance, in form and in color, including quartz crystals, rubies and sapphires.

In one technique that has largely been overlooked by amateur experimenters two or more chemicals, usually the salts of metals, are made to react in a gel. The speed of the reaction is fixed by the leisurely pace at which the chemicals diffuse through the medium. As a consequence crystals grow much larger than they do when formed by the same reaction in an aqueous solution. The gel also serves as a lattice that supports the fragile crystal formations during their initial stages of growth. By retarding some reactions selectively the gel also encourages the growth of exotic patterns of crystals that closely resemble those found in nature, particularly if the medium is silica gel. There is much evidence, according to Walter R. Averett, a chemist of Golden, Colo., that a large number of minerals were formed by chemical reactions in silica gel that later turned into quartz. The gel technique enables the experimenter not only to make interesting mineral reproductions but also to investigate the broad and fascinating subject of quartz mineralization.

"The events that led to the earth's deposits of minerals," Averett writes, "are surrounded by many puzzles. How does it happen that bands, crystals and suspensions of gold are found in quartz? How do pyrite crystals get inside hunks of quartz? There is a theory that gold that has been precipitated can be redissolved and transported by solutions containing ordinary salt and manganese. If this can happen in a silica gel that has not yet become dehydrated to quartz, these occurrences of gold in quartz are not at all mysterious. Although some phases of the chemistry of colloids and gels have received considerable attention, their role in mineralization still awaits detailed exploration. In part this is because a great many different reactions are possible among the inorganic salts that form minerals, and when such salts are combined in a gel, they react so slowly that only a few combinations can be studied in the course of a year.

"One of the earliest experiments of this general type, performed in the last century by the German chemist R. E. Liesegang, suggests how banded minerals such as agate may have been formed. He spread a thin layer of gelatin gel on a sheet of glass and then placed a crystal of silver nitrate in the middle of the sheet. Within a few days the glass was covered by a pattern of concentric rings, the space between the rings increasing logarithmically from the center somewhat as in banded agate. Certain other salts produce similar rhythmic banding, some exhibiting secondary logarithmic bands and others with bands that are periodic but not logarithmic. And some minerals are so marked. This does not necessarily imply that we have hit on the identical reactions that occurred in nature when the minerals were formed, but banded variscite, chalcedony and ferrous carbonates found in the Lake Superior region appear to have been formed by closely related reactions.

"In any case Liesegang's experiment can make an engrossing 'rainy afternoon' project for amateur mineralogists. To set it up, prepare a 3 per cent solution (by weight) of gelatin that contains .4 per cent (by weight) of potassium chromate. Three grams of plain, unsweetened, unflavored gelatin, for example, may be added to 96.6 milliliters of hot water (140 degrees Fahrenheit or more). Stir into the mixture .4 gram of potassium chromate. A shallow container such as a watch glass is filled with the solution and set aside to cool. When the mixture has gelled, a single drop of 20 per cent silver nitrate solution is placed gently on the gel at the center. (This concentration can be made by adding four grams of silver nitrate to 16 milliliters of water.) If all goes well, rings of silver chromate will start to form in a few minutes. The experiment can be made with reasonably pure tap water, but if tap water gives disappointing results, try distilled water.

"Although this experiment demonstrates rhythmic banding, no crystals will form because gelatin belongs to the class of 'protective' colloids; it prevents the direct union of particles. Silica gel, a nonprotective colloid, is the preferred medium for growing crystals.

"Silicon bears about the same relationship to the mineral kingdom as carbon does to the animal and plant kingdoms. Like carbon, it has four valence electrons and in some measure it forms compounds analogous to those of carbon. Furthermore, its compounds are almost as numerous and varied as those of carbon, and they exist as solids, liquids and gases. If silicon dioxide (the silica of ordinary beach sand) is heated with sodium carbonate, it yields a glassy composition consisting of various oxides of silicon and sodium. When the proportion of sodium is high, the mixture is water-soluble and is known as water glass: the familiar thick, sirupy solution commonly used as a cement, a preservative for eggs and a filler for pasteboard and soaps. When acid is added to water glass, the mixture sets up in the form of a highly permeable gel. Some naturally occurring quartz appears to have been deposited in the form of silica gel; it is tempting to suppose that these deposits played at least a passive role in a number of the inorganic processes involved in mineralization.

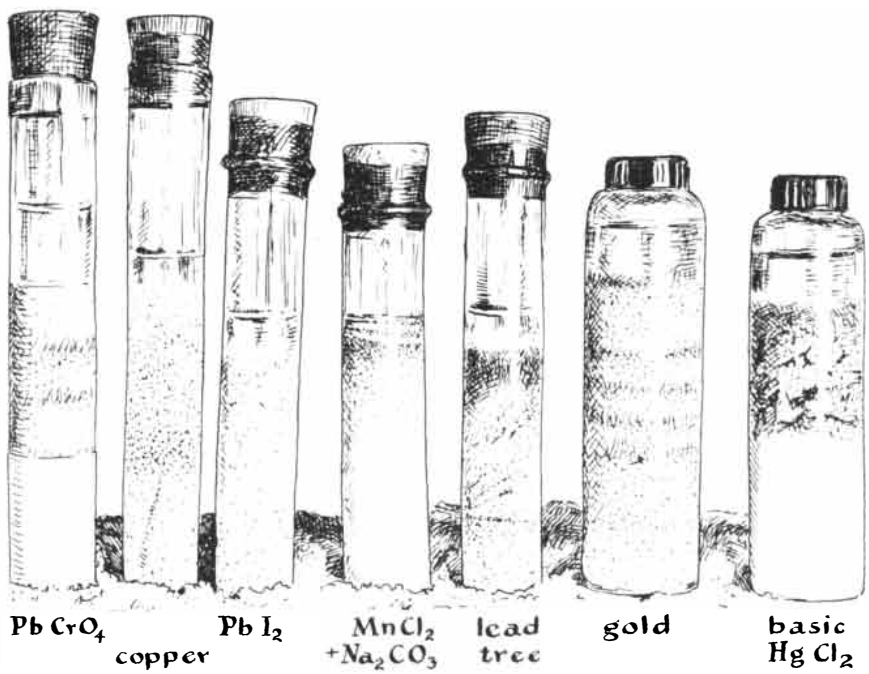
"Water glass is normally stocked by drugstores, and most of the other chemicals required by the experiments to be described can be procured through drugstores from dealers in chemical supplies. In addition to the chemicals, the experi-

menter will need a balance or spring scale capable of weighing tenths of a gram to 20 grams or more, a graduate calibrated in milliliters, a few wide-mouthed glass jars of one-liter capacity and a dozen test tubes or bottles of 100-milliliter capacity for holding the mixtures during reactions. I prefer the small bottles used for displaying samples of petroleum because they are easy to stopper and have flat bottoms for shelf storage. The experiments can be set up in any convenient room that is reasonably free of dust and where the temperature is reasonably constant, such as the average basement. One other most important item of equipment is a notebook. A precise record of the materials and concentrations involved in each reaction and a detailed description of the various phases of the reaction serve as an indispensable reference for evaluating the results and as a guide for planning future experiments. Finally, a note of warning: Many of the metallic salts are deadly poisons. Keep them out of your mouth, off your skin and away from children and animals.

"Most of my experiments are made with water glass that has been diluted to a specific gravity of 1.06. An easy method of making the dilution is to add water to the water glass as it comes from the supplier until a liter of the mixture weighs 1,060 grams. One can also measure the specific gravity with a hydrometer. (The float of storage-battery hydrometers sold by automobile-accessory dealers is usually calibrated in graduations of 25 units, but the desired value of 1,060 can be estimated with sufficient accuracy.) The stock of diluted water glass can be stored in fruit jars or other clean glass containers that can be tightly capped.

"In setting up an experiment I follow the sequence of first measuring out a desired quantity of adjusted water glass (enough almost to fill the reaction bottle) and then adding acid to gel it. One chemical to be reacted is added to a diluted solution of acetic acid, shaken vigorously and mixed with the water glass. (Some strong acids make the water glass gel instantly; gelling with acetic acid proceeds slowly.) The mixture is then transferred to the reaction bottle. After the gel has formed, a solution containing the second chemical is poured on top of the gel and the preparation is then placed on a storage shelf.

