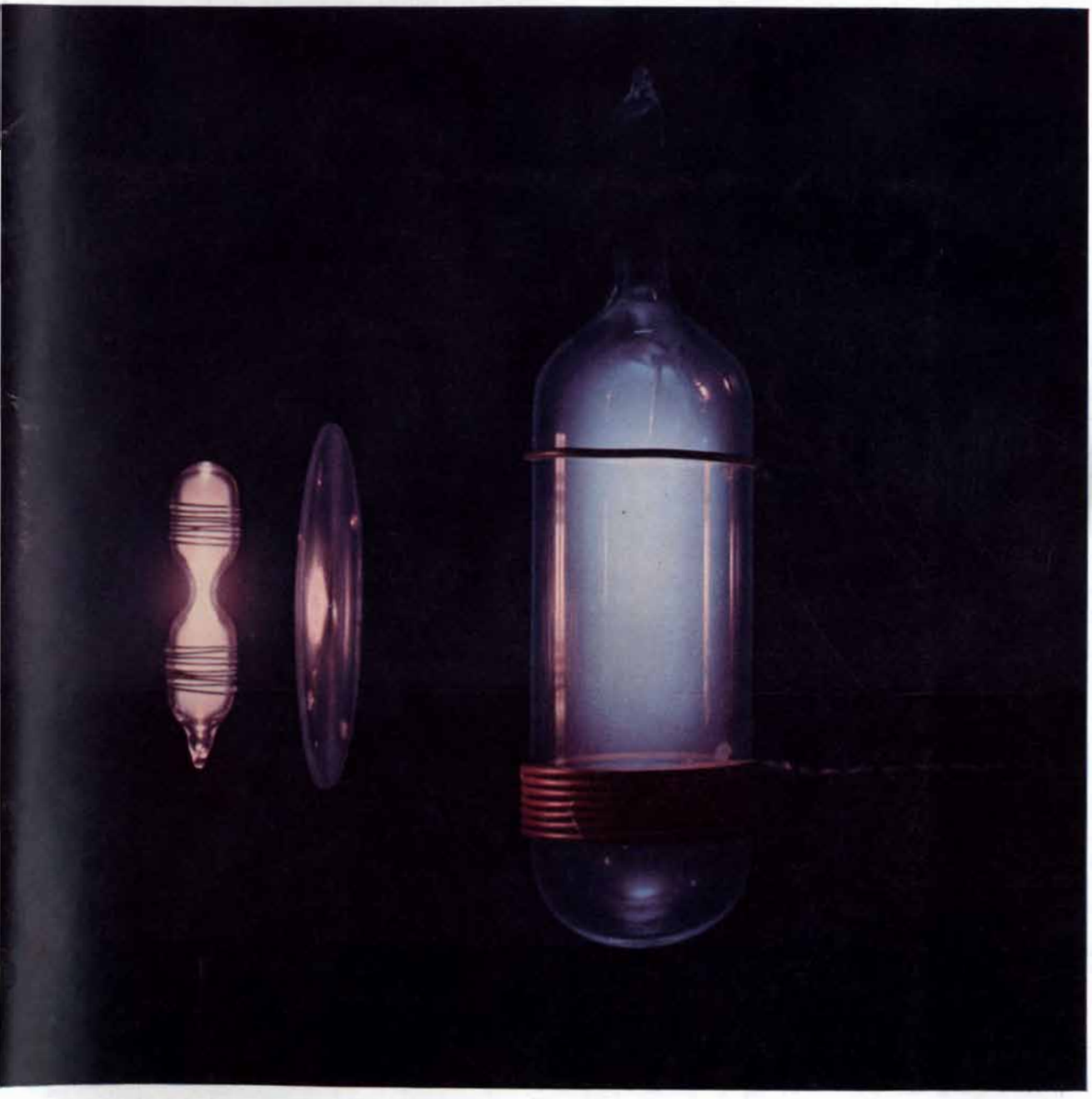
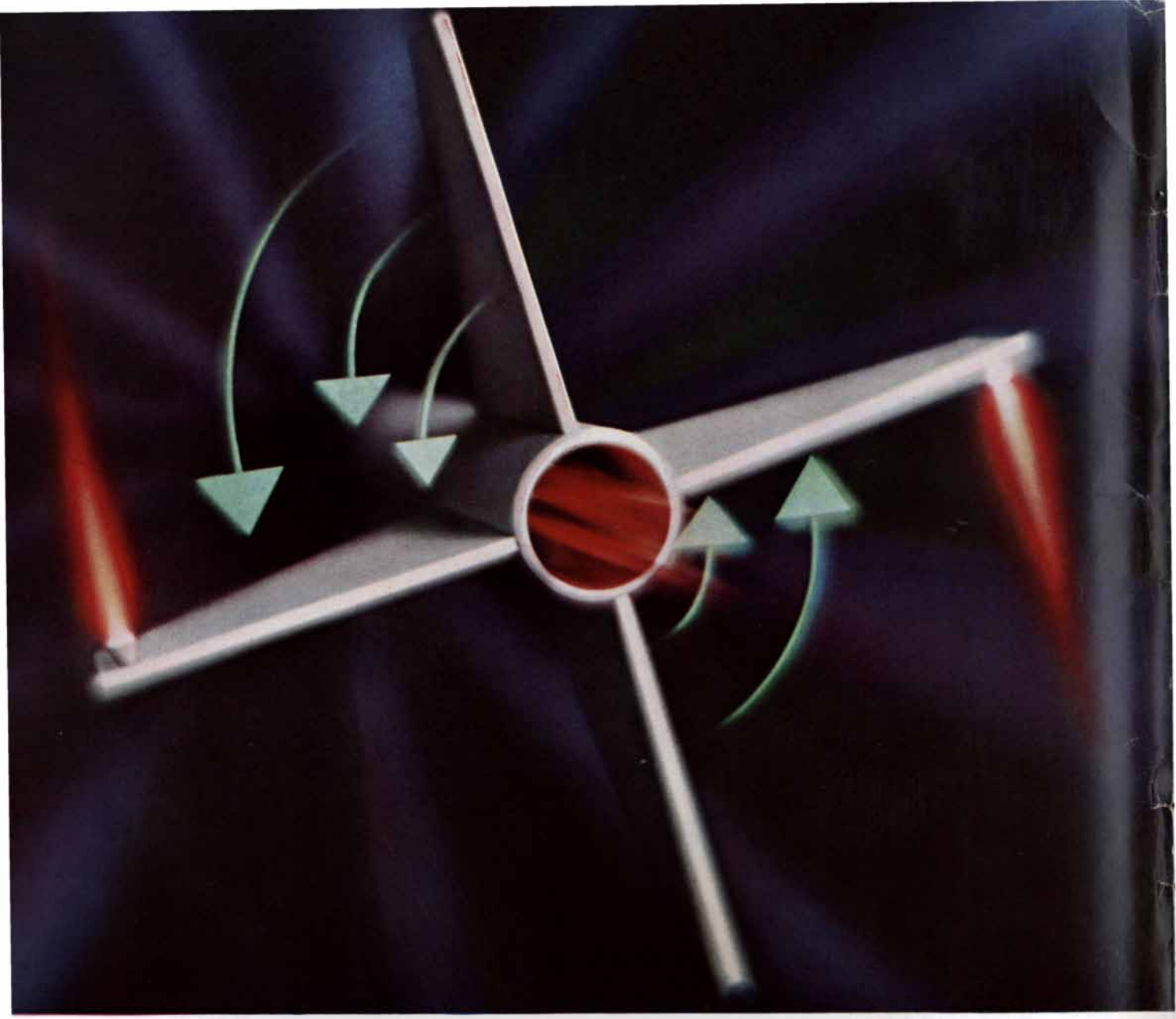
SCIENTIFIC AMERICAN



OPTICAL PUMPING

FIFTY CENTS

October 1960



Reaction controls at work in space — symbolized.

STEERING GEAR FOR ASTRONAUTS

Conventional aircraft control surfaces will not guide space ships and capsules. Rudders, ailerons and elevators find no resistance and hence produce no reaction to their movements where there is no atmosphere. Even at altitudes only half way up, they are sluggishly ineffective.

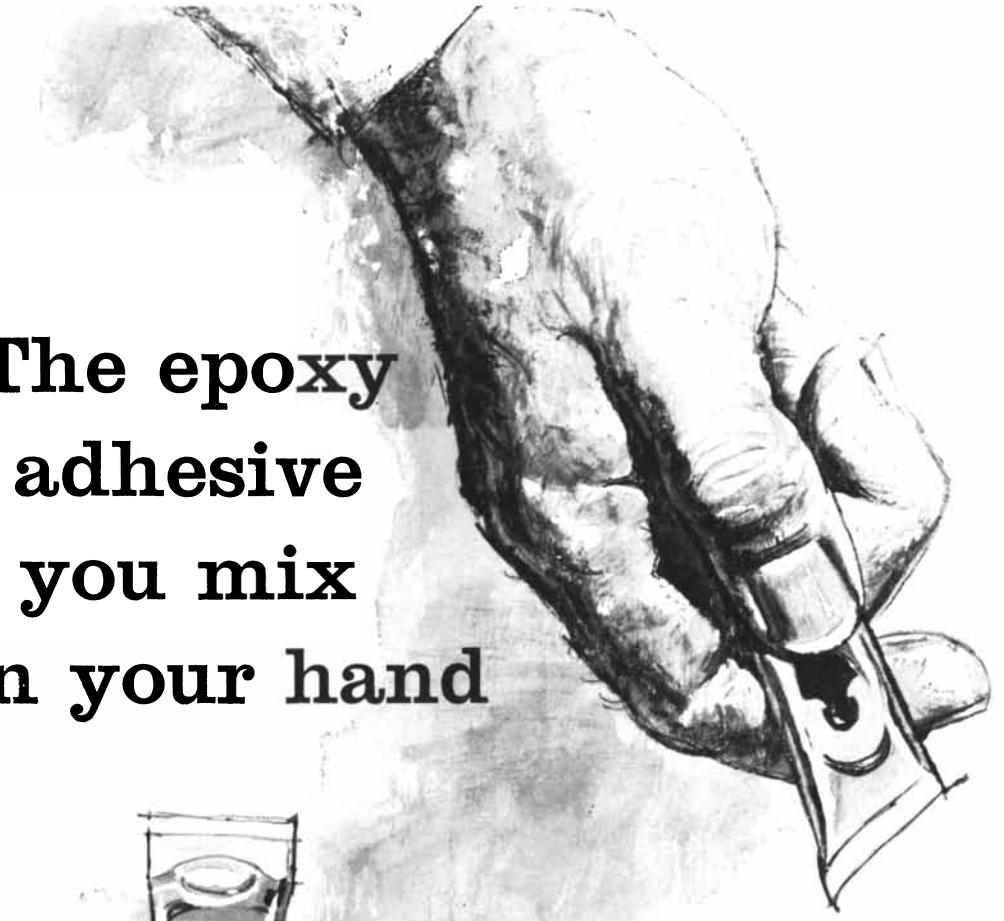
The accepted answer to a dependable steering mechanism for astronauts is a system of jet reaction controls developed and produced by Bell Aerosystems Company. First used on Bell's own supersonic X-1B several years ago, the system has been greatly improved and adopted for the X-15, the Mercury man-in-space project and other space vehicles.

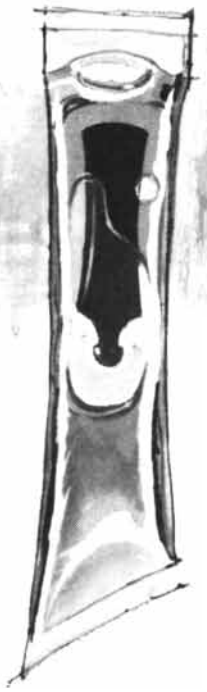
Through strategically located, low and high thrust (1 to 1500 pound) rocket engines, Bell's reaction controls not only position and guide the ship by controlling the roll, pitch and yaw, but they also provide for orbit changes and retro-thrust. Some of the jets are throttleable while others can be operated in combination to provide the astronaut positive and flexible control.

This revolutionary steering gear for space, available using monopropellants or high energy bipropellants, is just one of many advanced projects which are currently engaging the diversified talents of Bell Aerosystems Company in the fields of rocketry, avionics and space techniques. Engineers and scientists seeking challenging, long-range career opportunities can find them at Bell.

BELL AEROSYSTEMS COMPANY
BUFFALO 5, N. Y.
DIVISION OF BELL AEROSPACE CORPORATION
Successor to the Defense Group of Bell Aircraft Corporation

The epoxy adhesive you mix in your hand





Armstrong has developed a powerful new epoxy adhesive that any workman can mix as it's needed—**in his hand.** And the adhesive package is also the adhesive applicator. No measuring, no muss, no waste.

The pre-measured catalyst is contained within a capsule that floats in the epoxy resin. The complete adhesive unit—catalyst and resin—is sealed in a flexible plastic packet. To activate the adhesive, you simply crush the catalyst capsule with your fingers and knead the packet.

When mixed, snip the tip from the packet and apply the adhesive. It quickly achieves a powerful bond—without heat and with no more pressure than you need to insure good contact. We call this adhesive J-1158. Its tensile strength at room temperature is 1800 psi. It gets even stronger as the temperature drops to -65°.

One of this adhesive's most desirable properties is that it never gets brittle. Strong, yes. But J-1158 remains slightly flexible permanently.

This lets you bond dissimilar materials with widely varying coefficients of expansion without fear that the bond will fracture. For example, J-1158 is used to bond metal mirror brackets directly to glass windshields. The windshield breaks before the bond.

We know of no other epoxy adhesive that combines such basic simplicity of application with such high strength.

Packets of J-1158 come in many sizes, depending solely on the most efficient quantity for a given job.

Perhaps J-1158 is right for you. For an experimental kit of two adhesive packets, complete with technical data and instructions, send $3 to Armstrong, 8010 Inland Rd., Lancaster, Pa.

Armstrong ADHESIVES

1860-1960 Beginning our second century of progress

Louis Pasteur... on goals

"Young men, young men, have confidence in those safe and powerful methods, of which we know only the first secrets. And, whatever your career may be, do not let yourselves become affected by a denigrating and barren skepticism, do not let yourselves be discouraged by the sorrows of certain hours which pass over a nation. Live in the serene peace of laboratories and libraries. Say to yourselves first, 'What have I done for my education?' and as you gradually advance, 'What have I done for my country?' until perhaps you may have the immense happiness of thinking that you have contributed in some way to the progress and to the good of humanity. But whether or not our efforts bear fruit, let us be able to say, when we come near the great goal, 'I have done what I could'."

Academy of Sciences, December 27, 1892

Established 1845 **SCIENTIFIC AMERICAN** October, 1960 Volume 203 Number 4

ARTICLES

DEPARTMENTS

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THE COVER

The photograph on the cover depicts a helium optical-pumping experiment (*see page 72*). The bright, hourglass-shaped object at left is a helium lamp excited by a high-frequency oscillator via a length of a cable. A plastic Fresnel lens focuses the light on the helium-filled absorption cell at center. The light from the helium lamp "pumps" the atoms of helium in the cell to higher energy levels; as the atoms fall back to lower levels they emit light at certain wavelengths. Many of these wavelengths represent spectral lines that are normally difficult or impossible to observe. Large coil around cell carries radio-frequency energy to produce resonance effects between energy levels of helium atoms; small, single coil excites helium in cell, raising it to a state in which it can be pumped.

THE ILLUSTRATIONS

Cover photograph by Jon Brenneis

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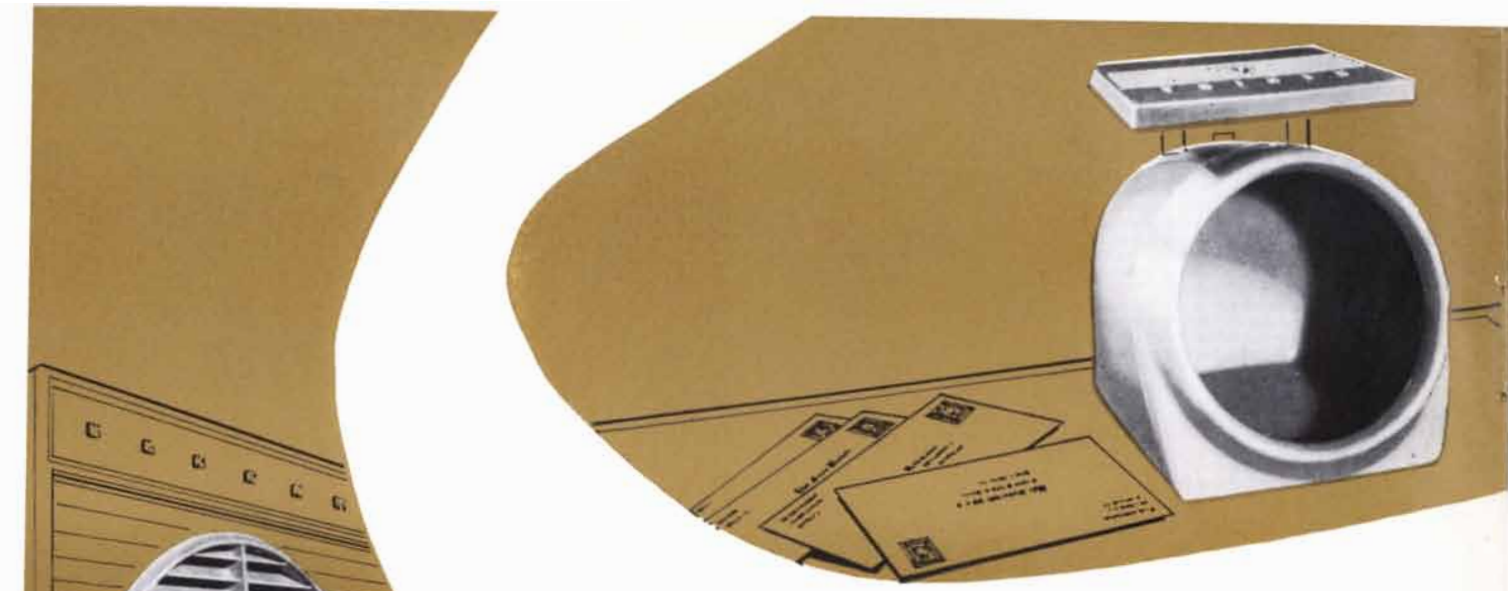


THE 3 BASIC REASONS IN

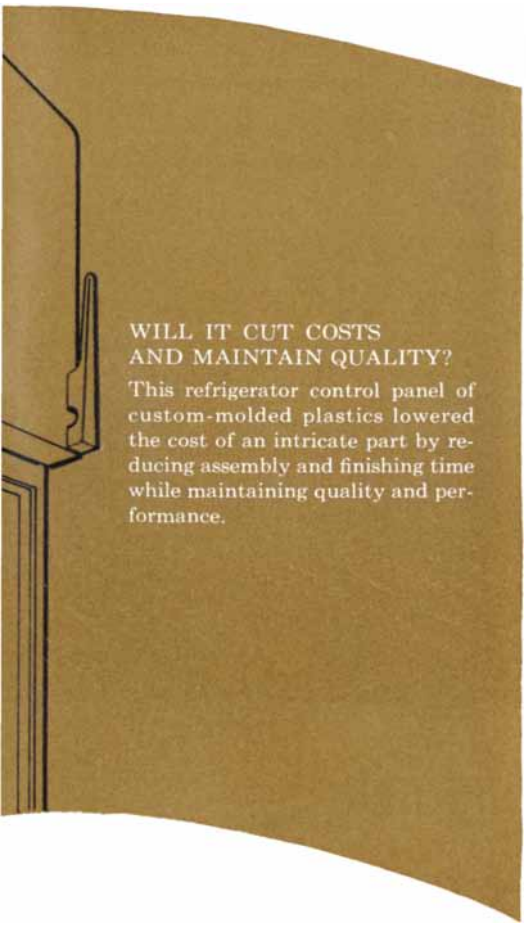
WILL IT CUT COSTS AND IMPROVE PERFORMANCE?

Molding this air conditioner vent decreased weight, eliminated costly finishing operations and reduced material cost. At the same time, possibility of rust, tarnishing or marring was minimized.

WILL IT IMPROVE PERFORMANCE AT NO MORE COST?

The re-design and custom-molding of this postal scale in high-impact plastics improved appearance and gained customer acceptance that was immediately reflected in increased sales.

DECIDING TO SWITCH TO custom molded plastics



WILL IT CUT COSTS AND MAINTAIN QUALITY?

This refrigerator control panel of custom-molded plastics lowered the cost of an intricate part by reducing assembly and finishing time while maintaining quality and performance.

"Without exception, the adoption of plastic parts over previously used materials is decided only if it makes possible a ❶ reduction in price, with the same quality; or ❷ an improvement in quality, with the price remaining constant; or ❸ a reduction in price and an improvement in quality at the same time."*

Plastics are measuring up to these demands—in the skillful hands of the custom molder. Well-known as a mass producer of molded parts and products, the custom molder is much more. He knows the design limits of the many plastics. He can recommend the best formulation for the job. He can engineer the design to capitalize on the inherent advantages of plastics materials and the efficiencies of plastics manufacturing. He builds the master molds to fine tolerances. He turns out plastics parts with unusually consistent quality, at rates to meet the tightest schedules and budgets.

Monsanto, as a leading plastics materials supplier, keeps the custom molder supplied with molding formulations of Monsanto Polyethylene, Lustrex® Styrene, and Opalon® Vinyl, specially developed and constantly perfected to meet the widening range of design requirements. Monsanto has also prepared a special report that can help you decide how custom-molded plastics can work best for you. For your free copy, mail the coupon.

*As reported by a leading newspaper. Reprints on request.

Monsanto

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MONSANTO CHEMICAL COMPANY
Plastics Division—Room 790
Springfield 2, Massachusetts

Please send me a free copy of "How To Buy Custom Molded Plastics."

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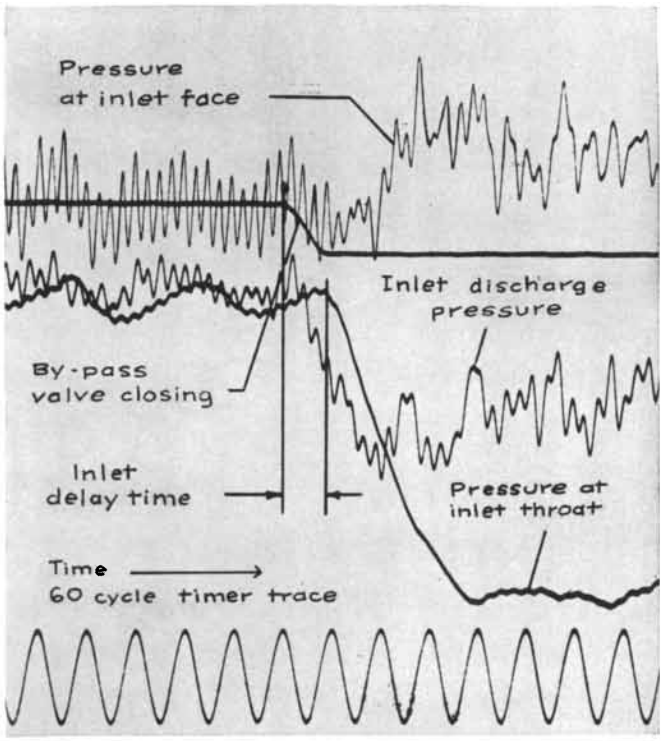
In research...

A Model 906 Honeywell Visicorder wrote this record of pressure fluctuations... "buzz"... for engineers at the NASA Lewis Flight-Propulsion Laboratory in Cleveland. "Buzz" is an unsteady variation in the pressure and airflow characteristics of a supersonic aircraft or missile inlet. These Visicorder studies defined the buzz-free operating limits of the inlet, and provided the designers with structural load information in case the inlet were inadvertently caused to operate on buzz during flight. This load information is vital, for inlet buzz can result in fluctuating structural loads of the order of 1000 psf... loads which could cause structural failure of the inlet and loss of the airplane. Visicorder records such as this have played an important role in the design of inlet control systems.

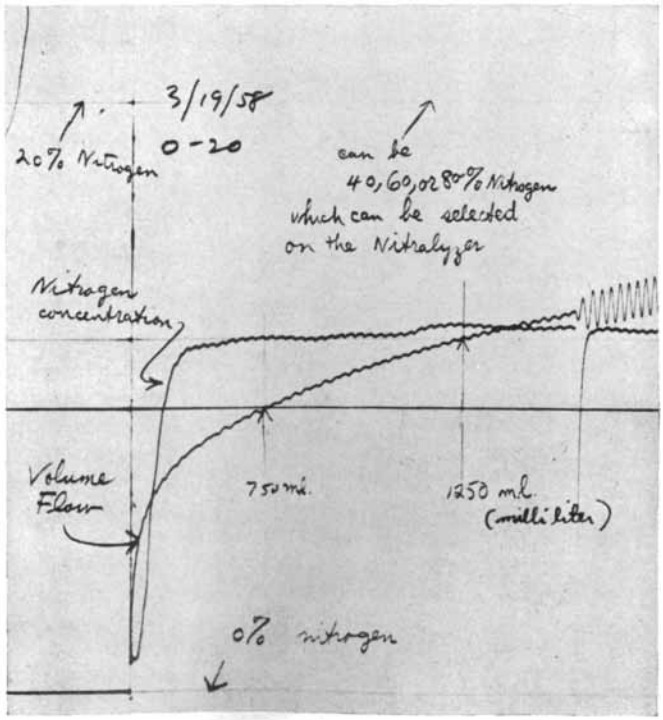


these are records of leadership

In medicine...

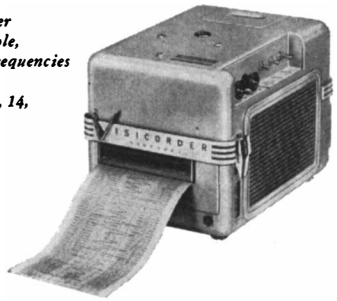
This directly-recorded Visicorder chart has told the scientists of the U. S. Public Health Service Occupational Health Program an important story about uneven alveolar ventilation in the human lung during a single breath of oxygen. In these lung function tests, the Visicorder measured anatomic dead space and abnormalities in the distribution of inspired gas in the alveoli of the lungs. The subject, under test, inhaled 100% oxygen to dilute nitrogen in the lungs. The Visicorder recorded the volume and the nitrogen percent of the exhalation. In these and in hundreds of other scientific and industrial applications, Visicorders are bringing about new advances in product design, computing, control, rocketry, nucleonics and production.

For information on applying the unlimited usefulness of the Visicorder to your specific problems, phone your nearest Honeywell Industrial Sales Office.



Visicorder records 2/3 actual size.

The Honeywell Visicorder provides instantly-readable, high-sensitivity data at frequencies from DC to 5000 CPS. There are models with 8, 14, or 36-channel capacities.



Honeywell

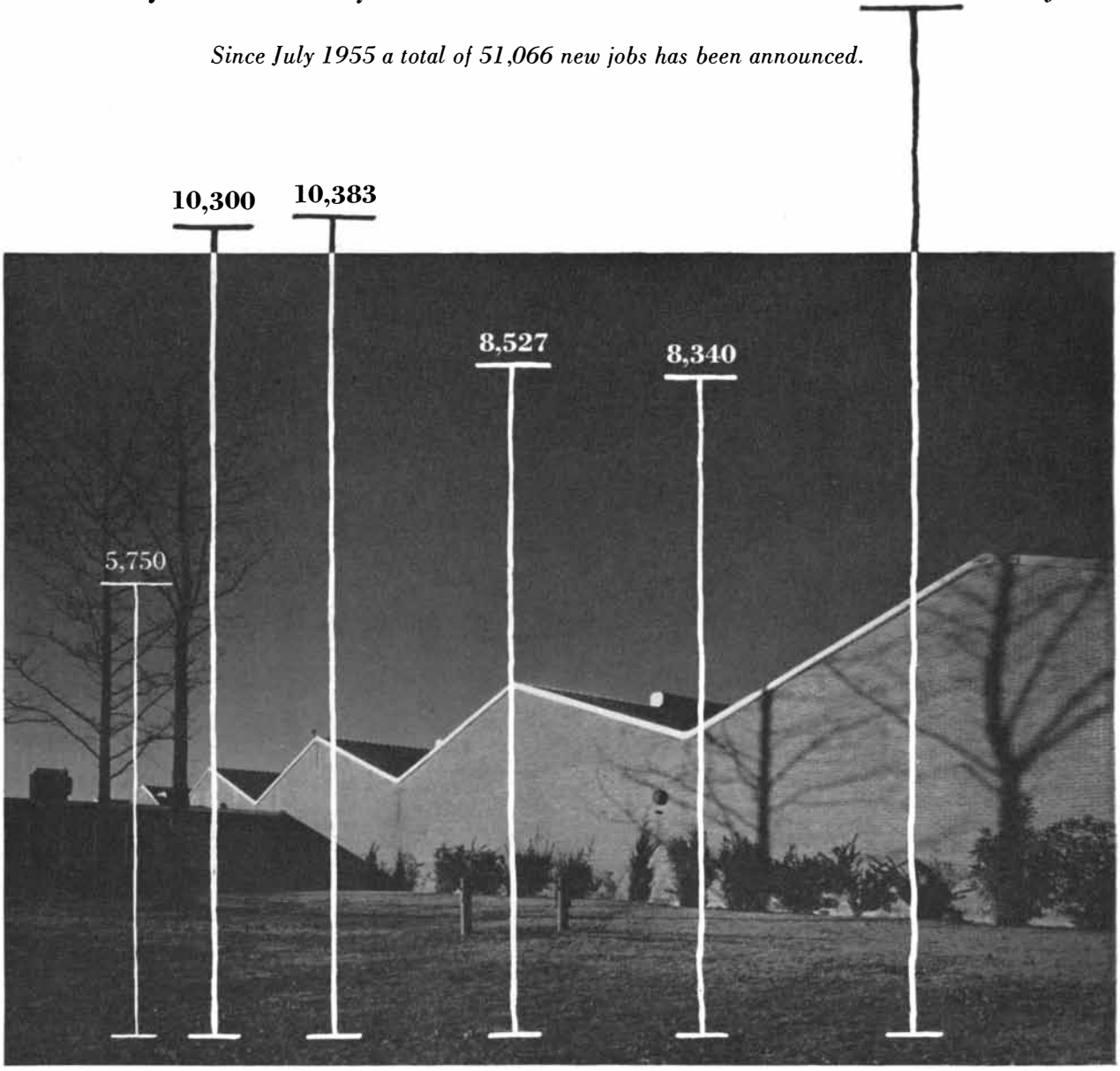
Industrial Products Group

Reference Data: Write for specifications on Visicorders 906B, 1108 and 1012.

Minneapolis-Honeywell Regulator Co., Industrial Products Group, Heiland Division, 5200 E. Evans Ave., Denver 22, Colorado

This year's industry has set a record for Arkansas: 13,516 new jobs.

Since July 1955 a total of 51,066 new jobs has been announced.



The Arkansas Industrial Development Commission, State Capitol, Little Rock.

ARKANSAS

Aerospace Corporation has been brought into being to serve the United States government by concentrating the full resources of modern science and technology on rapidly achieving those advances in space systems indispensable to the national security.

The corporation is non-profit, will share the findings of its research and laboratory experiments with all appropriate organizations involved in the government's missile-space program, and is not organized for manufacturing purposes.

The immediate responsibility of Aerospace Corporation is to aid the United States Air Force in bringing about the best possible ballistic missiles and military space systems on a continuing basis and within the shortest possible time.

In addition, it may furnish the National Aeronautics and Space Administration and other governmental agencies appropriate services whenever its participation in space exploration and related activities is desired.

THE MISSION of Aerospace Corporation, according to the Secretary of the Air Force, encompasses "the field of ballistic missile and space programs. Within this complete area, it has the responsibility for advanced systems analysis, research and experimentation, and initial systems engineering. It will also exercise such general technical supervision of ballistic systems as is appropriate. In special cases, and with the consent of the Secretary of the Air Force, Aerospace Corporation may assume broader responsibility for an Air Force military system."

The new corporation also provides support to the Air Force in its effort to achieve maximum interchange of knowledge with other military services and among universities, research foundations, and the scientific community in general.

THE FUNCTIONS of Aerospace Corporation in carrying out its responsibilities for the Air Force's missile-space programs include the performance of a wide range of scientific, technical, and administrative tasks.

The corporation will conduct extensive laboratory and field activities aimed at advancing the state-of-the-art and will augment these research and development activities by coordination with industry, universities, laboratories, and other agencies. It is intended that this combined effort will push forward the boundaries of technology on a broad front to fulfill military and other national requirements.

Aerospace Corporation will study the application of the advancing technology to military weapons, support systems, and other systems serving the national need. These studies will culminate in preliminary design and in recommendations for development programs.

Aerospace Corporation will then assist the Air Force or other appropriate government agencies in establishing space programs and in bringing the force of American industry to bear in carrying them out. Once development is initiated, Aerospace Corporation will assume responsibilities for the broad technical aspects of these new programs through their critical phases.

THE FACILITIES of Aerospace Corporation include a research and development center located near the Los Angeles International Airport and within easy reach of several attractive residential communities.

They constitute a modern administrative, scientific, and engineering headquarters which house some of the world's most advanced instrumentation and experimental apparatus.

In addition, the operations of Aerospace Corporation will be directly supported around the globe by a vast array of resources created by the government over the past six years. These will include: The Atlantic Missile Range in Florida; The Pacific Missile Range in California; The Rocket Engine Test Site at Edwards Air Force Base in California; and numerous other missile test facilities sponsored by the government in cooperation with private industry.

THE PEOPLE who make up Aerospace Corporation have been selected from industry, universities, and government. They constitute a cross-section of highly-developed engineering and scientific skills in the missile and space fields.

Extensive recruiting will continue as the new corporation assumes more and more responsibility. From the outset, the corporation is built on a foundation of proven scientific competence, imagination, and objectivity.

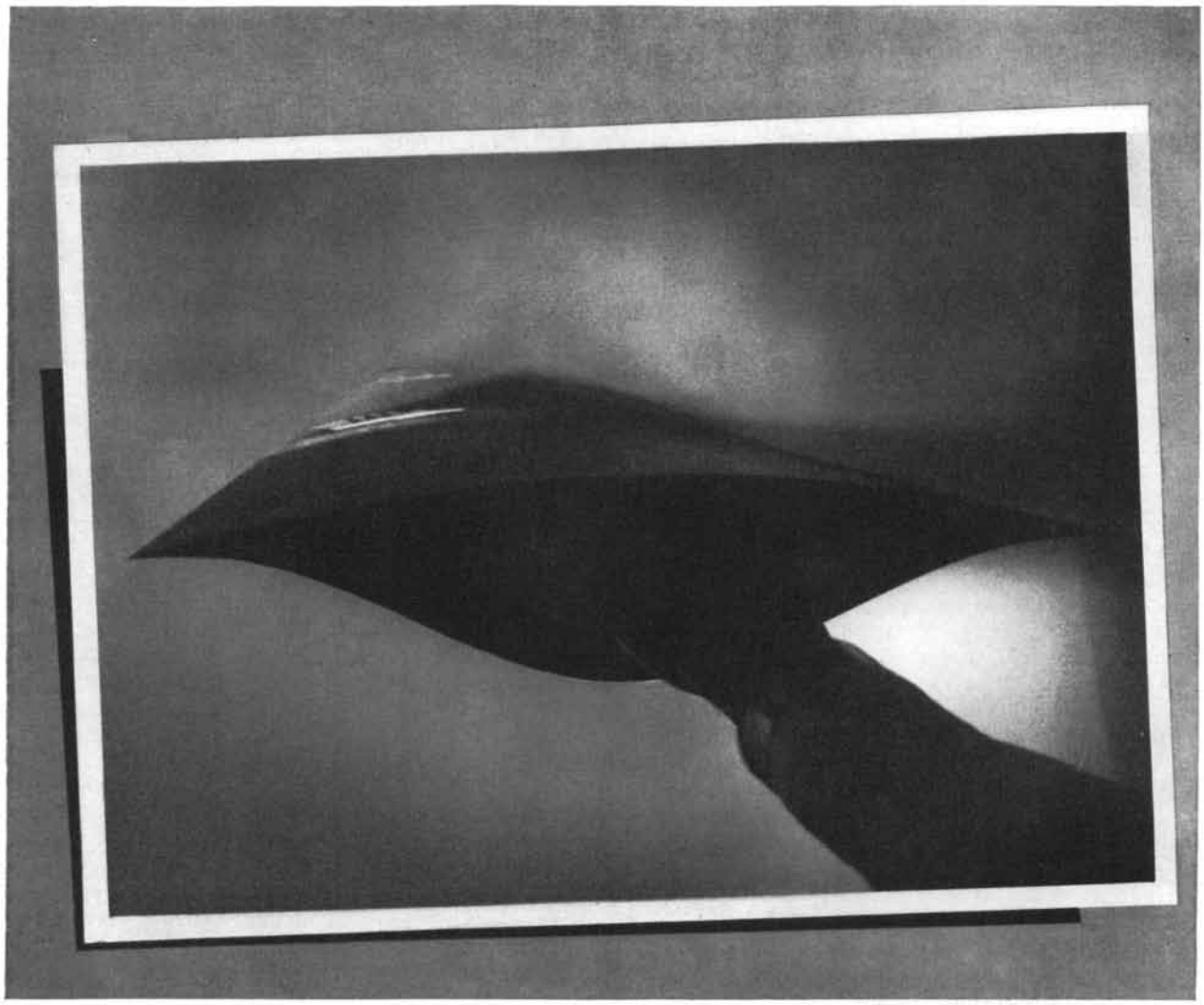
THE OPPORTUNITY awaiting those scientists and engineers who qualify to join Aerospace Corporation is equalled only by the magnitude of the corporation's mission – magnitude mirrored by the highly advanced nature of the programs in which Aerospace Corporation is engaged.

Typical systems projects include: advanced ballistic missiles; advanced military space boosters; recoverable boosters and satellites; space defense systems; early-warning satellites; reconnaissance satellites; communications satellites; and manned satellite systems.

Typical research programs concern: nuclear propulsion; astrodynamics; magnetohydrodynamics; inertial elements; millimeter waves; hypersonics; combustion kinetics; and materials research.

Those capable of contributing to state-of-the-art advances in these and related areas are invited to consider the advantages of becoming a part of the new Aerospace Corporation. Their resumes should be directed to: Mr. James M. Benning, P.O. Box 95081-E, Los Angeles 45, California.

AEROSPACE CORPORATION  2400 East El Segundo Boulevard • El Segundo, California



This photo of Grumman was taken at a speed of Mach 8

This is a vapor screen photo of hypersonic flow (Mach 8) about a Grumman research model, at Arnold Engineering Development Center. Expansion region above the body is discernible along with the separated region adjacent to the surface and the reflection of the light screen on the surface.

The photo shows something else, too: Grumman is on the move in the field of hypersonic aerodynamics. Add to that—continuing design and development work on orbiting observatories, unmanned scientific satellites, manned space craft, and re-entry vehicles, to name a few.

Advanced Ideas Grow Into Reality at...

GRUMMAN

AIRCRAFT ENGINEERING CORPORATION

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Anaconda American Brass Company
Waterbury 20, Conn.

Please send me a copy of your 8-page booklet which details properties of your four free-cutting, high-conductivity coppers, and suggested machining practices.

Name.....

Company.....

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City.....**Zone**.....**State**.....

4 ways to cut the cost of high-conductivity parts

There are now four free-cutting, high-conductivity Anaconda coppers that broaden the combinations of mechanical, physical, and fabricating properties available for boosting production and cutting costs of high-conductivity parts. They are furnished chiefly in rod and bar, but are available also as extruded shapes and, except for the leaded coppers, die-pressed forgings of simple design. All have good cold-working properties.

Leaded Copper-126 and Deoxidized Leaded Copper-129 have slightly higher electrical conductivity—98% IACS annealed, 95% IACS, minimum. The difference between them is that Alloy 129, being deoxidized, is not subject to hydrogen embrittlement when annealed or furnace-brazed in reducing atmospheres. Neither leaded alloy is recommended for hot working.

Tellurium Copper-127 and OFHC* Sulfur Copper have an electrical conductivity rating of 95% IACS annealed, 90% minimum. Both may be extensively hot worked and neither is subject to hydrogen embrittlement. Tellurium Copper-127 has the advantage of retaining its mechanical properties at temperatures higher than those tolerated by the other free-cutting coppers—and hence is widely used in the welding and cutting-tip field.

The free-cutting coppers may be machined at cutting speeds approaching those used for machining Free-Cutting Brass. For Tellurium Copper-127, however, carbide-tipped tools are recommended as the inherent copper telluride particles cause somewhat greater tool wear.

*Registered Trademark of American Metal Climax, Inc. 6047 Rev. L

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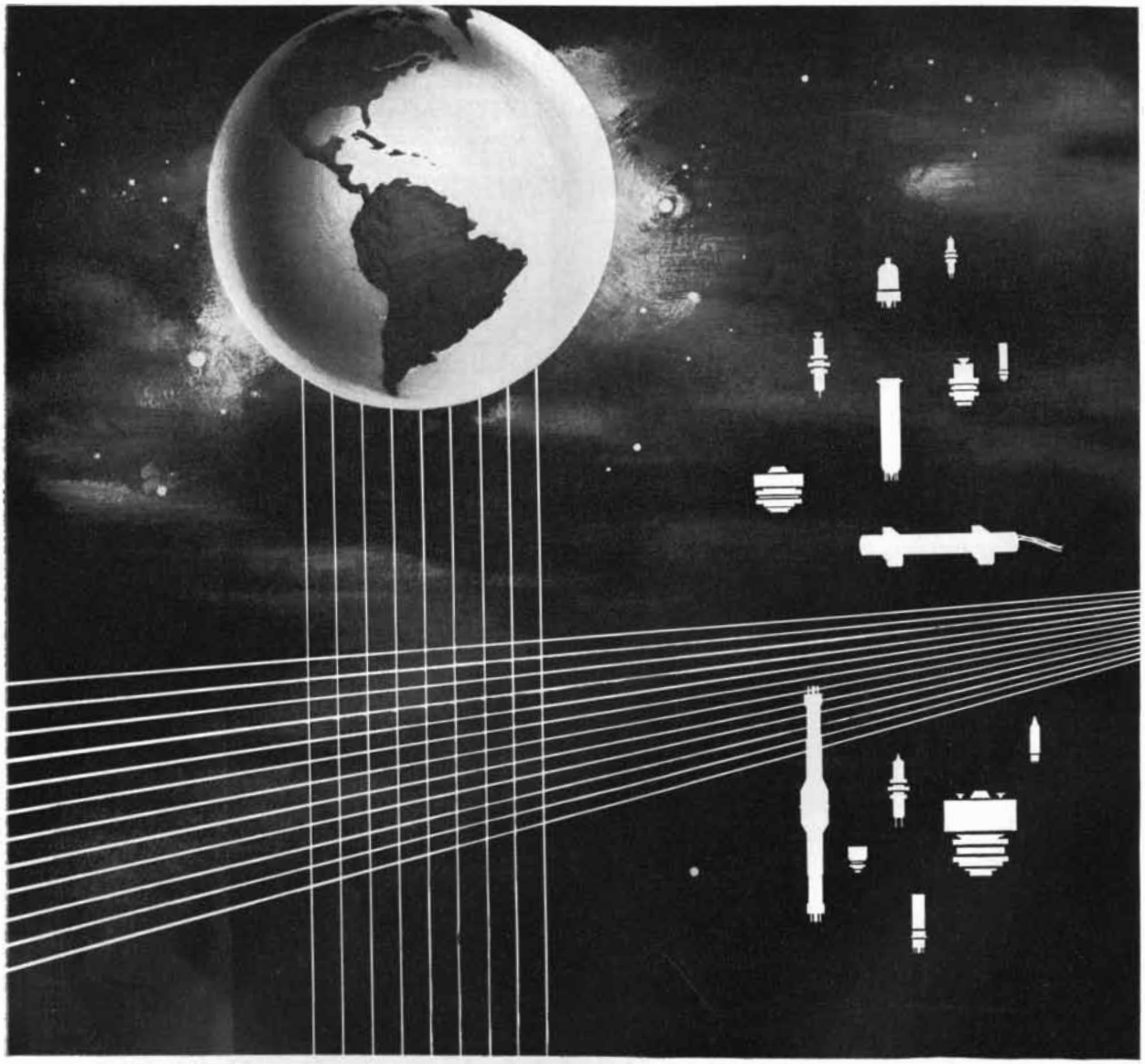
FREE-CUTTING HIGH-CONDUCTIVITY COPPER PRODUCTS

Anaconda American Brass Company



BEYOND THE BOUNDARIES OF KNOWLEDGE...

Huge radiotelescopes listen to the "sound" of colliding galaxies 300 million light-years away. From high altitude balloons, cosmic radiation is measured and plotted. Satellites and space probes are gathering information about the van Allen belts and other hitherto unknown phenomena of outer space, while other satellites are focused on the earth and send down pictures of its atmosphere and surface. On every frontier from the heart of the atom to the far-flung reaches of the universe, man's electronic eyes and ears are ferreting out the secrets of science.

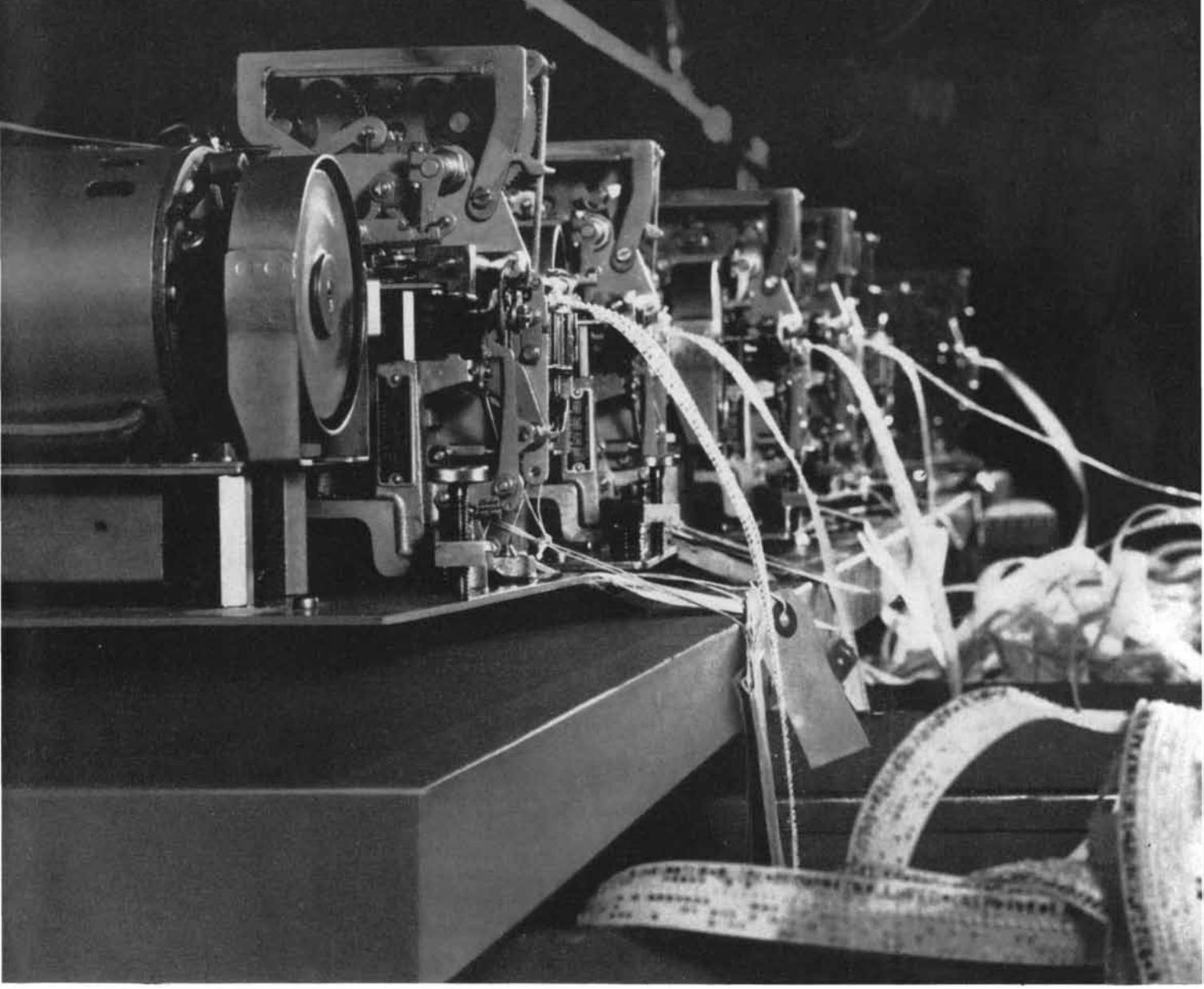
In the forefront of this electronic "reconnaissance" is RCA's Industrial Tube Products Department, developing the electron devices that make it possible. Major contributions have been made by RCA to megawatt electronics—including the most powerful electron tube on earth. RCA photosensitive devices are spanning the spectrum from ultraviolet to infrared. RCA Cermolox power tubes have greatly facilitated UHF communications.