"Some reactions proceed quickly and others stretch out over months, occasionally with surprising results. Give the mixtures plenty of time to react—six months or more. In one experiment I reacted sodium bicarbonate in the gel with manganese chloride on top. Manganese dioxide formed within hours, as I expected, but after several weeks some mysterious white bands appeared in the gel and opened the way to a whole new series of experiments. Such experiences demonstrate the error of discarding mixtures too quickly. It even pays to set 'failures' aside for a time on the chance



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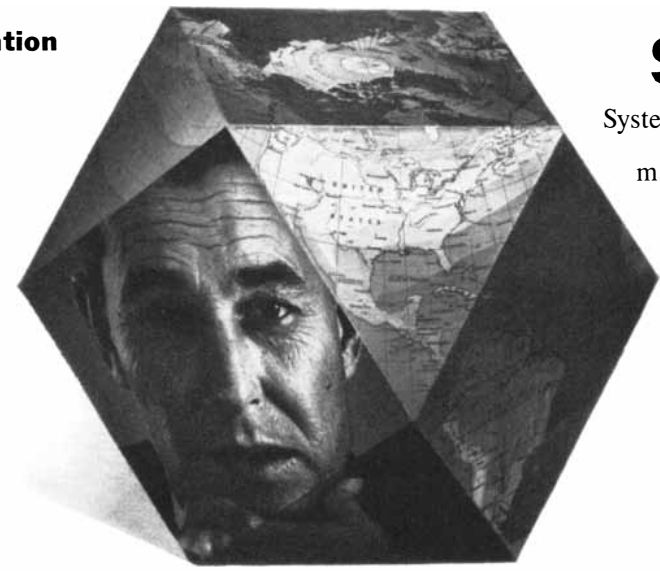

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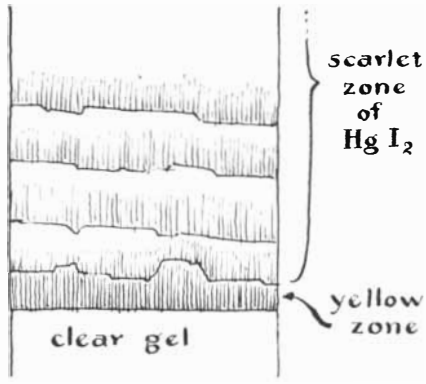
that a slow reaction will eventually turn up a formation of interest. Crystal culture, like nearly all experimental procedures, involves a significant proportion of art as well as scientific method. The art portion becomes scientific when it is eventually explained, and it is during the explanation phase that the notebook becomes invaluable.

"I gel the water glass by mixing it with an equal volume of 1-normal acetic acid solution. A 1-normal solution is one that contains Avogadro's number (6.02×10^{23}) of ions per liter. When acetic acid is added to water, each molecule of acid forms an ion. A 1-normal solution of acetic acid must therefore contain Avogadro's number of acid molecules, and in the case of acetic acid that number of molecules is equal, in grams, to the molecular weight of the acid. The molecular weight of acetic acid is 60. Water weighs one gram per milliliter. To make a 1-normal solution, therefore, 60 grams of glacial acetic acid are dissolved in 940 milliliters of water.

"A vivid reaction that makes a nice introduction to the procedure involves mercuric chloride and potassium iodide. Make up 100 milliliters of gel that is .1 normal to a solution of potassium iodide. [The molecular weights of most salts can be found in the reference texts listed in the bibliography on page 183.] Pour the mixture into a test tube (or reaction bottle) and let it set up. Stopper the container so that the top of the gel will not become dry. When the mixture has set, remove the stopper and cover the gel to a depth of a centimeter or more with .5-normal mercuric chloride.

"Within a few hours a yellow precipitate will form. Some evidence of scarlet mercuric iodide will appear shortly thereafter. The scarlet coloration will continue to develop for several days, the amount depending on the quantity of potassium iodide contained in the gel. At the end of two weeks pour off the unreacted mercuric chloride solution. About a month later you will find that the resulting mercuric iodide has solidified as a cluster of scarlet, needle-like crystals that grow up from the bottom of the deposit. Since the reaction is heavily influenced by the concentration of potassium iodide, the beginner will be repaid by setting up a series of reactions in which the normality of the gel to the salt is varied from .1 normal to 1 normal, say, in steps of .1 normal. The excess potassium iodide forms a salt without a name that is described by the formula K_2HgI_4, and it is this salt that accounts for the yellow precipitate.

"Reactions between the salts of lead



Mercuric iodide, showing stepped banding

and those of chromium, molybdenum, vanadium and the halogens constitute an engrossing introduction to the reproduction of minerals. Lead chromate is particularly interesting because of its natural occurrence as crocoite. A gel made .2 normal to potassium chromate and reacted with lead acetate of about the same concentration yields yellow lead chromate. In a basic gel (made by gelling with .5-normal acetic acid instead of 1-normal acid) the product will be both yellow lead chromate and orange-yellow basic lead chromate. I find that these chromates form sharp bands, very closely spaced. After standing for some months the chromate turns into a beautiful formation of deep-orange-colored crystals and blades. One could doubtless grow lead vanadate and lead molybdate in the same way, although I have not made these experiments.

"Native lead occurs so rarely that most geologists have never seen a specimen outside of a museum. But lead 'trees' are one of the easiest formations to prepare. A gel is set up .05 normal to lead acetate and a small piece of metallic zinc, tin or cadmium is pressed into the gel. Crystals of lead promptly appear in the form of needles and blades; the reaction will fill the entire vessel with crystals if it is allowed to continue. If the metal is introduced as a thin wire that runs through the gel from top to bottom, a treelike structure will form. My only failures with this experiment happened when I did not make the gel sufficiently acid, an error that is easily made when one works with solutions of low normality.

"Other native metals can be similarly prepared. If a gel is made .05 normal to copper sulfate, for example, and reacted with a 1 per cent (by weight) solution of hydroxylamine hydrochloride (poured on top), crystals of metallic copper will appear within a few days in the form of tetrahedrons, feathers and triangular

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blades. Eventually some of the crystals will join as three-bladed clusters that are identical in form to some occurrences of native copper in the Lake Superior region. A striking change in the size, form and color of the copper crystals can be induced by altering the acidity of the gel and the concentration of copper sulfate. Most of my copper formations appeared almost black unless viewed in direct sunlight, but one variation of the experiment produced crystals of a somewhat less bladed shape with the characteristic color and luster of polished copper, even when viewed in artificial light. All the crystals were quite small because they were grown in petroleum bottles and the copper sulfate could not be replaced as it came out of the gel. It might be possible to provide for replenishment by setting up the gel in the bottom of a U tube. Solutions of the two reagents could be added through the open ends of the U and large crystals should grow, but I have not yet tested this idea.

"A dazzling display of metallic gold can be produced by gelling the water glass with 3-normal sulfuric acid and adding two milliliters of a 1 per cent solution of gold chloride to each 25 milliliters of gel, and pouring a few milliliters of saturated oxalic acid solution on top of the gel after it has set. The gel sets up slowly, requiring a week or more, and the gold forms even more slowly. According to the reference texts, crystals of gold form in silica gel if the specific gravity of the gelled water glass is 1.06, and colored bands of colloidal gold form when the specific gravity of the water glass is 1.16. My only experiment was run at a specific gravity of

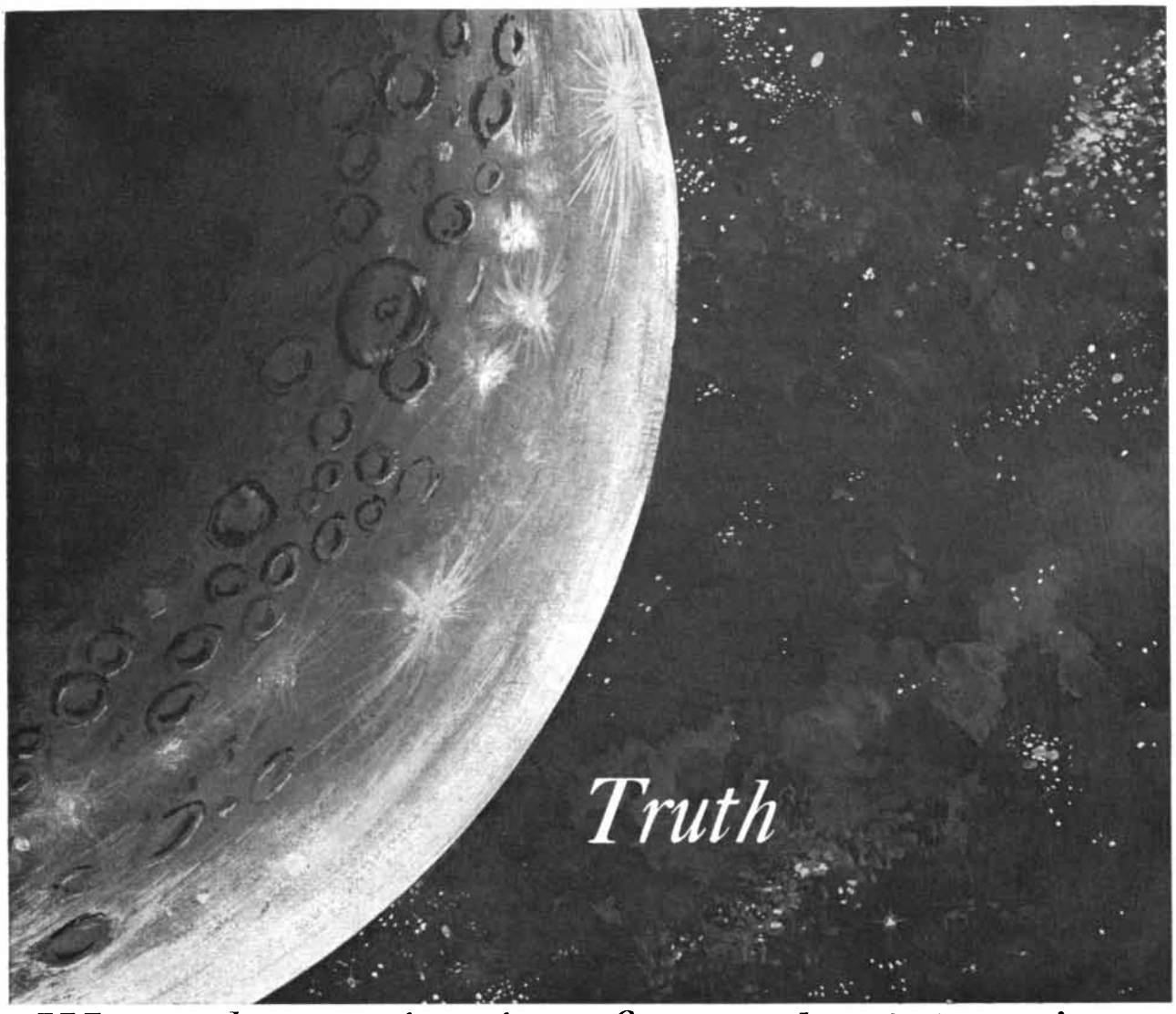
Crystals of lead chromate in clear gel

Copper crystals (10 times natural size)

1.06. Wide bands of colloidal gold formed, with myriad crystals distributed throughout the gel. It looked fabulously rich in gold—and when judged against the standards of the desert prospector the formation was pretty good. It would assay about $1,000 per ton!

"Herbert Freundlich, a specialist in colloidal chemistry, reports that gold crystals up to two millimeters in diameter have been grown in a gel containing sodium chloride and maintained at a temperature of 70 degrees centigrade. He also states that the gold will deposit as a sheet at the interface between the gel and the oxalic acid, if the concentration of acid is low. This suggests that many gold deposits in quartz could originally have been deposited in natural silica gel, because we have reason to suppose that high temperatures and an ample supply of reducing agents must have been present during eras of mineralization. At least one deposit of natural silica gel was discovered recently: a vein of silicic acid soft enough to be dug with the fingers was encountered by construction workers during excavation for the Simplon Tunnel in the Alps.

"One other characteristic of gold re-



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actions in gel merits special mention. Colloidal gold forms only in the presence of ultraviolet light, whereas crystals of gold form in the dark. Configurations of almost any desired shape can be grown in the colloidal region of the gel by exposing the preparation to sunlight through a mask. I once produced a fine grid pattern by exposing the test tube through window screening in the course of investigating the influence of light on the rate of reaction.

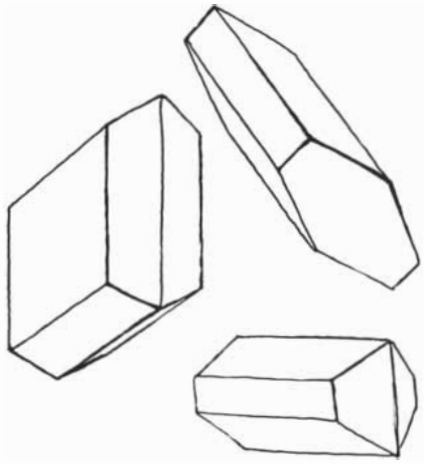
"There appears to be no limit to the variety of reactions that may be undertaken in gel media. All can be entertaining, many are of academic interest and a few are of practical value. There is much interest today, for example, in single crystals for electronic and ultrasonic applications. Only 3,000 different crystals that occur naturally have been described, but more than 12,000 others have been grown in the laboratory, mostly in aqueous solutions. The properties of new crystals grown synthetically are of great interest, and it appears that some varieties may grow more readily and to larger sizes in gel than in aqueous solutions. A recent description of an apparatus for growing large crystals of lead selenate in aqueous solution emphasized the care that must be taken to maintain a very low rate of ion migration. A tube of silica gel would provide automatic rate control and might well provide an effective growth environment.

"In the experiments suggested so far the sodium silicate functions merely as a mechanical agent. The gel does not participate in the reaction. Direct reaction does occur, however, when a solid lump of inorganic salt is dropped into a dilute solution of sodium silicate. In the case of copper sulfate and similar salts a colloidal membrane permeable only to water promptly forms around the lump. Water from the sodium silicate migrates through the membrane by osmosis, dissolves some of the copper sulfate and builds up pressure between the lump and the membrane. Eventually the pressure ruptures the membrane. A new membrane then forms and the cycle continues. The 'chemical gardens' that are sold as kits by novelty stores are based on this effect.

"As previously mentioned, silicon is the highly reactive element that dominates the mineral kingdom. Its negative ions combine with metallic positive ions, such as those of potassium and magnesium, to form the mixtures of salts that constitute many soils, clays and rocks. Silicon also appears to have played an essential role in structuring many other substances, including minerals, of which it is not a part. The inorganic salts, including those of silicon, are counted in the thousands, and the naturally occurring variety of their combinations, like the chords that can be built from the notes of the musical scale, is virtually endless. Not many of the reactions are fully understood, including some that have been observed for upward of a century, such as the phenomenon of the Liesegang rings. Many theories have been advanced in explanation of this periodic precipitation but I have not been able to make much sense of them. Most suggest that a band precipitates when more salt has diffused into the solution than the solution can hold, and nucleation occurs. Crystals then grow on the nuclei, deplete the solution and enable the migration to continue for a certain distance until supersaturation is again reached and another band of crystals is deposited. My personal reaction to this explanation is best expressed in the words of Omar Khayyám, as translated by Edward Fitzgerald:

Myself, when young, did eagerly frequent
Doctor and Saint, and heard great argument
About it and about: but evermore
Came out by the same door where in I went.

"In an informal report of this length it is not possible to do more than suggest a few introductory experiments in a broad field that I believe has been neglected. My purpose is to stir up interest in it. I believe that quite apart from the fun that amateurs can have in reproducing their own minerals there is a chance for serious and valuable crystal research in the medium of silica gel."



Copper salt crystals (enlarged 15 times)

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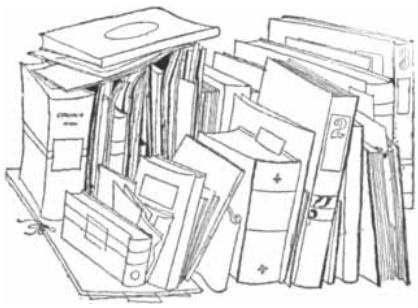

BOOKS

A Mexican family's life story provides an insight into "the culture of poverty"

by Robert W. White

THE CHILDREN OF SÁNCHEZ: AUTOBIOGRAPHY OF A MEXICAN FAMILY, by Oscar Lewis. Random House, Inc. ($7.50).