The applied imagination and the research and development capabilities that produced these electron devices are available to solve your problems...in defense, in industry and research. To draw on this unique reservoir of experience, contact the Marketing Manager, Industrial Tube Products Department, RCA Electron Tube Division, Lancaster, Pa.

RCA

The Most Trusted Name in Electronics

RADIO CORPORATION OF AMERICA

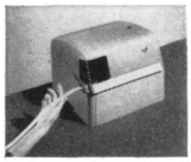


Continuous operation— a Teletype equipment tradition

All Teletype equipment . . . like the tape punches being final-tested above . . . are subjected to a rigorous quality-control program to insure that the units will give continuous, day-in, day-out performance in your service. Such performance is a Teletype tradition, established during more than fifty years of manufacturing data communications equipment.

To maintain this performance tradition requires much more than testing, however rigorous. It begins with the very design of the units themselves—the product of extensive research and development facilities, backed by cumulative experience. And it involves precision manufacture—employing the latest technological advances, from highly specialized machine tools and automated processes to electronic measuring and sensing devices.

When you select Teletype equipment to speed your communications and cut your paperwork costs, you can be sure of built-in quality. Teletype Corporation manufactures this equipment for the Bell System and others who require the utmost reliability from their data communications systems.



Typing Tape Punch

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LETTERS

Sirs:

On the basis of the following sentence from Mr. James R. Newman's review of *New Maps of Hell* by Kingsley Amis I am forced to conclude that he hasn't read much of H. G. Wells's science fiction. "Time machines and Martians (*The War of the Worlds*), monsters (*The Food of the Gods*), invisible men, carnivorous plants—these were used to entrance the reader, to create suspense and excitement rather than to satirize or weave an allegory." This is the reverse of the case in all but the instance of the carnivorous plant, which does appear in a light short story. *The Time Machine* is in large part a social satire concerned with the genetic consequences of perpetuating a layered class society of the 19th-century variety in which the upper classes would become progressively more over-refined and helpless as they did less and less, while the lower classes were increasingly toughened and brutalized. *The War of the Worlds* was an allegory of colonialism, showing the destruction of a primitive society by a technically more sophisticated one with no respect for its values and its culture. *The Food of the Gods* had its primary origin in a paper Wells read to the Fabian society about the way in which society was outgrowing its 18th-century and earlier administrative units. The story is not about monsters but about uncontrolled growth, and the particular subject of its allegory is the social problem created for an unprepared society by the application of the products of scientific research by people who do not fully understand them to fields undreamed of by the research workers. *The Invisible Man* (Wells only invented one of them) was an allegory or parable about the intellectual arrogance of the specialist who thinks that full command of his specialty entitles him to a place above all other men. In justice to my father I think it should be said that he rarely if ever wrote without a wholly serious idea behind the entertaining surface of his writing, and that in his science fiction his serious intentions were especially evident. . . .

ANTHONY WEST

The New Yorker
New York, N. Y.

Sirs:

I must correct Mr. West's impression. I have read the Wells science fiction to which my review refers and I have enjoyed what I read. But I share the view of Kingsley Amis that such stories as *The Time Machine, The War of the Worlds* and *The Food of the Gods* are primarily inventions for entertainment and are only secondarily satires and castigators of morals. This is not to deny that, as Mr. West points out, Wells "rarely if ever wrote without a wholly serious idea behind the entertaining surface of his writing." But what is bound to weigh with the reader is the method used to impart the social message; and this is especially true where the "counterfeiter of verisimilitude" is as skillful and spellbinding as Wells. Then the story is what counts and the moral is extra.

Obviously Mr. West knows a great deal more about his father's purpose in writing science fiction than I do; but granting that his main object was always criticism and instruction, he may have thought it best to coat the pill very heavily. Mr. West clearly feels that to stress the story at the expense of the social criticism is to belittle Wells. I disagree. If I give a man a box of chocolates, one of which is poisoned, hoping he will eat it sooner or later and expire, I must count the effort a total failure if he offers the poisoned chocolate to someone else. But if I write a good story which conceals a social message, and most of my readers are enthralled, without consciously perceiving the satire, I cannot be said to have failed. Wells's sharp insight into social evils and his elevated outlook were well served by almost everything he wrote, science fiction included; indeed they were the better served because he knew how to use his art without making it a clumsy messenger.

JAMES R. NEWMAN

Wellfleet, Mass.

Sirs:

The lore and the lure of pi are practically inexhaustible, and Martin Gardner's diverting article on the subject ["Mathematical Games," SCIENTIFIC AMERICAN, July] could be supplemented with many modern contributions to the wackier byways of piology. Here are two. In 1940 a famous English scientific journal published a letter whose author furnished data in support of his hypothesis that the mean gestation periods (in days and fractions of a day) of various mammals are simple multiples of pi. Again, anyone who cares to turn up *The Congressional Record* for June 3, 1960 (Appendix, pages A4733 and A4734), will learn of a Hawaiian gentleman who has recently trisected an angle, squared a circle and doubled a cube, and who is peddling the secret at $15 a throw in his book, *The Two Hours that Shook the Mathematical World*.

N. T. GRIDGEMAN

Division of Applied Biology
National Research Council
Ottawa, Canada

Sirs:

In his article "The Zodiacal Light" [SCIENTIFIC AMERICAN, July] D. E. Blackwell introduces Gian Domenico Cassini as a *French* astronomer, giving also his name first initial J. (Jean).

May I point out that G. D. Cassini was born in Perinaldo near Genova (Italy), studied first in this city and later in Bologna (Italy), where also in 1650 he became University professor and left a celebrated solar clock in San Petronio church?

About 45 years old and already famous, Cassini was collected by the French minister Colbert, as another star in the Louis XIV heavens; in France he stayed and worked until his death in 1712, leaving there a strong astronomically minded descent.

VALENTINO ZERBINI

Milan, Italy

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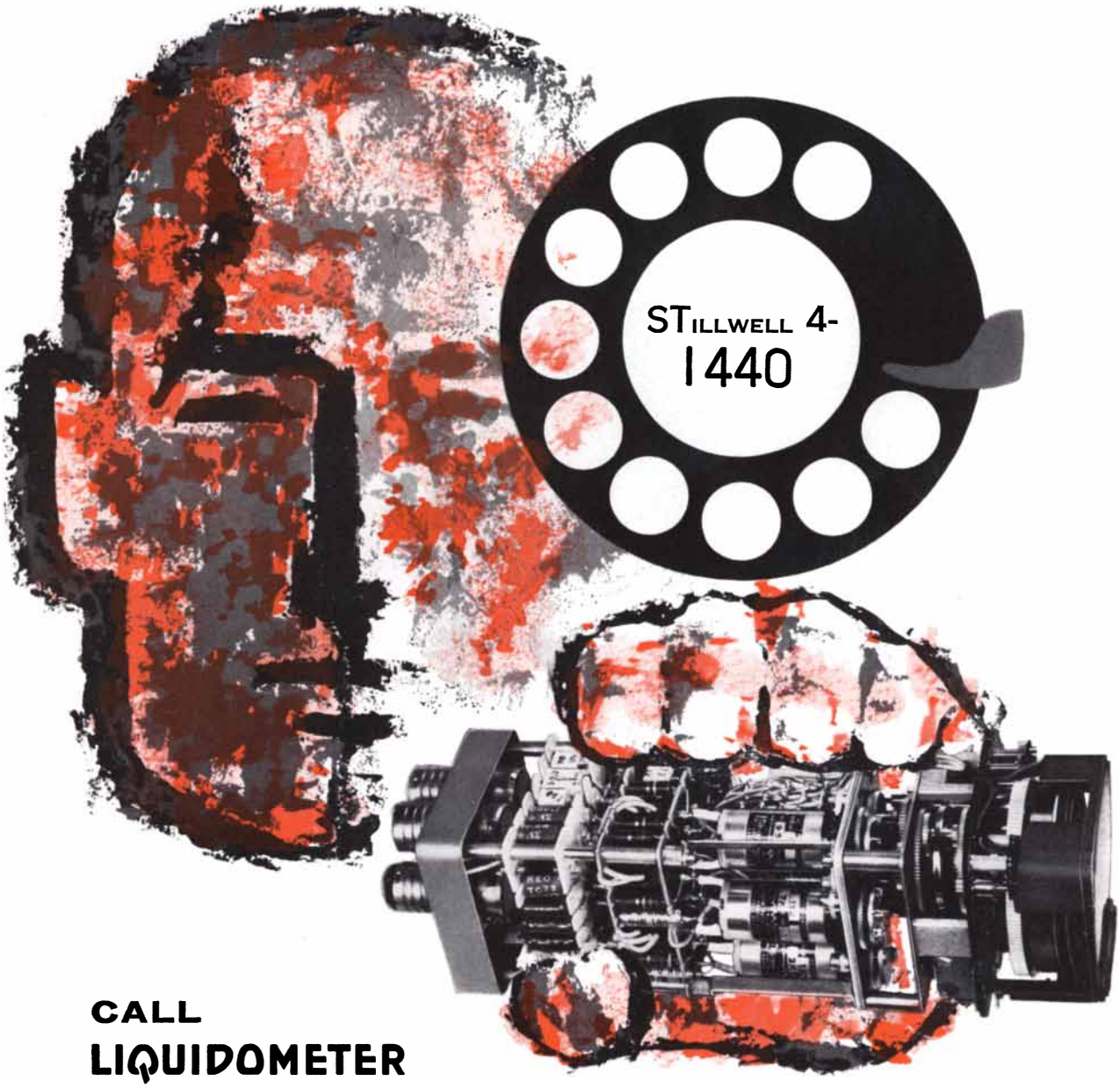

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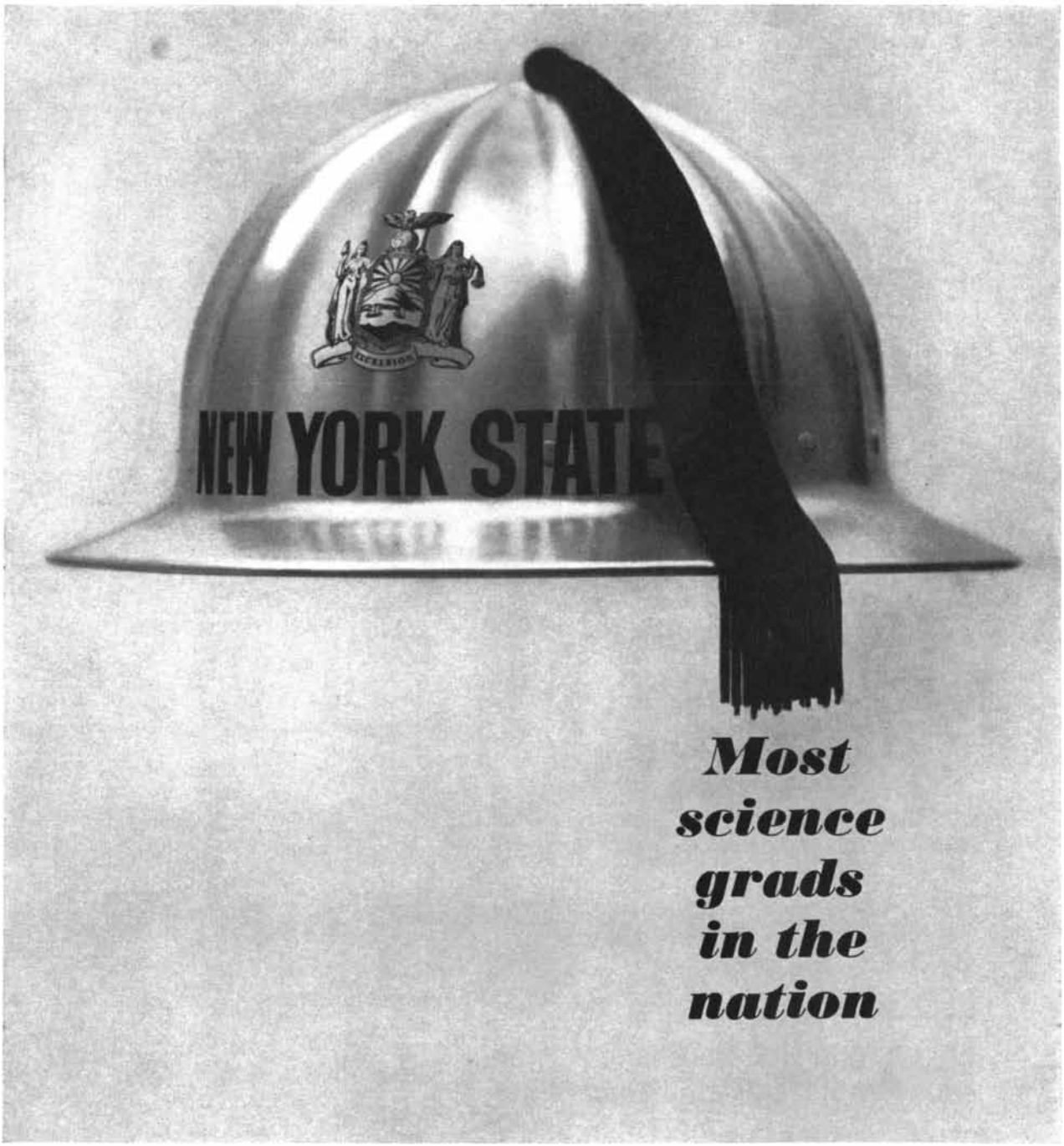


A tasseled hard hat shouldn't surprise anyone familiar with what has been happening in New York State's schools and research laboratories. The state's 170 colleges and universities turn out more graduates in physics, engineering, chemistry, mathematics and the natural sciences – and grant far more graduate degrees in these subjects – than any other state. ■ Young scientists have every reason to *stay* in New York State, too . . . for more than 1,000 industrial and university laboratories offer them a wide variety of challenging jobs. ■ The flow of ideas from laboratories to industry has been greatly stepped up by Governor Rockefeller's Advisory Council for the Advancement of Industrial Research and Development. This is one of the most important new elements in the favorable business climate of New York State.

We'll compile a report tailored to your specific new plant needs. Write Commissioner Keith S. McHugh, Dept. of Commerce, Room 558, 112 State St., Albany 7, N. Y. (All contact between your office and ours will be kept *under* our hat.)

GET UP TO DATE ON NEW YORK STATE . . . WHERE THEY'RE TALKING THE BUSINESSMAN'S LANGUAGE

COMP'UTENCE

TOTAL COMPETENCE IN COMPUTATION AND DATA PROCESSING—THE BREADTH, THE BRAINS AND THE BACKGROUND

For instance, ALRI: USAF Airborne Long Range Input Program, one more demonstration of Comp'utence—and Burroughs Corporation—throughout the contract team program. **The objective:** a seaward, airborne extension of SAGE via radar-equipped reconnaissance aircraft, processing data in flight and transmitting it through ground receiving sites to central direction centers. **Total competence:** the way Burroughs Corporation, as System Manager, directs the integration of the special skills and facilities of its team*. **Total comp'utence:** the way Burroughs Corporation, also a team member, develops ALRI's miniaturized airborne data processors—reflections of its breadth (R & D through field service), brains (such as the Atlas guidance computers, data processing for Polaris) and background (75 years devoted to computation and data processing).

*Lockheed Aircraft Service, Inc.◎Packard Bell Electronics Corporation◎Philco Corporation◎Military Electronic Computer Division of Burroughs Corporation◎Electronic Communications, Inc.◎GPL Division of General Precision, Inc. and◎AC Spark Plug Division of General Motors Corporation.

Burroughs Corporation

"NEW DIMENSIONS / in computation for military systems"

Parallel Processing in the Honeywell 800

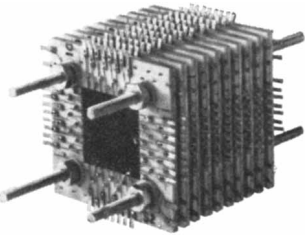
How it is achieved through automatic control techniques

In a modern transistorized computer, the central processor speeds that can be achieved economically are much higher than the top speeds of electromechanical peripheral devices. Such a central processor is being used inefficiently if it stands idle while waiting for information to be handled by relatively slower tape mechanisms, printers and card readers. The concept of time-sharing the central processor among several peripheral devices in order to utilize otherwise wasted time thus becomes attractive. This can be accomplished to a degree through programming techniques. By writing a special supervisory routine, it is possible to have two or more programs sharing the central processor. The supervisory routine coordinates the programs, establishes priority among the various steps of each of the programs and attempts to maintain efficient utilization of the central processor and the peripheral equipment involved. Depending on the number and nature of the programs, the master program can become very involved and cumbersome and the individual programs become interdependent.

To overcome these shortcomings, Honeywell took a completely new approach to the problem. In the Honeywell 800 data processing system an extremely powerful time-sharing capability is provided through automatic control functions that have been built into the equipment.

Individual Program Control Through Separate Control Memory

This special capability of the Honeywell 800 is called Automatic Parallel Processing. It permits up to eight completely independent programs to be run simultaneously, without the use of a super or master routine. Sequencing of multiple programs and the management of buffer transfers is handled automatically by a control memory, plus special built-in equipment called Multi-Program Control and Traffic Control.



The control memory is a small, magnetic core memory running out of phase with the main memory. It contains eight groups of 32 special program-control registers. Each of these groups provides the control functions for one program and operates independently of all others. Thus the Honeywell 800 is capable of performing from one to eight programs independently and simultaneously. One of the registers in the program control group is the sequence counter which contains the address of the next instruction in the program assigned to that particular group.

Multi-Program Control Coordinates Independent Programs

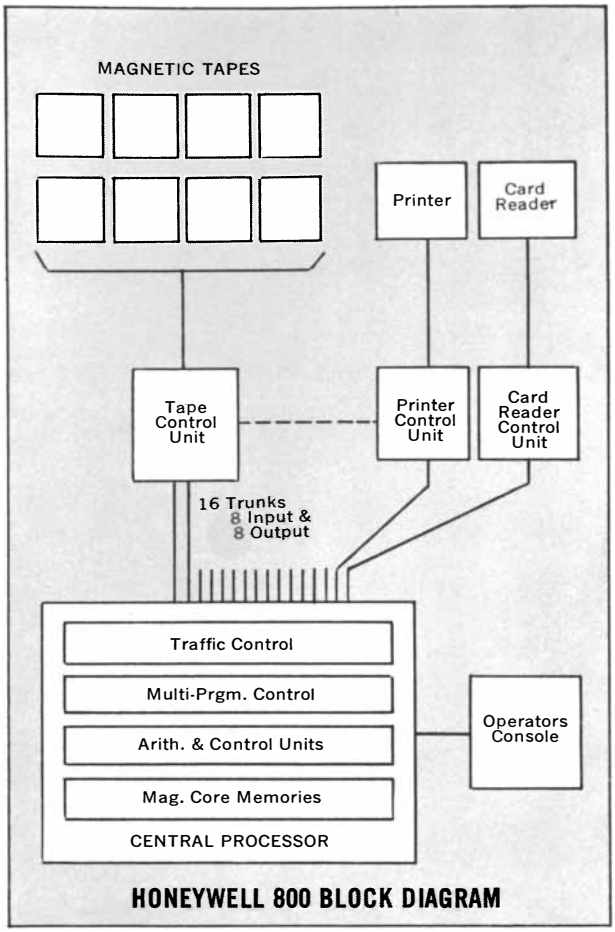
Each of the eight sequence counters in the control memory is connected to Multi-Program Control. Multi-Program Control permits the execution of one instruction from each active program, in rotation. It does this by returning a "go ahead" signal to the demanding control group. This signal causes the sequence counter in the control group to read out the address of the next instruction. This address goes back to the sequence counter via an automatic incrementing adder to become the address of the following instruction. It is also transferred to the address selectors of the main memory where it causes the present instruction to be transferred into the control unit.

Honeywell 800 utilizes three-address instructions consisting of a Command Code, A address, B address and C address. Typically, the action of a three-address instruction is as follows:

One main memory cycle is used to get the instruction into the Control Unit where it prepares the accumulator in accordance with the command code and loads the A address into the main memory address selectors. The second memory cycle is used to transfer the A operand into the accumulator and to set the B address into the main memory address selectors. The third memory cycle transfers the B operand into the accumulator where it is combined with the A operand in the way specified by the command code. The C address is then set into the main memory address selectors. Finally, the fourth memory cycle is used to deliver the result from the accumulator back into the memory at address C.

At this point, both the Control Unit and the Arithmetic Unit are free and ready to perform another instruction. Since they are not holding any information left over from the previous instruction it is immaterial to these units whether the next instruction is from the same program or from some other program.

The source of the next instruction has already been determined by Multi-Program Control and the sequence



HONEYWELL 800 BLOCK DIAGRAM

counter of the next demanding program is already loading its contents into the main memory address selectors.

Because Multi-Program Control operates out of phase with main memory, no time is lost by successive processing of instructions from different programs.

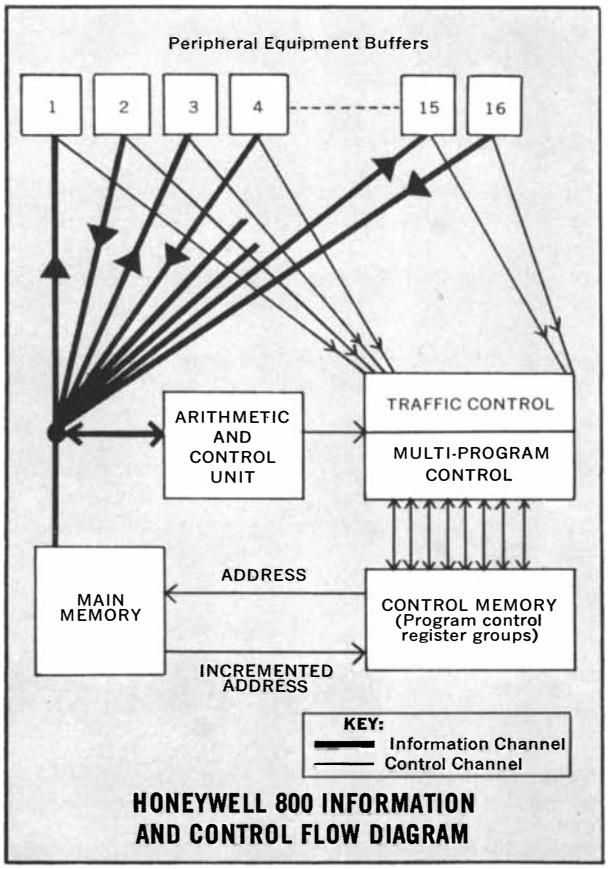
Traffic Control Permits Multiple Peripheral Operations

The Honeywell 800 central processor has eight input and eight output trunks. Each of the control units for peripheral devices uses one or two of these trunks depending on whether the controlled peripheral units are input (such as card reader), output (such as printer) or both (such as magnetic tape units). Some control units can handle several peripheral devices. For example, a tape control unit can control eight magnetic tape units. Coordination and control of the transfer of information between peripheral devices and the main memory is accomplished through a function called Traffic Control. Connected peripheral devices may be called for in any combination by any of the programs running in parallel.

Information from an input device is accumulated in the information store of its control unit. Whenever a stored word is ready for input transfer, Traffic Control suspends computation for one memory cycle to effect the input transfer. The control memory register associated with that input trunk is read and its contents used to select the main memory address into which the input word is transferred. The contents of that register are then incremented and restored to provide the address for the next word coming from the same input trunk. Output operations are essentially the reverse of this procedure.

Automatic Parallel Processing Is Exclusive With Honeywell

Development of a control memory to achieve automatic parallel operation of multiple programs is one of the many outstanding contributions Honeywell has made to the art of electronic data processing. Other contributions include Orthotronic Control, vacuum-actuated magnetic tape drives, redundant circuitry checking and what is recognized as the most advanced business compiler (FACT) and program test system yet developed.

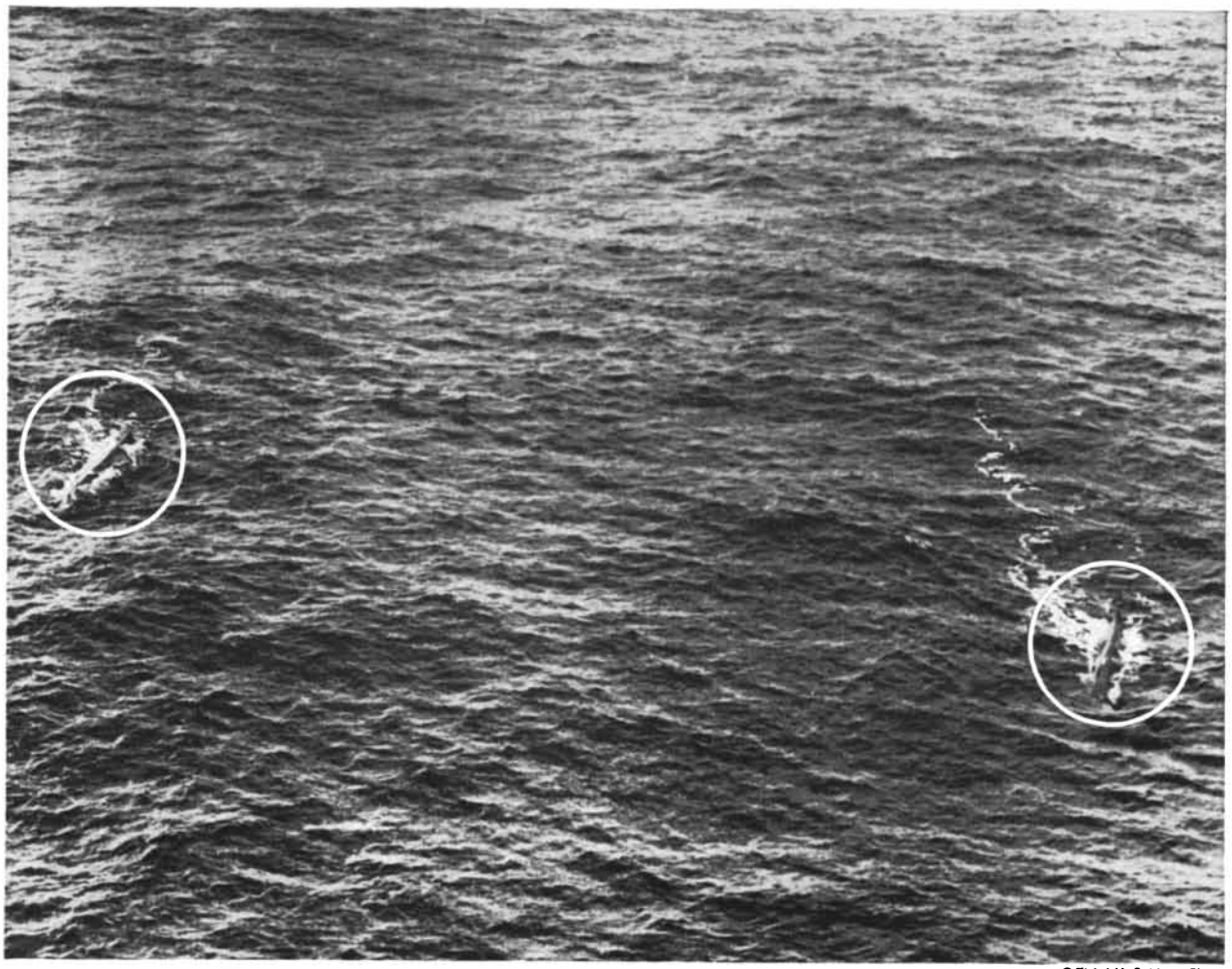


HONEYWELL 800 INFORMATION AND CONTROL FLOW DIAGRAM

If you would like technical papers on any of these subjects, or additional information about Honeywell transistorized data processing systems and Automatic Parallel Processing, write: Dept. SC, Minneapolis-Honeywell, Datamatic Division, Wellesley Hills 81, Mass.

Honeywell

Electronic Data Processing



Official U. S. Navy Photo

WHICH WAKE IS AN ENEMY SUBMARINE?

Thanks to its anti-submarine equipment, the U. S. Navy quickly determined that both suspected "targets" were actually whales. Had they been enemy submarines, however, the Navy was ready to take immediate action.

Protecting this Nation from surprise underwater attack is an ocean-sized problem that's being energetically tackled on a great many fronts. Bendix® —with its development and production background in depth recording and indicating instruments, underwater telephones, submarine detection and tracking sonar, scanning sonar, power steering, and other submarine gear— has been assigned the responsibility for much submarine operation and detection equipment.

Take sonar. It's a type of underwater radar that lacks the range of radar. The Bendix assignment: Increase its range.

A big Bendix contribution to undersea warfare has been the complete guidance systems used on the latest high-speed torpedoes whose missions are to destroy high performance submarines.

Another interesting Bendix development is "dunking" sonar. Dropped by cable from a helicopter, it scans literally hundreds of square miles underseas in an hour's time. We also manufacture control rod drive mechanisms for nuclear submarines and for the USS Long Beach, the Navy's first nuclear-powered cruiser.

Bendix has even adapted television to submarine use. When the USS Skate made her historic voyage under the North Polar ice cap, she carried aboard a unique Bendix TV system. By magnifying light thousands of times, and literally "seeing in the dark," this TV system showed the crew thin spots in the bottom of the ice pack through which the Skate surfaced safely.

About to be submerged, this Bendix-developed "underwater sound source" transmits sound waves beneath the sea. It is designed to increase sonar capabilities.

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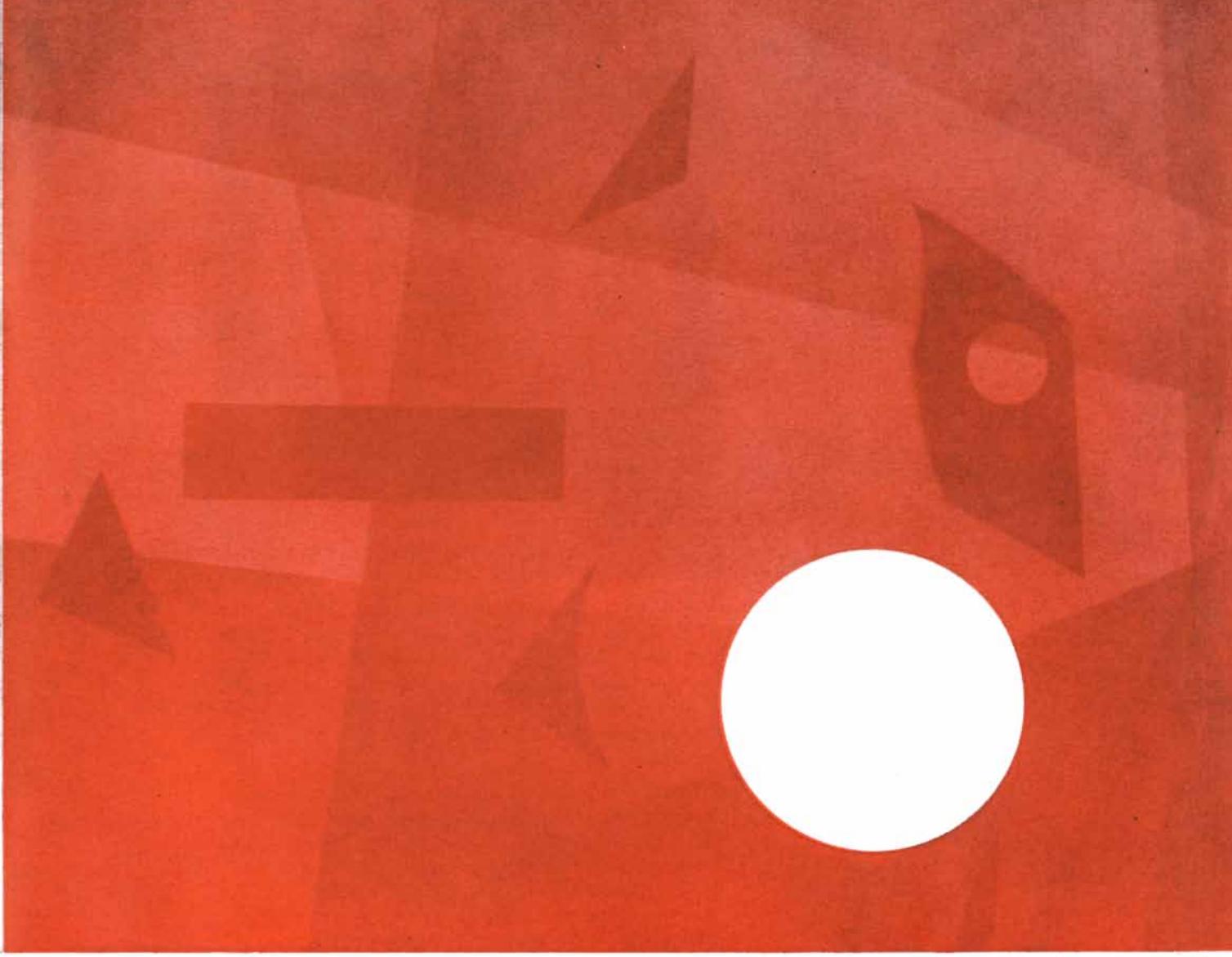

COMMUNICATION SYSTEMS . . . *the ultimate integration of the electronic arts*

Among the great names in the telecommunications and electronics industry, Kellogg today is one of the country's strongest sources of advanced communications equipments and systems. We have one major goal — to provide the finest communications that the electronic arts make possible . . . for industrial, commercial and military needs.

The Communication Systems Department of Kellogg, growing by leaps and bounds to keep pace with demands for wholly integrated communications means, provides large-scale communications systems from Alpha to Omega . . . from systems studies through engineering and production. Engineering is concerned with all phases of telephone, radio, data communications and automatic control circuit design. Principal areas of engineering organization include Project Engineering, Applications Engineering, Development and Systems Evaluation and Utilization and Reliability.

Typical of Kellogg's major systems engineering achievements is the provision of complete ground communications for the firing of Titan and Thor ballistic missiles and Discoverer and Samos space satellites at Vandenberg Air Force Base. Similarly, Kellogg has provided for the Atlas ICBM program nine separate systems for communication, control, maintenance and check-out, count-down, voice-recording and fire alarm — all functioning as an integrated system.

If you seek a dynamic organization in which to further your future, write Manager of Technical Staffing, Communication Systems Department, Dept. M-03(1).

ITT KELLOGG Communications Division, International Telephone and Telegraph Corporation

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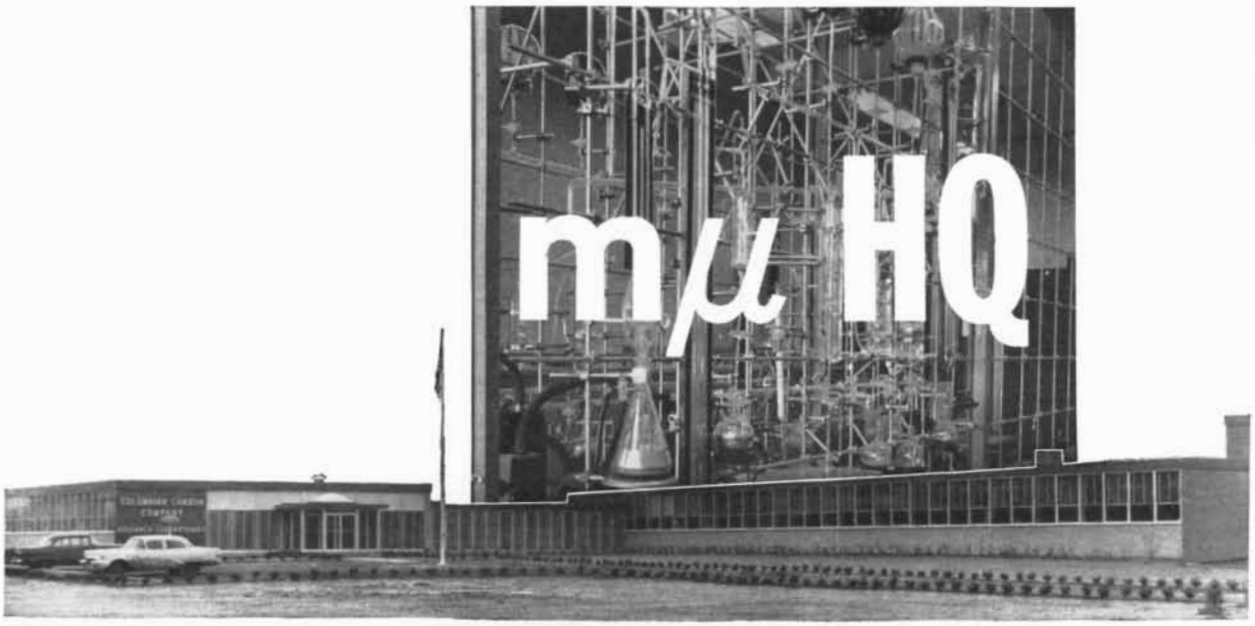

MILLIMICRON HEADQUARTERS is an apt name for Columbian Carbon's new research center in Princeton, N. J. Because it is devoted to the study of carbon black particles so tiny they must be measured in millimicrons . . . particles that play vital roles in the manufacture of rubber, paint, ink and plastic products.

Finding new frontiers for the use of carbon black . . . new ways in which it can contribute more effectively and efficiently . . . is an unending project that has earned Columbian credit for many "firsts" – the development of new types of carbon blacks . . . the use of electron microscopy to reveal new concepts of carbon black structure . . . data on pH effects . . . Columbian's Black Rubber process . . . and most recently low structure oil furnace carbons.

Perhaps Columbian research and carbon black can make a contribution to your industry . . . help you make a better product . . . and profit! Ask for complete information – today!

X 75,000 . . . Columbian pioneered the development of electron microscopy . . . now uses it as a research and quality control tool.

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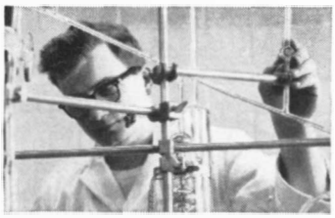


TOMORROW . . . much of Columbian's research is devoted to breaking barriers . . . turning the impossible into reality.

PEOPLE . . . An outstanding research staff whose accomplishments are well known . . . will direct laboratory activities.

How to use a 4-megacycle instrumentation tape recorder

Ampex's new AR-300 and FR-700 answer a whole new range of needs

For video-bandwidth phenomena

Radar, for instance, can now be tape recorded off receiver and played back repeatedly to scopes, analytical devices or radar guided equipment. Radar testing, reconnaissance and tracking are enormously aided by tape's live-playback capabilities. And for simulation and training, elusive transient phenomena now become repeatable at will.

For predetection recording and communications monitoring

The recorder's bandwidth catches everything at once – any 4-megacycle band of radio frequencies or the IF stage off a telemetering receiver. This simplifies on-site equipment. One kind of recording serves for all usual types of communications and telemetered data. Later you can play back through detector, discriminator and other equipment as many times as necessary to separate and process the desired channels of information.

For 5,000,000 binary bits per second

Super-efficient acquisition and reduction systems can be developed around serial pulse-coded data put directly on tape. One reel lasts 60 minutes – holds over seven billion binary bits. Compare this with previous PCM techniques on tape limited to less than 1,000,000 bits per second even at much higher tape speeds and proportionately shorter recording time.

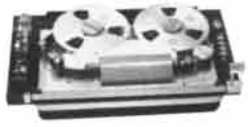
The essential data

The Models: AR-300 Mobile or airborne record only; FR-700 single-rack laboratory record/playback. Response: 10 cps to 4 mc (±3 db). Tape speeds: 12½ and 25 ips. Playing time: 60 minutes. Tape: 1.0-mil Mylar, 2-inch width, 10½-inch reels. Data tracks: two wideband plus two auxiliary. Electronics: all solid state. Environmental (AR-300): 10g vibration; 50,000 ft. alt.; −54°C to +55°C. Tape interchangeability: yes, among all AR-300/FR-700 recorders.

Write for full information

AMPEX DATA PRODUCTS COMPANY

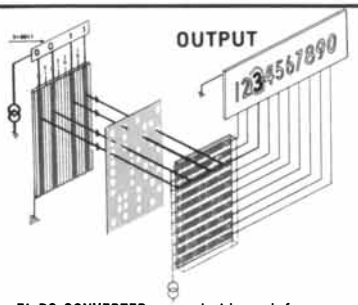
Box 5000 • Redwood City, California • EMerson 9-7111



AMPEX

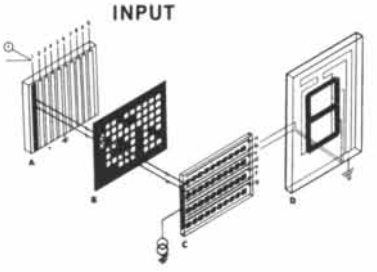
ELECTROLUMINESCENT-PHOTOCONDUCTIVE DEVICES

A phenomenon made practical . . . by SYLVANIA



EL-PC CONVERTER converts binary information to decimal form. The output of the CONVERTER can be used as the input to the TRANSLATOR shown below. EL-PC matrices for decimal-to-binary conversion are also available from Sylvania.

EL "READOUT" DEVICE is composed of strips of electroluminescent lamps, insulated from each other and separately terminated. By selective excitation of the "strips," alpha-numeric symbols are produced for readout purposes.



EL-PC "TRANSLATOR" makes practicable use of the luminous properties of EL phosphors on panel "A" and of photoconductive elements on panel "C." Mask "B" enables selective excitation of the electroluminescent phosphors on readout panel "D."

Physical dimensions of EL-PC panels are shown here in exaggerated scale for purposes of clarity.

FEATURING · Compact, flat construction · Minimal catastrophic failure · Exceptional reliability and long life · Simplified circuitry · Negligible power requirements

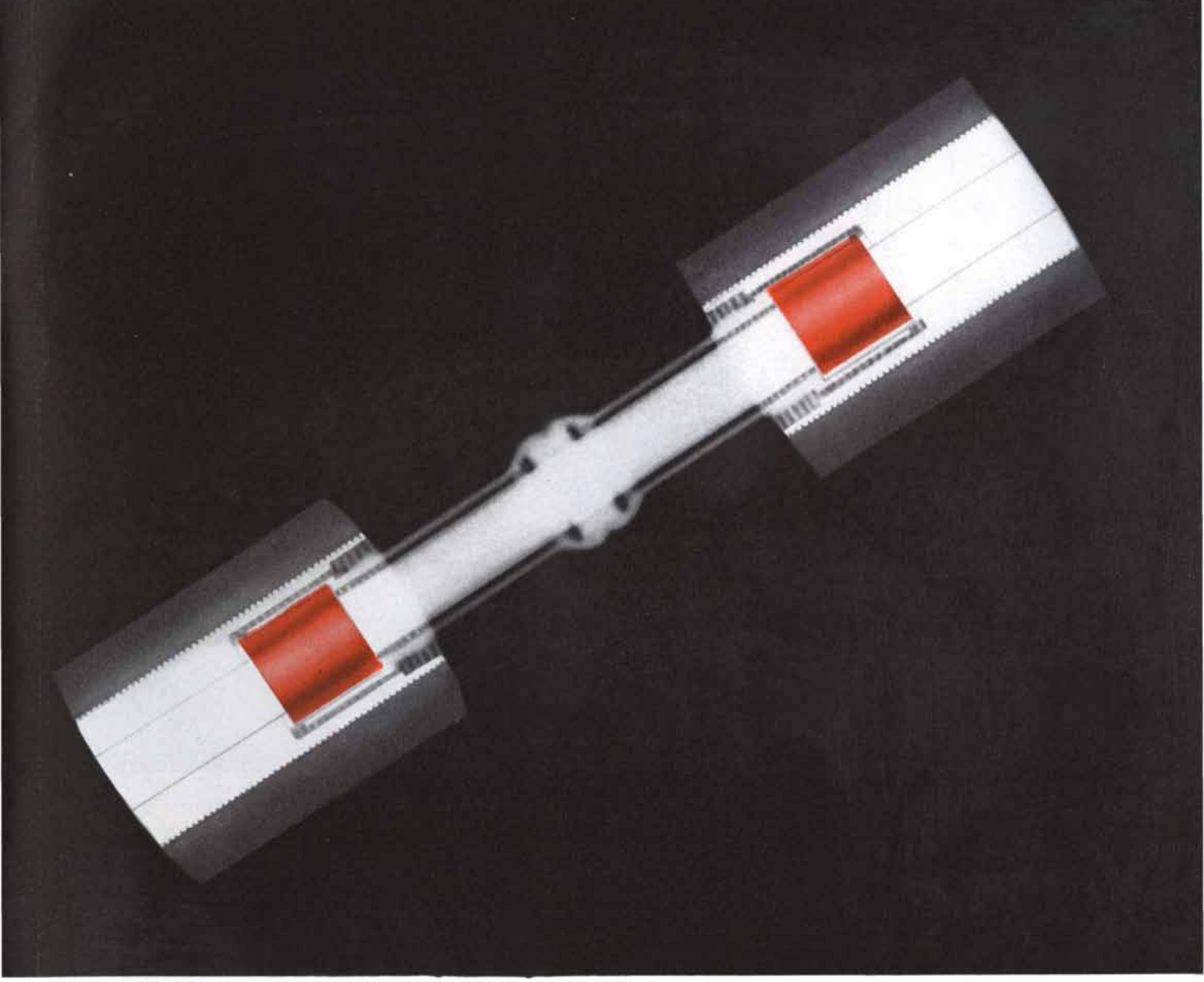
SYLVANIA combines photoconductive elements with the luminous properties of electroluminescent phosphors to provide design engineers with a group of alpha-numeric readout devices and components capable of performing simple and complex logic functions, the conversion of digital information, and the storage and memory of data. These offer new and significant possibilities for end-product miniaturization together with dramatically enhanced reliability.

For example, new "crossed-grid" panels have been developed that utilize conductive strips placed at right angles to each other on opposite sides of an electroluminescent phosphor layer. These "strips" when separately excited glow at the points of intersection. This provides a point of light that can be moved in X-Y directions to create a display that is exceptionally small in front-to-back dimensions and is highly useful in position-plotting applications.

Sylvania Sales Engineers can give you details on specific EL-PC devices. Too, write for ten-page brochure, "Sylvania Electroluminescent-Photoconductive Devices," to Electronic Tubes Division, Sylvania Electric Products Inc., Dept. 1051, 1100 Main Street, Buffalo, N. Y.

SYLVANIA

Subsidiary of **GENERAL TELEPHONE & ELECTRONICS**



Bearings of TEFLON used in Whitin roving and spinning frames.

THE INSIDE STORY: rolls that run with "unoiled precision"

In textile spinning machinery, rolls like the one shown above run in contact with driving rolls to hold yarn in a draw and twist operation. A runout of more than .003" shows up in uneven and patterned yarn. As a further complication, *lubricated* bearings cause trouble — the atmosphere is humid, full of lint, and there is constant danger of oil contaminating the yarn. The answer: bearings made with Du Pont TEFLON® TFE-fluorocarbon resins, which have a lower coefficient of friction than any other solid material. Over 3,000,000 of these non-lubricated bearings are now in use, running with required tolerances 24 hours a day, six days a week.

In a variety of difficult bearing applications the remarkable properties of TEFLON resins have been put to good use. In addition to low friction, TEFLON TFE resins offer virtually complete chemical inertness, and they are rated for continuous use from –450° to 500°F. Filled compositions and reinforced constructions are available to meet the requirements of increased loads and velocities or high wear resistance. The recent introduction of the new melt-processible FEP resin further extends the usefulness of TEFLON resins in mechanical and electrical applications. To find out more about the many opportunities for improved design with the family of TEFLON TFE and FEP resins, write to: E. I. du Pont de Nemours & Co. (Inc.), Polychemicals Department T-3910, Room 2526, Nemours Building, Wilmington 98, Delaware. *In Canada:* Du Pont of Canada Limited, P. O. Box 660, Montreal, Quebec.