The autobiography of a Mexican family—what manner of book is this?

It is indeed a family autobiography, being the life stories of the four children of Jesús Sánchez, 50-year-old restaurant worker in Mexico City, as told to an anthropologist and his tape recorder. The father contributes some remarks about his own life, but the bulk of the book comes from the lips of his two sons, Manuel and Roberto, and two daughters, Consuelo and Marta. Manuel, who at 32 has a family of four children by a woman already dead, occupies himself with gambling and with little ventures in the sale of stolen merchandise that have much the character of gambling. Roberto at 29 has done one stint in the army and three in jail. Consuelo, the most educated member of the family, at 27 has irregular employment as a secretary and dreams of a career as a dancer. Marta, 25, is a housewife taking care of four small children and a man who is not their father. The stories are told with candor and feeling; they convey the frustrations and furies, the tragedies and heartaches, the hopes and the all too fleeting moments of happiness that come to people who have grown up in the midst of poverty. They make good reading, up to a point.

To what extent can this book be regarded as a scientific document, as a contribution to the systematic body of knowledge that is science? At first glance one might suppose that the book would be miscast in this role. Although it conveys vivid experiences, they are not such as lead directly to generalities and the discovery of lawful relations. But we must remember that science has its beginnings in the observations of the keen-eyed naturalist who collects facts for the later work of hypothesis, measurement and experiment. Such observations are also of service in restoring factuality when the scientific process has got things too easily schematized, as often happens in sociology and psychology. At a time when social stratification has been rather fully studied, when we are all tending to use schematized ideas about how things are in different social classes, a true scientific purpose may be served by a publication that, as Oscar Lewis expresses it, can give "an inside view of . . . what it means to grow up in a one-room home in a slum tenement in the heart of a great Latin-American city which is undergoing a process of rapid social and economic change." He might have added that these detailed self-reports provide grist for the psychologist bent on understanding emotional development. Indeed, both sociology and psychology stand to benefit from a study in which social surroundings and emotional problems are so clearly intertwined.

Having said this much, it is necessary to enter a word of caution and to challenge one of the claims Lewis makes for the material. "This method of multiple autobiographies," he says, "tends to reduce the element of investigator bias because the accounts are not put through the sieve of a middle-class North American mind but are given in the words of the subjects themselves." But of course the words had to be translated into English, and I think it is fair to say that, except for an occasional flurry of four-letter words and a few unaltered Spanish exclamations, they are translated into middle-class English. For this we cannot blame Lewis (what else could he have done?), but we must allow, thinking of the English used in North American slums, that the sophisticated language in which the Sánchez family speaks is something of an illusion. More serious for Lewis' claim is the fact that he eliminated from the life stories all the questions he asked his subjects: "hundreds of questions" designed "to cover systematically a wide range of subjects: their earliest memories, their dreams, their hopes, fears, joys and sufferings; their jobs; their relationship with friends, relatives, employers; their sex life; their concepts of justice, religion, and politics; their knowledge of geography and history; in short, their total view of the world." Can we believe that this middle-class North American questioning did not act as something of a sieve? And must we not allow that these fluent, connected stories would make quite a different impression on us if we saw them interspersed with the anthropologist's questions? Of course the material had to be edited and shortened; otherwise few would have the patience to read it. But we must not settle uncritically for the idea that we are receiving raw material straight from the heart of a Mexico City slum.

These remarks are in point because there are various ways in which true raw materials can be subjected to rather searching technical scrutiny. It is possible to analyze content, the sequence of ideas, the frequency of topics, the motives expressed, the common and recurrent images and many other aspects of interview materials. For such purposes one would have to use the original tapes, not the contents of this book. We must accept these life histories not for what can be proved from them but for what they illustrate and illuminate.

Lewis is particularly concerned that they should illuminate what he calls the culture of poverty. The word "culture" is here used in the anthropological sense to denote "a design for living which is passed down from generation to generation." The lives of the poor cannot be understood only in terms of economic deprivation, disorganization or "the absence of something." The culture of poverty "is also something positive in the sense that it has a structure, a rationale, and defense mechanisms without which the poor could hardly carry on." This culture (or subculture) exists for people at the bottom of the economic scale, but this means a third of the population in Mexico, where the 50-year-old revolution has yet to accomplish many of its

basic purposes, and it means still larger proportions in undeveloped countries. In a previous book, *Five Families*, Lewis has argued that the culture of poverty has important universal characteristics that transcend national, regional and rural-urban differences. It is hardly necessary to point out the importance of understanding this culture at the present moment in world history.

In Mexico, as elsewhere, the culture of poverty is markedly local and in a sense provincial. "Its members are only partially integrated into national institutions": they participate little in labor unions, political parties and national welfare agencies, and they are hardly aware of the burgeoning business, educational and artistic facilities that catch the attention of North American tourists. The Sánchez family lives in and cares about a very small world consisting of the few streets and apartment buildings in which relatives and acquaintances live. Economically the culture of poverty is characterized by underemployment, low wages and an absence of reserves either of food or cash. Crowded living quarters, sparsely furnished with secondhand goods, make for an enforced gregariousness and lack of privacy. The Sánchez home, scene of large parts of the life stories, consists of one room with a small kitchen and crude toilet facilities, in which at certain times through the accretion of relatives there were as many as 17 inhabitants, most of whom slept on the floor. Psychologically the common characteristics of the culture include physical violence in child training and the settlement of quarrels, early initiation into sex, free unions rather than legal marriages, frequent abandonment of mothers and children, and a high incidence of alcoholism and like pathologies. "Other traits," Lewis adds, "include a strong present-time orientation with relatively little ability to defer gratification and plan for the future, a sense of resignation and fatalism based upon the realities of their difficult life situation." Toward the police and other symbols of the dominant classes there is lasting hatred and cynicism. The mistrust extends even to the Church: private prayer to the saints and pilgrimages to popular shrines take the place of regular attendance at confession and Mass.

The middle-class North American reader needs to know this much about the culture of poverty if he is to read the stories of the Sánchez children with sympathetic understanding rather than moral censure. These young people would be the picture of irresponsibility if they had grown up in an achievement-oriented subculture with real future opportunities and had still come out as they did. Yet these very "irresponsibilities" are in most cases characteristic of most of the people around them, forming the cultural pattern and setting the models of behavior that they learn to consider acceptable. When Manuel, grief-stricken at the death of his first spouse, wanders off to the U.S. to do farm labor, leaving his four children to the care of his father and sisters, when he sends little money home and loses the rest at a race track, when he shares his life with another spouse but carefully lives away from home lest the children interfere with this new relationship—we can hardly avoid siding with Consuelo in her shrill denunciation of her brother's selfishness, but it is nothing peculiar to Manuel; the culture of poverty does not consistently condemn this privilege of the male, which is being enjoyed by many of his friends. For the sake of understanding we must go as far as we can to see such behavior as congruent with the culture, and the culture itself as an attempted adaptation to the real circumstances of poverty.

The action of culture on individual growth is often described as a process of socialization, the implication being that children, with their strong impulses and lack of control, are a social menace until properly molded by culturally inspired training. Reading the Sánchez stories forces a rather drastic revision of this middle-class imagery. To a substantial extent the action of the culture of poverty has to be called a process of brutalization. The individual must become tough, mistrustful, self-sufficient and aggressive if he is to endure the life that lies before him. While the Sánchez children are still quite young they show those qualities of dependence and affection that make for educability in peaceful and constructive directions. Manuel and Roberto both recall a time when they felt no hostility toward other boys and were timid about getting into fights. The culture of the apartment-house courtyard deals imperiously with such inclinations and both boys become accomplished fighters. Consuelo wants neatness, cleanliness and quiet in the home, but the culture teaches her to forget such impractical nonsense. She is afraid of sexuality and does not in the least want to be a loose woman, but she learns that her body is the bribe she must offer if she is to expect employment and advancement. This is socialization in a sense, but in a confusing sense. The aggressive and sexual impulses that need careful channeling for middle-class exist-

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ence must here be culturally strengthened, whereas tender, orderly and constructive tendencies must be firmly suppressed.