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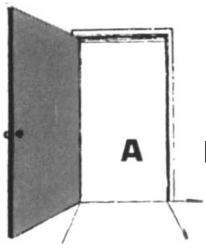
FLUOROCARBON RESINS

TEFLON is Du Pont's registered trademark for its family of fluorocarbon resins, including TFE (tetrafluoroethylene) resins and FEP (fluorinated ethylene propylene) resin.

BETTER THINGS FOR BETTER LIVING...*THROUGH CHEMISTRY*

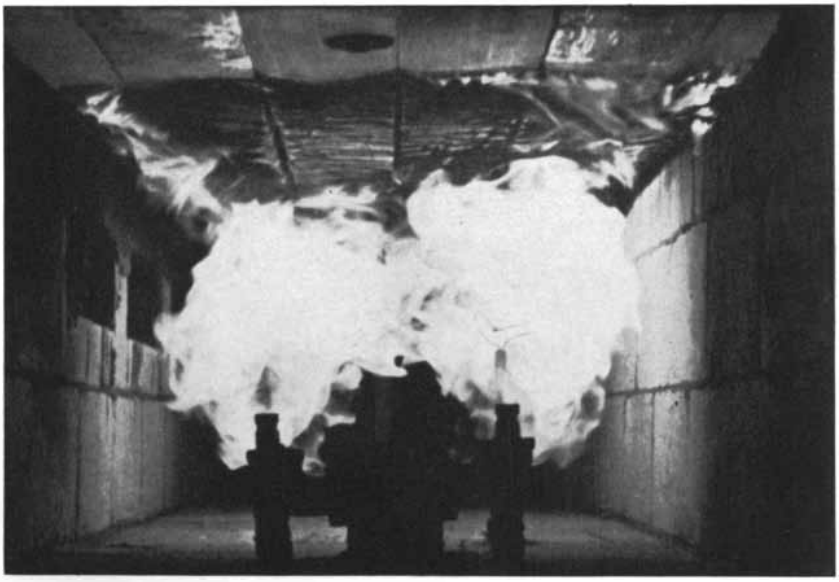


DOOR IS OPENED TO NEW DEVELOPMENTS IN PLASTICS, BUILDING MATERIALS AND URETHANE FOAM

What is your field of interest? Plastics molding? Plastic film? Gypsum products? Textile bleaching? Urethane foam? Here's a report from Allied Chemical research on new developments in each of these areas.

NEW FIRE-RESISTANT PLASTIC

We now have a truly flame-retardant urea plastic to offer the lighting appliance field, which has long been looking for a readily moldable, fire-resistant material. They need it to form the louver-type fixtures featured in modern "wall-to-wall" lighting (the "luminescent ceiling"). Our PLASKON® UFR-28 fills the bill. Underwriters' Laboratories says many approving things about it (see picture caption). UFR-28 is a development of our Plastics and Coal Chemicals Division.



UL "TUNNEL TEST" gives PLASKON Urea Molding Compound a flame-spread rating of 25 to 75, meeting requirements of municipal, state and national building codes. Photo courtesy of Underwriters' Laboratories, Inc.

NEW STRENGTH FOR POLYETHYLENE FILM

Plastic bag makers and packagers will appreciate *this* development. Producers of cast and blown polyethylene film now add a little of our A-C® Polyethylene to their regular polyethylene grades. Result: Thinner films of equal strength, equal moisture barrier—and a virtual end to all the "sticky" problems that beset those engaged in making, opening, filling or sealing polyethylene bags and wrappers. Further details on the advantages of A-C Polyethylene as a film additive may be obtained from our Semet-Solvay Petrochemical Division.

NEW GYPSUM PLANT NEEDS NO NATURAL GYPSUM ROCK

Not since Old Pharaoh issued his "bricks-without-straw" edict has there been an innovation like this in building materials manufacture. Come next year, a gypsum plant will be in operation at Claymont, Delaware, that uses no natural gypsum rock. Our Barrett Division has come up with a unique process to make wallboard and other gypsum products from chemically manufactured gypsum — identical to that found in the highest purity rock deposits. This will eliminate the need for transporting gypsum rock from Nova Scotia and other distant points. The Claymont facility will increase Barrett gypsum capacity more than 50%. To get back to Old Pharaoh, Cheops used gypsum in his Great Pyramid, 5,000 years ago. Nine out of ten homes use gypsum products today.

NEW PATENT FOR BLEACHING PROCESS

U. S. Patent 2903327 has been issued for our Solvay Process Division's Activated Hydrogen Peroxide Bleaching Process. This process, available on a non-exclusive and royalty-free basis, yields cottons of higher purity, greater brightness, and less tendency to yellow. Cuts the cost of bleach chemicals up to 50%, too.

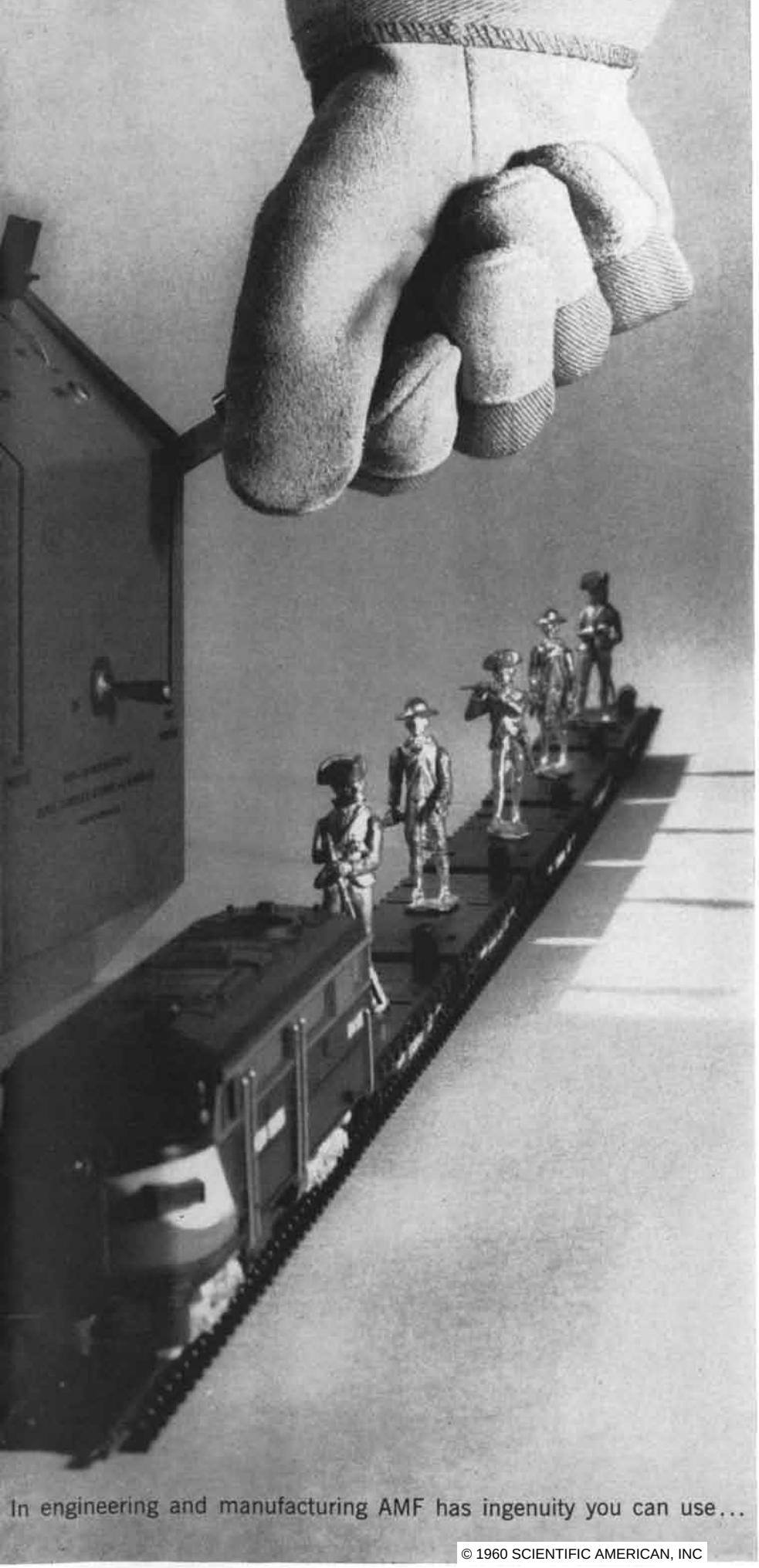
NEW TECHNICAL SERVICE ON URETHANE FOAM

Manufacturers of foam plastics are invited to learn how GENETRON® blowing agents can produce larger volumes of improved urethane flexible foams at lower cost — or how to get increased insulation value in rigid urethane foams — by contacting the special technical service laboratory recently set up by Allied's General Chemical Division. General produces GENETRON blowing agents for flexible and rigid polyurethane foams. Allied Chemical is becoming quite a factor in this business, by the way. Three other divisions make urethane foam components: National Aniline produces NACCONATE® diisocyanates, Plastics and Coal Chemicals makes polyester resins, and Solvay Process will be making polyethers in a new plant by next June.

LIKE TO KNOW MORE about any of these developments? Just write, on your company letterhead, to Allied Chemical Corporation, Dept. 106-S, 61 Broadway, New York 6, N. Y., or phone HAnover 2-7300.

Allied Chemical

BASIC TO AMERICA'S PROGRESS



He's got Minutemen "working on the railroad"

Hard basing is one way to protect America's force of retaliatory ICBM's. The problem was to find an alternate means of accomplishing the same mission. The Air Force solution was a new ICBM mobility concept—railroad car-mounted Minutemen, utilizing the nation's vast track mileage for numerical and geographical dispersion, creating a difficult target for enemy attack.

To put the Minuteman, its support systems and associated equipment on rails was a completely new problem in missile handling. The first requirement assigned by Boeing to American Machine & Foundry Company and ACF Industries, Inc., was a feasibility study of the existing limitations of roadbeds, rails, railroad operations and right-of-way. Unique tactical cars are being designed within these limitations to carry the Minuteman—cars that can handle the missile and its operating equipment, safely isolated from roadbed shock and ready for immediate retaliatory launching.

Single Command Concept

Whether for conceptual problems such as this one, or for challenges in design or manufacturing, AMF has ingenuity you can use. AMF people are organized in a single operational unit offering a wide range of engineering and production capability. Its purpose—to accept assignments at any stage from concept through development, to production, and service training...and to complete them faster in

- *Ground Support Equipment*
- *Weapon Systems*
- *Undersea Warfare*
- *Radar*
- *Automatic Handling & Processing*
- *Range Instrumentation*
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GOVERNMENT PRODUCTS GROUP, AMF Building, 261 Madison Avenue, New York 16, N. Y.

AMF

In engineering and manufacturing AMF has ingenuity you can use...

AMERICAN MACHINE & FOUNDRY COMPANY

50 AND 100 YEARS AGO

SCIENTIFIC AMERICAN

OCTOBER, 1910: "The international convention for the purpose of regulating aerial traffic has now proceeded so far in its work that at least 15 of the questions which were assigned to it for consideration have been definitely answered. Most of the governments have agreed to distinguish two classes of airship in military or other governmental service. Private airships must be inspected before they can receive a license. The convention has unanimously decided that the transportation of arms and explosives, photographic apparatus and wireless telegraphic apparatus shall be forbidden, no doubt for military reasons."

"In several respects the Vanderbilt Cup automobile race for 1910 surpasses any preceding race for this famous trophy. The steadiness of the running proved that, except possibly in the matter of tires, an all-round improvement has been made in the strength and running quality of the machines. As usual, the tire was the most frequent source of delay; and, wonderful as the new high-class tire has become in its ability to stand severe duty, it must be considered today the weakest part of the automobile. The tire is the most expensive element in the automobile. The high average speed of 65.4 miles per hour made by the winner, Harry F. Grant, in an Alco, must be regarded as very creditable."

"The recently founded Observatory of the Ebro, situated near Tortosa, Spain, is an embodiment of an idea that is every day gaining ground among progressive meteorologists; *viz.*, that fluctuations in the activity of the sun find a more or less immediate response in many phenomena of the earth's atmosphere—in addition to the effects long since recognized upon the earth's magnetic field."

"Having developed his storage-battery car to a point where it is available for commercial use, Thomas Edison has made another step in the evolution of suburban travel by the invention of a trackless storage-battery car. The car is a pay-as-you-enter type, and is in reality a large motor 'bus driven by electricity. At a recent test of this car, it was run over steep hills and typical suburban roads with perfect success."

"The French Naval Minister has given orders that the cruiser *Foudre* is to be rebuilt as an auxiliary to marine aviation. A platform 125 feet in length is to be erected on the deck of the warship, to enable aeroplanes to start while at sea. Experiments will also be made to test the possibilities of landing on such a platform."

Scientific American.

OCTOBER, 1860: "Nearly all of our microscopists, in their communications to Silliman's *American Journal of Science* and other kindred works, use the millimeter as their measure, and in Cooke's *Elements of Chemical Physics* and other standard works, the meter and kilogramme, as well as the degrees of the centigrade thermometer, are employed without translation. We are beginning to think seriously of adopting this course in SCIENTIFIC AMERICAN. The people are running ahead of our legislators in making this great reform in our weights and measures."

"The unit of heat is that which is sufficient to raise the temperature of one pound of water by one degree Fahrenheit. The unit of work is the raising of one pound weight through a vertical height of one foot—called a foot-pound. The experiments of Joule, of Manchester, indicate that if the whole of the heat could be rendered available, a unit of heat would raise 772 pounds one foot high; in other words, a unit of heat is equal to 772 foot-pounds. This is called Joule's equivalent. A pound of charcoal will raise 78.15 pounds of water 180 degrees, which is equal to 14,067 units of heat. This, multiplied by 772, gives 10,859,724 foot-pounds, which is equal to the production of 5½ horse power from the combustion of one pound of charcoal per hour. As the best engines consume nearly two pounds of coal per horse power per hour, it follows that only about one tenth part of the gross power of the fuel is utilized."

"The French scientific journals are full of accounts of the application of the new discovery, hypnotism. In *Cosmos* we find a detailed account of an amputation performed on a man aged 34, whose left knee was increased by white swelling to nearly double the size of the right knee, and was so painful that the least movement produced the most intense suffering. The hypnotism was produced by placing a bright spatula about eight inches in front of the root of the nose. Looking at this, the patient soon became insensible, in spite of the severe pain which he was in from being moved to the operating room. Insensibility was produced in 10 minutes, and the amputation occupied a minute and a half. The patient gave no sign of pain; his features were perfectly tranquil; his eyes only seemed to be wandering in search of the brilliant object which had been before them."

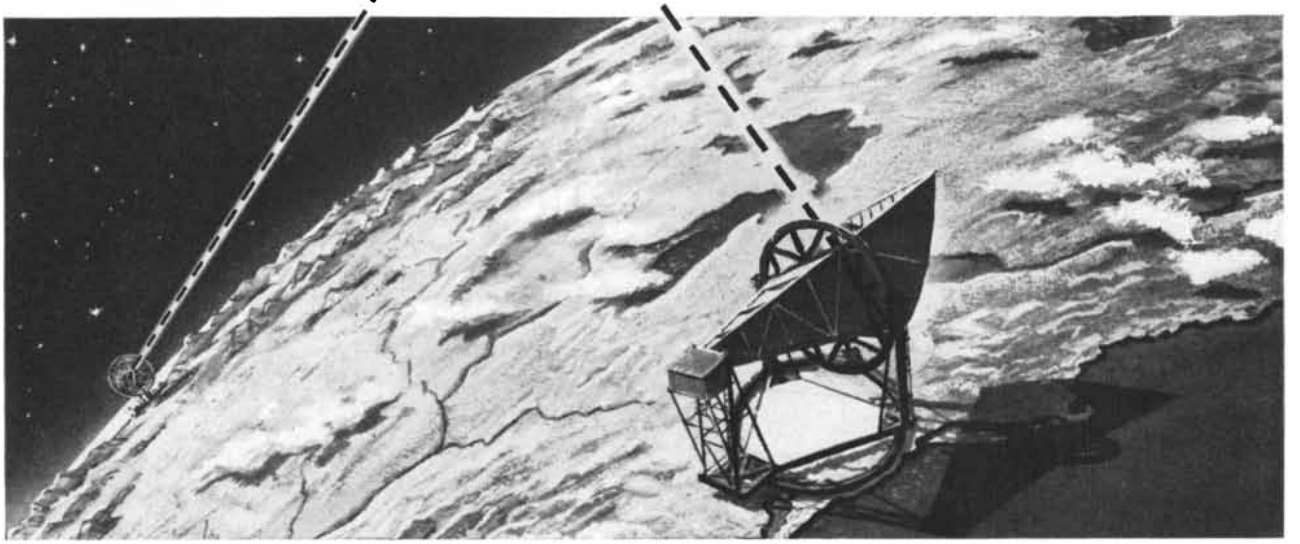
"Late intelligence from the oil districts reveals the fact that the celebrated Tideout well stopped flowing over the top after throwing out some 200 barrels. The famous Crosby well has dwindled from 70 barrels a day to six or seven, but the owner thinks the failure is attributable to the filling of the pumps, and hopes to do better when it is cleaned. Out of 267 wells on the creek above Titusville, only 34 are yet pumping oil, and many of the oil-seekers are just now in a state of very anxious suspense."

"By the latest news from England, we learn that the captain and the chief engineer of the *Great Eastern* have been discharged, and it is said that she is to be laid up all winter. Her bottom was examined at Milford Haven, and found to be tolerably clean, but a little rusty. It had been stated that her bottom had become so foul as to detract about two miles per hour from her speed in the voyage across the Atlantic. This turns out to have been fiction. It was expected that she would make a voyage with a cargo to New York this winter. This would be a true test of her qualities as a merchant steamer."

"When it was first proposed to light London with gas, Sir Humphry Davy gave his opinion against its practicability, solely on the ground of the impossibility of keeping the joints of the pipes from leaking. This great chemist was very deficient in mechanical talent, and was seldom able to make a tight joint for his pneumatic experiments; hence his opinion. Faraday, who became his assistant, being an excellent mechanic, soon showed him how easy it was to make tight joints for gas pipes."

FIRST PHONE CALL VIA MAN-MADE SATELLITE!

"Project Echo" satellite went into a near-perfect circular orbit 1000 miles high, circling the earth once every two hours. Its orbital path covered all parts of the U. S.



BELL TELEPHONE LABORATORIES BOUNCES VOICE OFF SPHERE PLACED IN ORBIT A THOUSAND MILES ABOVE THE EARTH

Think of watching a royal wedding in Europe by live TV, or telephoning to Singapore or Calcutta—*by way of outer-space satellites!* A mere dream a few years ago, this idea is now a giant step closer to reality.

Bell Telephone Laboratories recently took the step by successfully bouncing a phone call between its Holmdel, N. J., test site and the Jet Propulsion Laboratory of the National Aeronautics and Space Administration (NASA) in Goldstone, California. The reflector was a 100-foot sphere of aluminized plastic orbiting the earth 1000 miles up.

Dramatic application of telephone science

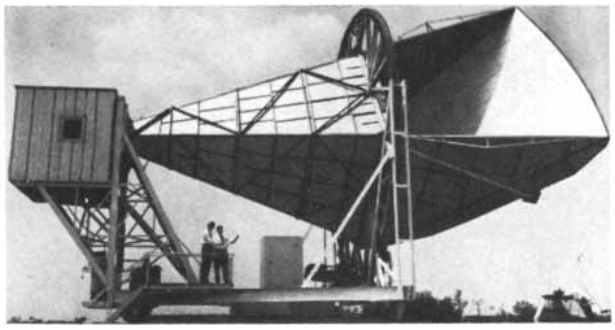
Sponsored by NASA, this dramatic experiment—known as "Project Echo"—relied heavily on telephone science for its fulfillment . . .

▪ The Delta rocket which carried the satellite into space was steered into a precise orbit by the Bell Laboratories Command Guidance System. This is the same system which recently guided the remarkable Tiros I weather satellite into its near-perfect circular orbit.

▪ To pick up the signals, a special horn-reflector antenna was used. Previously perfected by Bell Laboratories for microwave radio relay, it is virtually immune to common radio "noise" interference. The amplifier—also a Laboratories development—was a traveling wave "maser" with very low noise susceptibility. The signals were still further protected from noise by a special FM receiving technique invented at Bell Laboratories.

"Project Echo" foreshadows the day when numerous man-made satellites might be in orbit all around the earth, acting as 24-hour-a-day relay stations for TV programs and phone calls between all nations.

This experiment shows how Bell Laboratories, as part of the Bell System, is working to advance space communication. Just as we pioneered in world-wide telephone service by radio and cable, so we are pioneering now in using outer space to improve communications on earth. It's part of our job, and we are a long way toward the goal.



Giant ultra-sensitive horn-reflector antenna which received signals bounced off the satellite. It is located at Bell Telephone Laboratories, Holmdel, New Jersey.

BELL TELEPHONE LABORATORIES

WORLD CENTER OF COMMUNICATIONS RESEARCH AND DEVELOPMENT

Radio beacon transmitters no bigger than a matchbook—another RCA contribution to space-age technology.

Tiny RCA space radios help "ECHO" scientists find a pinpoint in the sky

The pinpoint is the 100-foot aluminized plastic balloon now orbiting about a thousand miles above the earth. Its purpose: to establish the feasibility of long-distance communications by bouncing radio waves off an object in space to distant points on the earth's surface.

The balloon carries two RCA radio beacon transmitters, each scarcely larger than a matchbook, yet capable of being heard for two thousand miles or more. They send signals earthward, telling scientists where to find the balloon at night or when clouds obscure the sky. Because the radios are sun-powered, they are expected to broadcast throughout the life of the balloon satellite.

These amazing radio transmitters were designed and built by the Astro-Electronics Division at RCA's Space Center at Princeton, N. J.—birthplace of the satellite and ground-based radio equipment for the "Talking Atlas" satellite, the TIROS "weather-eye" satellite system, and other space-age achievements.

This program—called "Project ECHO"—is sponsored by the National Aeronautics and Space Administration as the first step towards a new system of global communications. Eventually, television programs may be viewed around the world through the use of these orbiting "radio mirrors."

The same RCA engineering and manufacturing skills that are helping man conquer space assure the dependability of the RCA Victor black-and-white and color television sets, radios and high-fidelity systems you enjoy in your home.

RCA **The Most Trusted Name in Electronics**

RADIO CORPORATION OF AMERICA Tmk(s)®

METALGRAMS

UNION CARBIDE METALS

. . . news about metals and metal chemicals

SEPTEMBER - OCTOBER, 1960

NEW PEAKS PREDICTED FOR POLYPROPYLENE PRODUCTION. Brightest prospects are in over-wrap applications, and in automobile and appliance uses. Keeping step as a polymerization catalyst is our titanium trichloride. Latest interest is in the activated form of this product -- $TiCl_3$-1A -- just introduced. With the activated form, plastics producers are achieving higher conversion rates . . . yet consistently retaining the same clear, high-quality polymer previously provided by the unactivated material. Activated and unactivated titanium trichlorides are available from UCM in quantities for research and commercial uses. For additional data request TT2-S8.

* * *

VANADIUM BUTTERS TITANIUM-STEEL SANDWICH. A new technique developed by Titanium Metals Corporation of America uses vanadium metal as a "butter" between titanium and steel . . . Counters the usual problem of welding dissimilar metals. Called interlayer welding, this technique uses either a series of vanadium plugs or a thin, continuous sheet. Vanadium metal was selected because it provides the necessary engineering strength and corrosion resistance at the joint. The advance is expected to brighten the cost picture for companies anxious to use corrosion-resistant titanium sheet in chemical processing equipment. UCM makes vanadium metal in sheet or strip for use in the sandwich. Bulletin VM3-S8 gives general data on vanadium and the welding technique.

* * *

MAKING TOOL PRODUCTION TiC. Makers of cemented carbide tools are obtaining greater erosion and oxidation resistance, as well as cost economies, through the use of titanium carbide, TiC. One major tool manufacturer reports simplified quality control because of the consistent analyses of our high-purity material, e.g., free carbon, 0.2%; combined carbon, 19.3%. This refractory compound is also being used in newly developed titanium-carbide-base cutting tools and in cermet and ceramic shapes. UCM's titanium carbide is available in commercial quantities as powder $<$ 5 micron av. FSS. A variation of this product -- submicron high-purity titanium carbide -- is being studied for uses which require fine particle size. Request TC2-S8 for data on TiC.

* * *

VANADIUM AS YOU LIKE IT. As demand for vanadium metal grows, customers look for a wider range of mill products at minimum delivery time. The new focus: manufacture and processing of larger vanadium ingots. An ingot more than 9 in. in diameter -- believed to be the largest to date -- has just been cast for us by Universal-Cyclops. This means more vanadium mill products off the shelf from UCM, as we continue to meet customer requirements in size, as well as purity, with minimum lead time. For data on vanadium request VM2-S8.

* * *

HELPING OTHERS TO HELP OURSELVES. UCM will be keying its 1960 National Metal Show display to the theme: "Select The Right Metal For The Job...Ask Our Engineers To Help". The fact that alloying elements make metals better will be illustrated by outstanding applications of low-alloy steel, stainless steel, high-temperature alloys, and aluminum. Also featured will be a number of refractory metals with special emphasis on the promising new columbium alloys. To save time and expense send for free Admission Invitation AD1-S8.

* * *

Union Carbide Metals Company, Division of Union Carbide Corporation, 270 Park Avenue, New York 17, N. Y. In Canada: Union Carbide Canada Limited, Toronto.

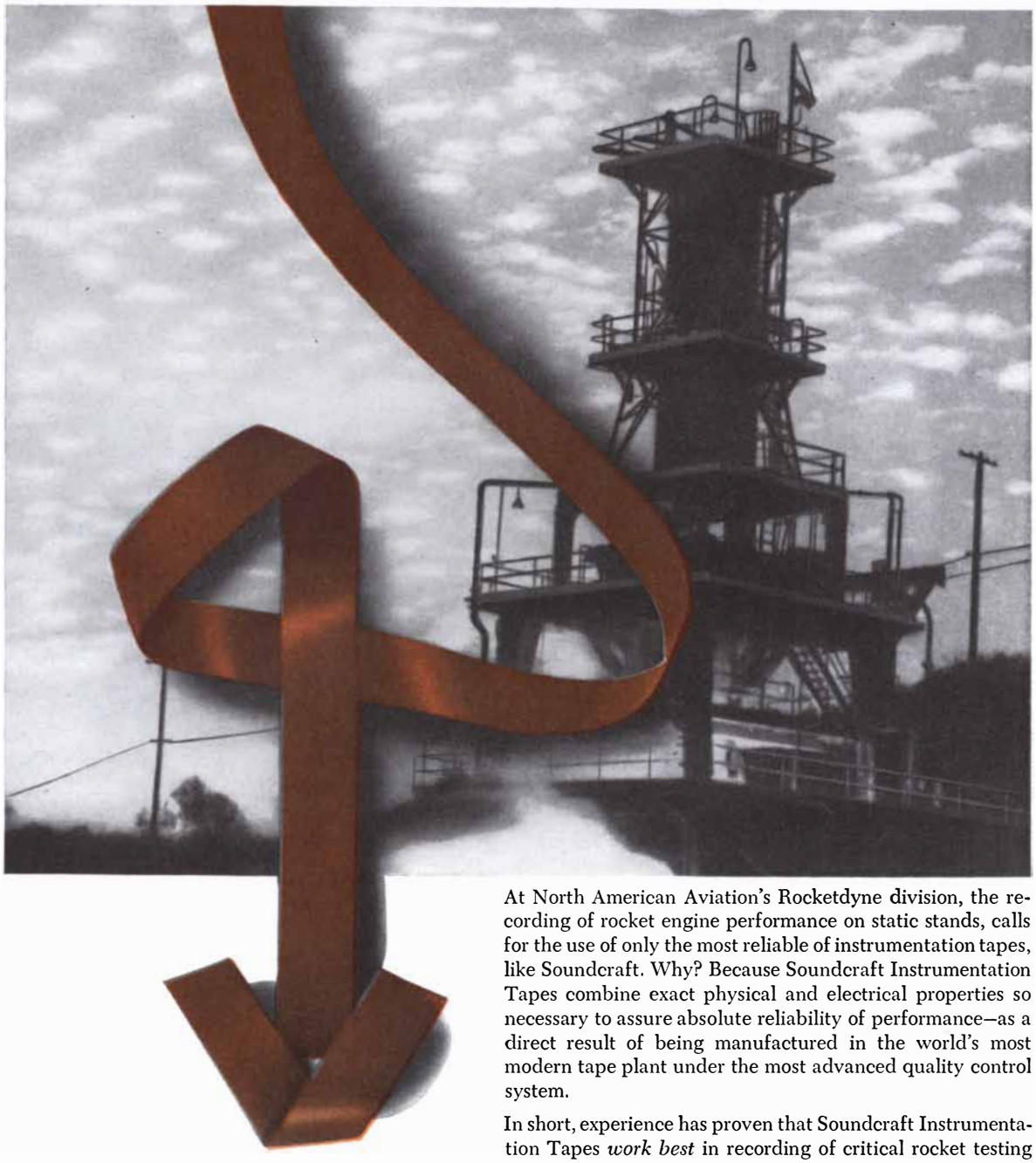
Teamwork: the best anti-submarine weapon

In the air, on the surface and under water, they work together. *Teamwork*, itself, becomes a science in hunting down a sub. Technically advanced equipment — teamed up with deadly precision — is being designed to leave enemy subs no escape. This future is taking shape now in broad studies at Vought Aeronautics. Aircraft, developed especially for most efficient use of electronic search equipment . . . advanced sonobuoys . . . even space systems, under study by Vought Astronautics. These and other ideas are undergoing analysis, or actual test in Navy ships and planes. By drawing on the broad resources of its sister divisions, Vought Aeronautics, like the Fleet, is using teamwork to serve the Navy's Number One Mission.

CHANCE VOUGHT AERONAUTICS DIVISION DALLAS, TEXAS

WORKING PARTNERS

ROCKETDYNE AND SOUNDCRAFT INSTRUMENTATION TAPES



At North American Aviation's Rocketdyne division, the recording of rocket engine performance on static stands, calls for the use of only the most reliable of instrumentation tapes, like Soundcraft. Why? Because Soundcraft Instrumentation Tapes combine exact physical and electrical properties so necessary to assure absolute reliability of performance—as a direct result of being manufactured in the world's most modern tape plant under the most advanced quality control system.

In short, experience has proven that Soundcraft Instrumentation Tapes *work best* in recording of critical rocket testing operations. Why not let precision-made, error-free Soundcraft Instrumentation Tapes go to work for you? Complete literature on request.

REEVES SOUNDCRAFT CORP. Great Pasture Rd., Danbury, Conn. • Chicago: 28 E. Jackson Blvd. Los Angeles: 342 N. LaBrea • Toronto: 700 Weston Rd. R-111

Florida

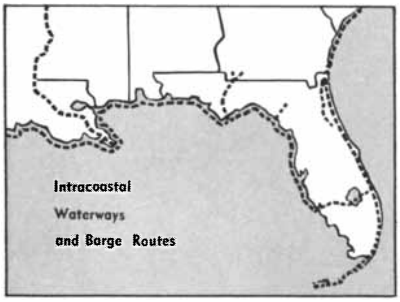
...trade center of the Americas

Forty million people in the 12 southeastern states and 80 million in the nearby Caribbean comprise markets which are being increasingly served by Florida. And these markets are growing steadily in buying power.

IN THE SOUTHEAST, retail sales for 1959 totaled $38 billion. This represents a gain of 34 per cent over sales for 1954. The national gain was only 28 per cent.

IN FLORIDA ITSELF, sales rose from $4,014 million to $6,625 million — an increase of 65 per cent.

The opportunities for serving southeastern markets from Florida are shown by some of the typical multi-state facilities which have been opened recently.



Barge routes skirt the Gulf of Mexico from Florida to Brownsville, Texas, and stretch up the Mississippi. In the Atlantic, the Intracoastal Waterway provides a sheltered shipping route from Key West to New Jersey and beyond.

MULTI-STATE DISTRIBUTORSHIPS

FOOD FAIR STORES opened a 700-man distribution center in Jacksonville.

BORDEN COMPANY'S new plant in Tampa is a multi-state center.

RAYTHEON serves several states from a new facility in Orlando.

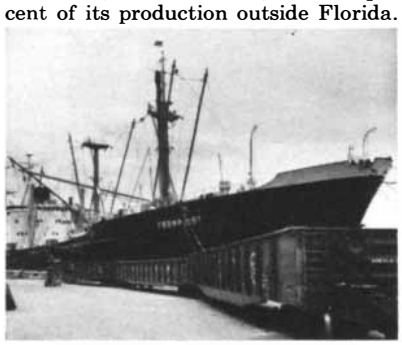
DAVIES CAN COMPANY established a distributorship in Tampa to serve the paint industry in the Southeast.

WALGREEN DRUG COMPANY'S new facility in Jacksonville serves North and South Carolina, Georgia, Alabama and parts of Tennessee as well as Florida.

ROOTES MOTORS opened a southeastern states distributorship in Pensacola for Hillman, Sunbeam and other British cars. Renault expanded its multi-state facility in the same city.

Wholesale sales for all three of the major metropolitan areas in Florida — Miami, Tampa-St. Petersburg and Jacksonville — more than doubled between 1948 and 1958. Only five other major areas in the nation did as well.

Manufacturers, too, find Florida's markets extend far beyond Florida's borders. Two-thirds of the sales of Marc-El Fashions of Miami, for instance, are to other states. A typical maker of aluminum furniture, Gay Products, Inc., of Clearwater, sells 60 per cent of its production outside Florida.



Thirteen deep water ports line both coasts of Florida. More than 65 shipping companies provide scheduled service, and 32 million tons of domestic and foreign cargo were handled in 1958. PORT OF TAMPA, shown here, has just completed a $15 million harbor improvement program, deepening the channel to a full 34 feet.

CARIBBEAN PURCHASES INCREASE

Trade between Florida and the rich Caribbean and Central American markets is growing steadily. In spite of the political unrest, exports by vessel to these areas totaled $189 million in 1958 — 69 per cent over 1954.

As evidence of the growing trade bonds between Florida and Central America, two shipping firms recently began operating trailer ships between Miami and Port Everglades and Matias de Galvez. From this Guatemalan port, trailers can be towed southward over the Pan American Highway.

TOTAL FOREIGN TRADE UP 48%

Overall, Florida's foreign trade has grown steadily. The 1959 total of $810 million was 48.4 per cent over 1955.

Chemicals for England are made in Pensacola, paper for the Netherlands in Panama City and Jacksonville, machinery for Israel in Tampa. Twelve million dollars worth of iron scrap is shipped to Italy and Japan each year. Florida produces a third of the world's phosphate.

WHY INDUSTRY MOVES TO FLORIDA

Besides its strategic location to serve rich markets, there are many reasons why industry is finding it increasingly profitable to locate in Florida.

People like to live and work in the Sunshine State. Companies such as Martin-Orlando, Pratt & Whitney Aircraft and Chemstrand Corporation have found it relatively easy to recruit skilled technicians and engineers from out of the state when their needs cannot be supplied by local manpower pools.

Taxes are favorable. Those levied directly on business accounted for only 8.8 per cent of the 1957-58 state income — less than half the national average.

Florida has a right to work law, and is the only state in the Southeast with an apprenticeship law, under which industry and state co-operate.

For those considering new ventures, the 2,100 new manufacturing plants which have opened in the state in the last three years give evidence of the opportunities which Florida offers.

Florida's importance as a distribution center is emphasized by the growing number of trucking companies making headquarters in the state. Mercury Motor Express (illustrated) moved its headquarters and 250 employees to Jacksonville this year. Central Truck Lines, Tampa, operates 1,175 trucks in five states. The giant Ryder Systems, Inc., has headquarters in Miami.

NEW PLANT LOCATION BOOKLET

If you are interested in opening a plant or branch in Florida, a new booklet explains in detail how the Industrial Services Division of the Florida Development Commission can help you choose the most advantageous location.

This booklet describes special studies which can be prepared for potential locations covering markets, manpower, transportation and supplier industries as related to your individual needs.

Meetings with community leaders may be arranged, but unless authorized, your identity will not be revealed.

Write to B. R. Fuller, Jr., Exec. Dir., Florida Development Commission, 4016-3 Carlton Building, Tallahassee.

For more general information about industrial Florida, ask for the nine-part file folder, "Profile of Progress."

See industrial Florida for yourself. Write State of Florida, Dept. B, Carlton Building, Tallahassee, for a 100-page color "Vacation Guide."

Air freight has greatly extended Florida's markets. Univis Lens Company, which recently moved to Fort Lauderdale, plans to ship 350,000 pounds of products by air each year. Westinghouse Electric Corporation supplies its South American markets with appliances from Miami. MIAMI INTERNATIONAL AIRPORT, shown here, handled over 207 million pounds of air cargo in 1959, and the largest volume of foreign cargo of any airport in the nation.

ASSURES PREDICTABLE PERFORMANCE OF BARDEN PRECISION BALL BEARINGS

One of the key factors behind the world renowned reliability of *Barden Precision* bearings is quality control. First step in Barden's advanced quality control procedure is inspection of bearing steel to assure its conformance to rigid specifications.

From here on, bearing parts are carefully checked — microscopically, mechanically and electronically — at *every* manufacturing operation. At the end of the line, functional testing of assembled bearing assures that, small quantity or large, every *Barden Precision* bearing will meet your performance requirements.

Typical of Barden quality control instrumentation is the Waviness Gage, a production tester used to check the accuracy of raceway grinding — one of Barden's many contributions to the advancement of the precision bearing art.

Barden quality control — together with Barden methods in manufacturing, bearing assembly, final inspection, lubrication, functional testing and sealed packaging — is your assurance that with *Barden Precision* bearings you get consistent quality from the beginning to the end of each production run.

Barden is a major supplier of standard bearings in sizes from .0469" bore to over 3" O.D., all manufactured to *Barden Precision* standards of dimensional accuracy, uniformity and reliability.

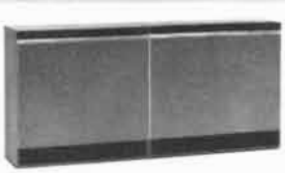
for reliability... specify

BARDEN PRECISION BALL BEARINGS

THE BARDEN CORPORATION. 216 Park Avenue, Danbury, Connecticut

Western office: 3850 Wilshire Boulevard. Los Angeles 5. California

BENDIX G-20



WITH ORGANIZATION CHART DESIGN

MEANS PRACTICAL EXPANDABILITY IN

BALANCE WITH APPLICATION GROWTH

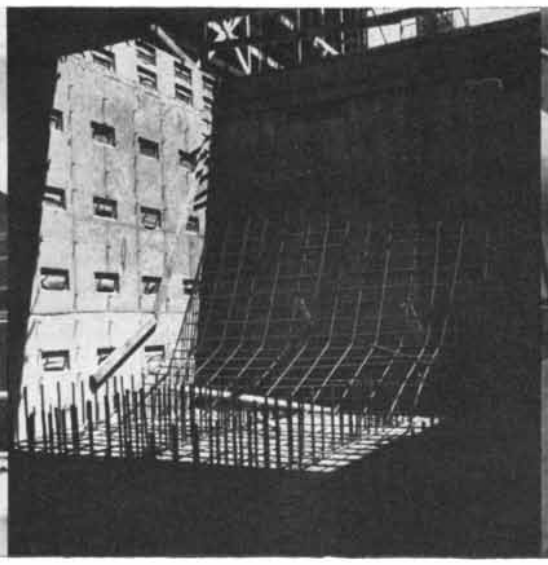
Just as the organization chart of any enterprise provides the framework for dynamic growth and adaptation, so "organization chart" design provides the framework for unparalleled expandability in the Bendix G-20 data processing system. This means that your G-20 can economically match, step by step, your expanding scientific or business computational workloads ... without sacrificing system balance. • Key to the organization chart efficiency of the Bendix G-20 is the ability of the Central Processor to "delegate" routine data handling tasks to control buffers, acting as "line supervisors." Thus freed, the Central Processor can make most efficient use of its high computation speed, its ability to schedule program priorities and direct accessory equipment assignments. • The ability to employ many control buffers gives new meaning to expandability in the Bendix G-20. Up to 70 input/output units can be directed by each of these "line supervisors." The Bendix G-20 has a complete line of accessory equipment including keyboard, paper tape, punched cards, high speed line printers, and 2 million word magnetic tape units. • Memory represents another dimension of G-20 expandability, ranging from 4,096 to 32,768 words. • Investigate the organization chart design of the Bendix G-20. See how it provides balanced, *practical* expandability ... at a cost that assures unequalled data processing performance per dollar invested. • *For detailed literature write:*

Bendix Computer Division
DEPT. C-27 LOS ANGELES 45, CALIF.

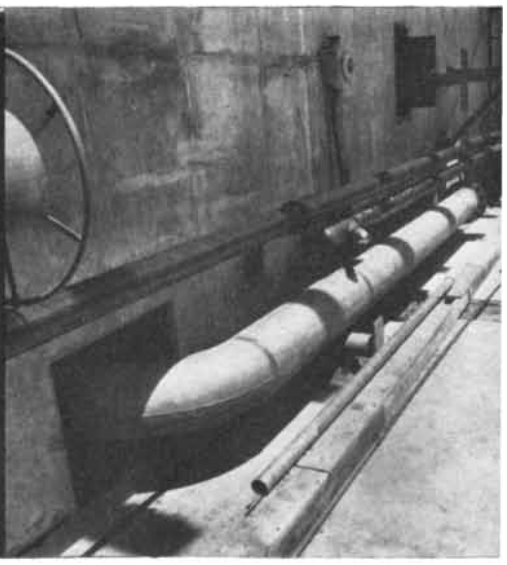
THE Bendix CORPORATION

Somewhere east of Laramie, on one of Wyoming's plains, you'll find the strangest government housing project ever built. Six concrete and steel buildings are being constructed to house Atlas missiles. The site is one of the operational intercontinental missile bases to be operated by the Strategic Air Command. This base is being constructed on the surface. Follow-on bases will burrow deep into the earth. In all these systems, the Air Force puts much emphasis into ground support equipment. Virtually all steels required can be purchased from one firm — United States Steel. Whether it's carbon

The U. S. Army Corps of Engineers is constructing this operational intercontinental missile base in Wyoming. In front of the partially completed Launch and Service Buildings are Col. Sidney T. Martin, in charge of construction, and Maurice K. Graber, a construction engineer for the Corps.



This is the inside of the blast pit of one of the launcher buildings. In all six of these buildings there are 1,040 tons of structural steel, 1,950 tons of reinforcing steel, over 48,000 tons of concrete aggregate, blocks and cement, and 8,040 tons of mechanical steel items.

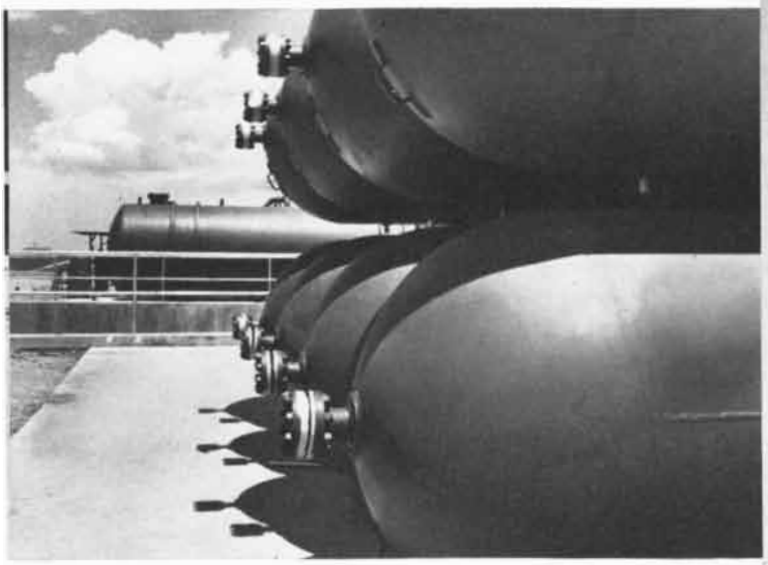


Fuel lines and process piping are Stainless Steel and operate at pressures up to 15,000 psi. The pipes are kept almost surgically clean to prevent contamination of fuel and subsequent malfunction. Vapor degreasing and chemical cleaning processes are used on the pipes.

steel, high-strength low-alloy steel, ultra high-strength alloy steels, Stainless Steel, steel fence, electrical cable, cement or wire rope, United States Steel maintains the technical services to assist in solving any problem on materials for ground support. When a ground support program goes to the drawing board, consult with

United States Steel

USS is a registered trademark



The Atlas is powered by a cluster of liquid propellant rocket engines that burn liquid oxygen and RP-1, a kerosene-like hydrocarbon fuel. 192 pressure tanks fabricated from alloy or Stainless Steel plate at this site store liquid and gases—liquid oxygen and nitrogen and helium gases which are used to inject the fuels into the missiles.

THE AUTHORS

E. F. KNIPLING ("The Eradication of the Screw-Worm Fly") is director of the Entomology Research Division of the U. S. Department of Agriculture. Born in Port Lavaca, Tex., in 1909, he acquired his B.S. at Texas Agricultural and Mechanical College in 1930. He received his M.S. from Iowa State University in 1932 and his Ph.D. in entomology and parasitology from the same institution in 1947. For his contributions to the development of insecticides and insect repellents during World War II, the Government awarded him the Medal of Merit. Knipling developed the sterile-male principle of insect control discussed in the present article, and directed the preliminary research that led to its application.

P. V. GLOB and T. G. BIBBY ("A Forgotten Civilization of the Persian Gulf") are respectively director of the Institute of Prehistoric Archeology at the University of Aarhus in Denmark, and head of the department of antiquities at the Prehistoric Museum in Aarhus. Glob was born in Kalundborg, Denmark, in 1911 and acquired his Ph.D. in 1945 at the University of Copenhagen. After serving as keeper of the National Museum in Copenhagen, he joined the faculty at Aarhus in 1949 as professor of prehistoric archeology. Since 1953 Glob has led a number of Danish archeological expeditions to the Middle East, among them the ones that resulted in the discoveries described in the present article. Bibby, a British citizen born and educated in England, became a staff member of the Prehistoric Museum in 1950. He took his degree at the University of Cambridge, and from 1937 to 1939 he did archeological field work in England and Scotland. Until 1946 he served with the British Army in Europe. For the next three years Bibby participated in archeological reconnaissance in Bahrain and Qatar while working for an oil company in the Middle East. He has accompanied Glob as deputy leader on the Danish expeditions during the past seven years.

ARNOLD L. BLOOM ("Optical Pumping") is a research physicist at the firm of Varian Associates in Palo Alto, Calif. He was born in Chicago, Ill., in 1923, and originally studied to become a concert pianist. Faced with the choice of several careers, he decided that his interest in physics would not allow him to pursue it "purely as a hobby." He took two degrees in physics at the University of California, receiving his Ph.D. in 1951, and joined Varian Associates in the same year. There he has specialized in studies in nuclear and paramagnetic resonance. His interest in optical-pumping techniques dates from 1956.

BRUCE C. HEEZEN ("The Rift in the Ocean Floor") is assistant professor of geology at Columbia University and senior research scientist at Columbia's Lamont Geological Observatory. He was born in Vinton, Iowa, 36 years ago, and acquired his B.A. at the University of Iowa in 1948. As an undergraduate studying invertebrate paleontology, Heezen became interested in submarine geology after hearing a lecture by Maurice Ewing, director of the Lamont Observatory. In 1947 Ewing chose him to head a small expedition which reconnoitered the continental shelf and slope off New England. He joined the Lamont Observatory in 1949, became a faculty member at Columbia in 1951 and received his M.A. in geology there a year later.

HARRY GRUNDFEST ("Electric Fishes") is professor of neurology at the College of Physicians and Surgeons of Columbia University. He received his Ph.D. from Columbia in 1930 and began to study electrophysiology at the University of Pennsylvania on fellowships from the National Research Council and the Johnson Foundation. Before going to Columbia in 1945, he was a staff member at the Rockefeller Institute for 10 years, a period that included service as senior physiologist with the U. S. Army Signal Corps during World War II. Grundfest's major interest is the fundamental processes involved in bioelectrogenesis. His research on electrogenic activity in different types of cells has included studies of the cells of protozoa, muscle, nerve and some 20 species of electric fishes.

A. C. CHARTERS ("High-Speed Impact") is supervisory aeronautical research engineer and chief of the Hypervelocity Ballistic Range Branch at the Ames Research Center of the National Aeronautics and Space Administration. A native Californian, he took his degrees at the California Institute of Technology, receiving his Ph.D. in aeronautical engineering in 1938. From 1939 to 1950 he was a civilian staff member of the Ballistic Research Laboratories at the Aberdeen Proving Ground. He went to work for NASA in 1952. In his work at the Ames Research Center, Charters has been primarily responsible for the development of the hypervelocity ballistic range, a new facility for studying the physics of flight speeds of up to 18,000 miles per hour under controlled laboratory conditions.

ARTHUR H. BENADE ("The Physics of Wood Winds") is associate professor of physics at Case Institute of Technology. The son of missionary parents, he was born in Chicago, Ill., in 1925 and raised in the Indian city of Lahore, where his father was chairman of the department of physics at Forman College. His college education, which began at Ohio State University and continued at the University of Minnesota, was interrupted by the war, during which he spent a year at Los Alamos as a technician. He completed his undergraduate studies at Washington University in Saint Louis, receiving his B.A. in 1948. He took his Ph.D. in physics at the same institution in 1952, joining the faculty at Case Institute later that year. Benade, who is an accomplished flutist, became interested in the theory of musical instruments while doing graduate work, and he undertook the restoration of a 175-year-old Zumpe piano. "Having since had a few students myself," he says, "I can now understand the dismay with which this project was received by my thesis adviser." At Case Institute he has "combined teaching with research in nuclear physics, with occasional bursts of activity in musical physics."

MITCHELL WILSON ("Count Rumford") is a novelist who began his career as a physicist. He was born in New York in 1913 and was educated at New York University and Columbia University, where he worked under I. I. Rabi. Later, as an assistant to Enrico Fermi, he did some early research on the meson. From 1940 to 1944 he worked on thin films and high-frequency heating, and wrote short stories in his spare time. Since that time Wilson has made writing his career, publishing three novels and a pictorial history of American science.

P. W. BRIDGMAN, who in this issue reviews Louis de Broglie's *Non-Linear Wave Mechanics: A Causal Interpretation*, was professor of physics at Harvard University until 1951 and University Professor there until 1954, when he retired. Bridgman was awarded the Nobel prize in 1946 for his work in high-pressure physics.

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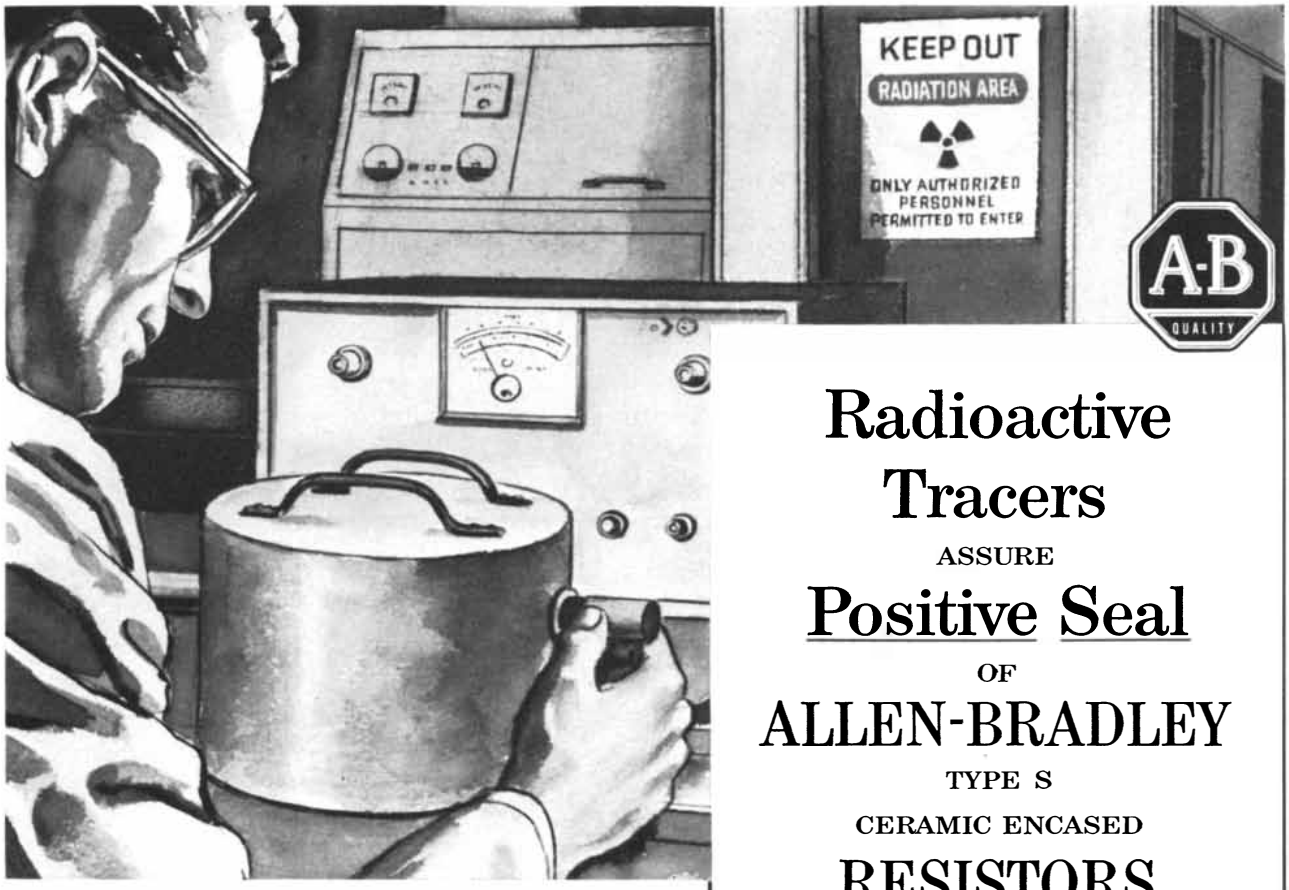

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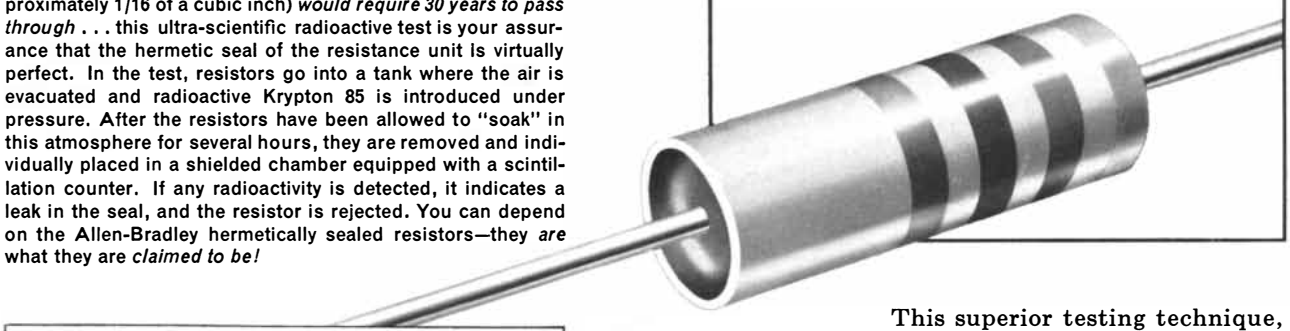

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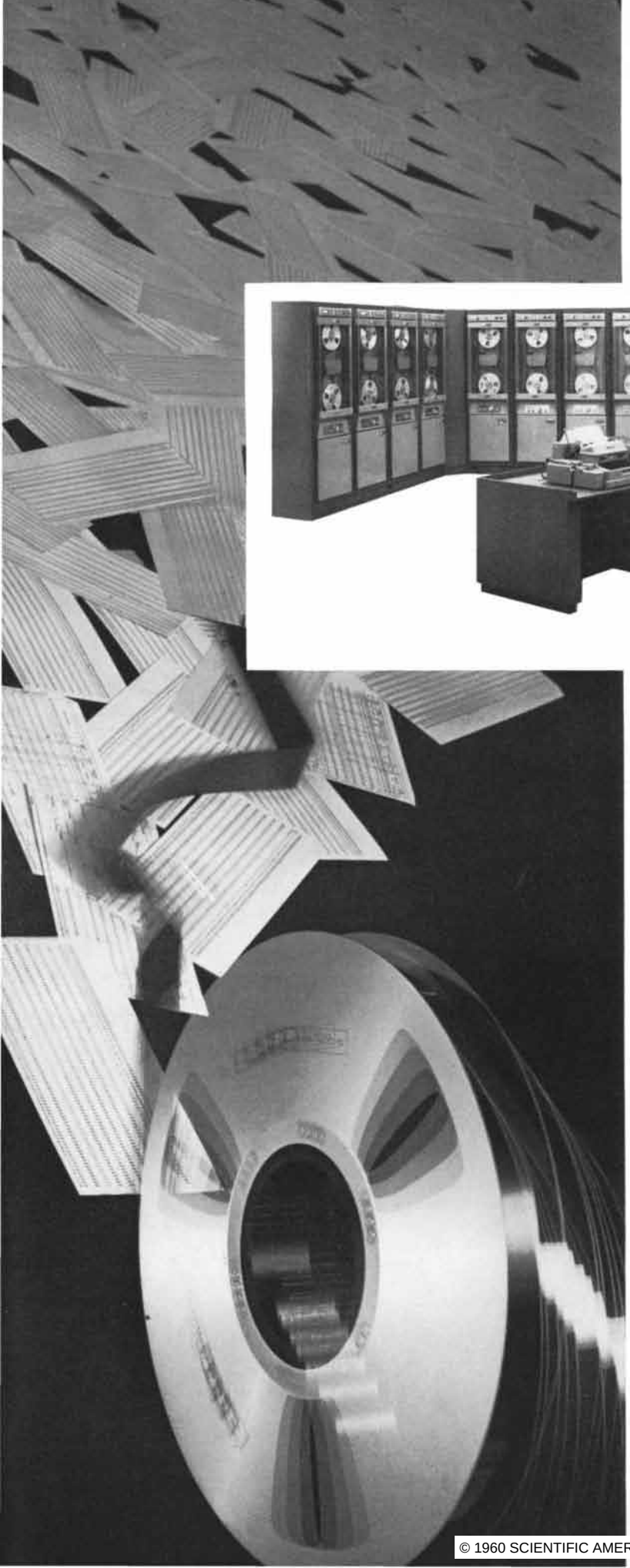

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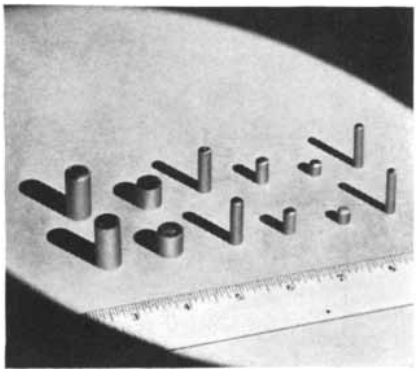

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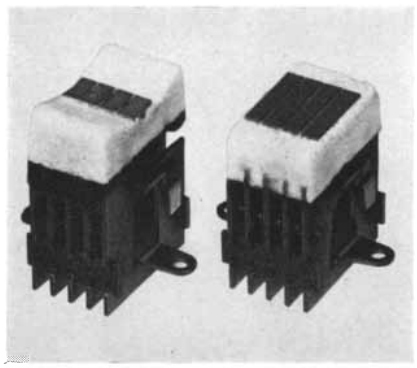

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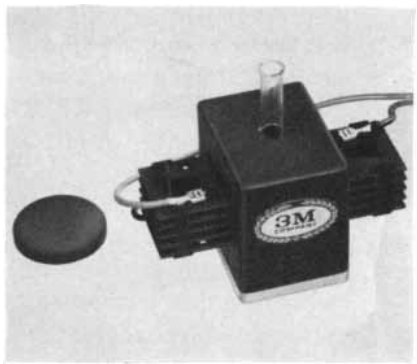

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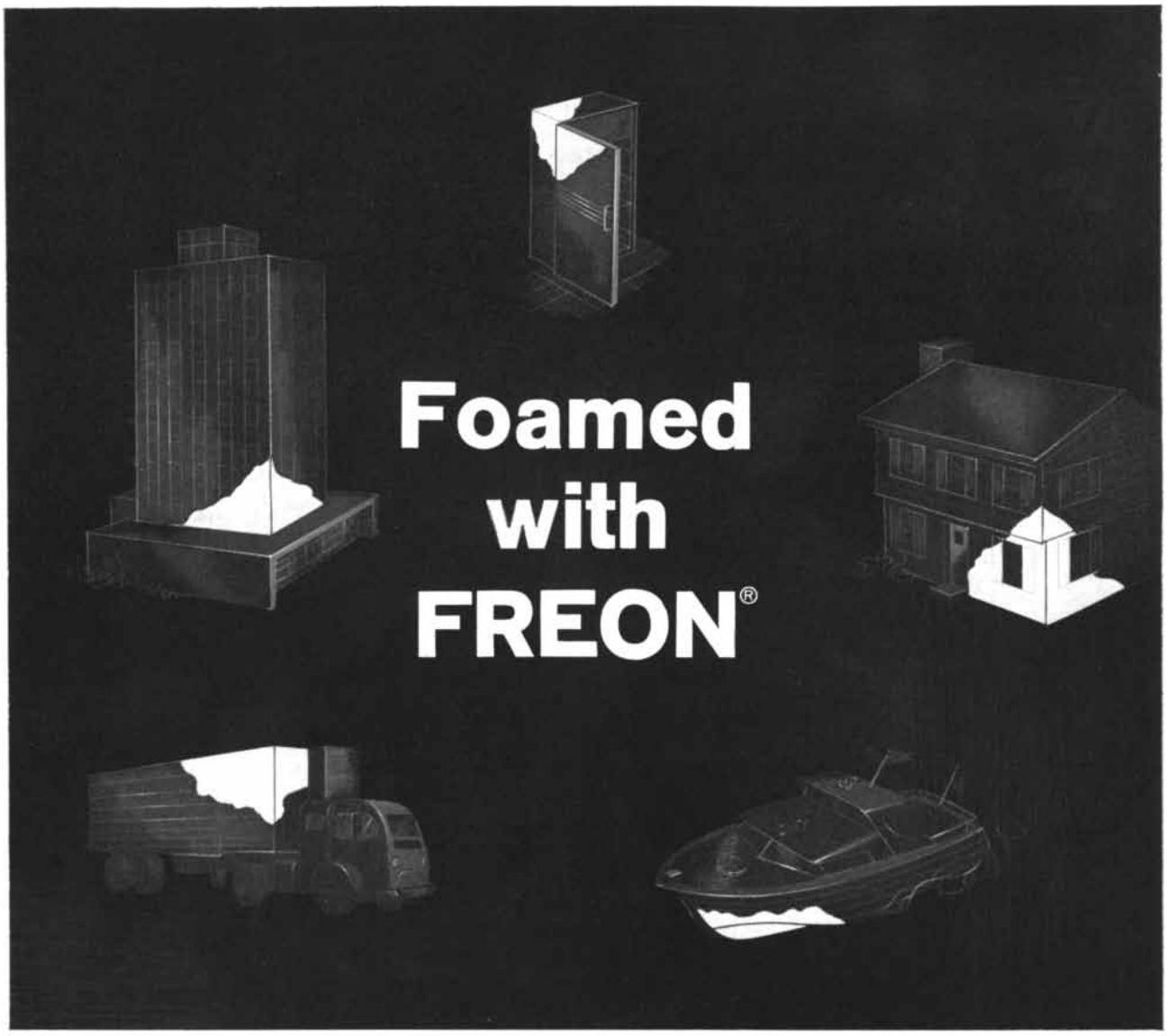

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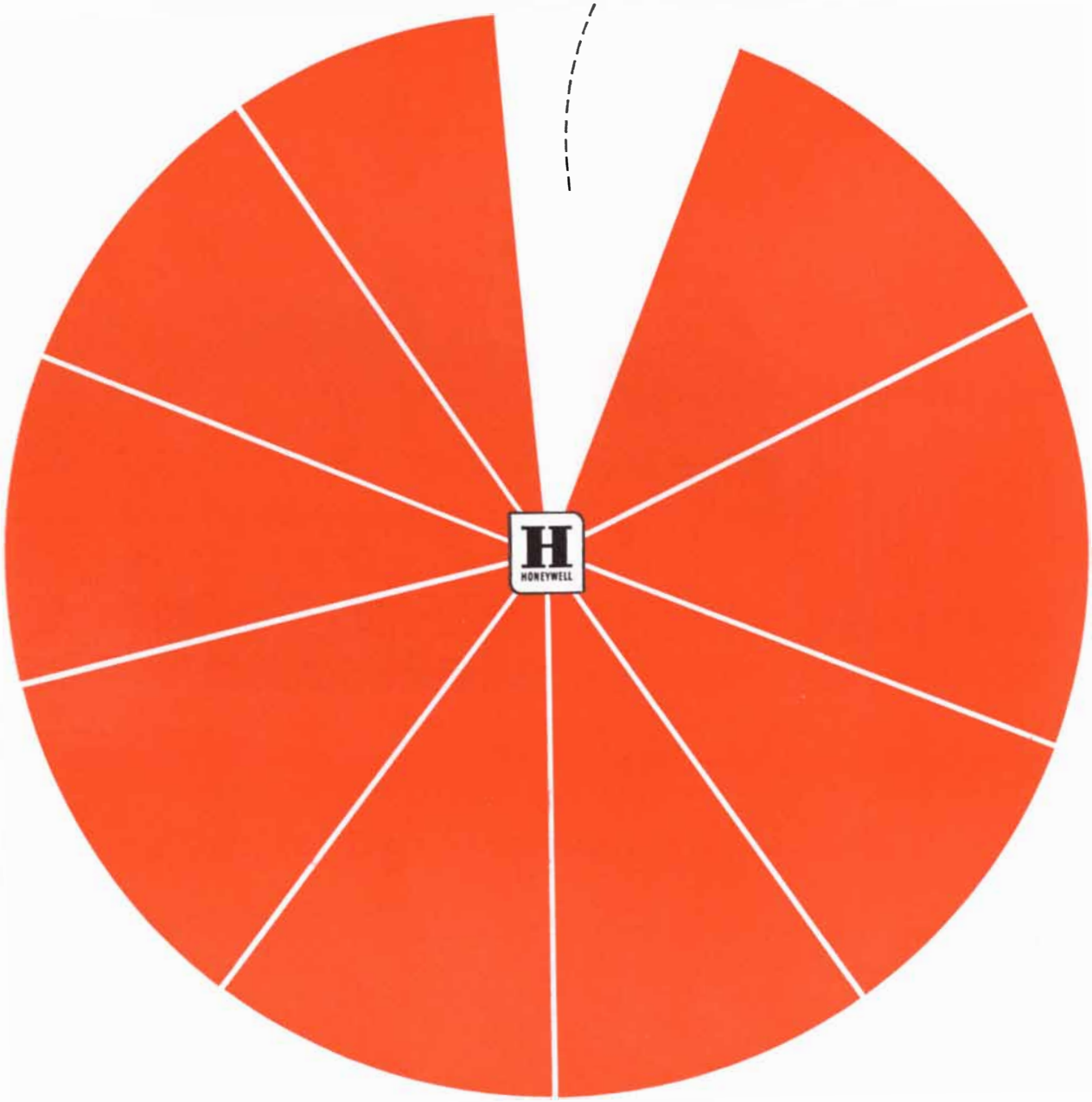

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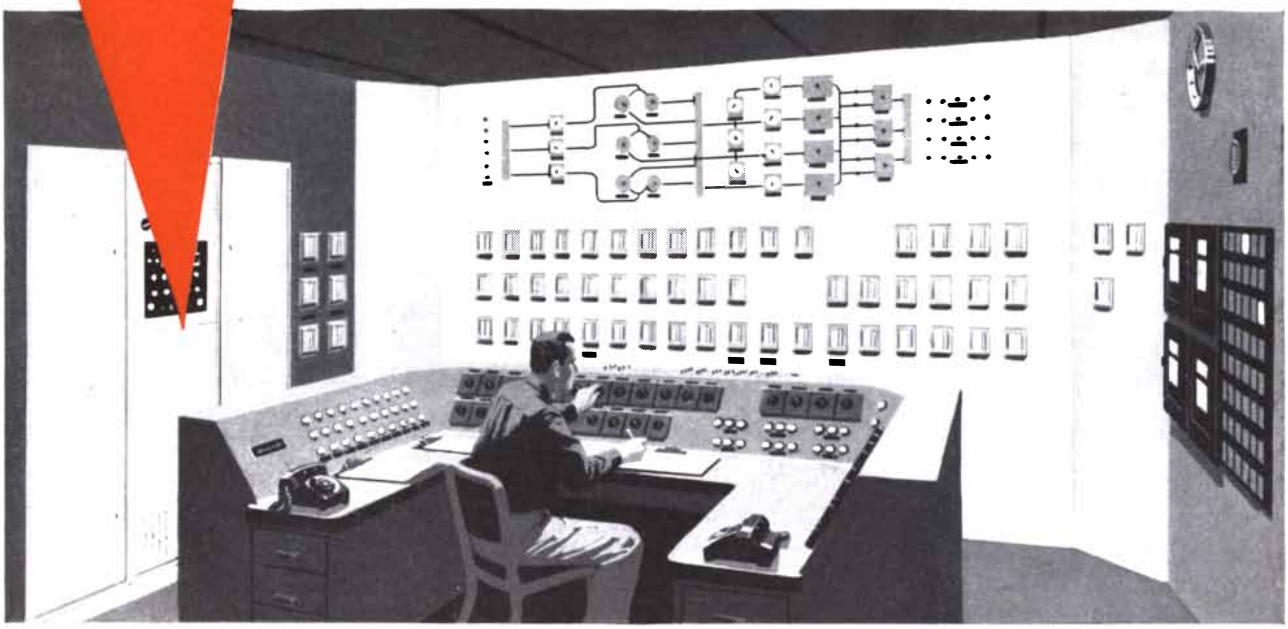

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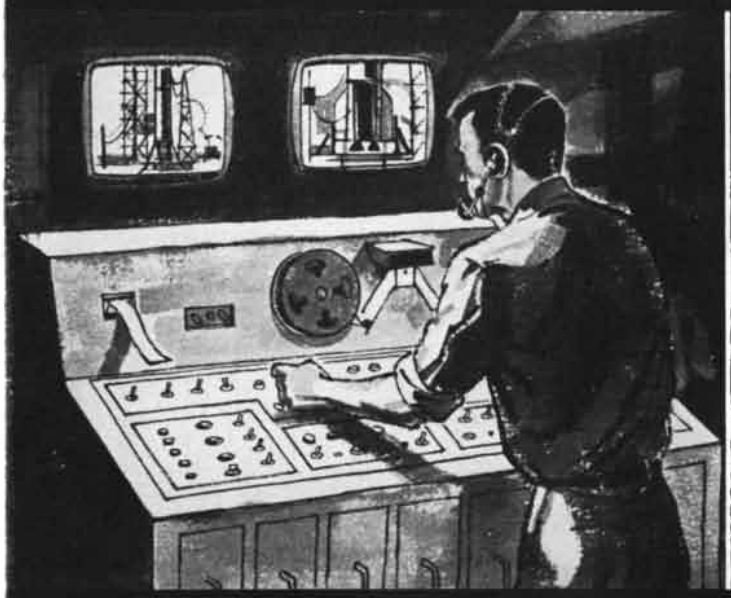

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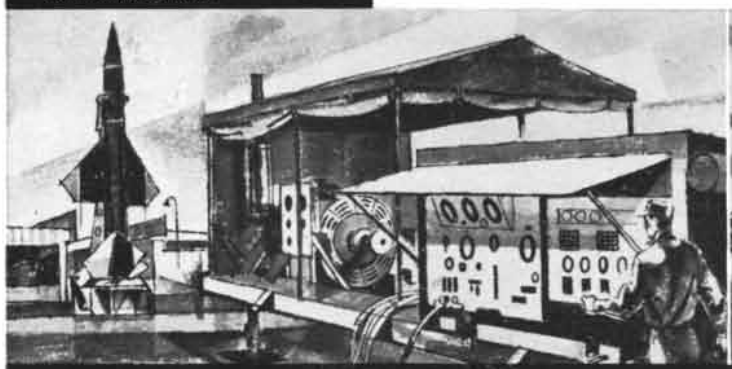

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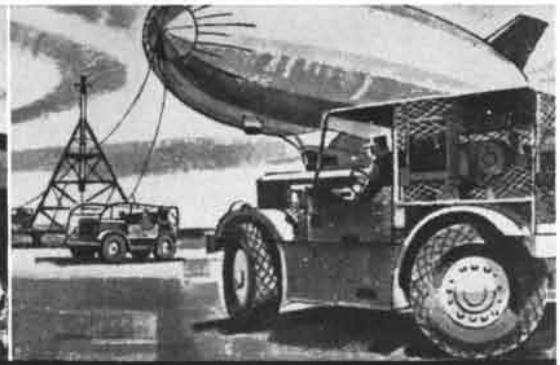

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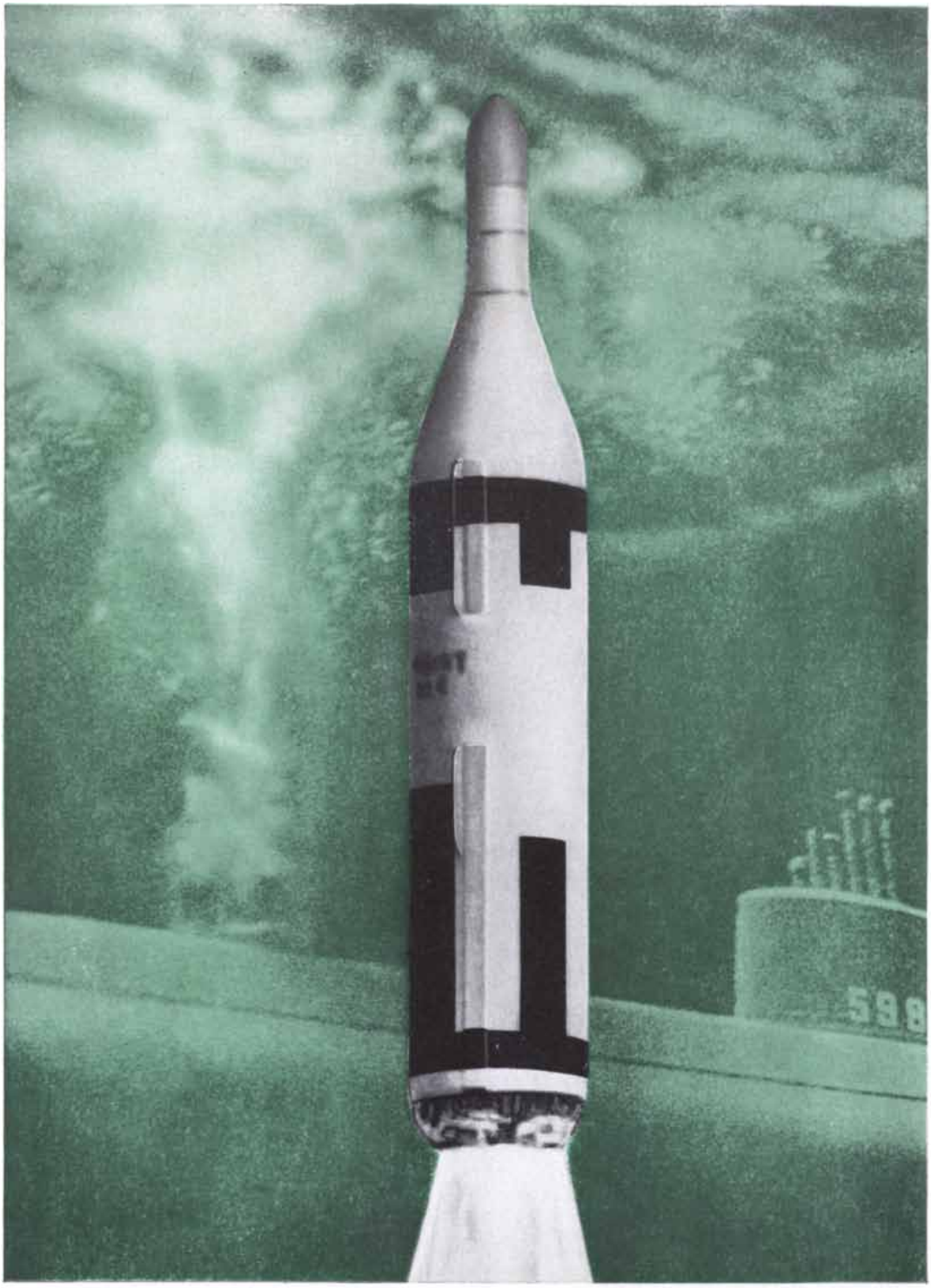

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The Eradication of the Screw-Worm Fly

This destructive parasite of livestock has been eliminated from the southeastern states by releasing large numbers of male flies that have been sterilized by ionizing radiation

by Edward F. Knipling

A fundamentally new method for controlling animal populations—one that enlists the reproductive process of the species in its own extinction—has entirely eradicated a major agricultural insect pest throughout a large continental region. The pest is the screw-worm fly which infests livestock; not a single screw-worm fly has been seen in the southeastern U. S. for almost two years. This unprecedented achievement was effected within a few months the first time the self-eradication method was tried on such a large scale. The success of the method against the screw-worm fly suggests that it may be applied with the same results to other insect species and to rodents and other pests.

Entomologists and veterinarians of the Agricultural Research Service of the U. S. Department of Agriculture and the Florida Livestock Board reared millions of screw-worm flies in what was literally a screw-worm factory. The insects were made sexually sterile by exposure to high-energy radiation. They were then released in the infested area. The sterile males, mating with the females in the natural population, nullified their reproductive capacity. The result was the complete elimination of the natural population.

The new method offers obvious advantages over conventional techniques which are directed at killing the living generations of the pest. In the first place it is highly selective, involving only the single target species and leaving the rest of the ecological system completely undisturbed. Secondly, no species can acquire immunity to sterile matings as it can to the insecticides that have been used in the past. There is a third and not so apparent advantage. Killing agents tend to become progressively less efficient as the pest population declines, and so leave a few survivors to begin the cycle of geometric population-increase all over again. The sterile-male method has the theoretical and, as has been shown in the case of the screw-worm fly, practical capability of becoming increasingly efficient as the pest population reaches the vanishing point.

There are nonetheless disadvantages inherent in the method when it comes to planning campaigns against certain species and throughout large geographic regions. But eradication of the screw-worm fly surely urges the search for similar opportunities to bring the method to bear. The screw-worm fly itself remains a major objective. It continues to infest the livestock of the Southwest, where losses are estimated at $25 million each year.

The adult screw-worm fly has a metallic blue body, about 3/8 inch long. It lays a compact mass of 200 to 300 eggs in the wounds of warm-blooded animals. Any accidental or surgical wound, a tick bite or the navel of a newborn animal may become a site for screw-worm attack. The insect is especially damaging to newborn animals; in areas heavily populated with screw-worm flies few newborn calves, lambs, kids, pigs or young of the larger game species will escape attack.

Tiny maggots hatch from the eggs in 12 to 24 hours. They begin feeding on the flesh head-down and closely packed in the wound. The feeding larvae cause a straw-colored and often bloody discharge that attracts more flies, resulting in multiple infestation by hundreds to thousands of maggots of all sizes. Death is inevitable unless the animal is found and treated.

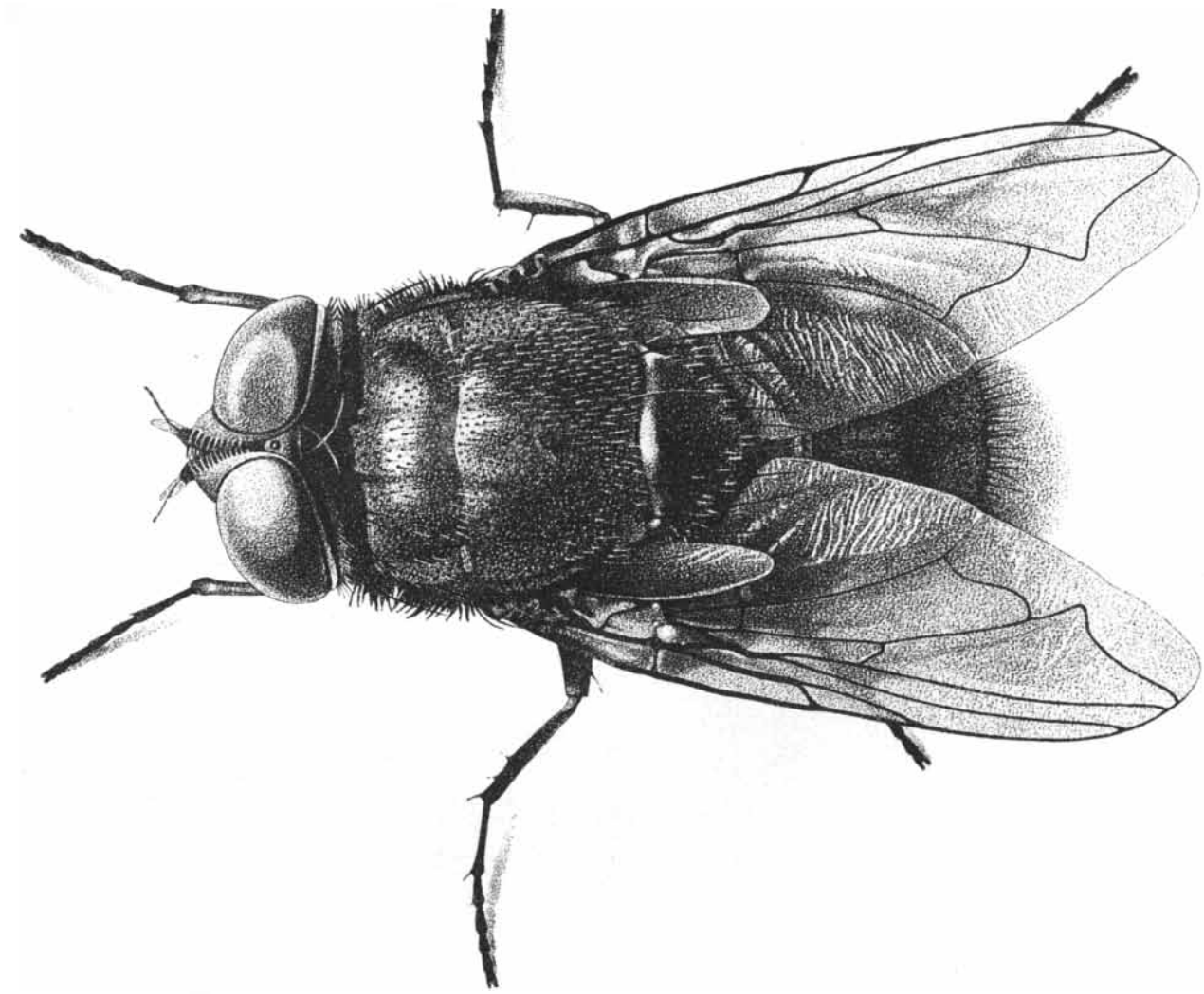
The maggots feeding in wounds become full grown in about five days, reaching a length of about 2/3 inch. Then they drop out of the wound, burrow into the ground and change to the pupal or resting stage in about one day. The adults emerge from the pupal case after about eight days during the summer months, live for two or three weeks and range for many miles, feeding on plant nectars, pollen, carrion, secretions of animal wounds and so on. They mate on about the third day after emergence, and the females are ready to lay eggs four days later, at which time they begin searching for suitable hosts on which to lay eggs and start the next generation. The generation period may thus be as short as three weeks and, in areas where the insect survives the year around, there may be from 10 to 12 generations during each year.

Fortunately the range in which the species may overwinter in the U. S. is

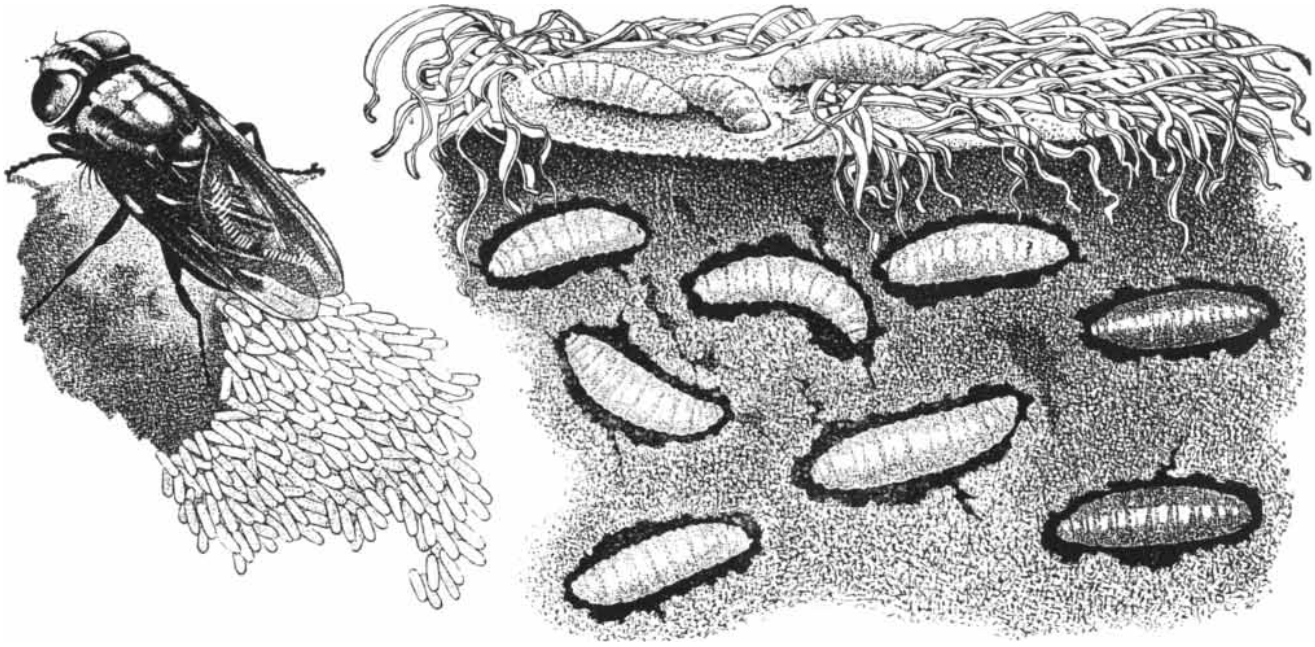
limited. During years of average winter temperatures, the survival area for the insect is in the lower quarter of Texas and in smaller areas in the southern parts of New Mexico, Arizona and California —and, until recently, lower Florida. The population density of the insect in the overwintering areas is greatly reduced. During the spring and summer the insect increases in numbers and spreads northward from the overwintering area, greatly extending its range of destruction. Much of the spread is by its own flight, but the shipment of livestock infested with undetected eggs or larvae often spreads the screw-worm fly to distant areas in the spring, when it can cause considerable damage to livestock before cold weather arrives.

In 1937 it occurred to me that it might be economically feasible to rear and release screw-worm flies in sufficient numbers to exceed the natural population. The idea was suggested, in fact, by the observation of my colleague A. W. Lindquist, of the Uvalde, Tex., station of the Department of Agriculture, that the number of screw-worm flies trapped during the winter in that region is exceedingly small. If some method could be devised to cause the artificially reared and released insects to destroy those in the natural population, I thought, this might provide a means for annihilating the insect. The development of a genetic strain carrying a factor that would be lethal under natural conditions was one possibility. Development of a chemical that would induce sterility in the flies before release was another. However, the most promising approach seemed to be the sterilization of the flies by X- or gamma-rays. As long ago as 1916 G. A. Runner of the U. S. Department of Agriculture had shown that cigarette beetles produce infertile eggs after exposure to X-rays, and at the University of Texas in 1928 H. J. Muller had demonstrated similar effects in fruit flies. Significantly for my purpose, it had been found that such exposure at the right stage in the insect's development had no other adverse effect.

The self-destruction approach to screw-worm control was discussed with a number of biologists during the next 12 years. The reaction was generally pessimistic. However, the possibilities, as determined by theoretical calculations, seemed too impressive to ignore. They indicated that, with the screw-worm population at a reasonably constant level, the sustained release of sterile males, initially outnumbering the natural population by two to one, could eradicate the population in four generations [*see illustration on page 61*]. Under favorable circumstances an insect population generally has a high potential for increasing in number from one generation to the next. But even under conditions that are favorable to a fivefold increase per generation, calculations showed that the release of sterile flies



SCREW-WORM FLY (*Callitroga hominivorax*) is about three times larger than a housefly, and has a metallic blue color. It lays its eggs in the wounds of warm-blooded animals such as livestock and game. The larvae that hatch from the eggs feed on the wound.



LIFE CYCLE OF SCREW-WORM FLY is depicted in these drawings. The female fly lays a compact mass of 200 to 300 eggs in the wound of a warm-blooded animal (*left*). Within a day the eggs hatch into larvae, and five days later the larvae leave the wound,

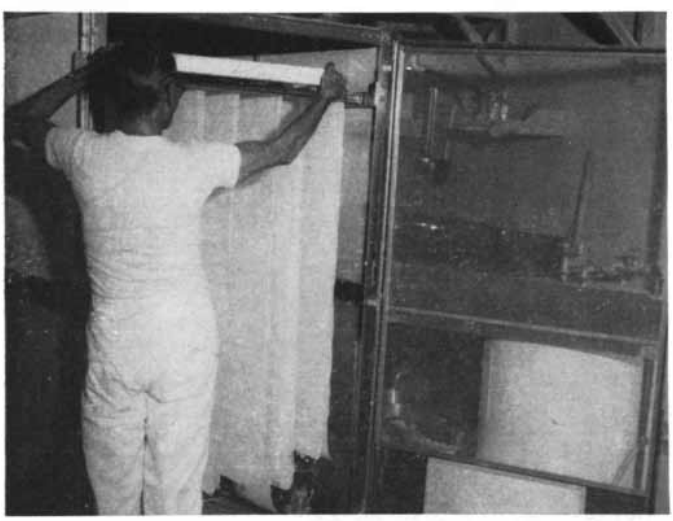
in an initial nine-to-one ratio to the natural population could eliminate the fly in five generations.

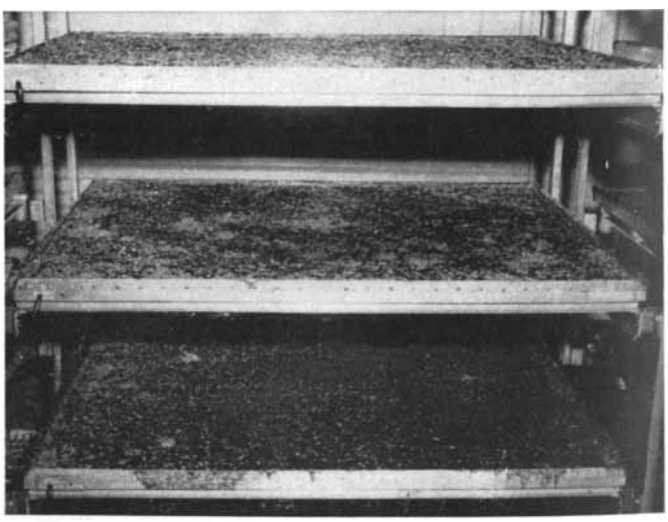
In 1950 I sought the counsel of Muller, as an authority on radiation effects on genetic material. With his encouragement the Department of Agriculture initiated research at the Kerrville, Tex., station, under the direction of R. C. Bushland. In a series of well-executed experiments Bushland and his assistant D. E. Hopkins developed the promising information that exposure of screw-worm pupae to 2,500 roentgens or more of ionizing radiation caused sexual sterility in the males without serious side effects. A dosage of 5,000 roentgens caused sexual sterility in the females.

Sexually sterile males were then placed in cages with normal males to test their ability to compete with normal males in mating with normal females. The results were extremely favorable. When the ratio of sterile to fertile males was one to one, about half the normal females produced sterile eggs. When the ratio was stepped up to nine to one, the sterility in the females was 83 per cent, sufficiently close to the theoretical expectancy of 90 per cent. The investigators showed that females of the screw-worm fly mate only once and do not discriminate between irradiated sterile males and normal males. The presence of irradiated sterile females in the caged population did not alter the results, which meant that it would not be necessary to separate the sexes before releasing the flies in the field.

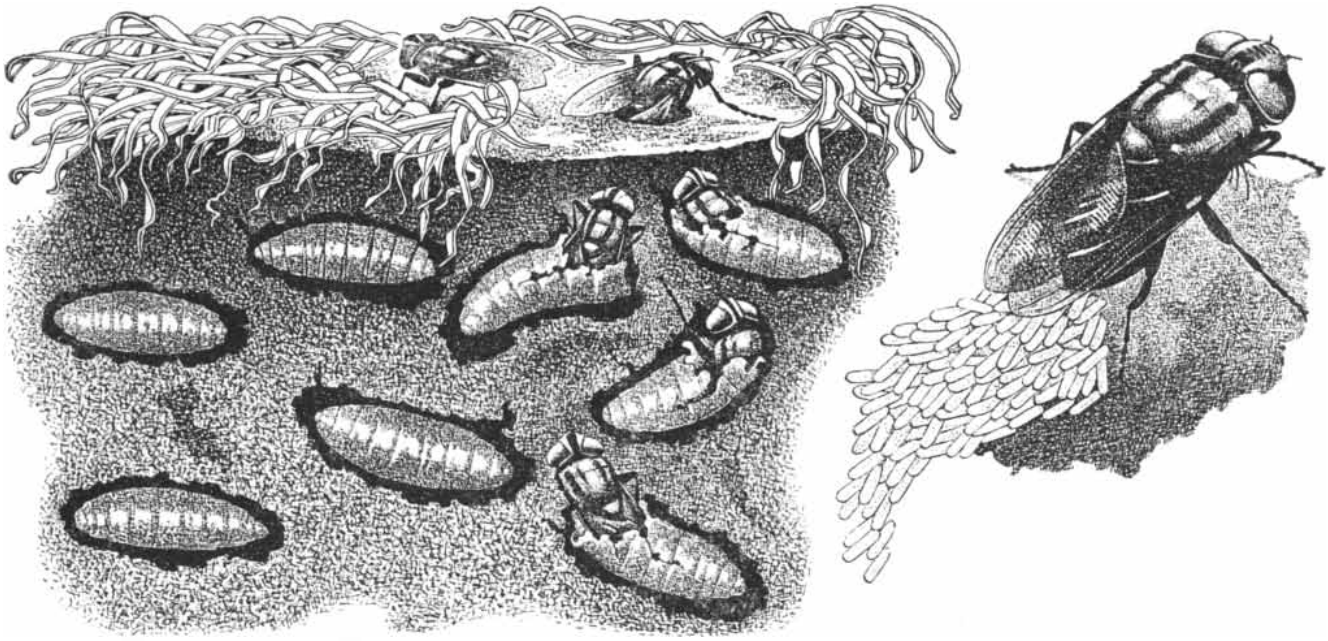
These findings clearly suggested that the sterile-male method was technically feasible. However, extensive field experiments would be required to demonstrate actual eradication.

In view of the long flight-range of the adult screw-worm fly it was not possible to conduct a valid experiment on a small scale within a large area infested with





SCREW-WORM FLIES WERE BRED in an airplane hangar at Sebring, Fla. The brood flies roosted on strips of cloth in screened cages (*left*). After the flies had laid their eggs and the eggs had hatched into larvae, the larvae were fed in trays of ground meat,



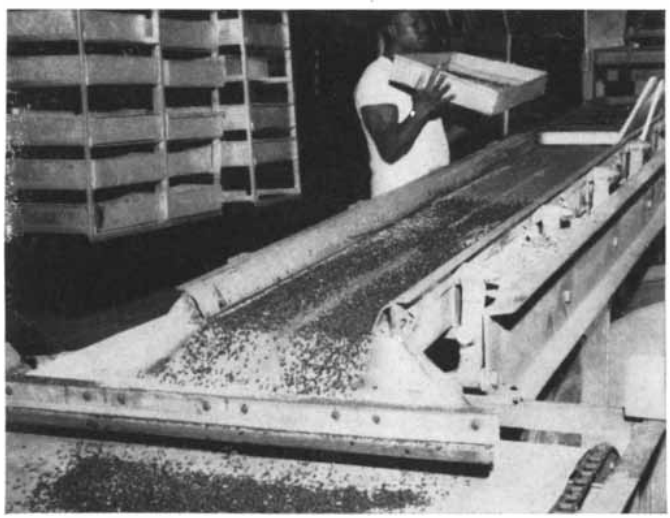
burrow into the ground and metamorphose into pupae (*second from left*). Some eight days later the pupae metamorphose into flies (*third from left*). About three days later the flies mate, and four days after that the female deposits her eggs (*fourth from left*).