The lives of the four children were strongly affected by the early death of their mother. The effects were most marked in the cases of Roberto and Consuelo, who were respectively five and three when the tragic event took place. When Consuelo was in her late teens and was driven from the house by fierce bickering, she retired to the hovel of an older woman of her acquaintance, where during the evenings she sat "listening to her sweet, kind voice which made me sense the thing I was always seeking—a home and a mother." Having been told earlier that her mother watched over her from heaven in the form of a star, she now began to "talk to that star in a whisper, begging it to give me strength, and, if it were really she, to stop what was going on. Why didn't she make my father see what he was doing to us?" Roberto's response took the form of a touchingly memorable scene in which, after saying to his brother and sister, "Don't cry, *mamá* is just sleeping," he secretly got into the bed on which she was laid out and was found sleeping beside her under the sheet. As an adult he still missed her, felt that he could never be happy, and found peace only by going off alone as a vagabond. This is the young man whose freely flying fists got him into constant trouble with the law.

It is in connection with money and employment that one can see most clearly the present-time orientation and lack of planning mentioned by Lewis as a cultural trait. Roberto relates that "by the time I was thirteen, I had been a stevedore, a locker boy, a glass worker, a baker and a mason. The next thing I tried was varnishing furniture." For Manuel too there were many jobs and many changes, interspersed with periods of doing nothing. From the ease with which jobs were obtained it seems unlikely that all their unemployment was forced on them. Their attitude toward money and planning is well illustrated by two incidents. Roberto helped a criminal on a job of burglary and received as his share what was for him a very large sum. With this in his pocket he could not resist the temptation to spend lavishly, ordering drinks for everybody and being a big shot for a few days until the money was gone. Manuel at one point started a small business of manufacturing shoes. As money came in he had the kindly impulse to raise the wages of his two helpers, not wanting to exploit them as he had often been exploited. Soon the business was in fatal debt, and then for the first time he sat down to do the arithmetic that would have shown this outcome was inevitable.

But now we come on a striking paradox that illustrates very well the danger of too hastily attributing behavior to cultural patterns. The father, Jesús Sánchez, is a steady, reliable worker who provides well for his children. He has provided a home, sufficient food and a certain amount of spending money not only for these four children but also for a second "wife" and two children (all still alive), a third "wife" (now dead) and a fourth "wife" and his children by her. In addition he is the main support for Manuel's four children, and he provides a haven for Marta and her brood at times when neither her "husband" nor her boy friend is congenial. Toward the end of the story Jesús is supporting three households containing up to 20 people. He does this by a steady job, held for many years, as food buyer for the La Gloria restaurant, piecing out his modest wage by raising birds and by keeping pigs in the outskirts of the city. A stroke of luck in a lottery enabled him to buy the materials to build a small house for one of his families, and he would like to do the same for the four children of this book. His vacation consists of one day, May 1, every year; otherwise he works seven days a week—the pigs cannot give him a day off. We are not surprised that he feels old at 50 and thinks of the day when he will drop in his tracks.

This is not congruent with the culture of the poor. Jesús may have, as his children suspect, his little rackets in the food market, but the main source of his income is hard, steady, devoted work, and work is one of his chief values and satisfactions. All the relatives point to him with admiration as a fine provider and a good father; his children deeply share this estimate. Perhaps he has come by his values through being the son of prerevolutionary rural parents, an earlier cultural tradition; at all events, he is deviant from the culture that surrounds his children and seems more like a man bent on moving upward to middle-class economic and social status. The children of Sánchez, therefore, were not exposed solely to the models provided by the neighboring courtyards and streets. Had they gone to work and tried to better themselves, as Consuelo attempted to do, there would be no trouble in pointing out the model they were copying.

It is here that psychological considerations become decisive. Perhaps we can say that Jesús was deviant from the

culture of poverty in only one respect, one that is difficult to imitate by itself unless a person has a special taste for it. He was certainly not deviant with regard to his sexual impulses, toward which he was highly permissive; the services of various women hired from time to time to help with the children included nocturnal obligations to the master that could hardly be a secret in the one-room home. He accepted the cultural value that law and religion are superfluous in the decision to found a family, and he did not subscribe even to the idea that one family at a time is enough. He chided Consuelo for trying to rise above her class. Finally, he was in perfect accord with the cultural expectation that children should be beaten but not heard.

This last feature of the father's character proved to be ruinous for the children. It seems a paradox, although psychologically it is not unfathomable, that a man should slave so hard to provide for his children without giving any outward evidence that he loved them. Here and there an incident occurs, such as his tearful embracing of Roberto in jail, that shows that in some deep way he did love them, but it must have been exceedingly hard for his children to feel assured of this possibility. His remembered utterances consist mainly of angry reproaches, furious invective and crushing belittlements, to which in the earlier years slaps and blows would be added. The two boys were so intimidated that even in their late 20's they would face these tirades with hanging heads and even with tears. "My father's words were destructive to everyone," said Consuelo; as with bitter disappointment she watched the family grow apart, she "always came up against the inflexibility of my father, who was like a hard rock. I wanted to hear him say with pride, 'These are my children!' But I heard only, 'Ungrateful wretches, that's what you are. You'll never be able to raise your heads.' " Apparently Consuelo was reporting correctly. Jesús himself told the anthropologist: "I am a person who bears grudges and I have a lot against three of my children, Manuel, Roberto and Consuelo. My body is becoming half-paralyzed from being so angry with these children of mine."

Taking into account the death of the mother, who might have provided an atmosphere of affection, and the father's constant irritability and shaming criticism, it is understandable that the children could not bring themselves to emulate their rugged model in the sphere of work. The very fact that he continued to support them may even have added to the difficulty. They were in the trap of admiring their father while burning with hot fires of resentment against his cruel attacks. What better than to fulfill his dire prophecies and enjoy life as much as possible, knowing that he would go on working and keep them from starvation? The culture of poverty certainly encouraged this course, but the Sánchez children needed it for reasons even more forceful than cultural conformity.

"Certainly the lives of the poor are not dull," says Lewis in his introduction. I think this is true in two senses but wrong in an important third sense. It is firstly true that these lives move rapidly from incident to incident, that no two days are alike and that in these young people there is a charming vitality even when they are most full of complaints. It is secondly true that the life stories will not initially be rated dull by middle-class North American readers who like to escape their own controlled life patterns by fantasies of sexual gratification, aggressive violence and a blithe disregard for ties that bind. But it is thirdly true, I believe, that few readers will finish the book without feeling sick to death of the children of Sánchez. I am glad that Lewis did not shorten the material to the point where this feeling could be overlooked, for these are real lives of real people still in early adulthood, and we should not be spared the perception that they are almost certainly going to go on just like this for as long as they live. Their lives are dull, then, in the sense that a badly plotted play is dull, having no feeling of motion from the first act to the last. There is a deeply tragic undertone that these young people are already finished, that there is nothing ahead of them except more of the same, which they will enjoy less and less and resent more and more as they get older.

Do they know it? If so, the tragedy is all the greater. "What am I waiting for?" asks Marta, pregnant with her fourth child, for which her boy friend is, as usual, making no preparation; "I'm waiting for nothing, exactly nothing!" Says Consuelo: "I will live half-blind, like the rest of the people, and so will adapt to reality." "Early or late," Roberto believes, "that which must happen will happen. That's the way the world is." And Manuel sums himself up as "a tangle of inexplicable emotions," a person who has led a life "so sterile, so useless, so unhappy that, *por Dios*, sometimes I wish I could die. I am the kind of guy who leaves nothing behind, no trace of themselves in the world, like a worm

WHAT THE TEST ON PAGE 39 REVEALS ABOUT YOUR PRESENT READING SKILL

NOTE: If you missed this little test and are interested in learning how fast and how retentively you now read, please turn to page 39 before reading what follows

THE PASSAGE on page 39 contains 214 words. To determine your reading speed, divide this word count, 214, by your total reading time *in seconds* and multiply by 60. The result is your reading rate in words per minute. The main fact contained in the passage is (d): "Yale brings $33,000,000 per year to New Haven." A trained reader would have grasped this basic fact in not more than 15 or 20 seconds—a rate of upward of 600 words per minute—by skimming, one of the most useful techniques of rapid reading. If it took you longer to cover this passage—and/or if you missed the main fact—you did not use the proper technique and thus are not reading as efficiently as you should.