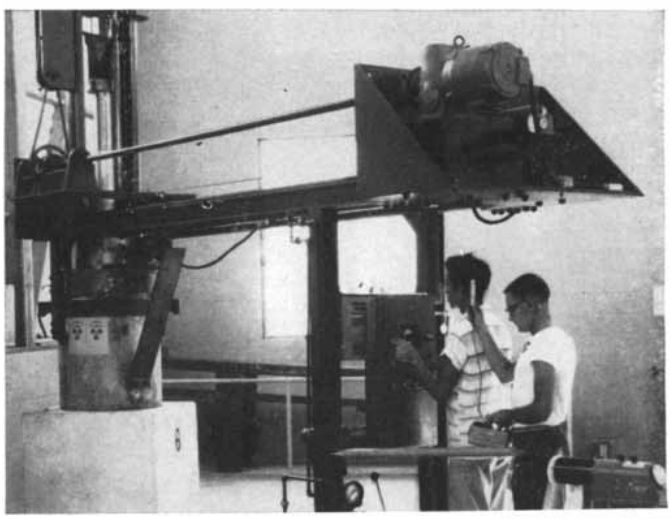
the insect. It would be necessary to release millions of sterile flies to achieve results in an area of several thousand square miles. The only hope was to find a small infested island where the total population could be exposed to a less astronomical number of sterile males.

We chose Sanibel Island, off the west coast of Florida near Fort Myers, as the site for field studies. It has an area of only 15 square miles and was found to harbor a natural population of screw-worm flies. Since it lies only two miles from the mainland, it did not afford the desired degree of isolation, but still it served our purpose.

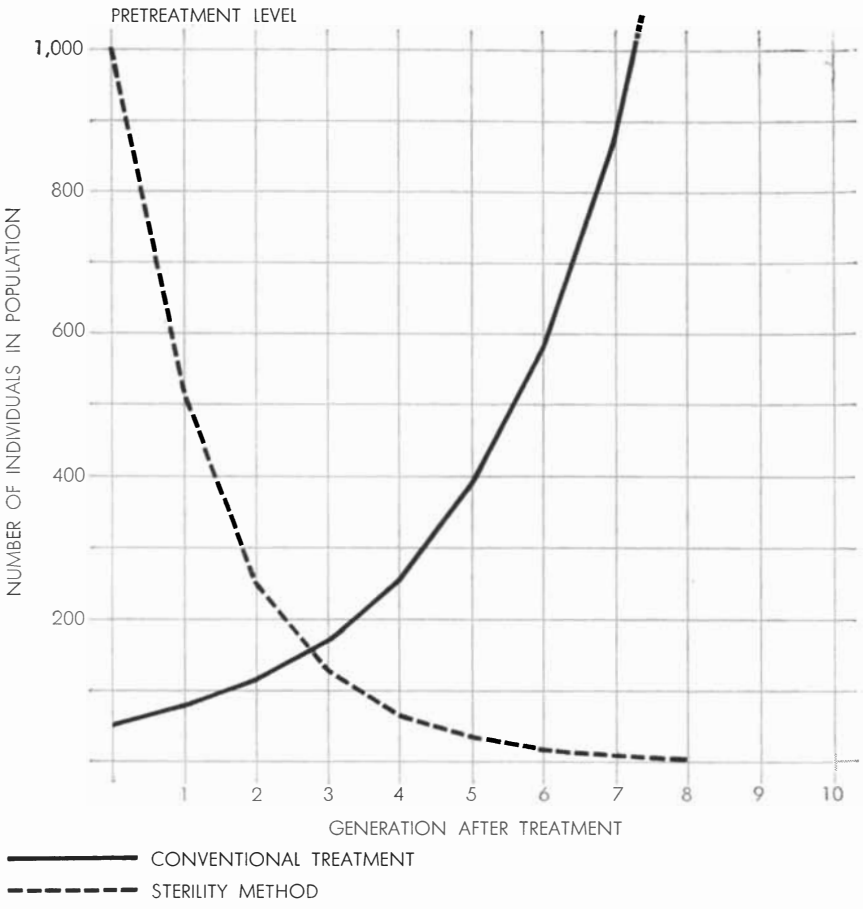
Irradiated sexually sterile screw-worm males were released on the island at the rate of 100 per square mile per week for a period of three months. Goats that had wounds susceptible to screw-worm attack were placed in pens on the island to collect egg masses deposited by the female flies in the natural population. Sterile egg masses showed up about a week after sterile-male releases were started. Within two months 80 per cent of the egg masses were sterile. By the third month the natural population of the insect virtually vanished. It was not possible, however, to demonstrate eradication, because some already mated fertile females had migrated to the island from the mainland.

The next problem was to find a site where a valid eradication experiment could be conducted with the financial resources available. That problem was solved by a routine inquiry from B. A. Bitter, a veterinary officer on the island of Curacao in the Netherlands Antilles, who reported that the screw-worm fly was causing severe losses of goats on the island. A survey by A. H. Baumhover, who had supervised the Sanibel experiment, showed Curacao to be an ideal site; among other things it has an area





blood and water (*second from left*). Larvae were then permitted to burrow into sand, and after they had metamorphosed into pupae, the pupae were screened from the sand (*third from left*). Pupae were exposed to radiation from a cobalt-60 source (*fourth from left*).



STERILITY METHOD of animal-pest control is compared with conventional treatment of merely killing the pest. The chart assumes a monogamous population of 1,000 with a rate of increase of 1.5 per cent per generation. If 95 per cent of the population are killed by conventional treatment, the remaining 5 per cent reproduce to equal or exceed the original population within eight generations (*solid curve*). If 95 per cent of the males in the population are sterilized, the population is eliminated within eight generations (*broken curve*).

of 170 square miles, and it is separated from other land areas by 40 miles. The Netherlands Antilles Government agreed to join in the experiment.

The insects were reared at Orlando, Fla., under the supervision of A. J. Graham. A cobalt-60 gamma-ray source loaned by the Oak Ridge National Laboratory irradiated the flies, and regular commercial airlines delivered them to Curacao, where crop-duster airplanes distributed them at the rate of 400 sterile males per square mile per week. In view of the large number of flies no attempt was made to segregate the males from the females. Since irradiated females are incapable of producing eggs, any sterility observed in the egg masses collected could be attributed to the sterile males only. As on Sanibel Island, daily collections of egg masses on penned goats provided a measure of the results accomplished. Before fly releases started, more than 99 per cent of egg masses were fertile.

The results on Curacao—100 per cent sterility of egg masses by the third generation and total eradication of the fly by the fourth—were more spectacular than any of the investigators had dared hope. The actual population trend completely confirmed the theoretical trends projected years before on paper.

When the success of the Curacao eradication experiment was announced in the press, the livestock industry virtually demanded that an eradication program be initiated in Florida. However, the Curacao experiment had required the production of only 170,000 screw-worm flies per week (including brood flies). To achieve a similar saturation of the 50,000 square miles of the southeastern U. S. would require the production of about 50 million screw-worm flies per week. Insect-rearing on such a scale had never been undertaken.

Nonetheless the Department of Agriculture set the Sanibel-Curacao experimental group to work on projecting the expansion of screw-worm fly production from pilot plant to full factory scale. In 1957 the Florida livestock industry obtained state appropriations to match Federal funds, and the project got under way. Construction of a screw-worm rearing plant in an airplane hangar at Sebring, Fla., was started by the Florida Livestock Board early in 1958, and was scheduled to go into operation in July of that year.

The winter of 1957 and 1958 proved, however, to be one of the coldest on record in Florida. Since the cold virtually destroyed all screw-worm flies as far south as central Florida, the pilot plant at Bithlo, Fla., which had been used for research purposes, started releasing sterile flies in January, 1958. Even though the initial capacity of the Bithlo plant was only two million flies per week, this was hopefully sufficient to establish a barrier north of the overwintering area. The opportunistic strategy proved decisive, because it prevented the usual northward movement of the pest in the spring and held its numbers down until the Sebring plant realized its capacity in August.

Production of the flies in the factory proceeded on an orderly schedule fixed by the life cycle of the species. The insects received the best of care in an air-conditioned, humidity-controlled room; thousands of flies roosted on cloth strips in each of a large number of screen cages. They were fed a diet of honey and extracts of ground meat, and after about eight days were induced to lay their eggs in a slurry of ground meat, blood and water in which pupae had previously been raised. The larvae generated factors in this medium that proved highly attractive to females ready to deposit their eggs, especially when the medium was heated to the body temperature of livestock (approximately 100 degrees Fahrenheit).

After hatching and five days of feeding, the larvae crawled out of the feeding vats into a large funnel, where they were collected in trays of moist sand. There they changed to pupae in about 24 hours. Screened from the sand into special screen baskets, the pupae were held at a controlled temperature of about 80 degrees. On the sixth day they were placed in cylindrical metal containers and exposed to 8,000 roentgens of gamma radiation from a cobalt-60 source, enough to assure the complete sterility of both male and female flies. The production line required six 500-curie cobalt-60 sources. After irradiation the pupae were packaged in small cardboard

boxes in readiness for delivery to the field when they emerged as adults about two days later.

Air-conditioned trucks transported each day's output to the airstrips. The airplanes, provided with special equipment to break open each box as it was released, dropped from 100 to 3,000 flies per mile as they flew their courses.

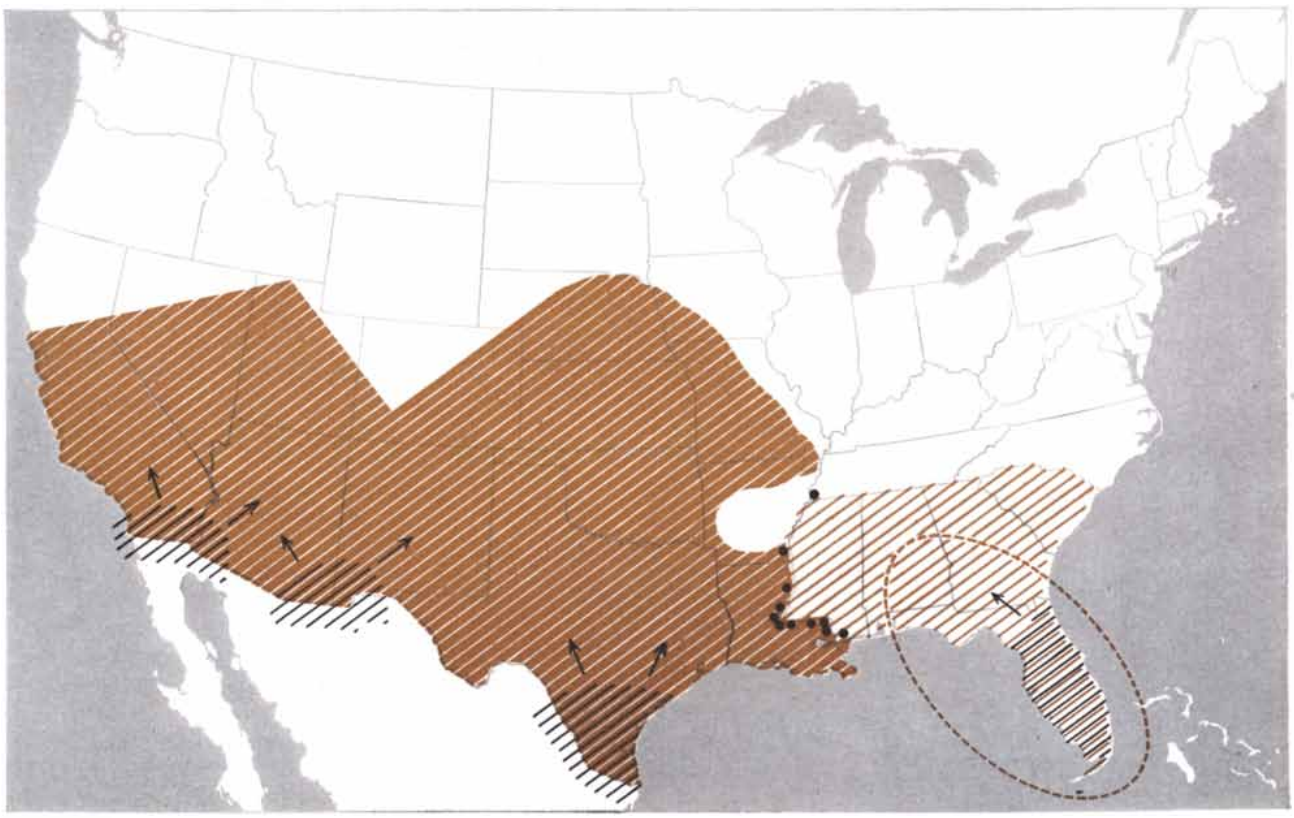
When the Sebring plant reached full capacity, it was rearing, irradiating and releasing more than 50 million screw-worm flies each week. More than two billion flies were released over a period of about 18 months in Florida, and parts of Georgia and Alabama. The area in which flies were released totaled about 70,000 square miles. More than 40 tons of ground whale- and horse-meat were required to feed the larvae, and a fleet of 20 airplanes handled the task of distribution. Without doubt this was one of the most extraordinary programs ever undertaken in the field of applied biology.

By February 19, 1959, or approximately a year after initiation of the program and six months after all areas were receiving sterile-fly releases, the insect appeared to be eradicated. Releases were continued, however, until November, 1959, when the screw-worm-fly rearing plant was at last shut down.

With the insect eradicated from its overwintering habitat in Florida, the entire Southeast is now free of the fly. The area between eastern Texas and northern Florida is unfavorable for screw-worm-fly survival throughout the winter and thus furnishes a barrier against natural re-establishment of the fly in Florida. To prevent the reintroduction of the insect into the Southeast by livestock shipped from the Southwest, the Department of Agriculture maintains animal inspection and treatment stations at all crossings on the Mississippi River.

Naturally livestock growers in the Southwest now want to see the same service performed for them. However, elimination of the insect from this region poses special problems that did not exist in the Southeast. In the Southwest continuous year-round survival areas for the insect extend from the southern part of Texas and parts of New Mexico, Arizona and California deep into Mexico and possibly into Central and South America. It is probable that the insect could be eradicated in the Southwest—but only for a time. There is as yet no known way to prevent reinfestation from Mexico. It may be economically feasible to establish a barrier zone 100 miles or so deep by making continuous releases of relatively few sterile flies. An animal inspection and treatment program such as that along the Mississippi River would have to be set up to prevent reintroduction of the insect through the shipment of infested animals. The Department of Agriculture, in co-operation with officials in Mexico, is studying these possibilities.

The screw-worm-fly precedent has now inspired workers in various countries to investigate the possibility of using equivalent methods to control many other varieties of pest: the oriental, melon, Mediterranean and Mexican fruit flies, the pink bollworm and the boll weevil, the sugar-cane borer, the European corn-borer, the gypsy moth and the codling moth. The laboratory phase of

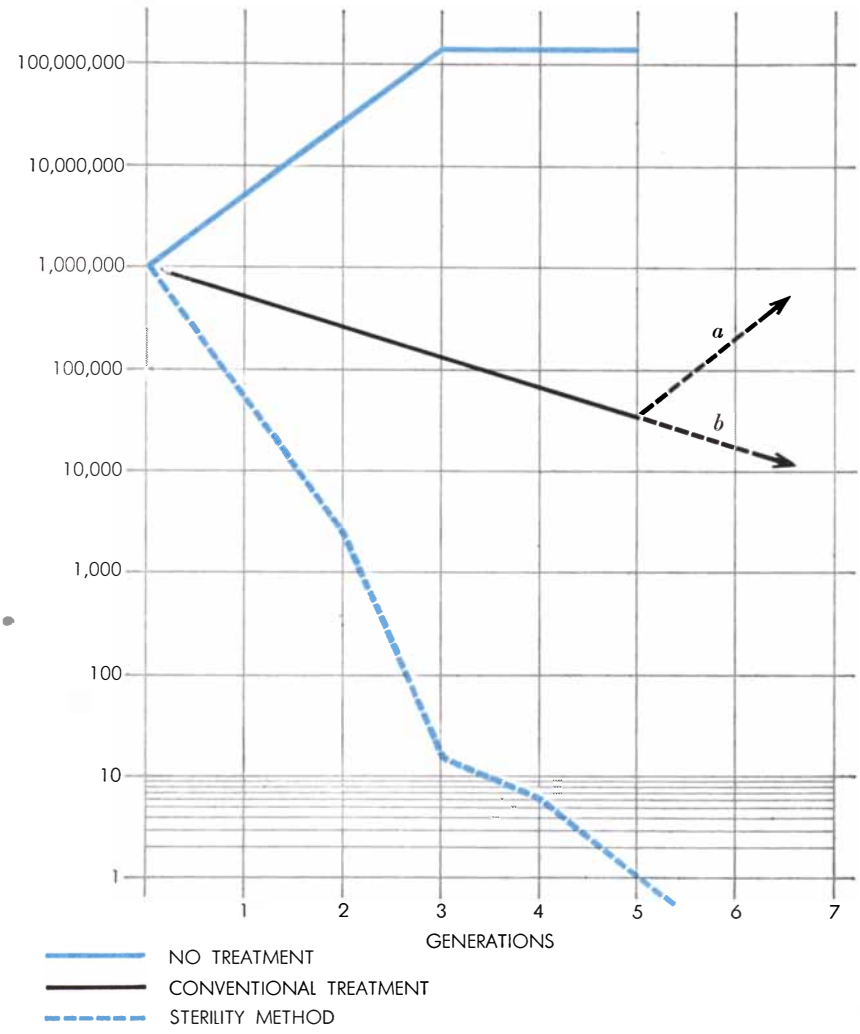


RANGE OF SCREW-WORM FLY originally included the entire southern part of the U. S. Release of sterile males in area indicated by broken line eliminated the fly from the southern states east of the Mississippi in 1958. The fly persists west of the Mississippi because it winters in areas adjoining vast areas of infestation in Mexico. Inspection stations along the Mississippi guard the southeastern states against reinfestation by cattle from the Southwest.

the fruit-fly effort has already been completed by the Hawaii Fruit Fly Laboratory of the Department of Agriculture. In co-operation with the U. S. Navy and the trust territories administration, the Department is now planning a pilot eradication campaign on the island of Rota in the southwestern Pacific. Of the insects that bother and menace man more directly, the mosquito is under study as a candidate for self-eradication in the Department of Agriculture center at Orlando, Fla., and the tsetse fly is being studied by the British and Dutch in Africa with this end in view.

In every case the same set of four criteria will determine the feasibility of the effort: Sexual sterility must be achieved without adverse effects on mating behavior, the insects must be rearable in large numbers, the sterile insects must be readily dispersable in a manner that will bring them into effective competition with normal males, and the huge (even though temporary) increase in the population of the species must create no serious harm to crops, animals or man. The screw-worm fly was plainly an ideal subject. With respect to the last criterion, for example, the release of sterile males brings immediate diminution in the harm done by the insect, since sterile eggs are no bother to animals in which they are laid. Because the natural population of many species is so large, it may be necessary to reduce its size by conventional methods before attempting eradication by use of sterile males. Contrary to popular belief, monogamous mating by the female is not a requirement, providing the sterile sperm are fully competitive with normal sperm when planted in the female genital tract.

Since the release of large numbers of certain organisms might be costly and also create damaging side effects, a more desirable way to utilize the sexual-sterility principle would be to induce sexual sterility in the natural population. A chemical agent that induced sterility in an insect species as readily as conventional insecticides destroy them would yield a very much greater return for the same effort. As the chart on this page shows, the conventional poison that kills 90 per cent of the population in each generation achieves a much slower population reduction from one generation to the next, and still leaves a significant breeding population in the fifth generation, the point at which the equivalent sexual-sterility agent would achieve eradication. The difference is easily explained. The sterilized insects do not themselves reproduce; this is the equivalent of death from the vantage of the survival of the population. But since the sterile males would nullify the reproductive capacity of 90 per cent of the females that escaped exposure to the sterilizing agent, the total effect would be a 99-per-cent population depression each generation instead of the 90 per cent produced by the killing agents.



CONTROLS AND NO CONTROLS on insect population that starts from low level and increases fivefold per generation result in trends depicted. Without controls, population would saturate environment and level off (*solid colored line*). Conventional controls (*black line*) which killed 90 per cent of each generation would require 20 generations to eliminate pest (*b*). Premature suspension of controls would lead to upsurge of population (*a*). Same effort with sterility method would eradicate pest by fifth generation (*broken colored line*).

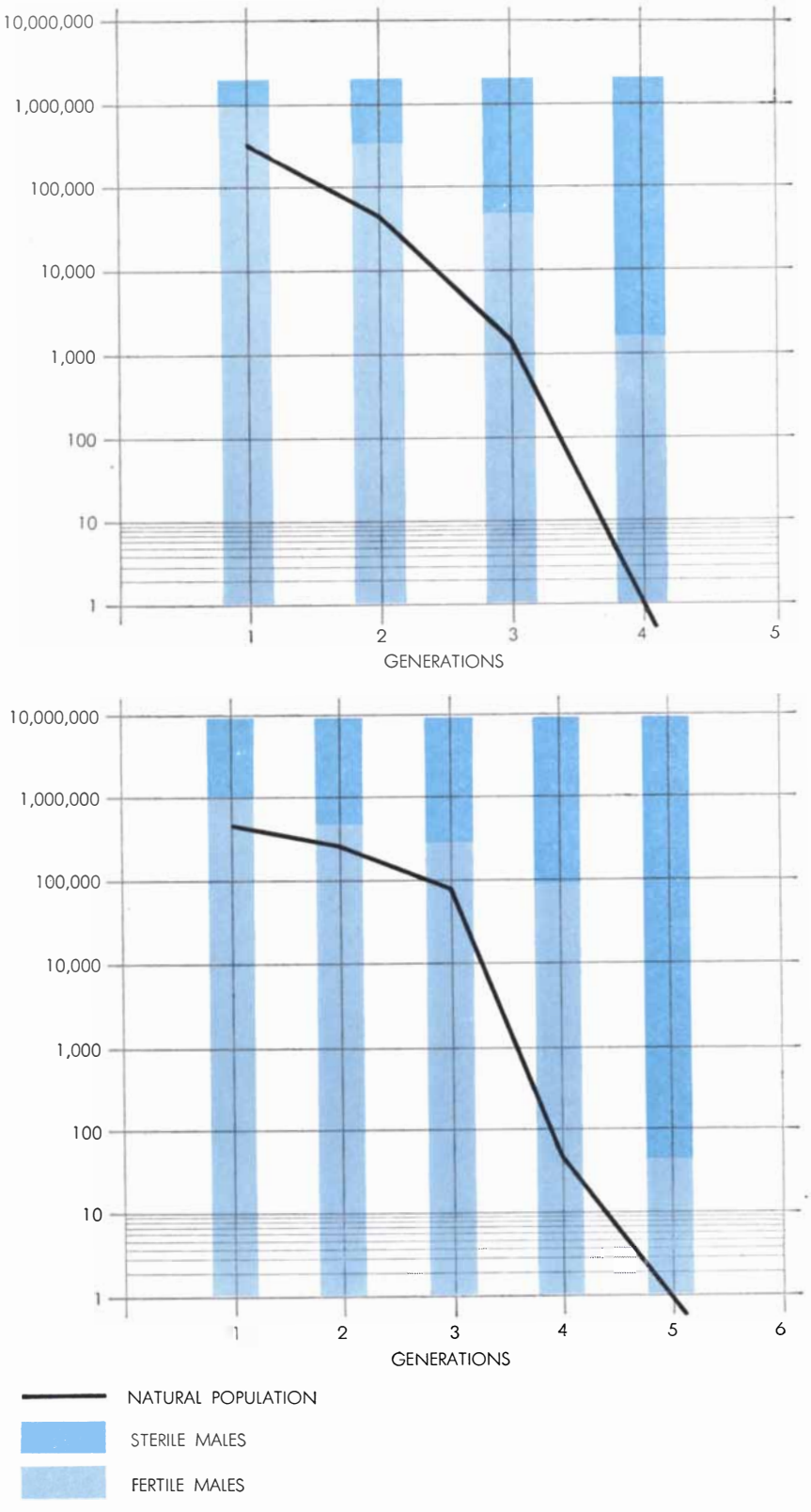
The Entomology Research Division of the Department of Agriculture has initiated exploratory investigations in a search for sexual sterilants for insects. Norman Mitlin, insect physiologist, has shown that several compounds will prevent ovarian development in the housefly. Research workers at the fruit-fly laboratory in Mexico City have shown that certain compounds will produce sterility in the Mexican fruit fly. Similar effects have been produced in the housefly with certain compounds under investigation at the Orlando, Fla., laboratory. To achieve the bonus effect over killing agents, the chemicals must produce irreversible sexual sterility in both sexes, and the males so affected must be fully competitive with normal males in mating with normal females in the population.

The potential advantage of the sexual-sterility approach over killing agents for population control is not limited to insects. Theoretically it can be shown that the relative effect would be equally or more dramatic when applied to higher animals. Under certain circumstances it may be desirable to eliminate noxious animals, such as rodents, predators, destructive birds or aquatic animals from certain areas, or merely to regulate the population of desirable animal species,

such as certain large predators or large game species.

In the case of higher animals the assumptions applied to the reduction of insect populations need be modified only to take account of the relatively longer lifetime of the individual and the lower reproductive rate of mammals as compared to insects. A typical net increase for mammals may be taken as 50 per cent per generation. The contrast between the effects of the killing and of the sterility agents is drawn most sharply when it is assumed that the object is to eradicate the population. Assuming that the killing agent reduces the population by 95 per cent at the outset and that there are 1,000 animals in the initial population, then the 50 survivors and their descendants would restore the original number by the eighth generation. If the same population were exposed to an equally effective sterility agent, none would be killed, but 95 per cent would be deprived of their reproductive capacity. This 95 per cent would in turn nullify the reproductive capacity of those that escaped the effect of the agent. The cumulative impact on the population would be drastic. By the ninth generation the original 1,000 animals would have no survivors. Reproduction would have ceased by the sixth or seventh generation, and only a few sterile individuals would survive through the ninth [*see illustration on page 58*]. Theoretically the same relative effect could be achieved by trapping and removal if, instead of removing both males and females, the males were appropriately sterilized and returned to the environment. Such calculations do not require monogamous mating habits even in the higher animals; the sterilization procedure need only leave the sterilized male or his sperm fully competitive with the normal.

At present the basic information and experience are inadequate to determine the extent to which the self-eradication procedure can be developed and applied for controlling insect and other animal populations. It is a biological axiom, however, that the introduction of sexually sterile but otherwise sexually competitive individuals into the natural population of an animal species has a greater influence in reducing the biotic potential of the population than does the elimination of the same number of individuals by destruction or removal. That axiom has been amply demonstrated by the eradication of the destructive screw-worm fly from the southeastern states.



DECLINE OF INSECT POPULATIONS during sustained release of sterile males is projected. Graph at top applies to a normally stable population. Constant number of sterile males released (*solid colored bars*) exceeds the original number of fertile males (*shaded colored bars*) by a ratio of two to one. Result is an increasing ratio of sterile to fertile males, and the decline of the natural population (*black curve*). Graph at bottom applies to a population that normally increases fivefold per generation. Constant number of sterile males released in this case exceeds original fertile male population by a ratio of nine to one.

A Forgotten Civilization of the Persian Gulf

On the island of Bahrain lie the grave mounds and buried cities of a culture contemporary with those of Sumer and ancient India. Recent excavations indicate that it was a link between the two

by P. V. Glob and T. G. Bibby

Bahrain Island, halfway down the Persian Gulf from the delta of the Tigris and Euphrates rivers, has been known to archeologists and grave robbers as an island of the dead. The yellow sand of the island is covered with uncounted large grave mounds—an estimated 100,000 of them. They rise in such weird profusion that they give the impression of some natural cataclysm, as though a boiling, bubbling wasteland had suddenly solidified at the dawn of time. Yet all is the work of man: each of the mounds covers a stone chamber (often two chambers one above the other), and each contains a human burial.

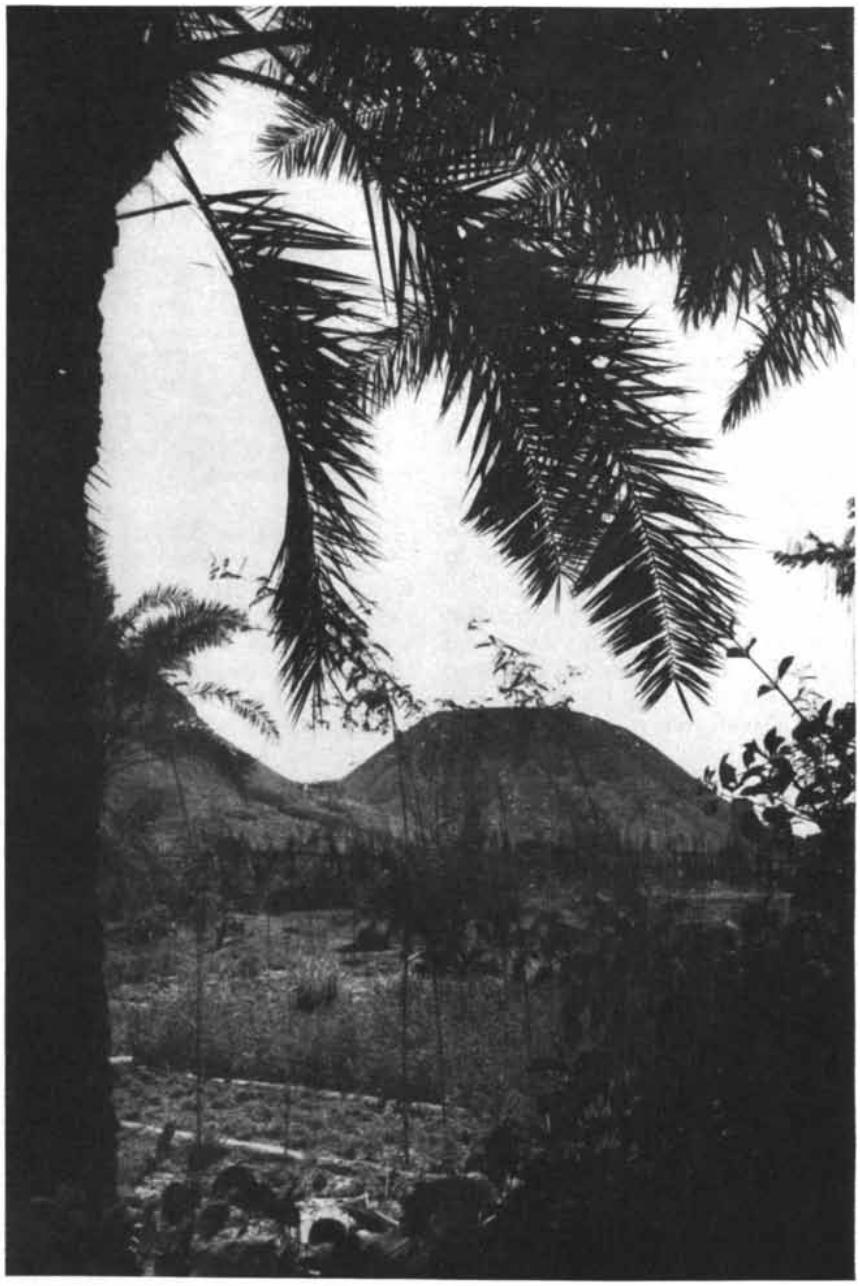
The wonder of the grave mounds became a mystery when several archeological expeditions came to the island after the turn of the century and found

GRAVE MOUNDS in this photograph are some of the estimated 100,000 that lie on Bahrain Island. Each of the mounds covers one or two stone chambers. The chambers contain human burials and objects of gold, copper and ivory that are more than 3,000 years old.

no trace of towns or cities. Inevitably the expeditions tended to concentrate on the excavation of the larger mounds. These proved to have been already visited by robbers in remote antiquity. But the gold, copper and ivory objects that still remained here and there in the massive tomb-chambers bore witness to the wealth they once contained, and indicated that the graves were at least as old as the Bronze Age—earlier than 1000 B.C. The fact that no settlements were discovered gave rise to the theory that Bahrain was solely a burial island, a cemetery for peoples dwelling on the mainland of Arabia.

This theory had an essential weakness: The island has a plentiful water supply and a soil that is productive where it is watered, while nearby Arabia is sandy and waterless. Accordingly in 1953 the Prehistoric Museum of Aarhus in Denmark dispatched a small expedition, comprising the two authors of this article, to Bahrain. Our objective was to reconnoiter the island as a whole and to resolve the mystery of the grave mounds by locating, if we could, the settlements of their builders.

This limited objective was achieved in the course of the first season's work. We discovered one large city, a number of smaller settlements and an extensive temple-complex, all dating to the period of the grave mounds and representing a hitherto unknown civilization. From this auspicious beginning, the work has continued on an expanding scale for the past seven years. While excavations have yielded an increasingly complete revelation of the center in Bahrain, reconnaissance has extended the outer marches of this civilization ever farther to the north and east along the curving coastline of Arabia. In the 1960 season the expedition consisted of 27 Scandinavian archeologists and was operating over a front of 600 miles, from Kuwait at the head of the Persian Gulf to Abu Dhabi and Buraimi in the east. Bahrain has proved to be the legendary Dilmun referred to in the cuneiform texts of Sumer, the bridge between that primary seat of the urban revolution and the civilization of the Indus Valley in what is now Pakistan.



LARGE MOUND in this photograph is about 35 feet high. Most of the large mounds lie at the edge of the desert. Their size probably explains why they were robbed centuries ago.

That we were the vanguard of one of the largest archeological expeditions ever to operate in the Middle East was not to be guessed when we landed at Moharraq airport on the northern island of the Bahrain archipelago and negotiated for the ancient station wagon that was to take us on our reconnaissance of the main island. Bahrain itself is a small island about twice the size of Manhattan. It is widest in the north, where most of the grave mounds lie, and tapers in the south to a sandy spit pointing to the head of the deep bay that lies between the peninsula of Qatar and the Arabian mainland, clearly visible on the western horizon. Along the north and northwestern coastal strip of Bahrain lie extensive plantations of date palms, interspersed with fields of alfalfa that provide fodder for humped Indian cattle, for goats and donkeys. The rest of Bahrain consists of open, windswept desert, plains of gravel and eroded limestone buttes, with the 440-foot Jebel Dukhan —the Mountain of Smoke—rising in the center. Of the 150,000 Arabic-speaking inhabitants of the archipelago, a third live in the capital city of Manama on the northeastern coast, a close-packed town of narrow streets, slender minarets and tall, windowless, whitewashed merchants' palaces. Another third live on the northern island of Moharraq, and the remainder in the villages strung out along the coasts. Here, in houses of interwoven palm fronds, the villagers live a life that can have changed little

over the centuries, working in the date and vegetable gardens, tending the fish traps that line the tidal channels around the coast and in the summer months sailing to the oyster banks to dive for pearls.

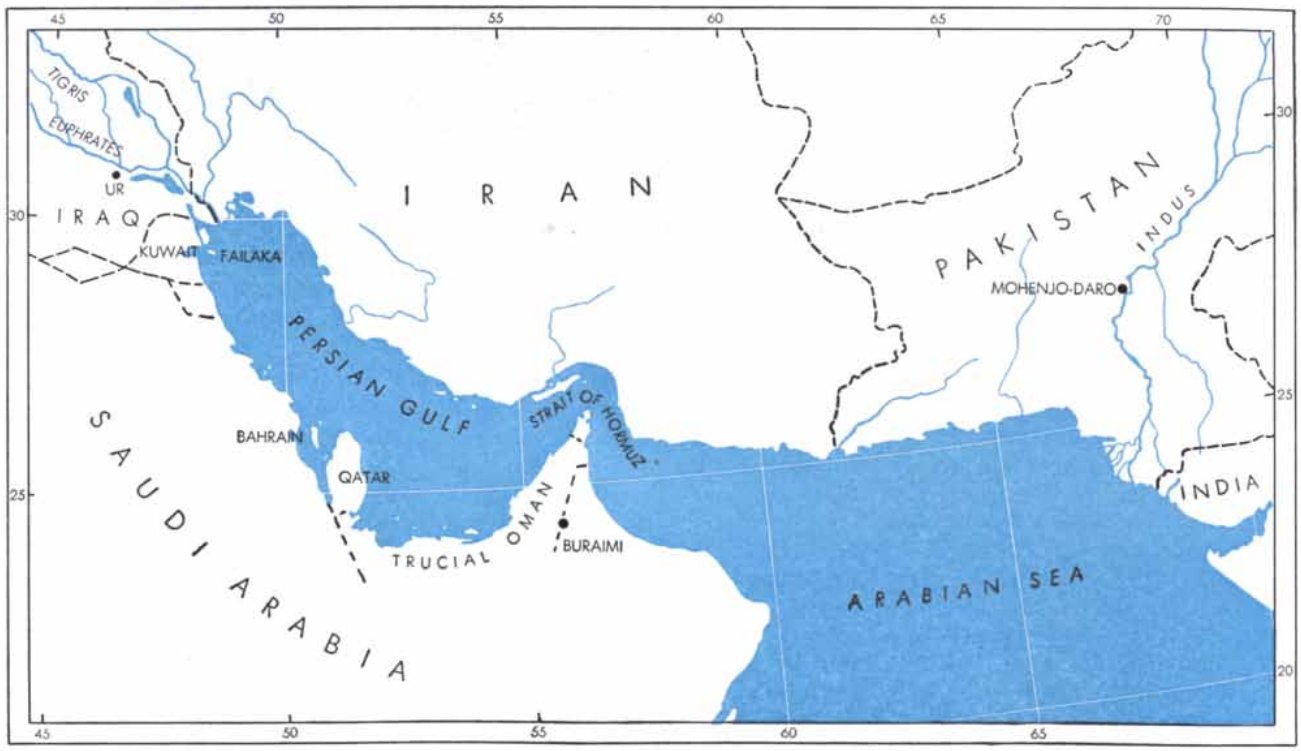
Pearling, however, is a dying occupation. A new source of wealth has come to Bahrain, the first state in the Persian Gulf in which oil was discovered. Now in increasing numbers the new generation is leaving its fish traps and gardens to work in the machine shops and offices of the oil company and at the huge refinery that dominates the east coast. In the center of the island, north of Jebel Dukhan, in a town of pastel-colored bungalows and green gardens, live the American and European oilmen and their families, in an area that 30 years ago was desert.

It was in this desert that the first traces of prehistoric settlements were discovered. These settlements, however, dated back to a time long before the burial mounds. Where the wind had exposed the ancient surface of the desert lay hundreds of chipped flakes of flint. They marked the chipping floors and settlements of men of the Stone Age, and they followed closely an ancient coastline now lying some two miles inland. A small number of finely chipped barbed and tanged arrowheads and toothed flint sickle-blades belonging to the first agriculturalists of the Neolithic period turned up among these artifacts, but the vast majority were the points and scrapers of the hunters of the Middle Paleolithic. These evidenced clear relationship with the early Stone Age cultures of northwestern India. The work in this realm of Middle East archeology has since been advanced with the finding on the Qatar peninsula of a succession of artifacts that lead back to the hand axes of 100,000 years ago. But these works of primitive, perhaps pre-*sapiens*, culture were scarcely clues to the mystery of the grave mounds.

The first month's wandering over the island also resulted, however, in the discovery of a large number of settlement sites: sand-covered ruins with scraps of pottery of many different types. Clearly it was necessary to determine whether the grave mounds contained the same types of pottery. We accordingly excavated two grave mounds and explored the slab-roofed burial chambers within. These are of a shape unknown outside Bahrain, with two alcoves at the western end giving the chamber a T-shaped plan. While both proved to have been robbed, they produced, in addition to copper spearheads and a drinking cup formed of an ostrich eggshell, a small quantity of distinctive red pottery.

With this encouragement we began to dig at a site where a large number of squared stone blocks, lying on the surface, argued an important building below the ground. A small underground well-chamber was found, with a flight of steps leading down to the wellhead, formed of a single square block pierced by a hole. Two decapitated statues of seated rams, which originally had stood at the head of the stairs, showed that this site was pre-Islamic. Further work was stopped, however, by water from underground and by the discovery in the meantime of a site of much greater importance.

This was a large mound near the village of Barbar on the northwestern coast. There a large block of hewn stone, projecting above the surface, tempted investigation. A trial trench laid bare a stone-flagged court surrounded by the lowest courses of a wall of cut limestone. In the center of this court the trench exposed part of a double circle of curved blocks. A widening of the trench showed these to be a plinth that must have borne statues or cult objects. To the east of the plinth two stone slabs stood upright, with a recess in the upper edge to take

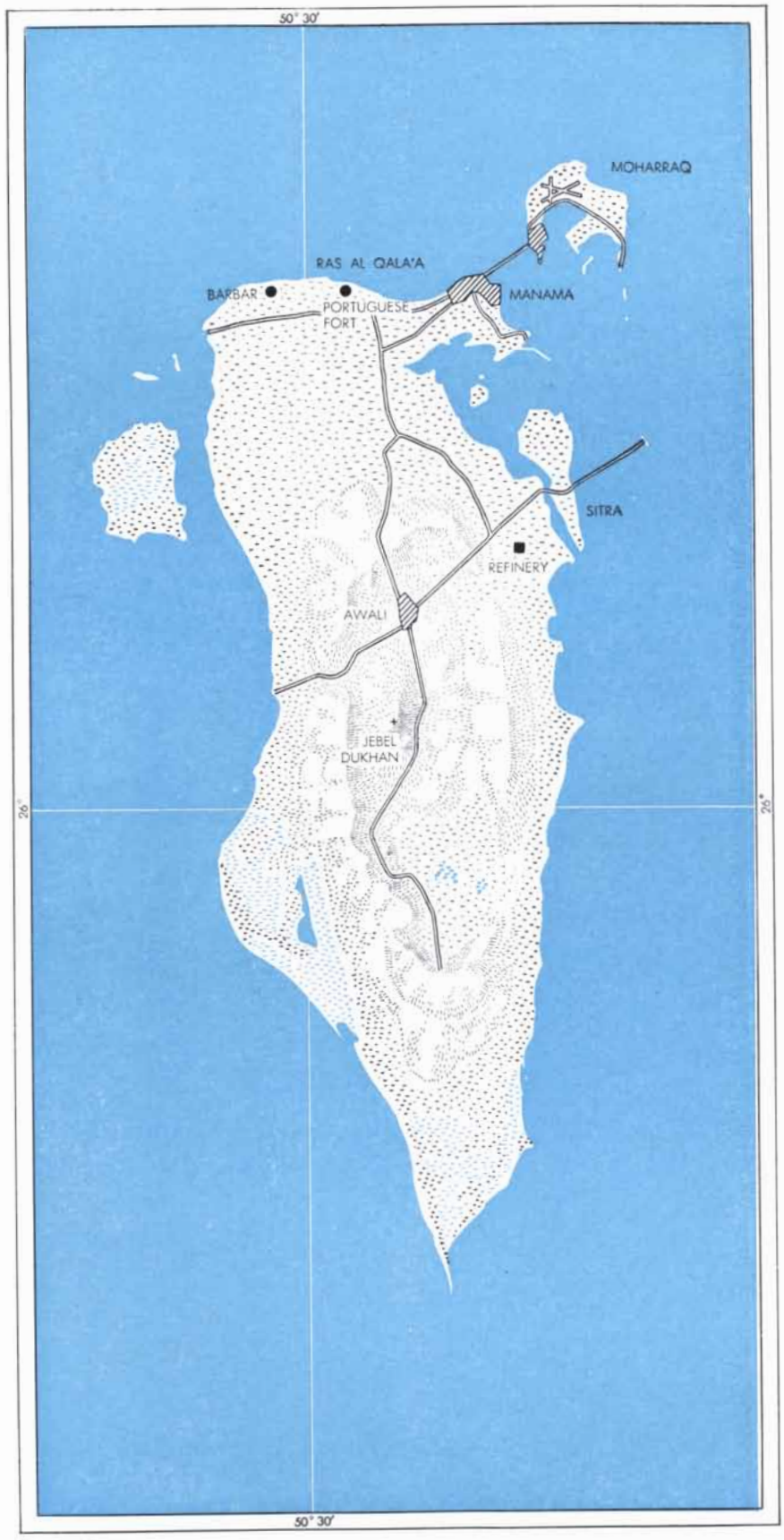


ANCIENT SITES are located on this modern map of the Middle East. Bahrain Island lies halfway down the Persian Gulf from the joint mouth of the Tigris and Euphrates rivers. Cuneiform texts describe the island as being some two days' sail from Mesopotamia.

a seat top, and before them was a square libation altar with a hollowed top, served by a stone-lined drain passing through the walls. To the north a square pit in the flags of the courtyard proved to contain a wealth of objects: lapis-lazuli beads and pendants, alabaster jars and objects of copper, including a figure of a naked and shaven priest in an attitude of prayer. We had uncovered the holy of holies of a temple. The statuette evidenced unmistakable Sumerian affinities —secure evidence for an early date. Moreover, several of the lapis-lazuli pendants were of a type found in the cities of the Indus Valley.

Now, after seven seasons of work on the temple of Barbar, the central area has been completely cleared. The square temple has been shown to stand upon a terrace supported by walls of finely cut and fitted limestone. A ramp leads down to the east to an oval enclosure full of charcoal from extensive and repeated burnings and containing stone foundations, perhaps blocks on which animals were sacrificed. To the west a flight of steps leads down from the terrace to a small tank or bathing pool. The temple is thus reminiscent in its layout of the temples of Early Dynastic Sumer, but, with its bathing pool, it also recalls the ritual baths of the Indus Valley cities. We have found the structure to be only the final stage of three successive building phases, each representing additions to the terrace and to the temple above it.

A wealth of small objects has been discovered within the complex—axes and spears of copper, a magnificent bull's head that calls to mind those that adorned the harps in the Early Dynastic royal graves at Ur of the Chaldees and eight circular soapstone seals. These seals are of a type well known to archeologists and much discussed. Among the thousands of cylindrical seals found in Mesopotamia there are a mere 17 of these round seals. They were not native to Mesopotamia, and appeared to date to the period between 2300 and 2000 B.C. Several bore inscriptions in the unknown language of the Indus Valley civilization. Moreover, three examples of the same type of seal had actually been found in the prehistoric Indus Valley city of Mohenjo-Daro. But they were obviously not native to the Indus Valley, where large square seals, found by the hundreds, had been shown to be the native type. It was now apparent to us that the round seals were native to Bahrain. The temples at Barbar could thus be placed in the third millennium B.C.; they belonged to a people who traded



BAHRAIN ISLAND is about twice the size of Manhattan. Most of the grave mounds lie in the northern part of the island. The cross at center marks the 440-foot Jebel Dukhan (Mountain of Smoke). Shaded areas are modern towns; double lines represent modern roads.

CLOSE-UP OF A MOUND shows the ruins of the circular stone walls that ring it. The stone-lined entrance shaft at top center leads to two T-shaped burial chambers within.

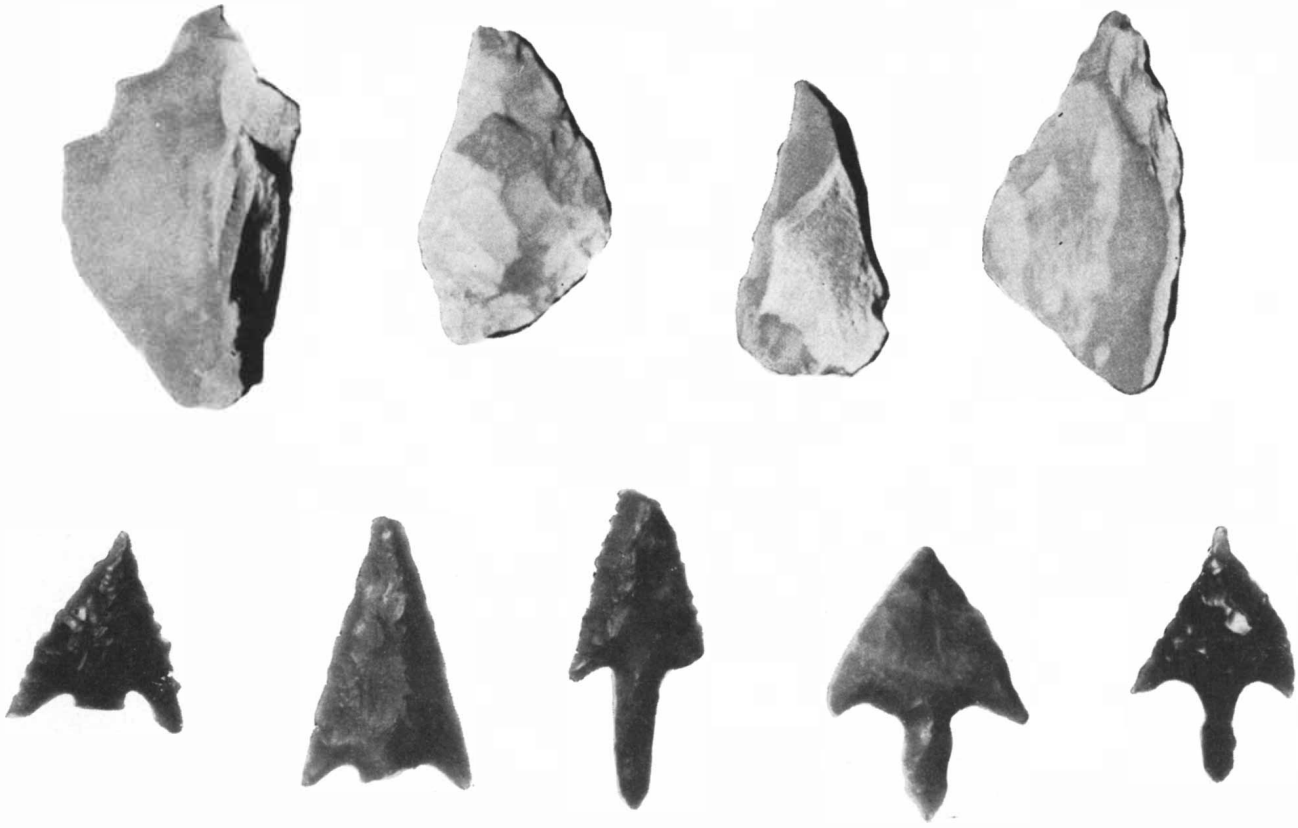
BURIAL CHAMBERS within the mounds are roofed with slabs of stone and sealed with large rocks. Although robbed, chambers contained spearheads, shell cups and pottery.

with both Mesopotamia and India and had a culture distinct from both.

The temples of Barbar have also yielded a large quantity of pottery. It is of a distinctive type—round-bellied jars of a red ware, decorated with horizontal ridges and often bearing a short spout. Further excavation of several more grave mounds with the distinctive T-shaped chambers has produced jars of precisely the same type. The link between the grave mounds and the temple-complex at Barbar is thus established beyond doubt.

Still another large site, discovered during the first season, has revealed the same Barbar pottery, and has at the same time greatly extended our knowledge of this forgotten civilization. Some miles to the east of Barbar, at a bend in the coast known as Ras al-Qala'a, a huge low mound is crowned by the ruins of a fort built by the Portuguese during their 100-year domination of the Gulf in the 16th century. The excavations of the first year showed this mound to be composed of the debris and ruins of a large city. The work of the subsequent years has laid bare a large area (though small in relation to the 200,000 square yards covered by the mound), and has shown that here lie seven cities, one buried below the other. The city second from the bottom has yielded the red-ridged pottery and round stamp-seals characteristic of the Barbar period. In the same levels are ruins of stone houses and a rectangular layout of streets, all surrounded by a massive wall of hewn stone, 14 feet thick. The city that lies below the Barbar city also yields round stamp-seals. But these are more primitive, with designs resembling more closely those of the Indus Valley cities than those found in Mesopotamia. The pottery, too, is related, but bears ridges pressed into a chainlike pattern.

The five successive cities that overlie the two third-millennium cities give a broad panorama of the history of Bahrain almost up to our own day. After the great days of the third millennium there comes a clean break in the style of pottery and other artifacts. It would seem that a different people now occupies the island. In many ways they are poorer and less artistic, and they seem to have deserted part of the city. And yet it is to their time that the most magnificent phase in the construction of a colossal building apparently belongs. This building was discovered at Ras al-Qala'a during the closing weeks of the first campaign. Built of squared stones a yard in length and more, it still stands



STONE TOOLS of Paleolithic man (*top*) and the barbed and tanged arrowheads of Neolithic man (*bottom*) lay scattered where wind had exposed ancient surface of desert. The Paleolithic tools are related to those of the Stone Age cultures of northwestern India.

OBJECTS FROM TEMPLE at Barbar include a copper figure of a naked and shaven priest (*left*), a copper bull's head (*center*) and a circular seal (*right*). Bull's head is similar to those found in the graves of the Early Dynastic Period at Ur; circular seal is evidence of trade connections between Bahrain, Mesopotamia and India. The three objects are not reproduced to the same scale.

to a monumental height of 16 feet, with imposing doorways and sheer walls. Begun perhaps at the close of the Barbar period, it was completed and occupied by the new invaders. Some time in the second millennium this third city was destroyed and left desolate.

After a lapse of years a new people with new fashions of pottery and implements reoccupied the site. The ruins of the immense building were now cleaned out, repaired and partially rebuilt of inferior materials, apparently as a temple to a snake goddess. In the huge entrance hall two mighty square pillars had originally borne a roof. But in this period the hall was roofless; one pillar had disappeared, and of the other only the bottom block, a yard square and two feet high, still stood like an altar. In front of this block we found 14 offerings in pottery bowls deposited in shallow holes in the floor. In seven of the bowls lay the skeletons of snakes, some up to five feet in length. With the skeletons in some cases were beads, while one of the offerings consisted entirely of a necklace of 26 beads of agate, amethyst, glass and porcelain, held by a silver clasp. Clearly these gifts of snakes and jewelry were either the offerings of women or were offerings to a female deity (or, most probably, both). They call to mind the snake goddess of fertility worshiped in the second and first millennia over a wide area, from India to Scandinavia, and best known from the Cretan statuettes of goddesses holding snakes.

Early in the first millennium the building was again abandoned, though it was for some time used as a burial vault. Its rooms now lay entirely below ground. Adults were buried in clay coffins, bathtub-shaped and painted with bitumen inside and out, while babies were buried curled up in large bowls. Most of these graves had been robbed, but in one lay a fine bronze wine-service, consisting of pitcher, bowl, strainer and ladle, together with an agate seal that securely dates the grave to about 700 B.C.

Outside the abandoned building the city extended its area, and its surface rose with the accumulation of rubbish and the demolition and rebuilding of houses. In these late levels we suddenly find sherds of black-painted pottery, the products of Athens in the fourth century B.C. Terra-cotta figures and a Greek name scratched on a potsherd show that not only Greek trade goods but also Greek art and speakers of Greek traveled the Persian Gulf before the time of Alexander the Great.

With the beginning of the Christian era and the fall of the successors of Alexander, the city of Ras al-Qala'a appears to have been once more deserted for some centuries. The two uppermost building levels of the city are Islamic, dated very neatly by Chinese pottery of the Sung and Ming dynasties to the 10th and the 16th centuries A.D. respectively. The last city is therefore contemporary with the 16th-century Portuguese fort that crowns the mound and within which the Danish archeological expe-

EXCAVATIONS AT BARBAR uncovered a stone-lined pool (*center*) similar to the ritual baths of the ancient cities of the Indus Valley. In the background is the terrace of a temple. The layout of the temple resembles that of Sumerian temples of the Early Dynas-

dition has pitched its camp these last five years.

It now seems clear that Bahrain was a center of urban life for at least 3,000 years before the Christian era. In the centuries around 2000 B.C. it was a place of considerable wealth and power. Its unique civilization was in close cultural contact with the Sumerians of Mesopotamia 150 miles up the Persian Gulf to the north and with the cities of the Indus Valley, 1,000 miles across land and sea to the east.

References to such a center of civilization turn up again and again in the extensive literature dug up in the cities of Mesopotamia over the past century. Commercial documents describe trading voyages down the Persian Gulf from the cities of Ur, Larsa, Lagash and Nippur. The historical accounts of the campaigns of the kings of Sumer, Babylon and Assyria tell of tribute and submission received from the countries of the "lower sea." Three lands down the Gulf are named with particular frequency: the kingdoms of Dilmun, Makan and Meluhha. They are always named in that order, presumably the order of their distance from Mesopotamia.

Henry Rawlinson, the British colonial official and scholar who deciphered cuneiform more than a century ago, was also the first to suggest that Bahrain might be the site of Dilmun. He based his theory on the discovery on Bahrain of a cuneiform inscription naming the god Inzak, who is cited in the god lists of Mesopotamia as the chief god of Dilmun. With the discovery of the rich cities and temples of Bahrain this theory may now be regarded as confirmed. Dilmun is described in the cuneiform records of Mesopotamia as an island with abundant fresh water lying some two days' sail, with a following wind, from Mesopotamia. Ships are frequently recorded as sailing to Dilmun with cargoes of silver and woolen goods to be exchanged there for the products of Makan (copper and diorite) and those of Meluhha (gold, ivory and precious woods). This would suggest that Meluhha was none other than the Indus Valley civilization, and that Makan must be sought between Bahrain and India. Dilmun is also named as supplying products of its own: dates and pearls. Clearly, however, Dilmun's main importance was as a clearing house for goods from farther east, the abode of merchants and shippers engaged in widespread commerce. This view agrees closely with the new archeological evidence.

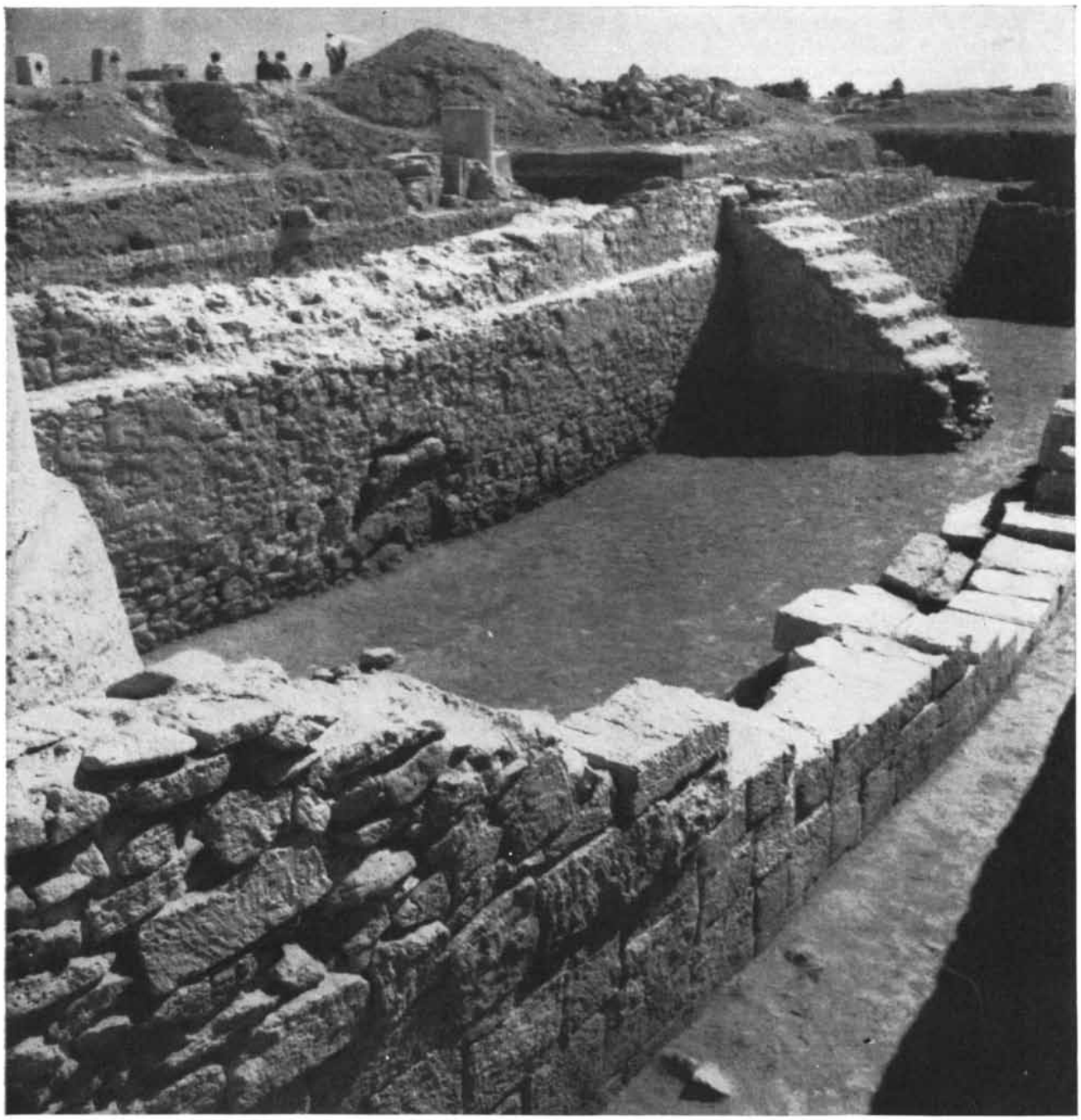
But Dilmun was more than this. The Sumerian poems and epics of gods and heroes tell of another Dilmun, a land that before the creation of man was the abode of the gods, the home of immortality, a paradise of gardens and fresh water in which neither sickness nor old age was known. It was to Dilmun that Zius-udra, the sole survivor of the Deluge, retired when the waters subsided and he had been granted immortality. And it was to Dilmun that the greatest hero of ancient Sumer, Gilgamesh, came

tic Period. Another view of this temple appears on next page.

EXCAVATIONS AT RAS AL-QALA'A unearthed the ancient water closet in center foreground. Dating back to first millennium B.C., water closet was complete with tank and running water.

in his vain quest for immortality. But of that golden age of Dilmun no traces have yet been found in the record.

In order to follow the ancient trade routes to the east and to the west the Danish archeologists have extended their research far beyond Bahrain to cover 600 miles off the coast of Arabia from Kuwait to the Trucial Oman on the Strait of Hormuz, the eastern entrance to the Gulf. Near Kuwait three seasons' work on the little island of Failaka, a three-hour sail from the coast, has uncovered two adjacent sites of unusual importance. One is an outpost of the Dilmun culture, a small but very rich settlement, producing the typical ridged red pottery so well known from the Barbar temples of Bahrain, as well as fragments of soapstone bowls carved with figures of animals and men, amulets bearing cuneiform inscriptions, and almost 200 round seals identical with those of the Barbar period of Bahrain. The other site, a fort, was built almost 2,000 years later by veterans of the army of Alexander the Great on their return from India. In and near it have been found Rhodian wine jars and molds for casting statuettes of Greek goddesses and even of the divine Alexander himself. And the campaign just completed has laid bare a pillared temple of Greek style. Standing before it is a slab that bears a long Greek inscription giving the instructions issued by the Greek king for



WALL OF TERRACE of the latest of the ancient temples at Barbar (*bottom*) masked the wall of the earlier terrace and its stone staircase (*top*). Three pierced stone blocks at extreme upper left were possibly tethering poles for animals awaiting sacrifice.

the foundation of this colony so far from the Greek homeland.

But perhaps the greatest perspectives are opened by the work that has now been going on for two years in the Trucial Oman. There, on a little island off the coast, and again at the oasis of Buraimi, three days' camel journey into the interior, groups of grave mounds have been found. The graves are of a completely new and imposing type, with perpendicular circular walls built with stones cut to fit the curve and standing to above the height of a man. Squeezing through tiny "porthole" entrances, one finds within cross walls supporting arched roofs. Unlike the single burials of the Bahrain mounds, these burial chambers each contains up to 50 skeletons, lying in disorder as they were successively pushed aside to make room for more bodies. Among them lie thousands of beads and a wealth of finely made painted pottery. This pottery resembles the pottery found in the Dilmun levels of Bahrain closely enough to determine that the burial vaults are of the same date as the Dilmun civilization. But it resembles even more closely the pottery of the Kulli culture of India, which is believed to have preceded the Indus Valley civilization. In this new culture, with its unique burial practices, we may be touching the fringe of the next great civilization toward the east, the kingdom of Makan.

GREEK TEMPLE at Kuwait, 250 miles north of Bahrain, was built at the order of Alexander the Great. A stone slab found in front of the temple contains a long inscription in Greek giving the instructions issued by Alexander for the founding of a Greek colony.

OPTICAL PUMPING

In this new technique of experimental physics light is used to "pump" electrons to higher energy-levels. The method is employed to study the interaction of atoms and radio waves

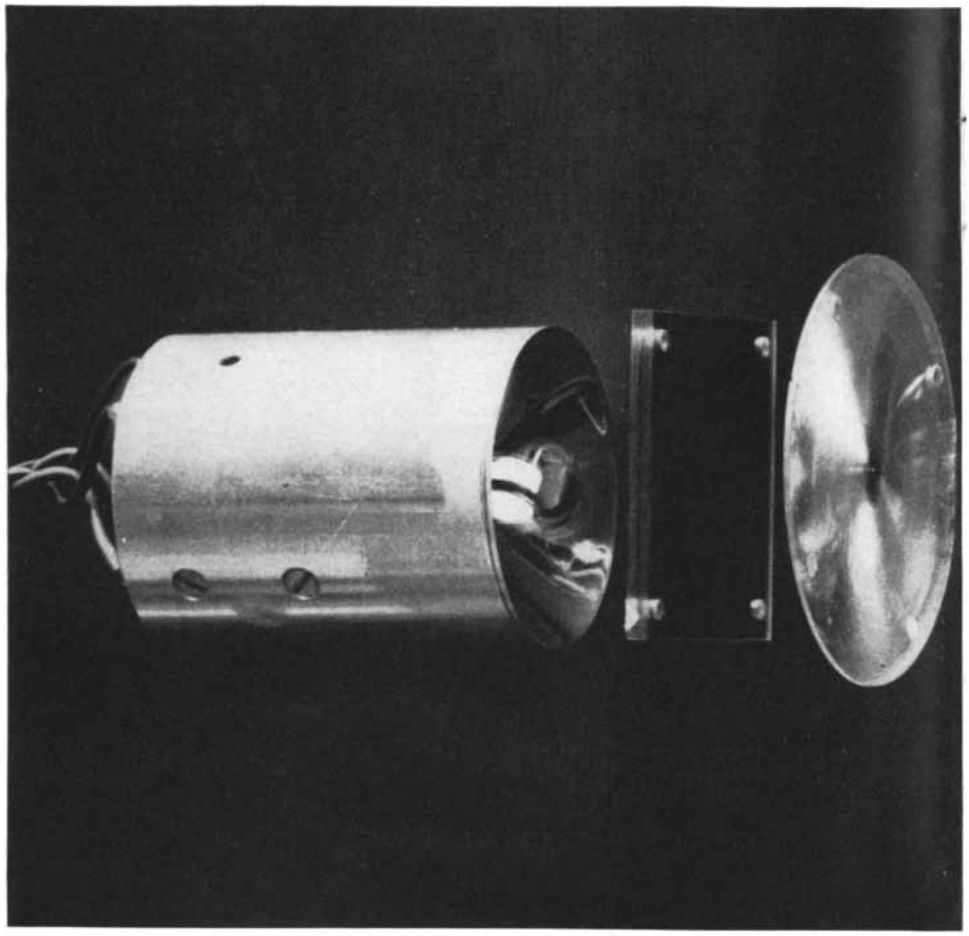
by Arnold L. Bloom

The rather odd term optical pumping means just what it says. In general "pumping" is a process of raising matter from lower to higher energy; for example, raising the potential energy of water by moving it from an underground well to an elevated tank. In this article we shall be concerned with the pumping of individual atoms from lower to higher states of internal energy. The word optical refers to the light energy that is the source of power for the pump.

Why pump atoms? The purpose is to prepare them for a special kind of spectroscopic analysis. When we think of a spectrum, we usually visualize bands of color. Actually atomic spectra extend far beyond the wavelengths of visible light (a few hundred thousandths of a centimeter) in both directions. Atoms can emit and absorb electromagnetic radiation ranging from radio waves (whose length is measured in hundreds of meters) to X-rays (a thousandth as long as light waves). The visible spectrum has been intensively studied for a century, and the X-ray spectrum for about 50 years. Among the results of these investigations is the quantum theory of atomic structure. But spectroscopy in the radio-frequency region is a very recent development, in part made possible by the technique of optical pumping, and only now beginning to be exploited. Paradoxically, long-wave studies are now revealing fine detail in the structure of atoms that is invisible at shorter wavelengths. And optical pumping has already led to a number of practical applications.

The reason for both the effectiveness and the difficulty of using radio waves for spectroscopy lies in their low energy. Like all other electromagnetic radiations, radio waves are divided into discrete packets, or photons, the energy of which varies directly with their frequency, or inversely with wavelength. Having frequencies millions or even billions of times lower than the frequencies of visible light, their energy is less in the same proportion.

When photons are absorbed or emitted by an atom, the atom gains or loses the energy they contain, changing its physical state in some way. The photons of light, with their comparatively high energy, involve the transition of an electron from one orbit to another. The photons of radio waves merely shift the axes of spinning electrons within an orbit. Since the electrons are tiny magnets with fields aligned along their axes, such a



RUBIDIUM IS PUMPED by beaming light from a rubidium-vapor lamp (*far left*) through a circular polarizer (*square at left center*) and a plastic condensing lens into an

shift produces a small change in the magnetic energy of an atom.

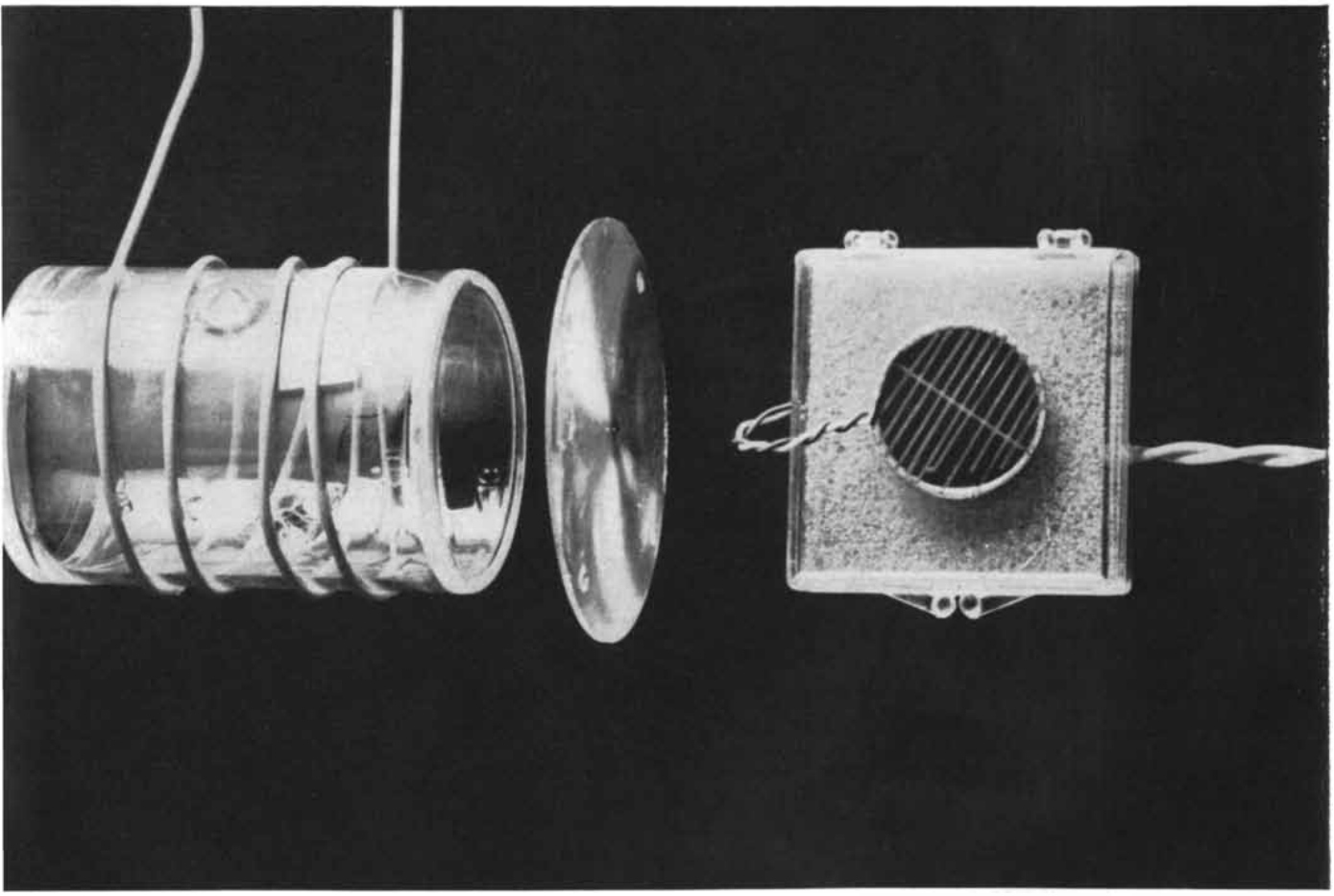
The transition between energy states, or levels, is a two-way street: atoms at a higher level tend to fall spontaneously into the lower one; those at the lower level will jump to the higher one if the requisite quanta of energy are available. If a transition is to be detected spectroscopically in a sample of matter, there must be a net excess either of upward or of downward jumps among its atoms. In jumping up, the atoms subtract photons from a transmitted beam of radiation, producing an absorption spectrum; in jumping down, they send out photons, producing an emission, or "bright line," spectrum. Generally speaking, matter must be in the form of a gas or a vapor to exhibit sharp emission or absorption lines. In solids and liquids interactions of neighboring atoms broaden the energy levels, so that the spectra consist not of lines but of wide bands of frequencies.

Now the energy associated with a quantum jump can be exchanged through the direct collision of atoms as well as by radiation. At room temperature atoms are not moving fast enough to raise one another up to the levels required for the emission of visible light. Therefore they are in a position to absorb energy from an external light source. On the other hand, by raising the temperature of a substance, collisions between its atoms can be made sufficiently energetic to excite them so that they emit light.

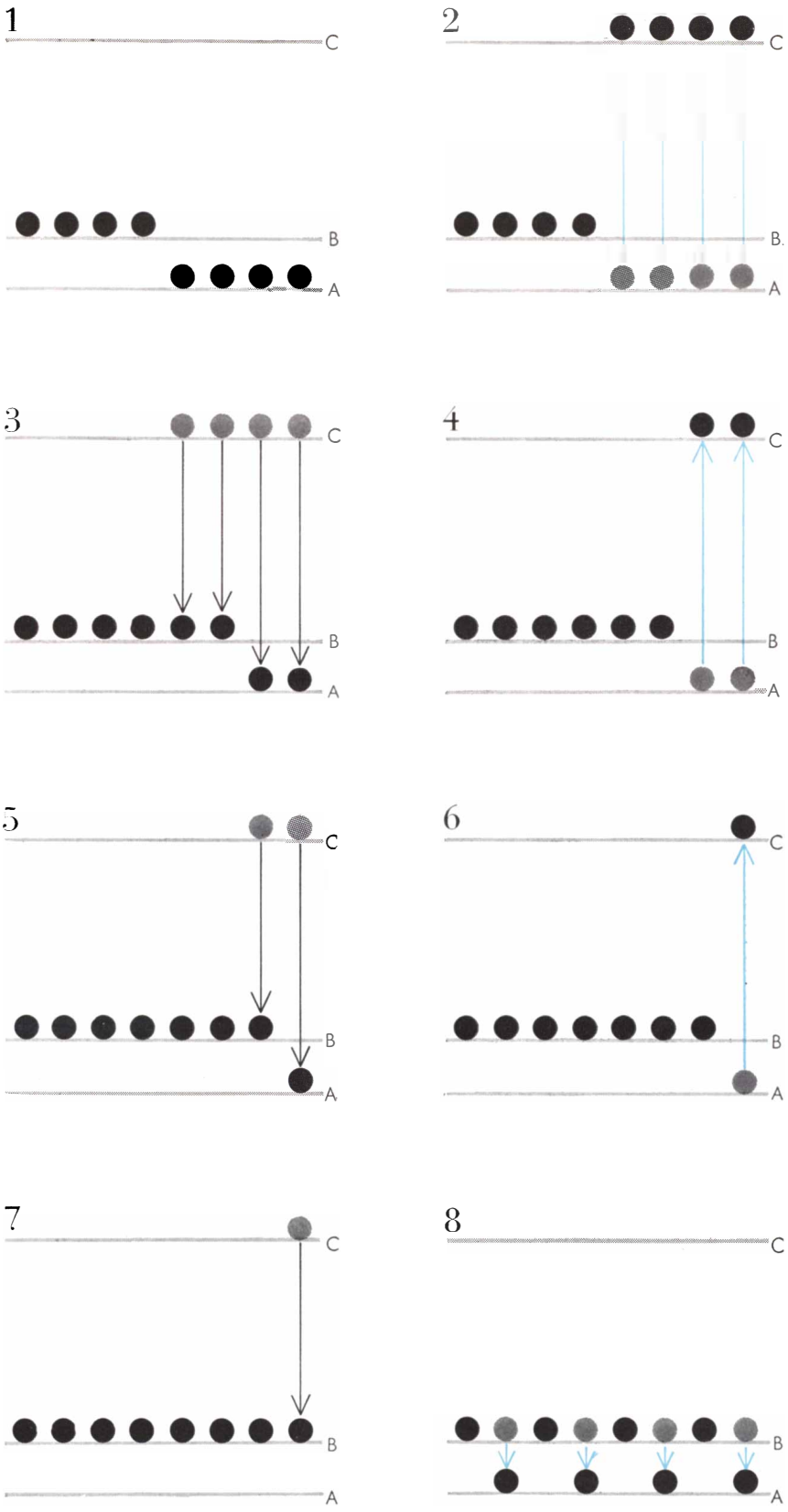
The situation is otherwise for the radio-wave spectrum. The minute quantity of energy necessary to shift atoms between the closely spaced levels is available many times over in thermal motion at room temperature. As a result the atoms continually shift back and forth, and those in the emitting state are almost exactly counterbalanced by those in the absorbing state. In order to do spectroscopy some way must be found to put a majority of atoms into one state or the other.

There are a few ways to accomplish this. The most direct is to cool a material to a point where it no longer has enough thermal energy to produce transitions even between closely spaced levels. Normally this means bathing the material in liquid helium. Another rather difficult technique is to pass a beam of atoms through a magnetic field, which separates them according to their energy states. More recently experimenters have been reluctant to use these relatively cumbersome approaches and have developed extremely sensitive radio receivers to detect emissions or absorptions arising out of the tiny differences in energy population (measured in parts per million) that exist naturally.

About 10 years ago A. Kastler and J. Brossel of the Ecole Normale Supérieure in Paris and Francis Bitter of the Massachusetts Institute of Technology hit upon a better idea, which Kastler named optical pumping. To understand the principle, consider a simplified atom with only three energy levels, which we shall call A, B and C [*see illustration on next page*]. Levels A and B are low-lying and very close together; the energy difference between them corresponds to a radio-frequency spectrum line, and ini-



absorption cell (*center*). Coil around cell sets up a fluctuating magnetic field. Some of the energy of the light beam is absorbed to pump atoms in cell to higher energy-levels; the rest passes through the absorption cell and is measured by the photocell at far right.



PUMPING PROCESS is depicted schematically in this diagram of the energy states of atoms. Before pumping, the atoms are divided evenly between energy levels A and B, as in 1. After absorbing photons from a beam of light (2) and being raised to energy level C, atoms drop back in equal numbers to energy levels A and B (3). As the process continues, only one atom is left in level A (5); finally it, too, ends up in level B (7). The atoms are then completely pumped. Pumping can be removed by a radio-frequency signal (8).

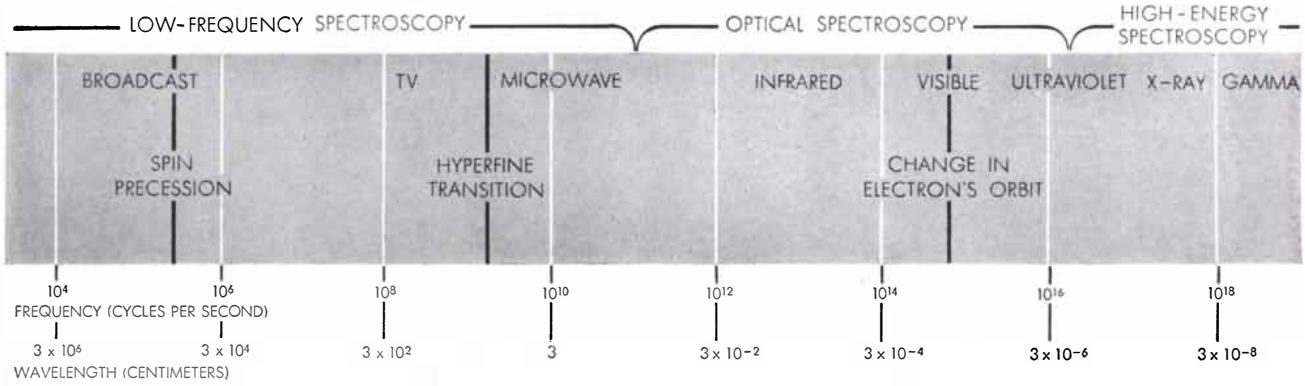
tially all the atoms are distributed equally between them. Level C is much higher; the transitions A-C and B-C correspond to lines in the optical part of the spectrum. Suppose we irradiate a sample of these atoms with a light beam from which the spectral line BC has been filtered. The beam contains photons that can excite atoms in level A but not in level B. Atoms excited out of A absorb energy and rise to C. They will remain there for a short time (as little as a ten millionth of a second) and then emit energy, dropping back either to the A or B state.

The proportion going to each state depends on the structure of the atoms, but the important thing is that occasionally an atom drops into B. When it does, it can no longer be excited by the incident light. If it returns to A, the light will raise it to the C state again, and again it will have some probability of dropping to B. Given enough time, every atom must end up in the B state, and the material is then completely pumped.

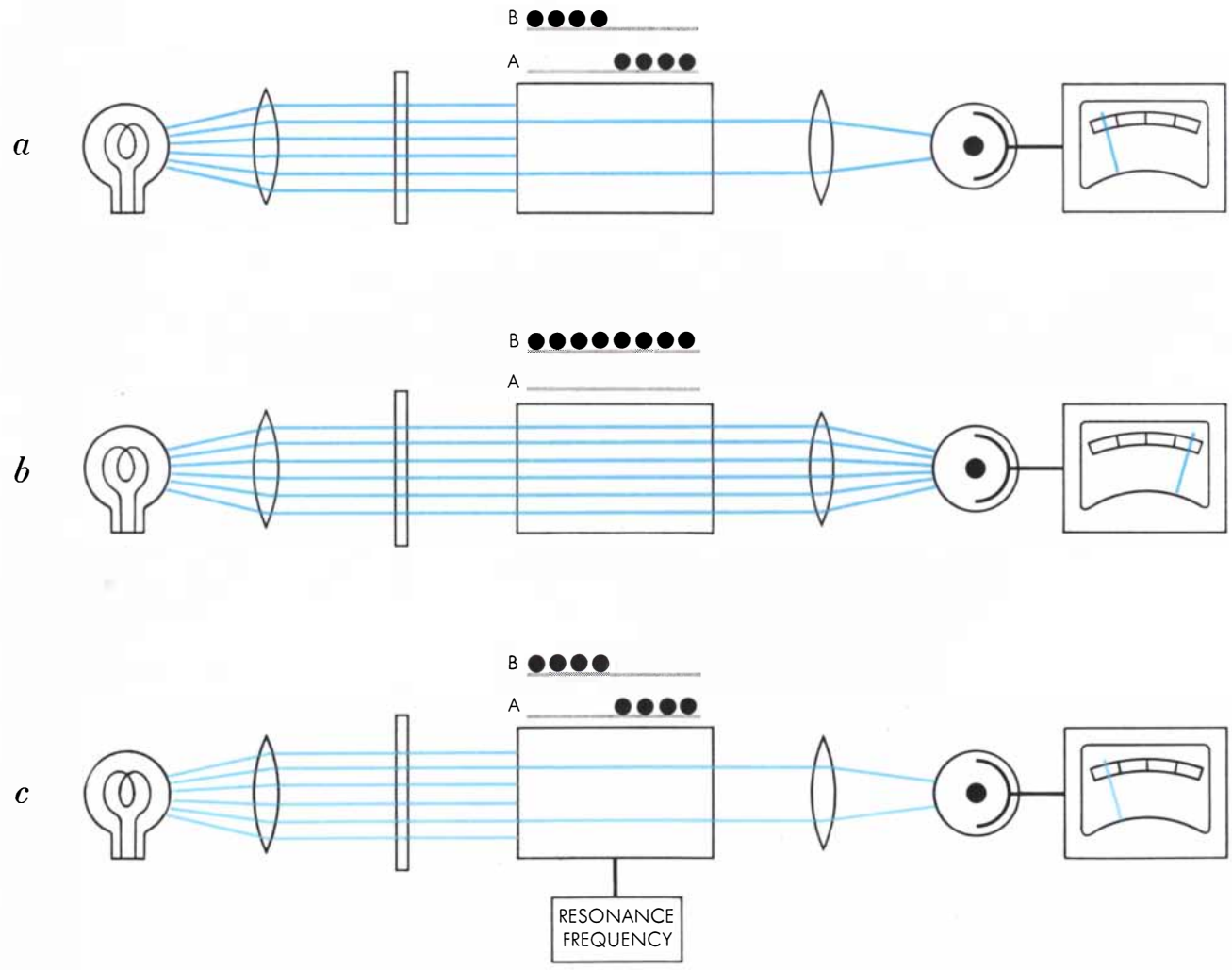
Once this condition has been attained, there are a number of ways to detect it. The simplest and most effective is the method developed by H. G. Dehmelt of the University of Washington. It depends on the fact that the transparency of the sample to the light beam varies with the degree of pumping. As atoms are removed from the A state, the material can absorb less and less of the pumping light, and more of it passes through, reaching a maximum when pumping is complete. Now if some atoms are suddenly returned to the A state, light will again be absorbed, and the brightness of the transmitted beam will drop sharply.

This can be accomplished by irradiating the atoms with radio waves at the frequency corresponding to the energy of transition between levels A and B. The effect is rather complicated in its details, but roughly speaking the radio-frequency photons cause the atoms to shuttle back and forth between the two states, thus effectively transferring some of them from B to A.

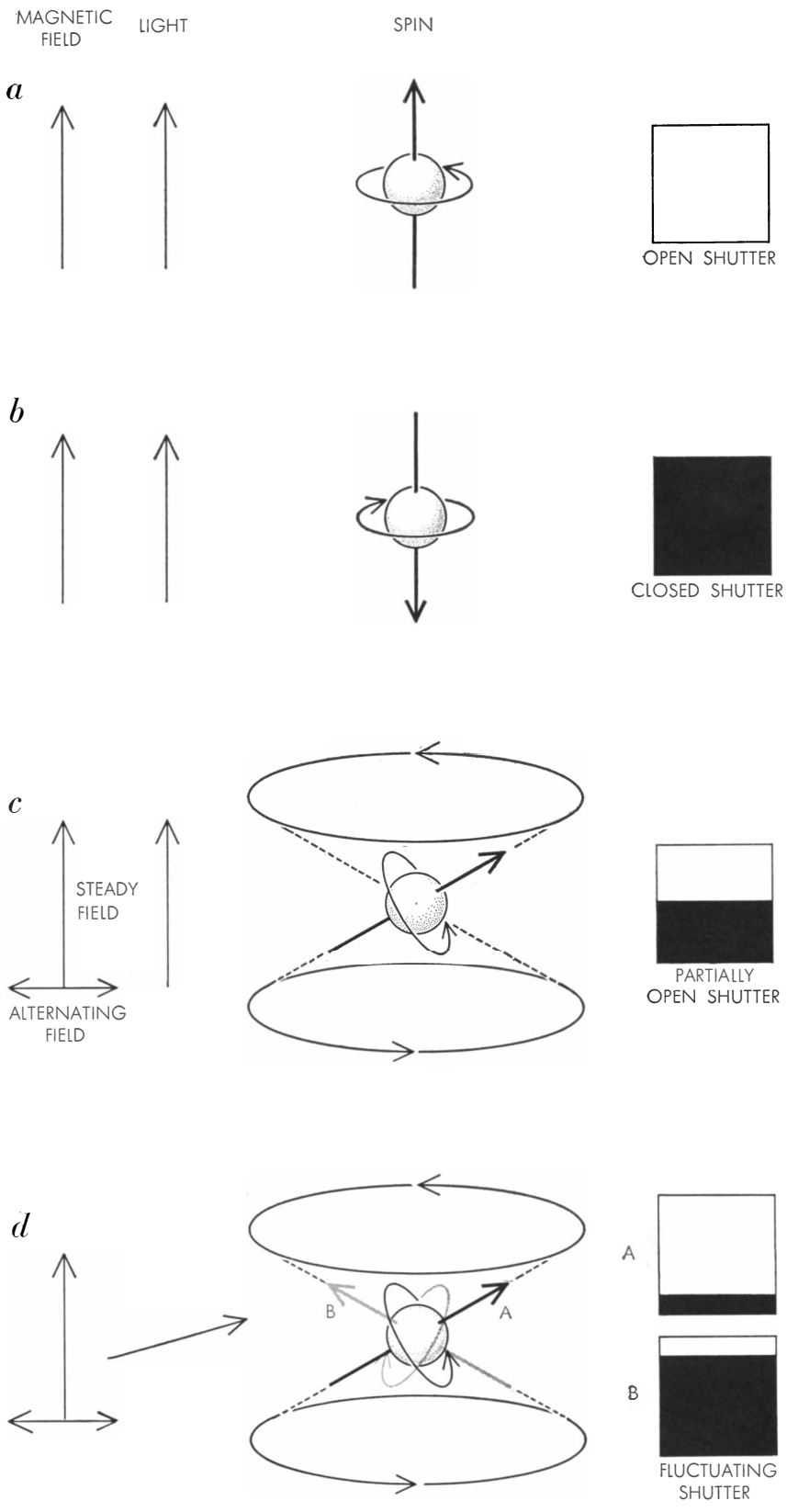
The technique is extraordinarily sensitive. A sample of vapor at a pressure of a ten millionth of a millimeter of mercury can reduce the transmitted light intensity by as much as 20 per cent when the correct radio frequency is applied. In effect every photon of radio-frequency energy undoes the pumping of at least one optical photon. Since the latter's energy is perhaps a billion times greater than that of the radio-frequency



ELECTROMAGNETIC SPECTRUM ranges from low-frequency radio waves (*left*) to high-frequency gamma rays (*right*). Vertical black lines show three spectral lines of sodium; labels on lines indicate corresponding transitions in energy levels of an electron.



EFFECT OF PUMPING on the transmission of a beam of pumping light is depicted schematically. Rectangles at center represent absorption cells; circles above them show energy levels of atoms within them. Little light gets through unpumped cell in row *a*, as is shown by the reading on meter connected to photocell at right. Completely pumped cell in row *b* is optically transparent; when pumping is removed by applying magnetic field that fluctuates at radio frequency, cell again becomes almost opaque (*c*).



ELECTRON SPIN determines whether absorption cell will act as an "open shutter" that transmits pumping light or as a "closed shutter" that blocks it. When spin axis of electron is parallel to that of magnetic field across cell, and to the polarization of the light, as in diagram *a*, electron acts as a miniature open shutter. When spin is reversed, electron acts as closed shutter (*b*). When an alternating magnetic field is applied (*c*), electron precesses and acts as partially open shutter. When polarization of light is changed, the presence of the alternating field causes electron to act as a fluctuating shutter (*d*).

photon, we have in effect an amplifier whose gain is a billion!

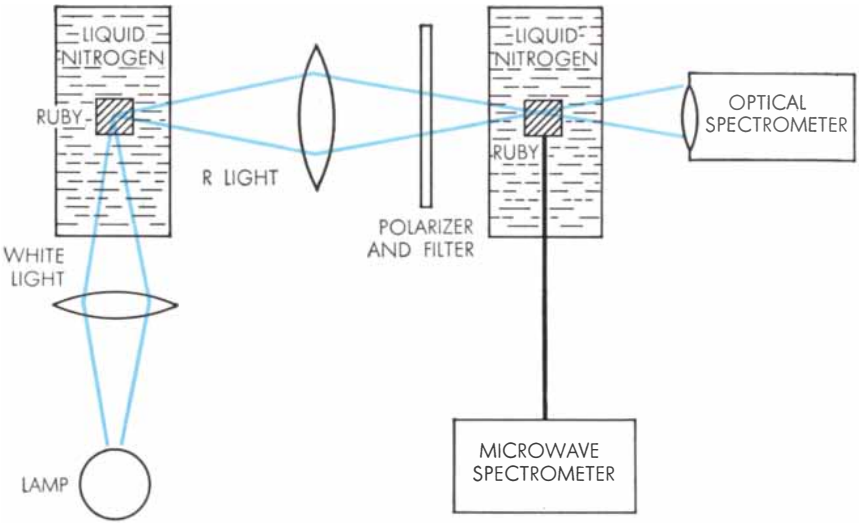
Our description thus far has glossed over a complication that accounts for the fact that this basically simple effect was not discovered long ago. When atoms arrive in the B state, they are not firmly caught there, but "leak" back into the A state through collisions with one another or with the walls of the container. To be effective, pumping must be faster than the leaks. Even in extremely dilute gases, where collisions between atoms are infrequent, each atom will bump into the walls of the container perhaps 10,000 times a second. Since an atom can absorb no more than about 1,000 photons per second from existing spectral lamps, the leak is clearly much too fast. Successful optical pumping had to await the discovery of methods for slowing down the leak.

The discovery came through one of those happy accidents that every scientist hopes for. Kastler and his associates did their early experiments on sodium vapor contained in highly evacuated glass bulbs. They were barely able to keep ahead of the leaking, but they did observe a very small pumping effect. Then one day in 1955 a defective vacuum system filled one of the bulbs with hydrogen instead of evacuating it. When this bulb was tested, it was found, to everyone's amazement, to show a much larger pumping effect. The investigators had known that a foreign gas could act as a buffer and slow the drift of sodium atoms to the walls. What they had failed to realize was that collisions between the sodium atoms and the buffer atoms would not undo the pumping. The reason is that the shapes of the electron orbits of the sodium atoms and the buffer atoms prevent the magnetic interaction of their electrons. And it is by this interaction that pumped atoms leak back to the unpumped state.

Capitalizing on the lucky error, Kastler began to try hydrogen and helium as buffers, and was able to use them at pressures as high as one millimeter of mercury. Further he could not go, because the buffer interfered with the process by which he detected the pumping effect. At about that time Dehmelt was developing his method of monitoring transmitted light, which is much less sensitive to the presence of buffer gas. Thus he was able to work at much higher pressures. In a sodium experiment with an argon buffer at 40 millimeters of mercury, he found that the time required for the pumping to leak away

could be made as long as a 10th of a second. Thus he had achieved a "relaxation time" 100 times longer than the time between photon absorptions.

This was a remarkable result, but Dehmelt then proceeded to do even better without the buffer gas! He reasoned that, since the gas does not completely stop atoms from hitting the walls, a better solution would be to coat the walls themselves with a buffer. The coating should resemble argon in its electronic structure, but should remain solid near 130 degrees centigrade, the temperature at which sodium is pumped. Dehmelt concluded that the requirements could best be met by hydrocarbons with long, straight-chain molecules. Using substances with as many as 40 carbon atoms per molecule, Dehmelt and others have obtained relaxation times as long as two seconds. These experiments are performed with rubidium and cesium, which behave like sodium but which can be pumped at lower temperatures. Apparently the only reason relaxation occurs at all is that once in every 20,000 collisions or so an atom hits the tiny spot of rubidium or cesium metal placed in the vessel to maintain the vapor.