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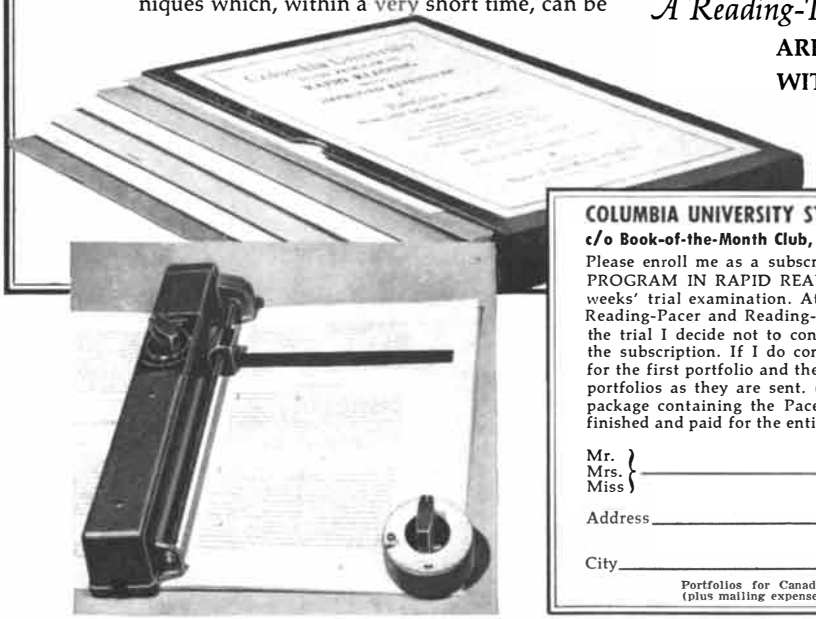

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dragging itself across the earth." He would like to do better, but this means winning a fight against himself, a fight he has lost consistently during his 32 years. I greatly fear that the children of Sánchez know in their hearts how little the future has in store.

How can it be otherwise for them? Even Jesús knows that he is "a simple worker" and will always be that way. His aspirations are limited to building a home for his children "so they can live there together. But they don't want to help me." Each child in his own way cherishes the goal of the family living happily together and with it has an awareness that this will never come to pass. Beyond this small local hope they expect nothing, unless it be by some improbable stroke of fate. They cannot influence their lot by group action, by voting, by any institutional participation: all these are rackets controlled by another class. They cannot enjoy the company of friends, who will look out only for themselves; only relatives are safe. They do not expect to guide and control the mysterious course of impulse in their own behavior. They do not trust the Church sufficiently to find any lasting consolation in its ministry or in the thought of a future life. Theirs is a pervasive sense of helplessness. Small wonder that their lives become so centered on excitement and the gratification of impulse.

The children of Sánchez certainly show most of the qualities described by Lewis as characteristic of the culture of poverty. In some respects their lives illustrate his further contention that the culture of poverty is a positive thing that molds its members in an adaptive fashion. We have seen examples of its brutalizing action as it fits children for their rough surroundings. But his way of expressing this must not lead us to overlook the self-defeating elements in the culture of poverty. Perhaps there is here, after all, an important "absence of something," a degree of failure by the cultural pattern to assist the poor in carrying on their lives.

Students of primitive societies are forever pointing out beliefs and customs, often fantastic to us, that have the effect of shielding people from a full realization of their helplessness against evils and calamities. The culture of poverty seems inclined rather to magnify helplessness by encouraging a mistrustful attitude toward everyone, thus blocking off whatever possibilities there might be in friendship, co-operation, religious ministry and the offerings of a government not wholly disinclined to fashion a

welfare state. As illustrated in this book it is a thin, materialistic, hopeless culture. Probably it represents what happens when dominant contemporary urban values—basically materialistic, proudly undeluded, yet an almost boundless faith in technological progress and increasing comfort—filter down to a social level that has little understanding of technology and little hope of profiting from its gains. Mistrust, with its consequent helpless isolation, can be understood psychologically in terms of frustration, aggression and the mechanism of projection. The culture of poverty seems to have let these processes get out of control. Perhaps we can say that, having invoked them adaptively to protect its members from boundless exploitation and to legitimize the solace of short-range hedonism, the culture has now failed to control their tendency to destructive expansion. It is no new anthropological principle to say that a cultural pattern can miss its adaptive target and encourage damaging values. But the reader of this book will find the world of the poor bad enough as it stands and will feel sorry that in some respects the culture of poverty makes it worse.

Short Reviews

JANE'S FIGHTING SHIPS, 1961–1962. McGraw-Hill Book Company, Inc. ($35). The extensive revisions of, and additions to, the 64th issue of *Jane's* include 380 new illustrations, reference tables and technical ship data. Navies are still having a hard time catching up to technical advances in other fields, but enormous sums of money are being spent on such items as nuclear submarines and various types of floating missile platform so as to achieve the new look. The U.S., it is said, has 23 nuclear-powered submarines, of which seven are armed with Polaris missiles; little is known about what the U.S.S.R. has achieved in this department, but painful surprises in the past have led both British and American naval circles to be cautious about underestimating Soviet nuclear-powered strength. The exuberant joy over the end of colonialism in Africa and the emergence of many new countries is somewhat tempered when one learns that among the first things these countries have done is to establish navies, so that there are now no less than 16 new naval forces.

ON GROWTH AND FORM, by D'Arcy Wentworth Thompson; abridged edition edited by John Tyler Bonner. Cambridge University Press ($5.95).

Thompson's celebrated and fascinating book, primarily an analysis of biological processes from their mathematical and physical aspects, was first published in 1917 and reissued in much enlarged form in 1942. Many of Thompson's mathematical descriptions and physical analogies are ingenious and suggestive; some are wrong and could have been proved wrong even when he put them forward; not a few, although novel in his time, have simply been superseded by advances in biophysics, mathematical biology and allied disciplines. All the same, although its influence on biological thought has been "intangible and indirect," it must be accounted a suggestive, exciting and important work; and its style, reflecting the blend of Thompson's rare gifts as a classicist, mathematician and naturalist, and his passionate interest in learning and the humanities, has led P. B. Medawar to characterize *On Growth and Form* as "beyond comparison the finest work of literature in all the annals of science that have been recorded in the English tongue." The Princeton University biologist John Tyler Bonner has had the happy thought of abridging the book so as to make it more attractive to the general reader and to eliminate sections that are quite clearly out of date. He has not condensed or rewritten Thompson's material; the words are all Thompson's own. Certain entire chapters—on the rate of growth, on the internal form and structure of the cell, on absorption, among others—have been cut out; but the favorites—such as "On Magnitude," "The Forms of Cells," "On Form and Mechanical Efficiency," "On the Theory of Transformations, or the Comparison of Related Forms"—are all here. A sound plan, well executed; it should give much pleasure to those who have not made the acquaintance of the original.

A HISTORY OF MEDICINE. VOL. II: EARLY GREEK, HINDU, AND PERSIAN MEDICINE. By Henry E. Sigerist. Oxford University Press ($11). This is the second, and unfortunately the last, volume of what was originally part of a proposed eight-volume history of world medicine by the foremost medical historian of our time. Immensely learned, yet carrying his learning lightly, and broadly sympathetic to all aspects of human civilization, Sigerist was uniquely qualified to write this history, whose aim is to describe the state and growth of medicine in its social, economic, political and cultural setting. His account therefore goes much beyond diagnoses, discoveries, methods and medical practices.

In each section—on "Archaic Medicine in Greece," "Hindu Medicine," "Medicine in Ancient Persia," "The Golden Age of Greek Medicine"—the book presents a graceful, illuminating and succinct essay on the society that produced its own characteristic form of medicine. This approach enhances not only readability but one's understanding of the peculiar attributes of medical knowledge in a given place and time. Attached to the last page of the typed copy of the manuscript was a note in Sigerist's handwriting saying, "Here my legacy ends." Like the editor, Ludwig Edelstein, who assumed the responsibility for this volume and who was moved by these words to execute the publication of the book as "a token of my indebtedness to him as scholar and friend," the reader will be filled with regret that this great and humane scholar did not live to complete his ambitious undertaking.