RUBY IS PUMPED by red light from another ruby. First ruby (*left*) fluoresces in the red (R) region of the spectrum when illuminated by intense white light. Pumping effect was detected by the optical spectrometer at right, but not by the microwave spectrometer at bottom.

The actual pattern of energy states in sodium, cesium and rubidium that makes them suitable for optical pumping is a bit more complicated than that of our example. Their atoms contain a single, unpaired electron in their outermost electron shells. According to the rules of quantum mechanics the magnetic field of the electron (and therefore its spin axis) can take only two directions with respect to an external field: parallel or antiparallel. The two conditions correspond to our levels A and B. They are distinguished not only magnetically, but also in terms of the "angular momentum" associated with the spin. When the electron's axis points one way (the B state, say) the atom as a whole has one more quantum unit of angular momentum than when the direction is reversed (the A state). In many of their excited states the atoms can have still greater angular momentum than in the B state. The important point, as we shall see in a moment, is that at least one level (our level C) can have no more angular momentum than the B state.

It is important because light photons also have one unit of spin or angular momentum. In an ordinary light beam the spins take on all directions. However, it is possible to restrict them to a single direction, in which case the light is said to be circularly polarized. When atoms absorb photons from a polarized beam, their angular momentum necessarily changes by one unit, increasing or decreasing depending on the direction of polarization.

Suppose we have a mixture of atoms in the A and B states and illuminate them with light of the proper wavelength to raise them to C. If the light is polarized so as to increase angular momentum, then the atoms in A can absorb it. They move up to C, gaining one unit of angular momentum in the process. But the atoms in B already have as much angular momentum as the maximum allowable in state C. Hence they cannot absorb the light. This is precisely the condition for optical pumping.

In Dehmelt's classic sodium experiment [*see top illustration on next two pages*] pumping light is obtained from a sodium-vapor lamp. Its beam is directed parallel to the earth's magnetic field, which serves as the external field to distinguish the A and B states. After passing through a circular polarizer, the light enters the sample cell: a glass bulb containing sodium metal and a trace of vapor plus argon as a buffer gas. Around the bulb are two sets of coils, one to feed in radio waves and the other to vary the strength of the earth's field slightly. Light transmitted by the bulb falls on a photocell, the output of which is amplified and displayed on an oscilloscope.

When the experiment begins, comparatively little light reaches the photocell because half the sodium atoms are in the light-absorbing state. As pumping proceeds, the vapor rapidly increases in transparency, giving rise to a sharp upward curve on the oscilloscope. The trace soon levels off, showing that pumping is complete. Now the pumping can be undone by applying radio-frequency energy to flip the electrons over. The exact energy, and hence frequency, required to do this depends on the strength of the magnetic field; in a field of one half gauss, typical of the earth's magnetism at middle latitudes, the frequency at which sodium resonates between the A and B states is about 350 kilocycles per second. The most convenient way to observe the resonance is by varying the earth's field a little in recurrent cycles, or "sweeps." Each time the field passes through the correct value for the radio frequency the brightness of the transmitted light drops sharply, and the drop registers as a dip in the oscilloscope trace. If the field strength is known, the resonance serves as a measure of the radio frequency. Conversely, if the frequency is known, the experiment can be used to determine the earth's magnetic field with high accuracy.

A still more sensitive method of measuring the geomagnetic field takes advantage of an auxiliary resonance-effect. Dehmelt had predicted that, under certain conditions, resonance would not only decrease the over-all intensity of the transmitted light, but would also make it flicker at the radio frequency. The effect was soon observed experimentally by W. E. Bell and the author at Varian Associates in Palo Alto, Calif. It can best be understood in terms of the classical picture of electrons in a magnetic field. On this view the radio waves do not flip the electrons back and forth, but cause them to wobble, or

precess, around the field direction at the radio frequency, much as a top precesses around the gravitational field. With respect to the pumping light, the wobbling electrons act as a shutter that is open widest when the axes tip one way and almost closed when they tip the other way [*see illustration on page 76*]. Since the shutter opens and closes about 350,000 times a second, it produces a flicker at the same rate in the transmitted light. This flicker allows us to "watch" the electrons precess in more than a figurative sense.

When the flickering light strikes the photocell, the electrical output pulsates at the same frequency. Suppose this oscillation is suitably amplified and fed back into the radio-frequency coils around the bulb. Now the circuit can produce its own radio waves. In other words, it is an atomic oscillator. As we have said, the resonant frequency of the electrons depends on the strength of the external field. Hence the frequency of our oscillator, which can be determined very accurately, is a direct measure of the earth's magnetic field.

Magnetometers using pumped rubidium as an atomic oscillator have been built in the author's laboratory. They are more sensitive than any previous instrument, and yet the entire electronic circuit, aside from the lamp, consists of one amplifier. Installed in satellites and rockets, they should be able to measure fields in outer space as weak as a hundred thousandth of a gauss.

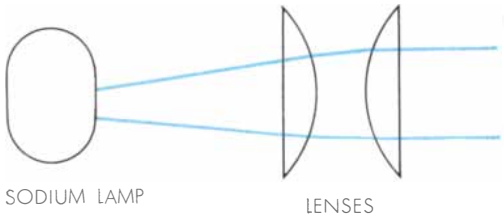
The second important application of optical pumping to appear thus far is in atomic clocks and frequency standards. Here the magnetic field that distinguishes the energy levels is supplied not from the outside, but by the nucleus of the atom itself. Until this point in the discussion we have been able to ignore the fact that the nucleus has a spin and a magnetic field. In an alkali atom, such as that of sodium or rubidium, the magnetism of the nucleus and of the outer electron are strongly coupled, and the two precess about an external magnetic field as though they were a single particle. By exciting the atom with microwaves, however, it is possible to uncouple them and make the electron precess about the nucleus. Since the strength of the nuclear magnet is a constant of nature, the frequency at which the electron resonates is precisely determined.

Atomic clocks employing cesium atoms in a beam had been in existence for several years when it occurred to Robert H. Dicke of Princeton University that pumped rubidium vapor in a glass bulb might provide a more convenient and stable standard. However, if the container held only rubidium atoms, their irregular thermal motion would cause Doppler effects, shifting the resonant frequency by a different amount for each atom, and thus smearing out the resonance line. Dicke proposed that the effect might be reduced by adding a buffer gas. (At the time the effectiveness of a buffer in enhancing optical pumping had not been discovered.)

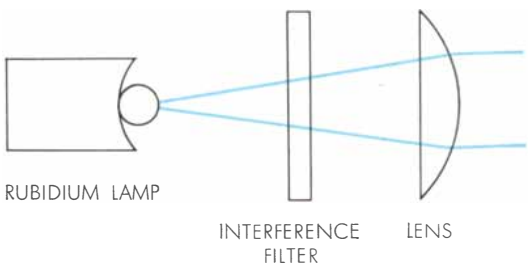
Trying out various gases and using the monitoring technique that Dehmelt had recently developed, a number of workers soon discovered that a buffer did sharpen the resonance line, and that it also shifted the resonant frequency by a small amount. The shift turned out to be directly proportional to the pressure of the buffer gas, and to be upward in light gases such as hydrogen or helium, and downward in heavy gases such as krypton. Because of the pressure shift, an optically pumped atomic clock is not an absolute standard, as is an atomic beam. Instead it is a highly accurate secondary standard that can be precisely tuned, within a narrow range, by adjusting the gas pressure.

In the past few years a number of workers, notably Peter L. Bender of the National Bureau of Standards, have built optically pumped atomic clocks. Bender's rubidium cell, pumped with light from a rubidium lamp, resonates to a microwave-resonance signal at about 6,834 megacycles per second that is stable to within one part in 100 billion. The device is sufficiently compact to be carried in a satellite, where it could be used to check the gravitational red-shift predicted by the general theory of relativity.

In addition to its practical usefulness, optical pumping offers considerable promise as a research tool. Studies of the pressure shift itself, which is not too well understood, should tell a good deal about the forces between atoms when they collide. A variety of substances other than the alkali metals can be pumped. Experiments on mercury vapor, applying the combined techniques of optical and radio-frequency resonance, have yielded information about details in the optical spectrum that are too fine to be resolved by the best optical spectrograph. Helium atoms, although they do not have the proper structure for optical pumping in their normal state, can be raised to a long-lived, or metastable, excited state that is amenable to pumping. As shown by Peter Franken of the University of Michigan, low-frequency spectroscopy can then be used to measure the lifetime of the metastable state. Here again, as with sodium, the frequency of the resonance is directly



SODIUM IS PUMPED by light from a sodium-vapor lamp (*left*). Absorption cell

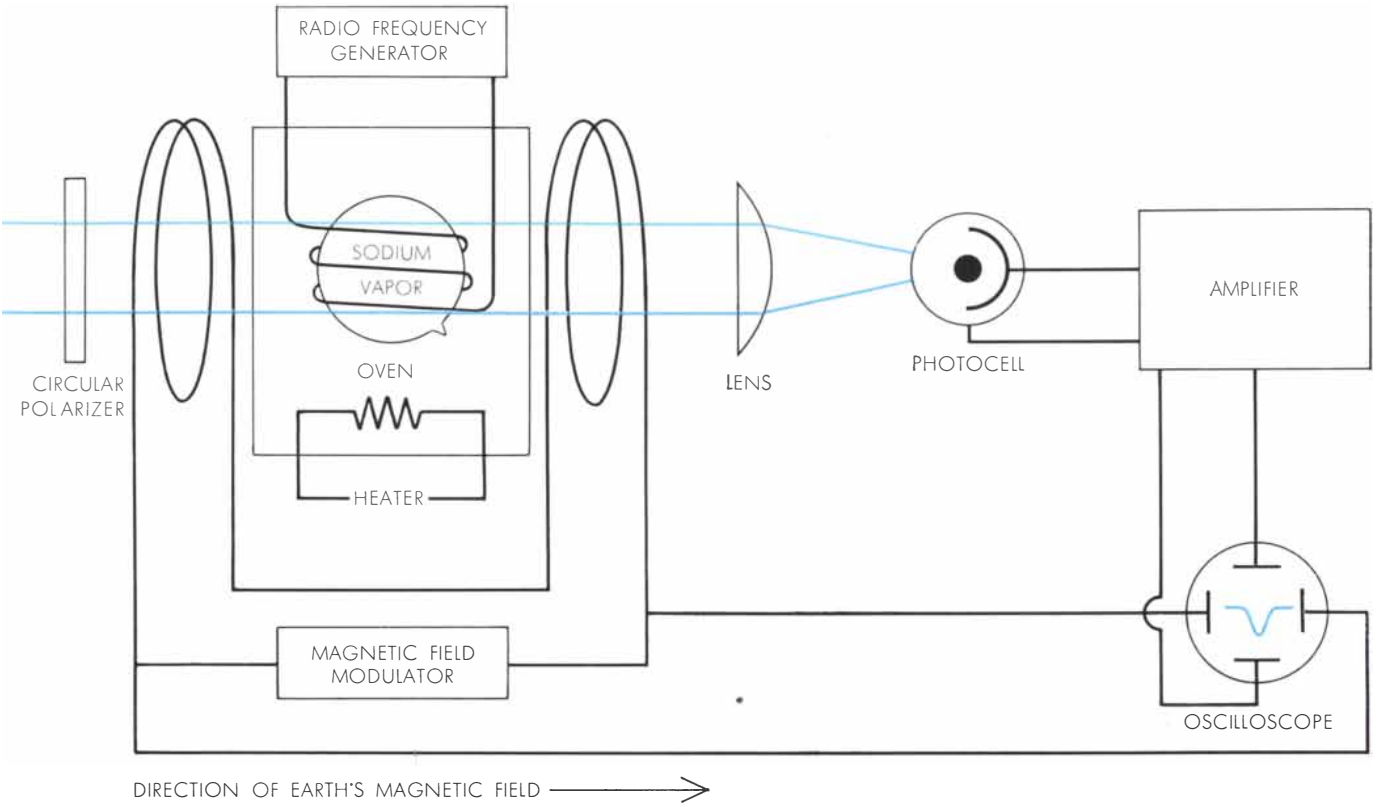


RUBIDIUM MAGNETOMETER is actually an atomic oscillator. Feedback circuit that

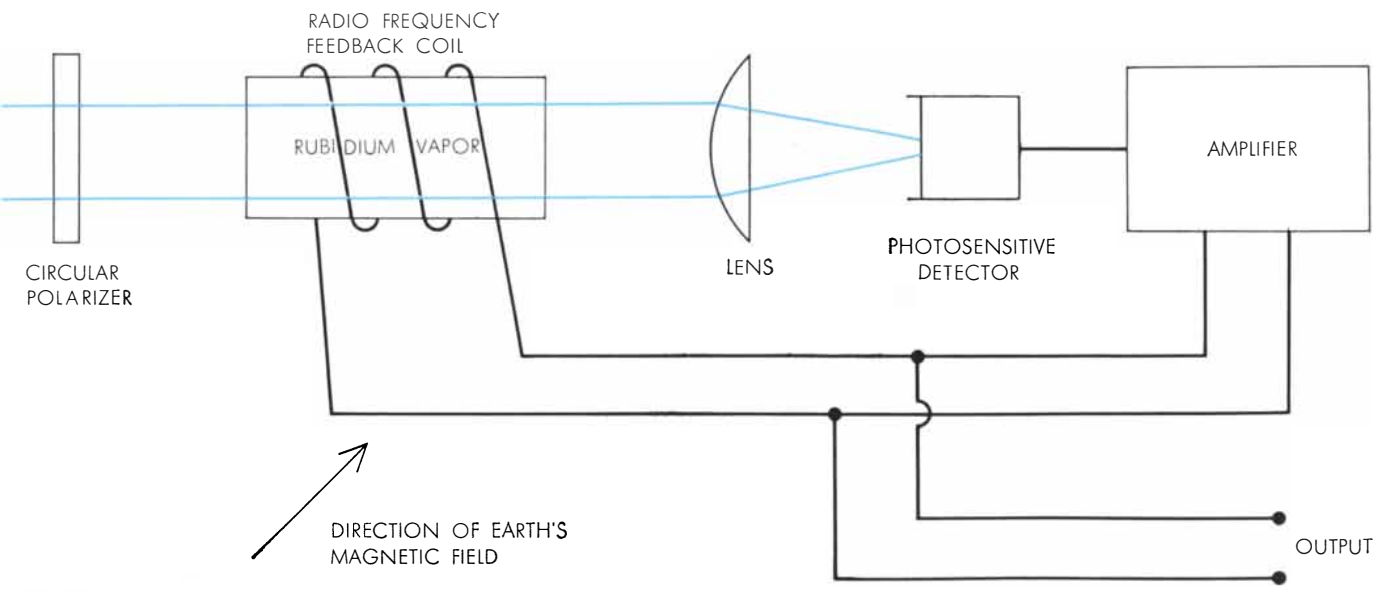
proportional to the strength of the applied magnetic field, and very sensitive measurements of the earth's field can be made in this way.

It is also possible to do low-frequency spectroscopy on vapors that cannot themselves be optically pumped. This is accomplished by mixing them with atoms of a pumpable substance and taking advantage of a process known as "spin exchange," in which angular momentum is transferred between the materials. Nitrogen and hydrogen have already been investigated, and there is no reason why the method cannot be extended to many other vapors.

A particularly interesting development is the recent discovery that optical pumping can be applied to certain solids. It has been known for some time that a ruby, stimulated by a strong white



at center contains sodium that is vaporized by a heater. Light (*colored lines*) transmitted by cell reaches photocell at right. Amplified signal from photocell is fed to oscilloscope. Coils at center are used to vary the magnetic field across absorption cell.



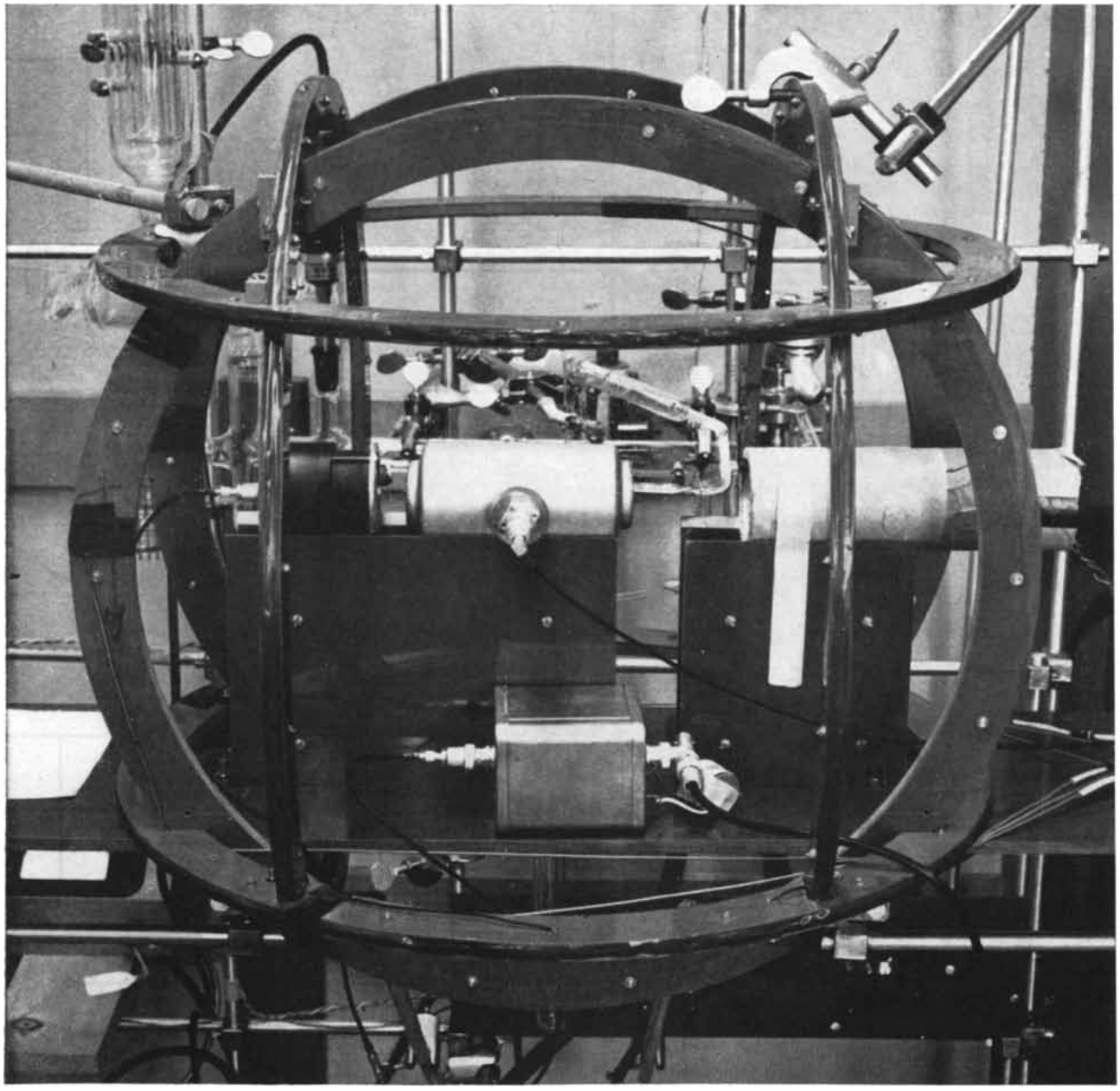
connects the photosensitive detector to the amplifier and the coils causes the light transmitted by the absorption cell to flicker at a radio frequency. The frequency of output signal at terminals at bottom depends on the strength of the earth's magnetic field.

light, will emit a red glow, known as R light, in a very narrow band of wavelengths. Irwin Wieder of the Westinghouse Research Laboratories has successfully used the R light to pump a second ruby in a conventional radio-frequency resonance experiment.

Of much greater potential importance is the first step, in which white light is converted to R light. Again we can picture the process in terms of three energy-levels, but now the large gap is between A and B rather than B and C. Furthermore, C is not a single energy but a rather broad band. Thus the atoms in A can absorb photons of various energies in the white light, and move up to the C band. Thermal motions then cause them to leak, or rather spill, into the B level almost immediately. From here they fall to the A level far below, emitting light photons of sharply defined energy and frequency.

In this way the energy spread over a wide range of frequencies has been channeled into a narrow band. In effect the energy in this band has been enormously amplified. Moreover if the white light is applied in extremely powerful pulses, then *all* the atoms are pumped at once to level B and fall back to A almost simultaneously. When this happens, a co-operative effect can take place between the atoms that causes them to emit their R photons in unison, or coherently. It is as if the atoms, emitting light waves, are so engulfed by the waves produced by their neighbors that they are forced to radiate synchronously with them. Such coherent radiation in the visible range, now available for the first time, makes possible light devices of unprecedented efficiency. For example, coherent light can be focused into a pencil beam that will not spread more than five feet in 12 miles.

T. H. Maiman at the Hughes Aircraft Company has already observed some degree of coherent emission from a ruby, and he as well as workers at several other laboratories are trying to put R light to practical use. Although a working light amplifier may still be some time away, its prospects now seem excellent.



FREQUENCY STANDARD is tuned by regulating the pressure of buffer gas in a rubidium vapor cell (*inside aluminum cylinder at center*) while it is still connected to the vacuum system. Rubidium lamp is in tube at right. Large coils control magnetic field.

Kodak reports on:

our logical position in butyronitriles . . . 19 pages of savvy on schlieren . . . the sweetest little old solid-state amplifier and transducer known to man . . . how to straighten out the Eastman Organic Chemicals Dept.

Through a hot pipe

Firms requiring an efficient source of supply of acetonitrile, propionitrile, or 2-ethylhexylnitrile for chemical manufacturing should inquire of Eastman Chemical Products, Inc., Kingsport, Tenn. (Subsidiary of Eastman Kodak Company).

The reason we think we can make them is that we have been making isobutyronitrile and n-butyronitrile, and the process runs smooth as silk.

The reason we are making the butyronitriles is that one customer asked us to make one and another customer asked us to make the other. (We think one of them is making an insecticide, but we're not sure and don't pry.)

The reason the process runs so smooth is that through a hot pipe packed with the appropriate catalyst we run butyraldehyde, ammonia, and air, viz.

$$2\ RCHO + 2\ NH_3 + O_2 \longrightarrow 2\ RCN + 4\ H_2O.$$

The reason we used this method is that we have a lot of butyraldehyde in Texas.

The reason we have a butyraldehyde plant is to make butyric acid.

The reason we need butyric acid is to make cellulose acetate butyrate.

The reason we make cellulose acetate butyrate is that it is a better plastic for many purposes than plain cellulose acetate.

The reason we became involved with cellulose acetate was that it made a safer base for movie film than cellulose nitrate.

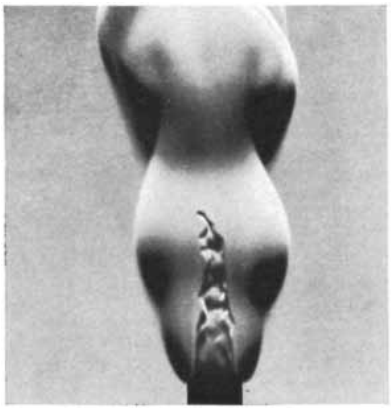
The reason we began making film in 1888 was that it made photography easier than with plates.

The reason George Eastman began making photographic plates was that banking failed to intrigue him.

Thin air can be photographed

The technique of schlieren photography has now been debased to the point where a man can send in to Kodak for a free booklet on how to do it, can carefully read all 19 pages, and can set himself up as a schlieren man. Yes, and perhaps a case can be made that it is not necessarily immoral to go at it just that way.

Though the schlieren method of photographing refractive index gradients in gases and liquids has been around for quite a while, general literature about it is scant; most of what has been published about it dwells on some particular application. You can find packaged schlieren outfits advertised, but the advertisements are low-pressure. Everybody who is doing schlieren now learned the hard way and is entitled to respect. One such savvy schlieren group works at Battelle Memorial Institute and another at Cornell Aeronautical Laboratory, Inc.



Here is an enchanting display item from Battelle's gallery—a turbulent Bunsen flame, frozen in a 13-microsecond schlieren portrait. Areas lighter than background represent decreasing index in an arbitrary direction within the plane of the picture; darker areas represent change in the opposite direction. To measure the quantitative rate of change with distance demands the very considerable elaboration of interferometric technique. A third method, called shadow photography, delineates the second derivative of refractive index with distance. Our slim volume merely hints at the existence of these other methods. Given enough encouragement to expand it some day, we might cover them in useful detail.

To start encouraging us, send for "Schlieren Photography" to Eastman Kodak Company, Sales Service Division, Rochester 4, N. Y.

Rapid-access photography

The silver halide crystal of suitable size and suitable dislocations, with a suitable organic compound or two clinging to it, makes the sweetest little old solid-state amplifier and transducer known to man. It is doing just fine, despite a few misconceptions that have arisen due to the following circumstances:

1) The idea was developed by artists before words like "solid-state physics," "amplifier," and "transducer" were coined and even before science was recognized as profitable.

2) The crystal is employed in very large numbers, dispersed in a dried-down broth from hides and bones. Superficially regarded, this seems archaic. By referring to the preparation as a "photographic emulsion," the notion is dispelled.

3) Memories from childhood suggest that after a photographic emulsion is exposed, one must wait until Dad brings the results home from downtown the week after next. This is no longer true.

Purpose of this message is to make it perfectly clear that today the delivery of photographic results within virtually any desired time interval after exposure is wholly feasible technologically. There are many ways of accomplishing quick delivery, some currently on the market and others on the way. The manufacturer wagers on what the public will buy. As far as goods for the general public are concerned, that's the way it has to be. But on goods for the professionally technical public—rational, organized, deliberate, articulate—*must* the betting be so blind?

We have had a flash of genius. Let's ask them first what they want! Then, as patterns appear in the answers, markets can be defined and gauged. If this works, rapid-access and simplified technical photography will encounter fewer custom problems to be solved at custom prices or else given up for less satisfactory alternatives.

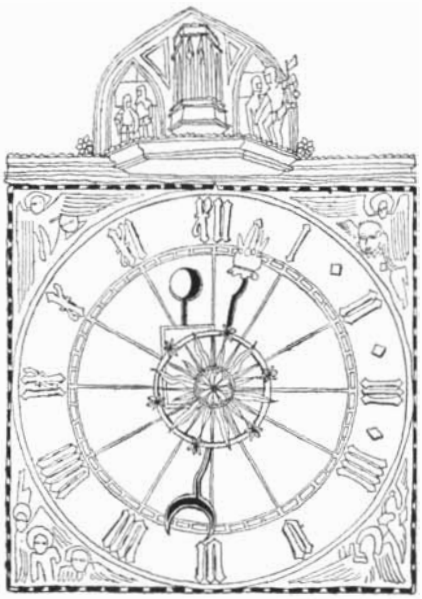
Responsible organizations confronted with technical problems, major or minor, where rapidly or instantaneously available photographic images would be helpful, are invited to describe their wants to Eastman Kodak Company, Special Sensitized Products Division, Rochester 4, N. Y.

Only the green is up-to-date

A new catalog of some 3800 Eastman Organic Chemicals for laboratory use has now been mailed out to every living soul of whose interest we are currently certain. It has a green cover and is marked "No. 42." If you have not received it by now, its absence indicates we don't know you want it. A note to Eastman Organic Chemicals Department, Distillation Products Industries, Rochester 3, N. Y. (Division of Eastman Kodak Company) will straighten us out.

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

Satellites

Two mileposts in the evolution of space technology have recently been passed. Artificial satellites, placed in orbit around the earth, have been returned safely to the ground. One carried a pair of dogs as passengers, the first true space travelers to negotiate a round trip. And an aluminum-coated plastic balloon is now in use as a communications relay station, reflecting signals between points as far apart as New Jersey and California.

The distinction of recovering the first object ever retrieved from an orbit around the earth fell to an unnamed U. S. Navy helicopter pilot. On August 11 he fished out of the sea north of Hawaii a 300-pound capsule ejected not many minutes before from *Discoverer XIII*, a satellite launched 29 hours earlier from Vandenberg Air Force Base in California. Twelve previous U. S. attempts to eject and recover a re-entry capsule from orbit had ended in failure. *Discoverer XIII*'s capsule was started back to earth on the satellite's 17th circuit of the globe.

A more resounding success was scored on the next U. S. try. On August 19 a capsule ejected by *Discoverer XIV* was caught in mid-air by a trapeze-trailing Air Force cargo plane as the capsule, its fall through the lower atmosphere slowed by a parachute, descended 300 miles south southwest of Honolulu. *Discoverer XIV* was also launched from Vandenberg Air Force Base and also ejected its re-entry capsule on the 17th trip around the earth.

Hardly a day later a five-ton Soviet "space ship" landed on a collective farm near the Caspian Sea at the start of what would have been its 18th orbit of the earth. A capsule, separated from the main vehicle after re-entry into the earth's atmosphere, made a separate landing with a cargo of experimental plants and animals, including two dogs. The dogs—white for easier visibility over the television equipment that was among the monitoring instruments aboard, and named Strelka (Little Arrow) and Belka (Squirrel)—were reported to have endured the journey with no ill effects.

The radio-reflector satellite *Echo* was fired from Cape Canaveral on August 12. Two minutes after reaching orbit, explosives split the casing of the payload container, permitting the release and inflation of a 100-foot balloon inside. Whenever the balloon satellite was above the horizon, engineers in Holmdel, N. J., and Goldstone, Calif., were able to carry on a two-way conversation via microwaves reflected from its surface. The success aroused particular interest among telephone engineers because of the importance of microwaves in long-distance telephony, and because a system of *Echo* satellites could prove less expensive than the system of relay towers and coaxial cables now required for transmitting microwaves over long distances. At the end of August the total number of satellites still in terrestrial or solar orbit stood at 17 out of a total of 34 launched.

Live-Virus Polio Vaccine

By next spring a live-virus vaccine against poliomyelitis will be in limited but regular use in the U. S. Leroy E. Burney, Surgeon General of the U. S. Public Health Service has announced that licenses will be granted to manufacturers, as each qualifies, for commercial production of the vaccine developed by Albert B. Sabin of the University of Cincinnati. The Sabin vaccine is to be employed in community immunization programs only; for the present the Public Health Service is not recommending it for individual immunizations by private physicians.

The licensing of the Sabin vaccine caps 10 years of heated controversy between supporters of live-virus vac-

cines and those who have favored killed-virus vaccines of the Salk type. Advocates of live-virus vaccines have contended that a vaccine containing living polio viruses attenuated to eliminate risk of paralysis would give longer lasting, more certain protection against paralytic polio than a killed vaccine, and that live-virus vaccine would be simpler to administer because it can be given by mouth. (The Salk preparation must be injected.) Extensive trials, conducted chiefly abroad, have made it clear that there is actually little to choose between killed-virus and live-virus vaccines in the percentage of "takes" or in protection against paralysis. The Public Health Service was led to approve a live-virus vaccine primarily by the greater effectiveness of such a vaccine in preventing inapparent infections of the digestive tract with polio virus (an important pathway for spread of the disease), and the hope that the oral vaccine would make it possible to reach persons who have not yet been immunized. Recent outbreaks indicate that immunization must be extended to many more than the 70 million persons under 40 years of age (out of the 116 million in that age group) who have had three or more Salk shots, in order to eliminate paralytic polio.

Although the Sabin vaccine is more effective when the three types of vaccine—one for each type of polio virus—are given separately, all three types will probably be given together. Three or more doses will be needed. The winter will be the preferred season for its use, because of the low prevalence of polio and of infections that could interfere with the vaccine's action. Two other live-virus polio vaccines—those developed by Hilary Koprowski of the Wistar Institute and Herald R. Cox of Lederle Laboratories—were excluded from licensing because tests of these preparations in the laboratories of the Public Health Service have indicated that they are not always so low in virulence as is the Sabin vaccine.

Antarctic Treaty

The U. S. has become the sixth nation to ratify the Antarctic Treaty. The pact reserving the frozen continent for peaceful scientific pursuits and prohibit-

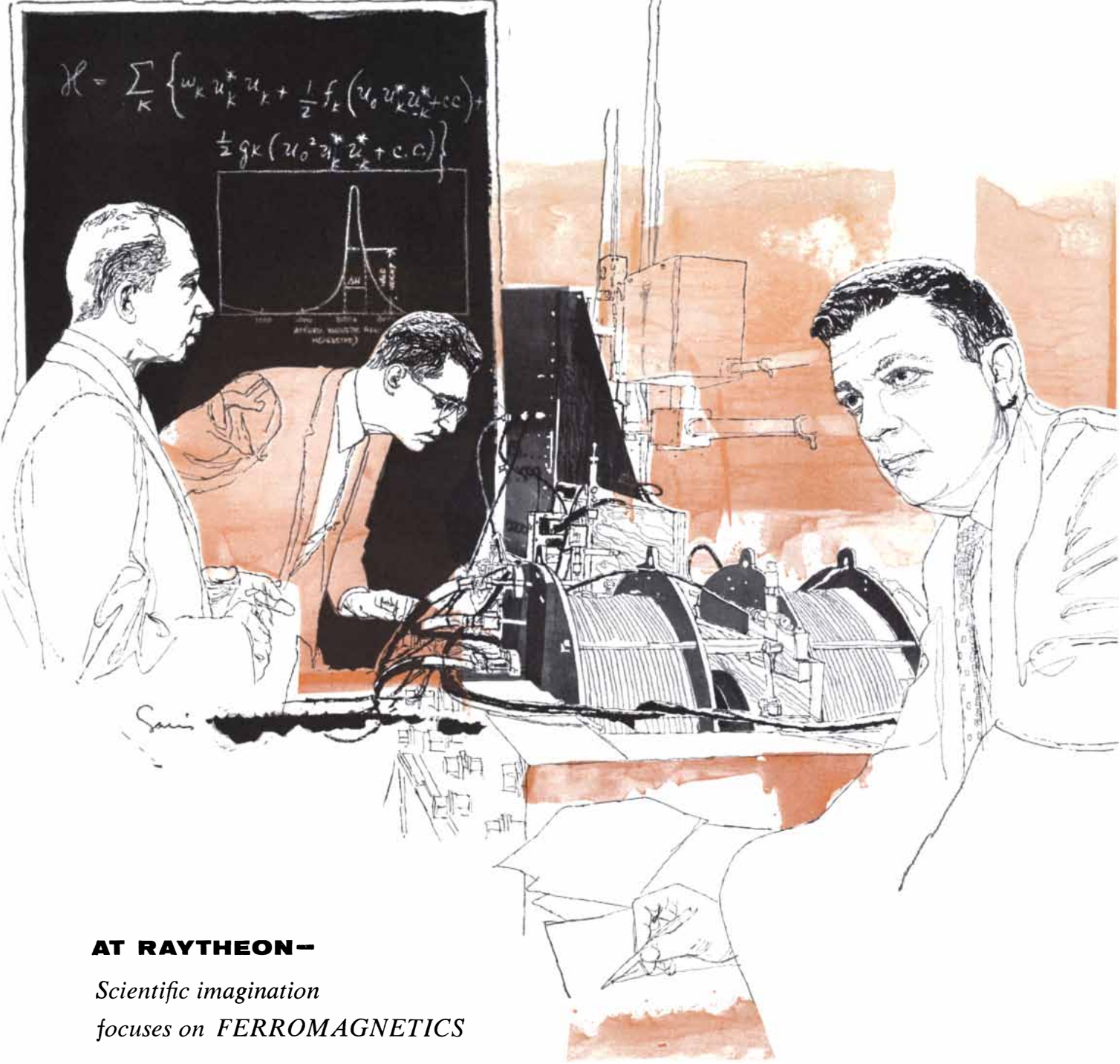
ing military activities within its confines won Senate approval late in August by a 66-21 vote, eight votes more than the required two-thirds majority. The Treaty, which also shelves all territorial claims in the Antarctic for 34 years (the life of the Treaty), was proposed and largely carried through by the U. S., and will come into force as soon as it has been ratified by all 12 signers. Among countries ratifying ahead of the U. S. were Great Britain and Japan. Among those whose ratification was still awaited were Australia and the U.S.S.R.

On the day the Senate voted to ratify the Antarctic Treaty, the Atomic Energy Commission announced the award of a $4-million contract for a 1,500-kilowatt atomic power plant for the U. S. base at McMurdo Sound. Similar plants have also been authorized by Congress for Little America and the U. S. South Pole station as a result of a study showing that nuclear plants could produce heat and electricity in the Antarctic at one fourth the cost of plants using conventional fuel. In accordance with the Antarctic Treaty, no radioactive wastes from the new plants will be deposited in Antarctica.

Meanwhile Australian and Soviet glaciologists report that the antarctic icecap is growing in volume at a rate of nearly 300 cubic miles a year. According to Pyotr Shoumsky, a Soviet glaciologist, studies during and since the International Geophysical Year indicate that Antarctica has an annual snowfall equivalent to more than 600 cubic miles of ice, but at least half the annual fall is lost or offset in several ways, especially by the formation of icebergs. Similar estimates have been made by Malcolm Mellors of Australia. The increase in antarctic ice is not considered incompatible with the warming of the climate and the retreat of glaciers that have been occurring in other parts of the world. Meteorologists point out that the warming could contribute to the growth of antarctic ice by making more atmospheric moisture available for antarctic snowfall.

Soviet Ore Find

An iron-ore deposit believed by Soviet officials to contain nearly as much high-grade ore as is known to exist elsewhere in the world has been found in the heart of European Russia. Located 300 miles southwest of Moscow, the deposit is part of the Kursk magnetic anomaly, a region known since 1784 for aberrations of the magnetic compass. Efforts to find the magnetic ores re-



AT RAYTHEON—

Scientific imagination
focuses on FERROMAGNETICS

Ferrites, ceramic materials derived mainly from magnetite, combine high electrical resistivity with ferromagnetic properties. These characteristics make possible microwave devices such as isolators—units which conduct radio waves in one direction, but not the other—modulators, phase shifters and microwave switches. Unlike conventional microwave hardware, ferrites are simple, highly efficient solid-state devices.

New types of microwave tubes require ferrites capable of operating at multi-megawatt levels. However, at high power, heat generated within the ferrite may cause a gradual loss of magnetic properties. And at low frequencies, interaction among microwave, external and ferrite magnetic fields may seriously attenuate the transmitted signal.

Through design innovations, new material formulations and special ceramic production techniques, Raytheon scientists and engineers have successfully minimized these effects in developing the first commercially-available UHF (350 to 400 mc) isolator for high-power—10 megawatt peak—radar.

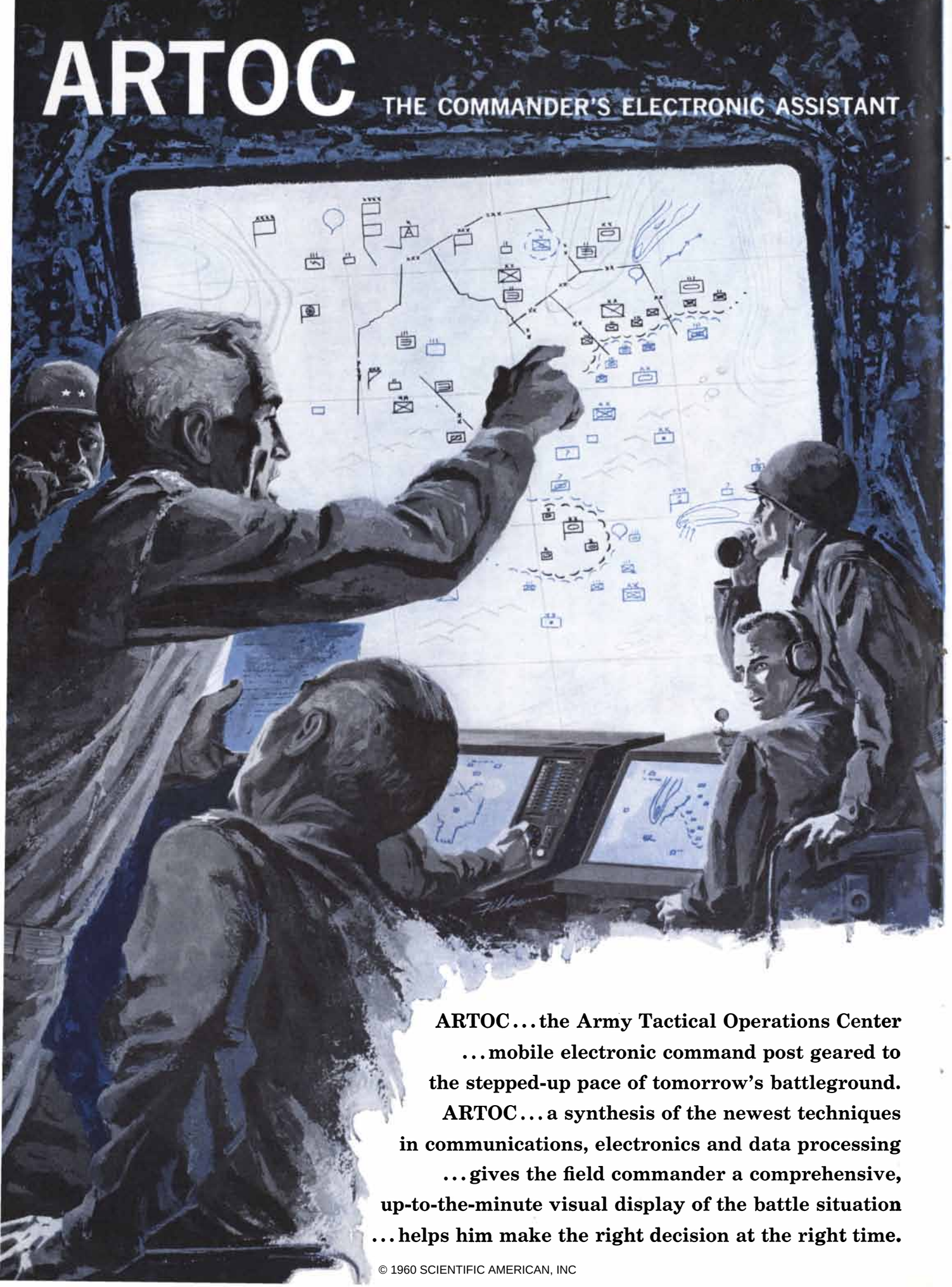
Out of the combined efforts of many professional disciplines—mathematical physics, metallurgy, physical chemistry—have come major contributions to fundamental understanding of ferromagnetics and microwave behavior.

Dr. M. H. Sirvetz of the Research Division, Dr. H. Scharfman, head of the Special Microwave Devices Operations, and Dr. S. L. Blum also of Research are among the many Raytheon personnel contributing to these fields.

Excellence in Electronics RAYTHEON **RAYTHEON COMPANY, Waltham, Mass.**

ARTOC

THE COMMANDER'S ELECTRONIC ASSISTANT



ARTOC... the Army Tactical Operations Center ...mobile electronic command post geared to the stepped-up pace of tomorrow's battleground. ARTOC... a synthesis of the newest techniques in communications, electronics and data processing ...gives the field commander a comprehensive, up-to-the-minute visual display of the battle situation ...helps him make the right decision at the right time.

sponsible for the aberrations had previously led only to the discovery of low-grade ferrous quartzites requiring extensive upgrading to suit them for the blast furnace. The high-grade ores were found far below the surface, at a depth of about 3,000 feet.

Preliminary estimates based on magnetic surveys and the drilling of some 100 test holes put the size of the deposit, which consists of magnetite, at 30 billion tons or more. Surveyed reserves of high-grade ore in other parts of the world total approximately 40 billion tons. The high-grade Kursk deposit is described, moreover, as comparing favorably with high-grade Swedish ore, both in iron content (56 to 69 per cent) and in freedom from troublesome impurities, especially sulfur. Mining of the ore has already begun and is to reach 36 million tons a year by 1965.

Strontium-90 Peak

Provided nuclear-weapons tests are not resumed, the worst of the strontium-90 fallout problem appears all but over. New measurements, reported in *Science* by J. Laurence Kulp and his associates at the Lamont Geological Observatory of Columbia University, indicate that the peak concentration of the hazardous fission product in the human diet occurred in 1959, and that the peak in the growing bones of children occurred this year. Moreover, equilibrium levels in bone—the amount that can be considered permanently incorporated in the skeleton—will be five to 10 times lower than had been expected.

The new Lamont estimates stem from a continuing study of strontium-90 concentrations in human bone, plus new information on the behavior of the bomb product in the atmosphere and on the ground. Strontium 90 had been expected to settle out of the air very slowly after nuclear-bomb explosions and to enter crop plants via the soil over a period of many years. Recent studies show that the isotope actually settles out of the air quickly—half reaches the ground within six to 12 months after a bomb is fired—and that at least 80 per cent of the strontium 90 in plants comes from contaminated rain, chiefly during the period of heavy fallout, rather than from the soil. Hence strontium 90 poses less of a long-term hazard than had been feared previously.

Actual concentrations of strontium 90 in bone from individuals in the U. S. and western Europe in 1959 were found to range from 2.6 micromicrocuries (millionths of millionths of a curie) per gram

of calcium in one-year-olds down to just over .3 micromicrocurie in persons over 20 years of age. Peak values, to be attained this year, are expected to be less than 2.7 micromicrocuries in one-year-olds and .4 micromicrocurie in adults. The National Committee on Radiation Protection estimates the maximum permissible bone concentration in man as 33 micromicrocuries.

But if strontium-90 fallout is not so great a long-range threat as anticipated, the short-term hazard, especially in the event of a nuclear war, is that much greater. Kulp and his group point out that the explosion of 3,000 megatons of fission bombs in the Northern Hemisphere would raise the long-term bone concentration to an average of only 45 micromicrocuries, a level easily compatible with prolonged survival. But the rapid fallout would add greatly to the problem of short-term survival.

Tsunami Warning

Tidal-wave experts from Australia, Chile, Japan, the U.S.S.R. and the U. S. have agreed to expand the U. S. tidal-wave warning system in the Hawaiian Islands into a network serving the entire Pacific Basin. Under the agreement, scientists from each participating country will ask their government to designate a seismological station to forward earthquake data to the Honolulu Magnetic Observatory of the U. S. Coast and Geodetic Survey, which has operated the Hawaiian warning service since its inception 13 years ago. Additional tide-observation stations will also be sought. The Coast and Geodetic Survey alone hopes to establish 12 new tide-observation stations.