THE LEWIS AND CLARK EXPEDITION, by Meriwether Lewis ($12.50); ASTORIA, by Washington Irving ($8.50). J. B. Lippincott Company. These two attractive sets, the first consisting of three volumes and the second of two, initiate this publisher's "Keystone Western Americana" series, which is to include classic narrative histories reprinted from their original editions. The Lewis and Clark volumes consist of the 1814 edition, unabridged, of Lewis' story, which was based on diaries and journals covering the events of this most important expedition. Washington Irving's famous *Astoria,* first published in 1836 and also presented in unabridged form, is a fascinating account of the history of Western enterprise based on the materials that John Jacob Astor made available to Irving in 1835.

MATHEMATICS: A CULTURAL APPROACH, by Morris Kline. Addison-Wesley Publishing Co., Inc. ($7.75). A textbook for a one-year terminal course in mathematics, this volume addressed to the college liberal arts student exhibits the author's well-known skill in explaining mathematical ideas, in showing how they are applied to problems of the physical world and in relating mathematics to our civilization and culture. A superior survey that makes available to the teacher and the student the ideas Kline has presented in his earlier writings addressed to the general reader.

THE PHILOSOPHY OF C. D. BROAD, edited by Paul Arthur Schilpp. Tudor Publishing Co. ($12.50). This volume in the series "The Library of Living

Philosophers" describes the thought and work of one of the leading nonpositivistic British philosophers. It follows the same form as earlier volumes: an autobiography (very well written, as one expects of Broad's things), a series of critical essays on Broad's philosophy, a lengthy reply "to my critics" and a bibliography.

MAN AND DOLPHIN, by John C. Lilly. Doubleday & Company, Inc. ($4.95). A discursive and popular account of Lilly's continuing researches, whose purpose it is to communicate with dolphins. Dolphins are gentle and friendly, have a brain about equal in size to ours and make sounds that mimic the sounds we make. These attributes led the author to undertake his investigations. Lilly never succeeds, however, in making it clear why the fact that dolphins can mimic our conversations makes it any more likely that they understand us than the fact that we can imitate the noises they make enables us to understand them.

THE WANDERING ALBATROSS, by William Jameson (95 cents); SHEARWATERS, by R. M. Lockley ($1.25); HORSES, by George Gaylord Simpson ($1.45); FROM FISH TO PHILOSOPHER, by Homer W. Smith ($1.45). Doubleday Anchor Books. These paperbacks appear in a series called "The Natural History Library," which consists of books on the life and earth sciences. Jameson's study, now slightly revised to include observations of this remarkable bird recently made in the Australasian sub-Antarctic islands, was reviewed at length in these columns two years ago. It is a delightful book and readers are lucky to have access to it in this inexpensive format. Lockley's record, based on 12 years of observation, of the breeding and migration habits of the Manx shearwater is equally readable and a solid contribution to ornithology. The study of the horse family through 60 million years of history is the subject of Simpson's book, a wonderfully illuminating study of the evolutionary process. The eminent physiologist Homer Smith builds his fascinating book around the function of the kidney, showing how it has played a major role in vertebrate evolution by permitting adaptation of animals to different environments in water and on land.

A GLOSSARY OF GEOGRAPHICAL TERMS, edited by L. Dudley Stamp. John Wiley & Sons, Inc. ($10). A useful compilation that defines by example—

intended to show origin, previous usage, current use and misuse—the words and expressions used by modern geographers. Physical, economic and agricultural geography are covered and also terms borrowed from related sciences such as meteorology and geology.

THEORY OF FILM, by Siegfried Kracauer. Oxford University Press ($10). Kracauer, whose *From Caligari to Hitler*, a history of the German film in a crucial period of that country's agony and corruption, was a book of conspicuous merit, here presents a study of the motion picture, dealing with the development of the medium, its functions and main tendencies, its capacity to capture and reveal the everyday world, the special role of the actor in films compared with that of the stage actor, the problems of dialogue and sound, the use of music, the part played by the spectator, the experimental film, the documentary, the adaptation of literature to cinematography, the historical film. A most sensitive work, a penetration in depth of this art form that has in 50 years changed the thought and habits of large parts of the world.

PLANETS AND SATELLITES, edited by Gerard P. Kuiper and Barbara M. Middlehurst. The University of Chicago Press ($12.50). This third volume of a series that collects and systematizes information on the solar system contains 18 chapters by leading specialists covering such topics as the planet Earth as seen from space, the trans-Neptunian planet search, orbits and masses of planets and satellites, the stability of the solar system, planetary interiors, photometry applied to planets and satellites, polarization studies, temperature measurements, radio observation, visual and photographic studies. Included are a number of fine pictures made from artificial satellites, from the observatory on the Pic du Midi in the Pyrenees and with the 200-inch telescope on Palomar Mountain.

GEOLOGY OF THE ATLANTIC AND GULF COASTAL PROVINCE OF NORTH AMERICA, by Grover E. Murray. Harper & Brothers ($24). A comprehensive synopsis of geological data about the coastal region between Newfoundland and Spanish Honduras. This detailed work, the product of many years of study, including the author's own researches and a synthesis of hundreds of papers that have been written on the subject, presents a three-dimensional picture of the continental shelf, coastal

plain and certain plateau and mountain elements once part of the Mesozoic and Cenozoic coast. Abundantly illustrated with maps, diagrams, charts and photographs.

Notes

AUTOMATIC DATA-PROCESSING SYSTEMS, by Robert H. Gregory and Richard L. Van Horn. Wadsworth Publishing Co., Inc. ($11.65). An introductory text on business-data-processing, requiring no previous knowledge of electronic computing systems.

ATOMS TO GALAXIES: INTRODUCTION TO MODERN ASTRONOMY, by James Stokley. The Ronald Press Company ($6). A general reader's introduction to modern astronomy by the former director of the Fels Planetarium in Philadelphia. Illustrations.

THE ASTRONOMICAL WORKS OF THĀBIT B. QURRA, by Francis J. Carmody. University of California Press ($6). A critical edition of the works of Thābit, who played an important role in the renaissance of the mathematical sciences at Baghdad about A.D. 870 and who is remembered for his research on lunar phenomena and, more important, for his discovery of basic errors in Ptolemy's *Almagest*. He also demonstrated the variation in rate of precession of the equinoxes.

AUGUSTINE TO GALILEO: VOLS. I AND II, by A. C. Crombie. Harvard University Press ($5.50). A reissue, in a less expensive format, of the second edition of a standard survey of the technology and science of the Middle Ages.

THE ACTINOMYCETES: VOL. II, by Selman A. Waksman. The Williams & Wilkins Company ($15). The second volume of this treatise is entirely concerned with classification, identification and descriptions of genera and species.

MAN AND THE CHEMICAL ELEMENTS, by J. Newton Friend. Charles Scribner's Sons ($6). Revised edition of an interesting work that describes how man sought and found the chemical elements and adapted them to his use. Illustrations.

MOTION AND RELATIVITY, by Leopold Infeld and Jerzy Plebánski. Pergamon Press, Inc. ($7.50). A monograph giving the final results of a study by Infeld and Plebánski of the exceedingly difficult problem of motion in gravitational

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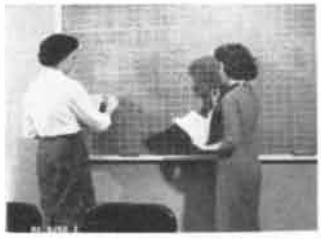




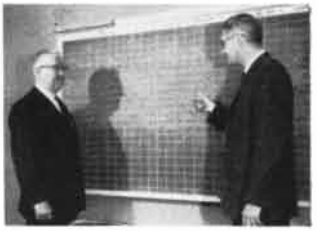

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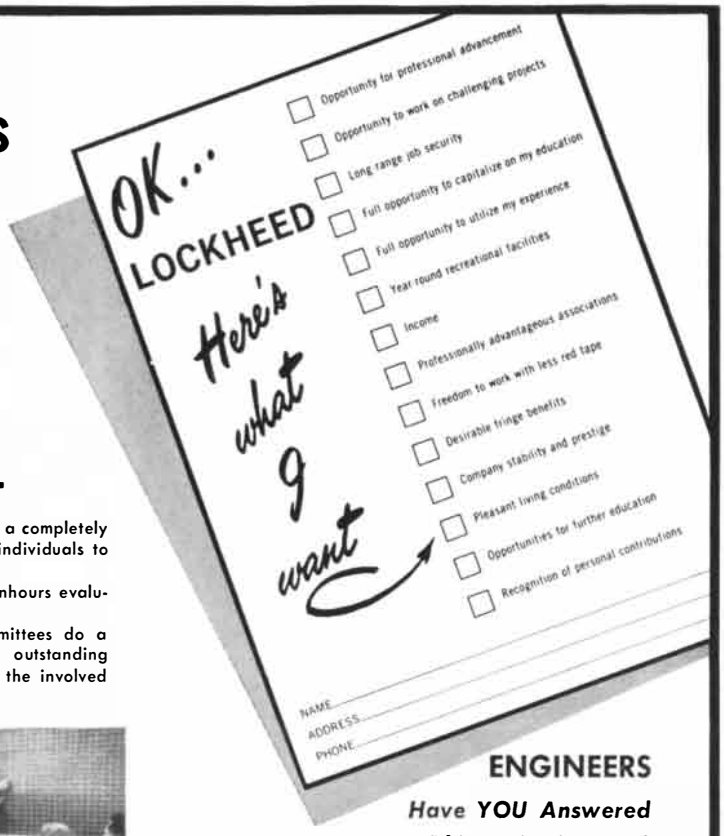

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theory. In spite of the fact that this is a technical work, mainly mathematical, the lucid accompanying text, which gives a physical explanation of the mathematics, reflects Infeld's uncommon skill as an expositor of the intricacies of relativity theory.

THE SCIENTIFIC PAPERS OF J. WILLARD GIBBS, edited by Henry Andrews Bumstead and Ralph Gibbs Van Name. Dover Publications, Inc. ($4). This collection of papers by Gibbs brings together, in their original form, all his contributions to thermodynamics, dynamics, vector analysis and multiple algebra, and the electromagnetic theory of light. An unabridged republication, in soft covers, of the first (1906) edition, including a biographical sketch by Bumstead.

LIGHT WAVES AND THEIR USES, by A. A. Michelson. The University of Chicago Press ($1.50). A paper-backed reissue of Michelson's lectures given at the Lowell Institute in Boston in 1899, which summarize the results of his first 20 years of research in optics, including his brilliant and revolutionary experiments with the interferometer.

MILK: THE MAMMARY GLAND AND ITS SECRETION, edited by S. K. Kon and A. T. Cowie. Academic Press Inc. ($26). A co-operative treatise on the morphogenesis, structure, growth, functional physiology and biochemical activities of the mammary gland; on lactation in man and farm animals, nutrition of the lactating animal and the nutritive value of milk.

AMERICA FACES THE NUCLEAR AGE, edited by Johnson E. Fairchild and David Landman. Sheridan House ($5). This book is a Cooper Union Forum, comprising lectures on such topics as the impact of the nuclear age, nuclear power, radiation hazards and so on. Although the lectures are pretty uninspired, the price of this 150-page unillustrated book proves that American readers do have to face up to the nuclear age.

DARWIN'S FINCHES, by David Lack. Harper Torchbooks ($1.40). An inexpensive reprint of Lack's charming book on the Galápagos finches, the study of which played a key role in leading Darwin to his idea of evolution.

CELL AND PSYCHE, by Edmund W. Sinnott. Harper Torchbooks (95 cents). Soft-cover reprint of Sinnott's well-known essay on the "biology of purpose."

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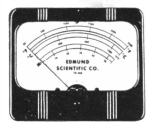

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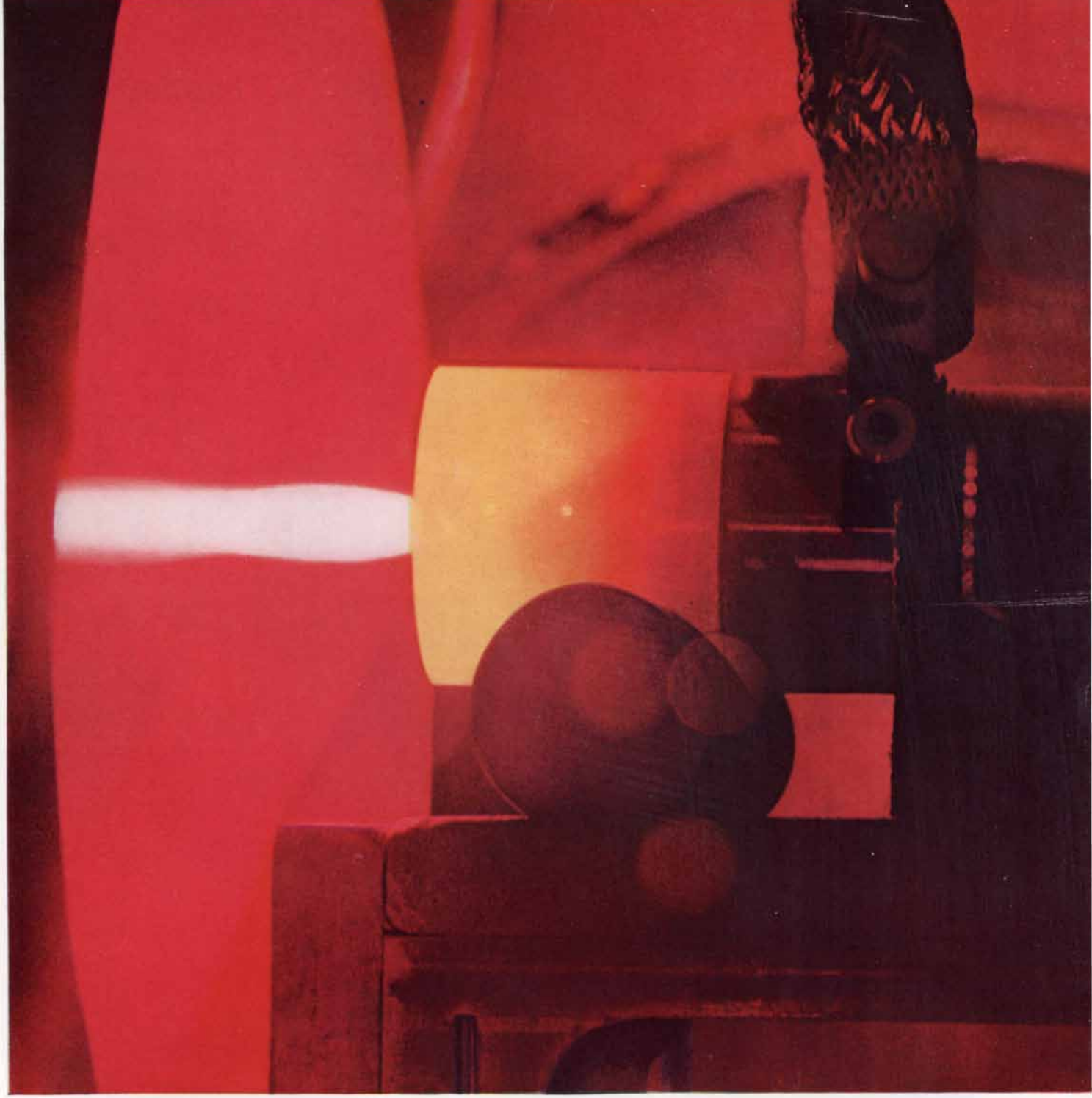

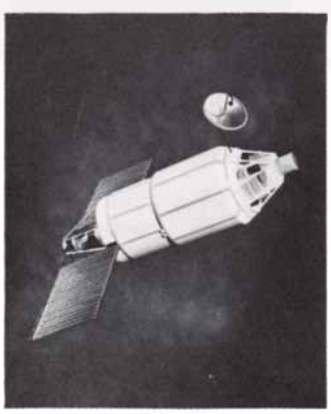

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