The agreement is an outcome of the destructive tidal waves, or tsunamis, that sped across the Pacific last May following the Chilean earthquake. Fifty-seven deaths occurred at Hilo, Hawaii, where, largely because of previous false alarms, the tsunami warning was widely ignored. In Japan 139 persons died, apparently because a warning message from Honolulu did not reach the proper officials in time. In informal discussions held during scientific congresses in Geneva and Helsinki, tidal-wave specialists decided upon the expansion and improvement of the Hawaiian warning system, rather than the establishment of a new international service, as the simplest means of providing more effective warning of tsunamis. Special arrangements will be made, however, to send warnings from the Alaska-Aleutians-Ryukyus area

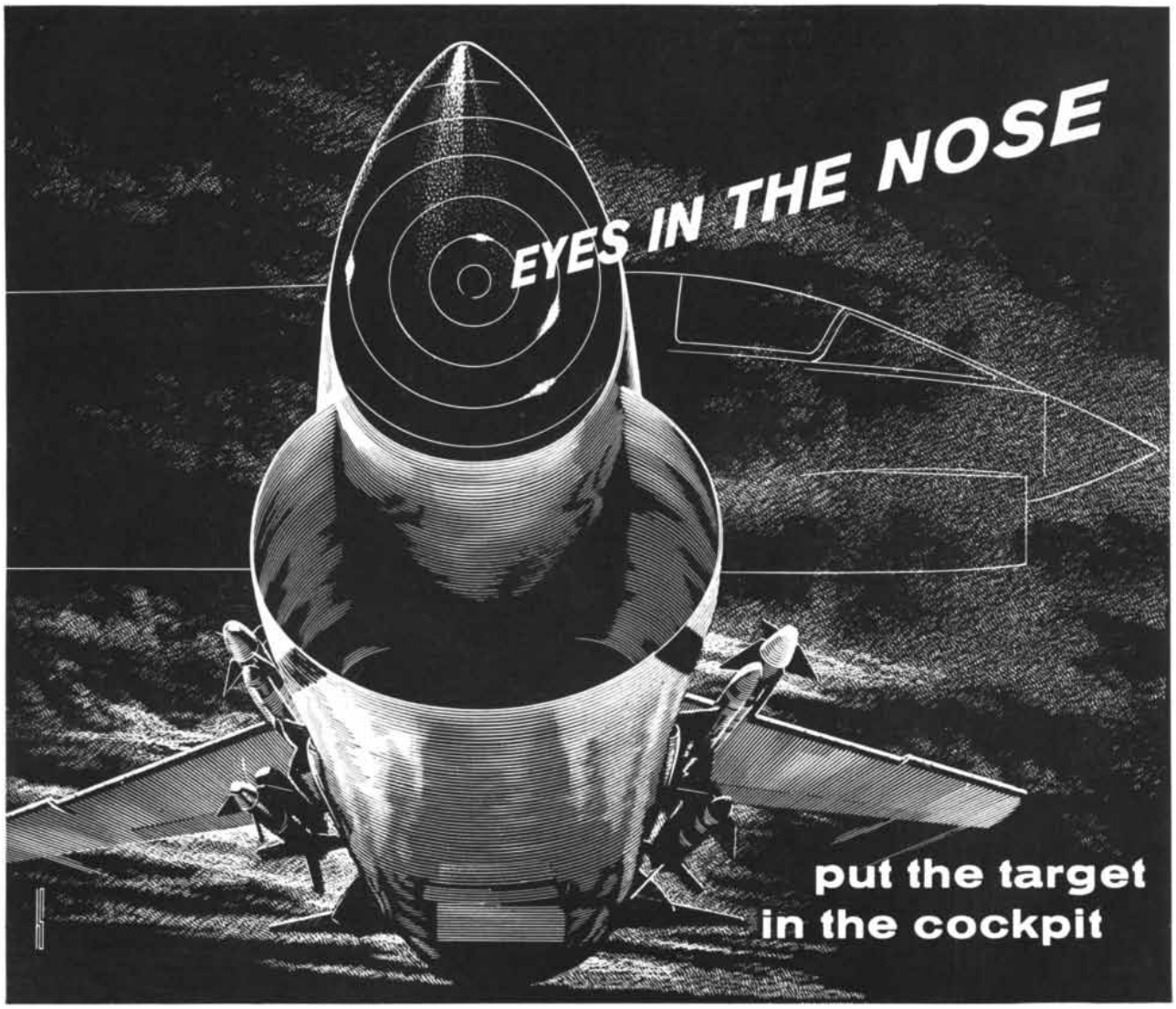
direct to Tokyo as well as to Honolulu. Tsunamis travel at such high speeds that destructive waves originating in that area can be expected to reach Japan in an hour or less.

Foreign-Doctor Problem

A sizable proportion of the 5,800 community hospitals in the U. S. may soon be without house physicians as the latest development in a perplexing problem that has harassed U. S. medicine since before World War II. During September foreign physicians serving as interns or residents in U. S. hospitals had a last chance to take an examination testing their knowledge of medicine and of English. Those who failed must be discharged from their posts by December 31. Hospitals that keep them on or after that date will become subject to a variety of penalties, including loss of approved status.

Officials of the American Hospital Association estimate that about 4,000 of the 12,000 foreign doctors now believed to be serving in U. S. hospitals in one capacity or another will be forced out. This will accentuate an already acute shortage of hospital physicians arising from the financial stringency under which most hospitals operate and the traditional practice of meeting the need for house physicians with interns and residents (doctors undergoing specialized training), who are paid much less than regular physicians. During recent years, partly because of the growing need for house doctors, the number of internships and residencies has grown beyond the ability of medical schools to turn out young men and women ready to fill them. Many hospitals have sought to bridge the gap by the expedient of recruiting interns and residents abroad. The practice has led to difficulties involving both differences in training and the patient-doctor language barrier. The American Medical Association and other agencies accordingly set up the Educational Council for Foreign Medical Graduates to administer examinations to check the training and the knowledge of English of foreign medical graduates serving in U. S. hospitals. After this year foreign graduates will be required to take the examination, which is given twice a year both in the U. S. and abroad, before appointment to a U. S. hospital.

The weeding out of foreign doctors will have the greatest impact on medium-sized community hospitals, which treat many hundreds of thousands of patients. A few of these hospitals plan



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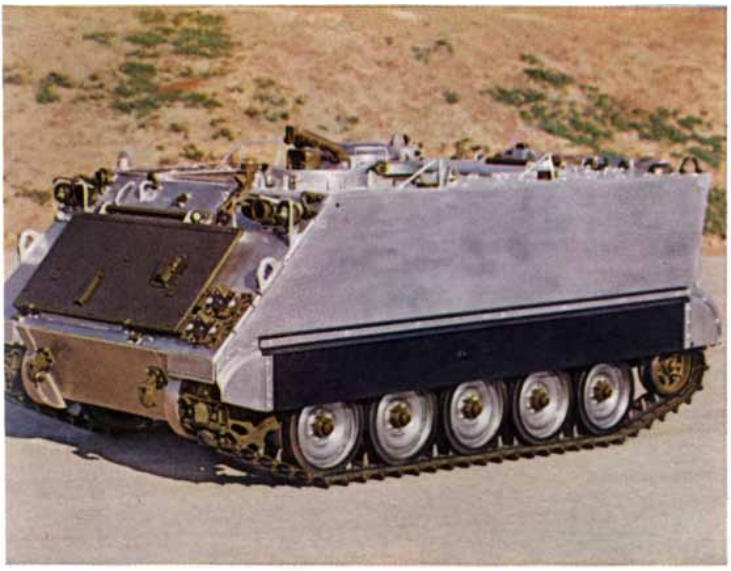

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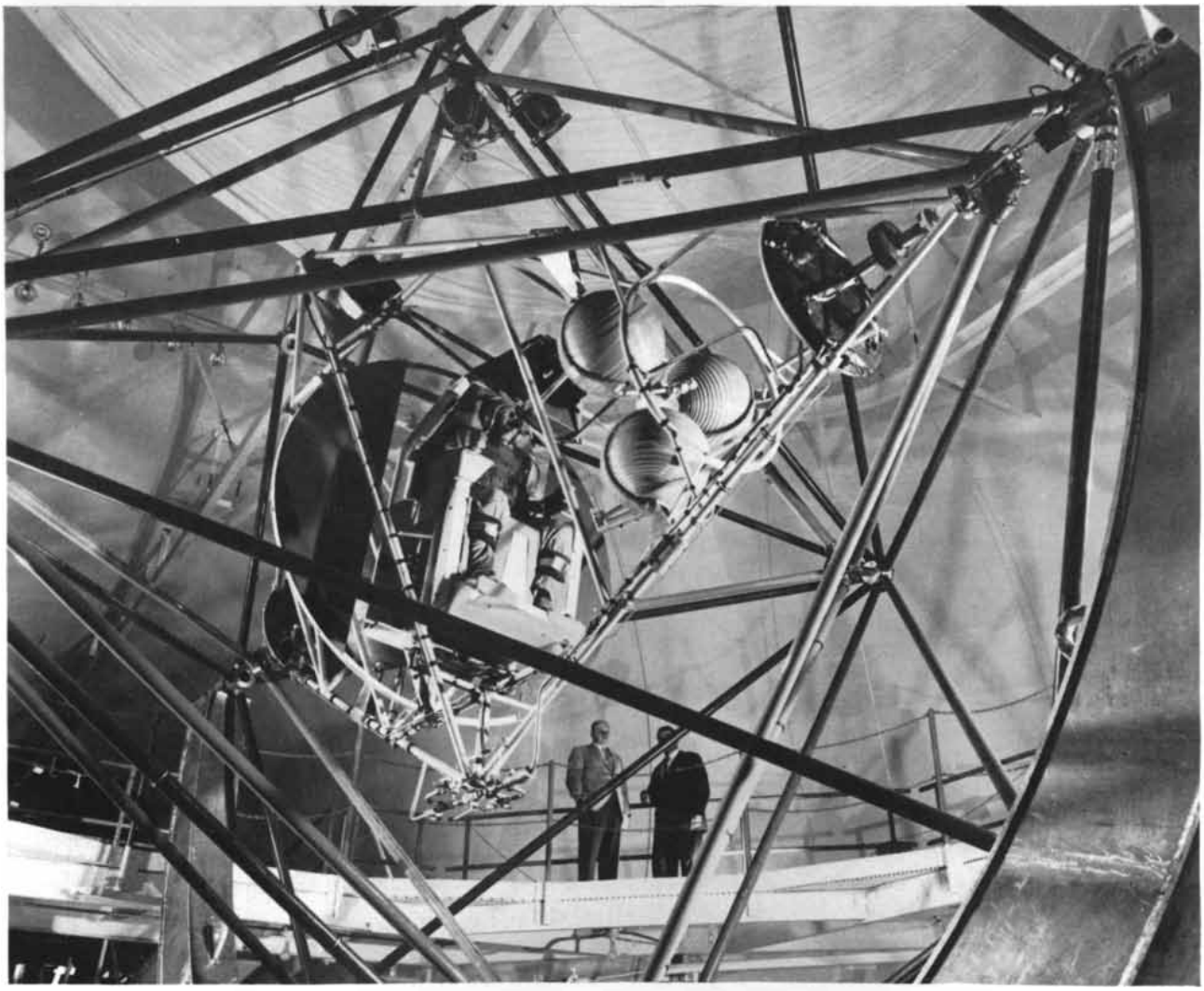

MULTIPLE AXIS SPACE CONTROL AND ORIENTATION FACILITY (MASCOF)
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FAFNIR
BALL BEARINGS

to hire regular physicians. Hospital officials concede, however, that most cannot afford them and will have to return to the old system of having doctors on the attending staff take turns at being on call for emergencies.

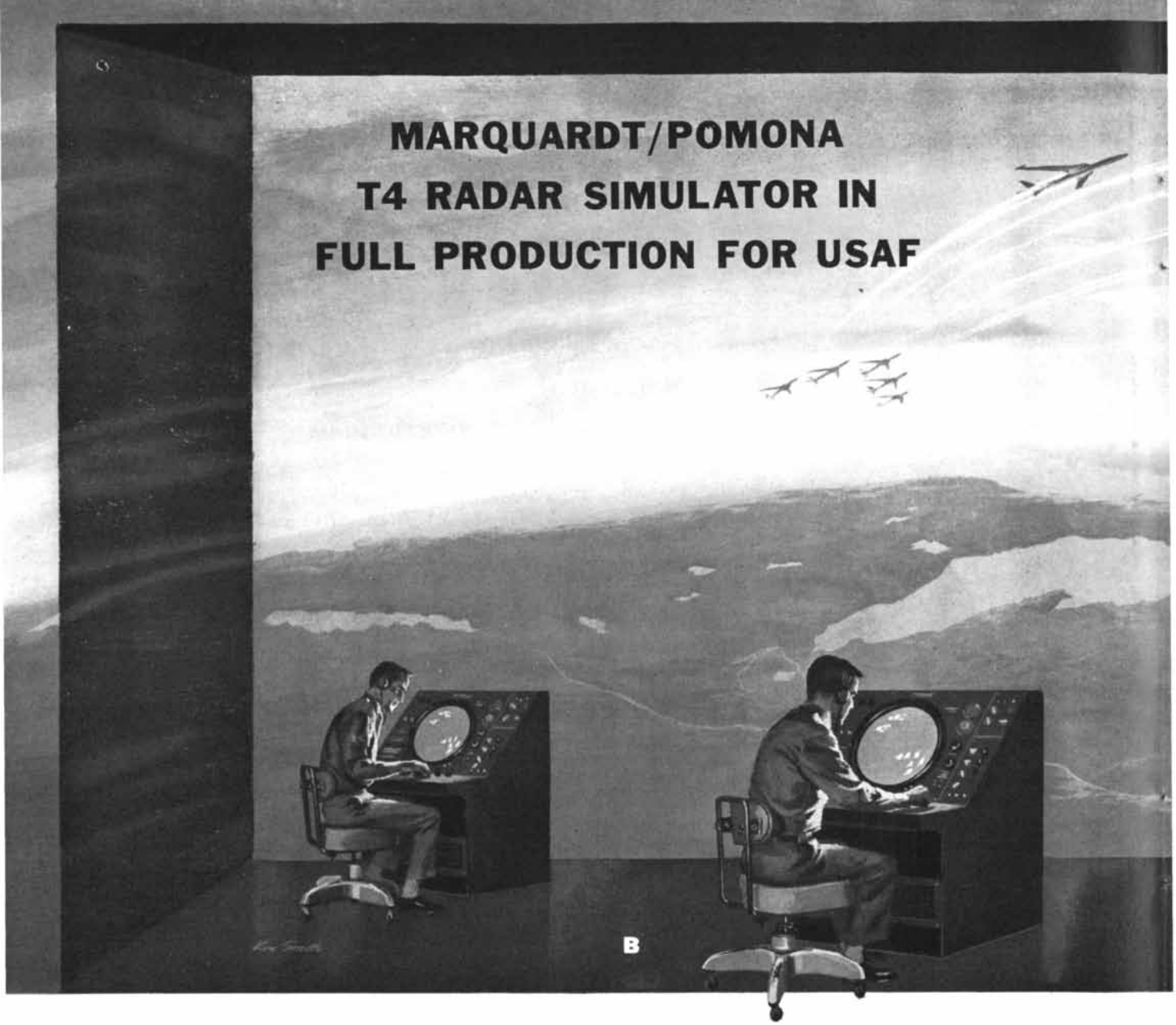
Ocean-Bottom Meteorology

A new instrument has opened up the novel possibility of tracking and forecasting storms at sea through microseisms—minute vibrations of the earth's crust. The instrument, described at a congress of the International Union of Geodesy and Geophysics, is a seismometer that can be dropped to the bottom of the sea and will record and report movements of the earth's crust below the sea so long as its power supply holds out.

Shortly after World War II microseisms were studied, under U. S. Navy sponsorship, as a potential storm-tracking aid. The study was stimulated by the belief that microseisms, which have been appearing as "noise" on seismograph records for years, were a result of the transmission of storm disturbances to the earth's crust through ocean water. The investigation was inconclusive, largely because of lack of suitable instruments.

A pilot model of the new bottom seismometer, which was developed at the Lamont Geological Observatory of Columbia University after nearly a decade of effort, was dropped in the sea near Bermuda last year. The bottom was found quiet enough to permit the use of instruments 100 times more sensitive than those that can be employed on land. Such seismometers should be adequate to record microseisms clearly, and to settle the question of their connection with the weather.

Maurice Ewing, director of the Lamont Observatory, pointed out that bottom seismometers may also offer a highly effective means of detecting nuclear explosions, and may open up striking possibilities in undersea research. One is the investigation of a curious phenomenon noted at a number of seismological stations in recent years. For some reason some types of earthquake wave originating below the oceans and recorded at island stations fail to reach land stations; similar waves originating on land also fail to reach island seismographs. If a barrier to the passage of earthquake waves between land and sea portions of the globe really exists, it will constitute strong new evidence for the division of the earth's mantle, as well as its crust, into distinct continental and oceanic provinces.



Radar Signal Simulators now in full production at Marquardt's Pomona Division will soon be in place at major USAF bases in the continental United States. Designated as the AN/GPS-T-4, the training system eliminates costly "real" flight operations and provides highly accurate flight plan simulation of as many as a dozen targets. Plug-in modules control flight characteristics and fuel consumption of the aircraft under simulation — assuring accurate computations. The system has many current and potential applications:

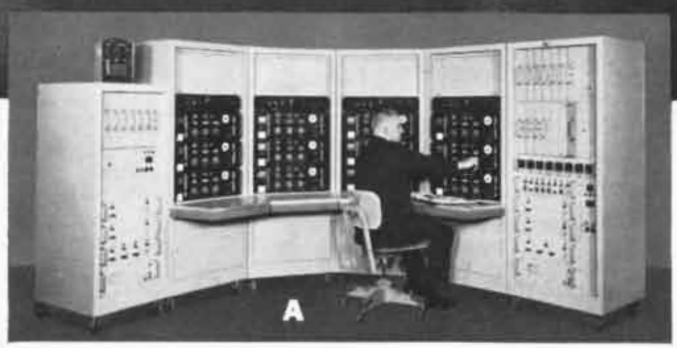
The T-4 is now in use in classroom operation for radar controlled interceptor simulation training by the USAF. Pilot simulators (A) operate target generators and trainees (B) man their usual stations and operate radar indicators as they would under tactical situations, while an umpire (C) controls the problem. Modular plug-in controls deliver completely realistic information of the particular aircraft's flight, range, and fuel capabilities. The T-4 system cuts both training time and costs to a fraction of normal operating methods.

Simulation of every type of missile mission is only one of a variety of potential military applications of the T-4 program. This aspect of training reduces costs and operational hazards as no other method can.

Airport traffic control training is simple and realistic with the T-4 concept. Modular plug-in operational characteristics of conventional passenger aircraft can simulate approach, landing, and take-off patterns and the system can be modified to accommodate as dense traffic conditions as desired.

Broad capabilities in radar simulation and training have been developed by the Pomona Division of Marquardt and even wider concepts are now in design stage. Detailed information on these and many other applications are available by writing Dr. Wendell B. Sell, Vice President-General Manager, The Marquardt Corporation, 2709 North Garey Avenue, Pomona, California.

Engineers and scientists experienced in these or related fields will find it rewarding to discuss their career futures with Marquardt. Founded in 1944, Marquardt today employs 4000 — of whom one-third are professional people. The company's growth is a parallel to the atmosphere of challenge and rewarding accomplishment that has existed since the firm's beginning.



FOUR TARGET generator cabinets, each housing three target generators, form the heart of the T-4 Trainer. One man operates six targets.

PLUG-IN MODULES accurately simulate flight characteristics and fuel consumption of the F-89, F-100, F-101, F-102, F-104 and F-106.

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TENSION CRACK, or *gjá*, within the Central Icelandic Graben (depression) was photographed from the air by the author of this article. The Graben is the extension of the mid-Atlantic rift through Iceland and contains many active fissures such as this.

The Rift in the Ocean Floor

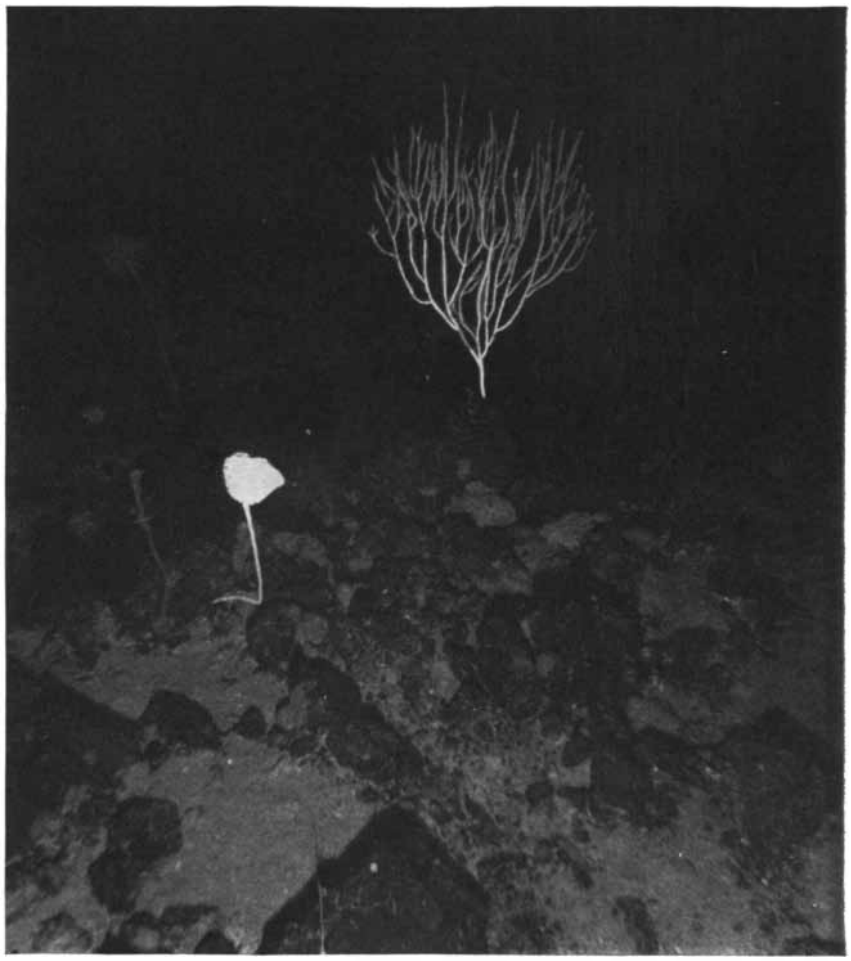
The discovery of a world-wide undersea mountain range that has a deep fissure down its center has suggested to some geologists that the earth may be slowly expanding rather than contracting

by Bruce C. Heezen

The topography of the earth has three first-order features. Two of them—the continents and the ocean floor—come easily to mind. The third is much less familiar. It is a submarine mountain range that runs for 40,000 miles across the bottom of all the oceans and covers an area equal to that of all the continents. The existence of this mid-ocean ridge is a recent discovery of oceanography, and the mapping of it is still far from complete. But the stretches that have been charted show a most curious aspect. Down most of its length the ridge is split by a deep canyon, or rift, in which many earthquakes originate. The ridge is apparently the locus of a crack in the crust that runs nearly twice around the earth. The discovery at this late date of the mid-ocean ridge and rift has raised fundamental questions about basic geological processes and the history of the earth, and has even had reverberations in cosmology.

The segment of the ridge that underlies the mid-Atlantic has received far more attention than any other. It came to light in 1873 when investigators aboard the British ship *Challenger*, on its epoch-making three-and-a-half-year oceanographic cruise around the world, employed a 200-pound weight on a hemp line to take laborious soundings approximately every 100 miles. These revealed that the middle of the Atlantic, contrary to what had been expected, is less than half as deep as two broad troughs located about a third of the way across from either shore. On the basis of such widely spaced soundings it was not possible to tell whether the central elevation was mountainous or simply a broad, smooth rise. In 1925, 1926 and 1927 the German ship *Meteor*, making the first extensive application of echo-sounding gear, produced detailed profiles of the ocean bottom that showed the Mid-Atlantic Ridge to be a rugged mountain range. Temperature and salinity measurements made from the *Meteor* indicated that the water of the South Atlantic is divided into eastern and western masses, lending support to the idea that some sort of barrier divides the ocean into two basins.

At the turn of the century widely spaced soundings made by Alexander Agassiz from the *Albatross* had revealed a relatively high elevation on the bottom



TOP OF WESTERN RIFT MOUNTAINS of Mid-Atlantic Ridge appears in this photograph to consist of basaltic material. Branched growth is a coral, and other growths are sponges. The photograph was made in the North Atlantic at a depth of 1,410 fathoms (8,460 feet).

of the eastern Pacific southeast of central Mexico. In 1929 echo soundings from the oceanographic vessel *Carnegie* showed that this so-called Albatross Plateau is in reality a mountain range. On a cruise during the late 1920's the Danish research vessel *Dana* discovered a similar structure—later named the Carlsberg Ridge—in the northern Indian Ocean. Although the Mid-Atlantic Ridge, the Albatross Plateau and the Carlsberg Ridge resemble each other in form and in their positions in the respective oceans, they were long regarded as isolated features.

Data from Earthquakes

It has only recently been suggested that these undersea ridges belong to a continuous world-wide system. Since such a small part of the ocean bottom has been sounded and mapped, this idea would have carried little conviction without the converging evidence produced by the study of earthquakes. Before the seismograph came into use late in the 19th century, the determination of earthquake epicenters depended upon reports from earthquake-devastated areas. As a consequence most earthquakes at sea went unrecorded. The early seismograph networks in Europe and America soon showed that earthquakes occur quite frequently in the mid-Atlantic, and that they are apparently associated in some way with the Mid-Atlantic Ridge. With more accurate location of epicenters, geologists came to realize that most of the earthquakes occur within a 100-mile-wide belt down the center of the 1,000- to 1,200-mile-wide ridge.

In 1953 Marie Tharp of the Lamont Geological Observatory and I were making a detailed physiographic diagram of the floor of the Atlantic, based upon a large number of echo-sounding profiles [*see illustration on pages 104 and 105*]. As the preliminary sketch emerged, Miss Tharp was startled to see that she had drawn a deep canyon down the center of the Mid-Atlantic Ridge. Detailed study of the profiles confirmed the existence of this rift valley. It was discovered, moreover, that the rift coincides with the earthquake belt.

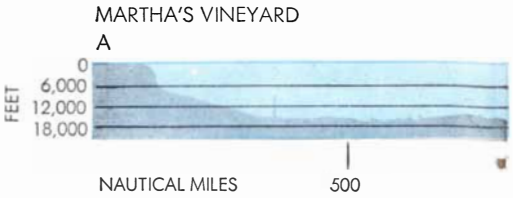
The floor of the rift valley ranges from 9,000 to 15,000 feet below sea level, and the crests of the mountains flanking it are only 3,600 to 7,200 feet down. The Grand Canyon of the Colorado River averages perhaps 4,000 feet in depth and four to 18 miles in width along its most majestic 50 to 60 miles; the mid-Atlantic rift averages more than 6,000 feet in depth and ranges from eight to 30 miles in width for hundreds of miles. Almost all of the epicenters of mid-ocean earthquakes lie within it. The few outside usually lie within the limits of error of the earthquake-detecting network. The rift valley is undoubtedly an active fracture in the crust of the earth, and crustal movement along this fracture generates the earthquakes.

The earthquakes of the mid-ocean rift, like most of the earthquakes recorded, occur at the relatively shallow depth of 30 kilometers below the earth's surface. Deep earthquakes, with epicenters as much as 700 kilometers below the surface, are associated almost exclusively with the area of the highly seismic submarine trenches and island chains that surround the Pacific Ocean. In contrast, and by way of evidence that the mid-ocean rift is a quite different kind of structure, no earthquakes have been observed there at a depth of more than 70 kilometers. The shallow depth of this seismic activity may indicate that the earth's crust in the mid-ocean is quite thin and weak.

Perhaps because a greater number of seismograph stations are located around the North Atlantic Basin, more earthquakes have been detected and located there than in any other ocean. By the mid-1950's, however, seismographs had traced a 40,000-mile-long belt of mid-ocean earthquake epicenters along the bottom of the Atlantic, Indian, South Pacific and Arctic oceans, with branches reaching into the western Pacific and into the continents at several places. Because the Mid-Atlantic Ridge and its rift valley are so closely associated with the earthquake belt, Maurice Ewing, director of the Lamont Geological Observatory, and I predicted in 1956 that a continuous rifted ridge would be found to coincide with the mid-oceanic epicenter belt and its branches throughout the world.

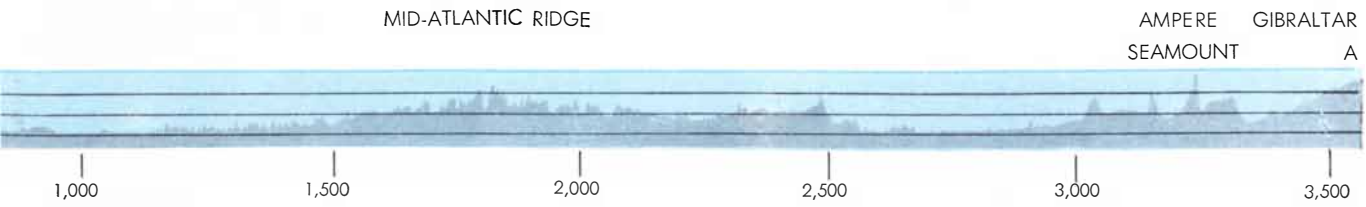
Confirmation by Soundings

During the past four years the Lamont Observatory research vessel *Vema* and other ships engaged in International Geophysical Year studies have confirmed the existence of the ridge and rift in many parts of the earth. Early this year soundings by the *Vema* across the epicenter belt between Prince Edward Island and Rodrigues Island in the western Indian Ocean traced the expected profile [*see illustrations on pages 106, 107 and 108*]. This ridge meets the



PROFILE across the bottom of the Atlantic Ocean from Martha's Vineyard to Gibraltar was made by research vessel *Atlantis* along

MID-OCEAN RIFT runs for 40,000 miles across the bottom of all the oceans. It is



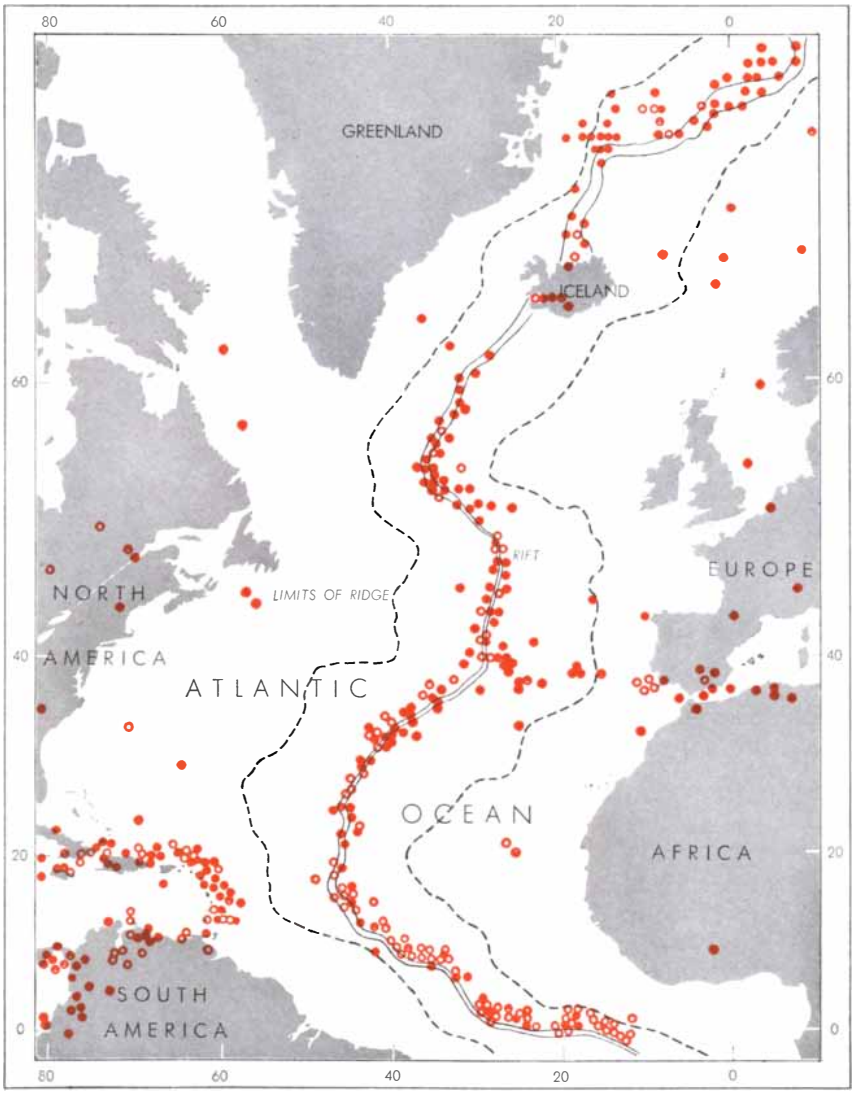
track indicated by line A-A on the world map below. Mid-Atlantic Ridge starts 1,200 nautical miles east of the U. S. East Coast and ends 2,550 miles out. Ampère Seamount is a submarine mountain rising high above the ocean floor. The vertical dimension of this profile and of all other profiles accompanying this article has been exaggerated 40 times in order to present topography clearly.

indicated here by the broken colored line. In the Far North the segment that touches Siberia is really a continuation of the Mid-Atlantic Ridge, which goes across the "top" of the globe near the North Pole. The Mercator's projection distorts its position.

Carlsberg Ridge, which extends into the Gulf of Aden. The *Vema* has also detected the ridge and rift along the epicenter belt southeast of New Zealand, and an expedition from the Scripps Institution of Oceanography has found the same structure along the branch of the oceanic earthquake belt that extends from the vicinity of Easter Island to southern Chile.

Since the epicenter belt runs across the bottom of the Arctic Ocean, some investigators were inclined to regard the Lomonosov Ridge, the great Arctic Ocean mountain range discovered by Soviet oceanographers in 1948, as the northward extension of the Mid-Atlantic Ridge. But although the belt of earthquake epicenters parallels the Lomonosov Ridge, the belt lies about 200 miles away from the ridge, approximately bisecting the basin formed by the ridge and the Eurasian continental slope. This puzzling situation was resolved when soundings from the nuclear submarines *Nautilus* and *Skate* revealed a rugged formation along the epicenter belt. The *Skate* profiles even showed a central valley in the ridge, but the submarines did not make enough echo-sounding profiles to demonstrate that the ridge is a continuous feature.

From the sounding profiles and from cores and samples brought up from points along the mid-oceanic ridge and rift, it is plain that this formation differs in appearance and origin from the familiar mountains and canyons of the continents. Gorges such as the Grand Canyon are cut by rivers; no such agent could have been at work in the mid-ocean rift. Volcanic mountain ranges consist of rows of volcanic peaks partly buried in their own debris. While lava has been dredged up from the mid-ocean ridge, the structure of the ridge is quite unlike that of known volcanic ranges. "Folded" mountains such as the Jura of northern France and the Appalachians of the U. S. are huge wrinkles in strata of sedimentary rock. These sediments are five to 10 miles thick; the fact that the sediments of the mid-oceanic ridge are only half a mile thick seems to rule out the possibility that it is a range of folded mountains. The Rocky Mountains represent a type known as faulted mountains. Great blocks of the earth's crust tilted upward along fracture lines, these mountains have a shattered appearance and are without a central valley. For more than a century geologists attributed the formation of folded and faulted mountains to a compression of the earth's crust by the shrinkage of the planet's circumference that supposedly attends its cooling.

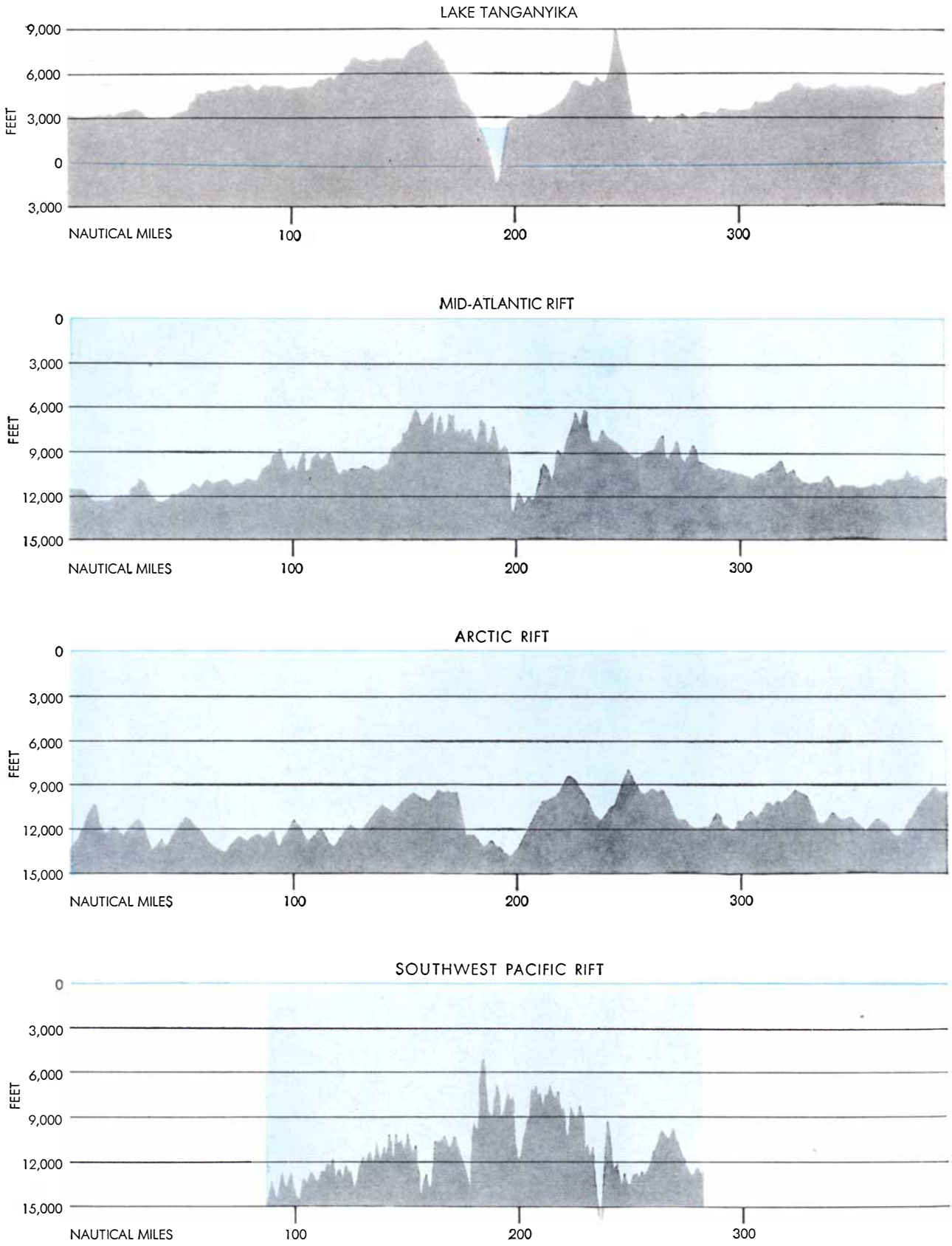


EARTHQUAKE EPICENTERS (*colored circles*) in the middle of the Atlantic almost all fall within a narrow belt that coincides with the rift valley of the Mid-Atlantic Ridge. Open circles indicate strongest earth shocks; solid circles represent the weaker earthquakes.

The East African Rifts

There is one continental feature that does bear resemblance to the mid-ocean ridge and rift. This is the rift valley system of the rugged East African Plateau. Geologists who held with the shrinking-earth theory were at a loss to explain this formation when it was first entered on topographic maps at the turn of the century. The valleys appeared to be huge tension cracks in the earth's crust—as if the crust had been stretched at right angles to the axes of the valleys until it had split. Unlike the Rockies, the Juras and the Appalachians, the mountains and valleys of the East African rift country have only thin layers of sedimentary rock and much more lava than is found in folded or even faulted mountains.

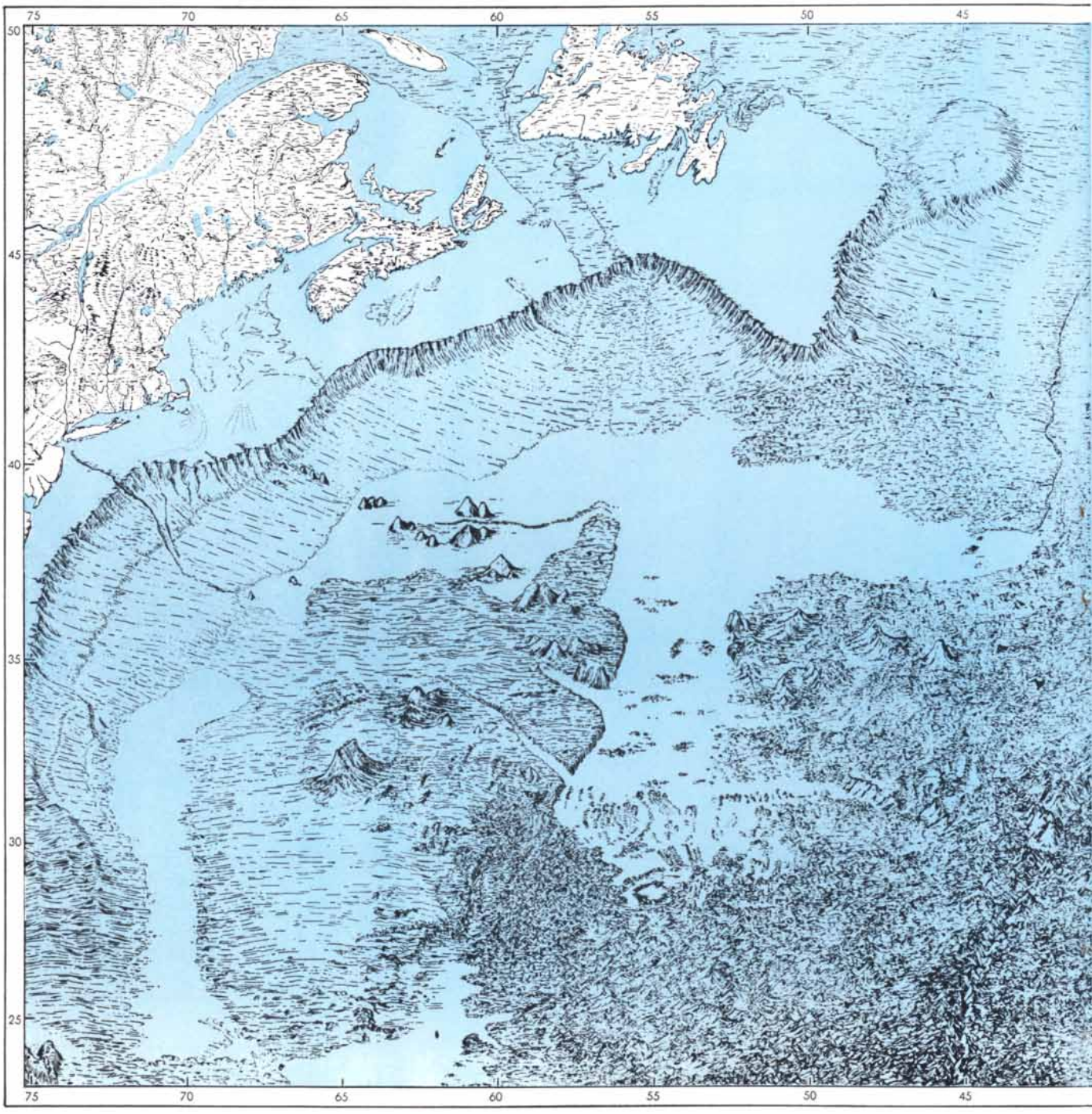
A typical cross section of the mid-ocean rift and ridge has a profile that is strikingly similar to that of the African rift [*see illustration on opposite page*]. Indeed, the continental formation appears to be a landward extension of the Carlsberg Ridge, which comes ashore in East Africa through the narrowing trench of the Gulf of Aden. The mid-ocean ridge and earthquake-epicenter belt also come ashore in Iceland, cutting across the island through the depression known as the Central Icelandic Graben. All the recent volcanic activity of the island is limited to this valley, and almost all of its earthquakes originate there. The Graben gives every appearance of being



WIDELY SEPARATED PROFILES show similarity of ridge and rift throughout the world. At top a profile across African Rift Mountains shows Lake Tanganyika within rift. The arctic profile was made a few hundred miles south of North Pole by the submarine *Nautilus* on voyage under the polar ice. The arctic profile was furnished by Robert S. Dietz of the Navy Electronics Laboratory in San Diego. In each of these profiles the rift is approximately above the 200-mile mark. Color denotes water.

a great tension crack. Studies of the long cracks, called *gjá*, within the Graben reveal that it is growing wider at the rate of 3.5 meters per 1,000 years for every kilometer of its width.

The mid-ocean ridge probably also has something in common with other land features. From the Gulf of Aden a branch of the Carlsberg Ridge runs up the narrow channel of the Red Sea to join the Palestine rift, in which the Dead Sea and the Jordan Valley lie. In the southwestern Pacific the mid-ocean ridge connects with the Great Alpine Fault of New Zealand. The eastern Pacific segment strikes into the North American continent through the Gulf of California to join the San Andreas Fault, goes out to sea again at Cape Mendocino in northwestern California and enters the continent once more through the long riftlike Lynn Canal of the Alaska panhandle. The San Andreas Fault, however, shows evidence of slip-

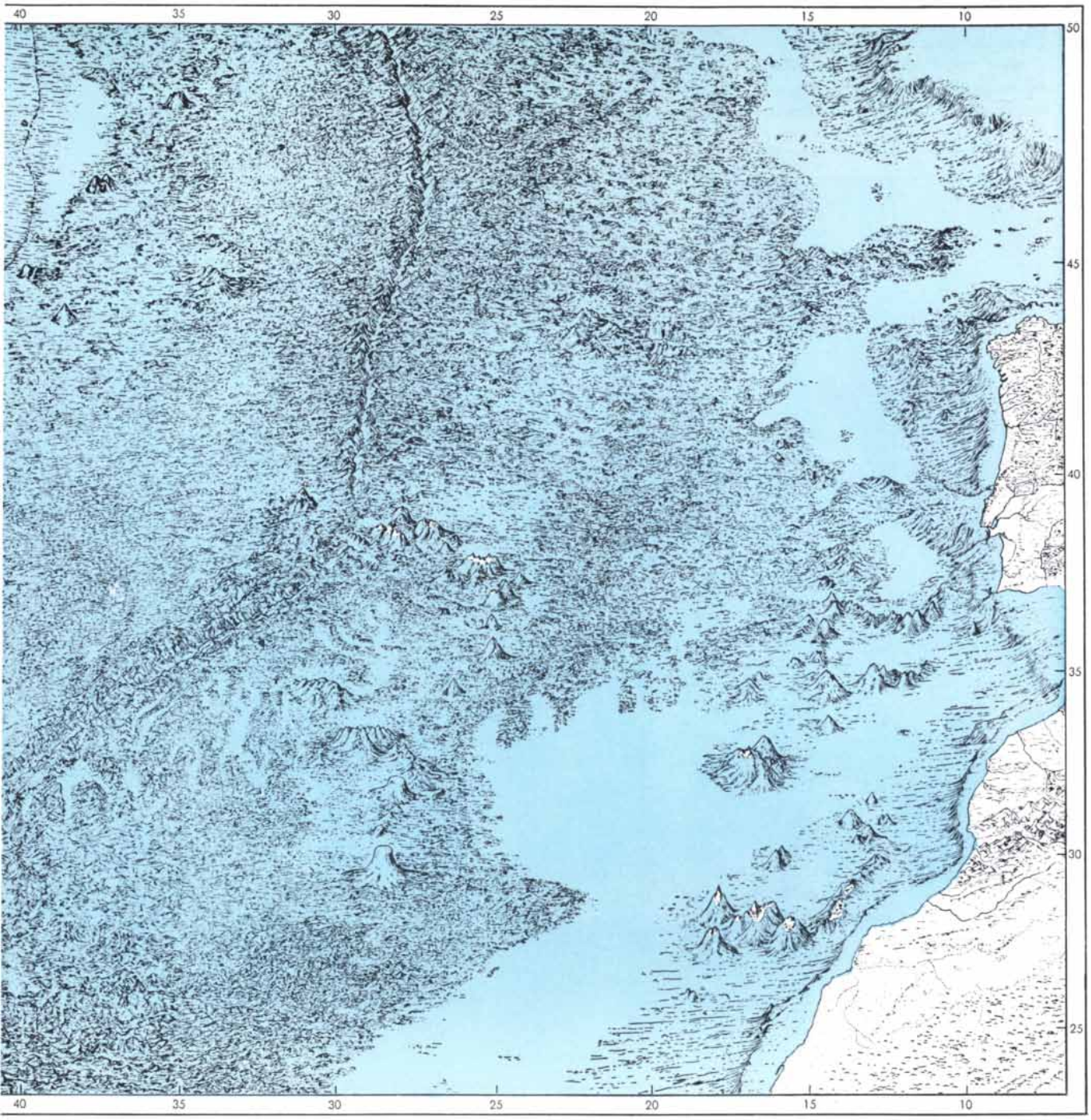


BOTTOM OF THE NORTH ATLANTIC is shown in this topographic diagram by Marie Tharp and the author of this article. It is reproduced by permission of the Geological Society of America. The mid-Atlantic rift goes from about 28 degrees west longitude at the top of the diagram to 45 degrees at the bottom. Miss Tharp discovered the rift while making sketches for the diagram. It is

page of the crust along its long axis, rather than tension at right angles to this axis.

The Continental-Drift Theory

Ever since the discovery of the Mid-Atlantic Ridge, geologists have been debating theories of its origin. Probably the earliest explanation was "continental drift," which postulated that the continents were originally joined together in one or two large masses that broke up and slowly floated apart. The familiar jig-saw-puzzle fit of the Atlantic profiles of Africa and South America was often cited in support of this idea. One school of drift theorists held that the Mid-Atlantic Ridge is a fragment of the original great continent, left behind by the edges of the new continents as they moved apart. Another group believed that the ridge was formed by a mass of sediment that filled the crack created by the

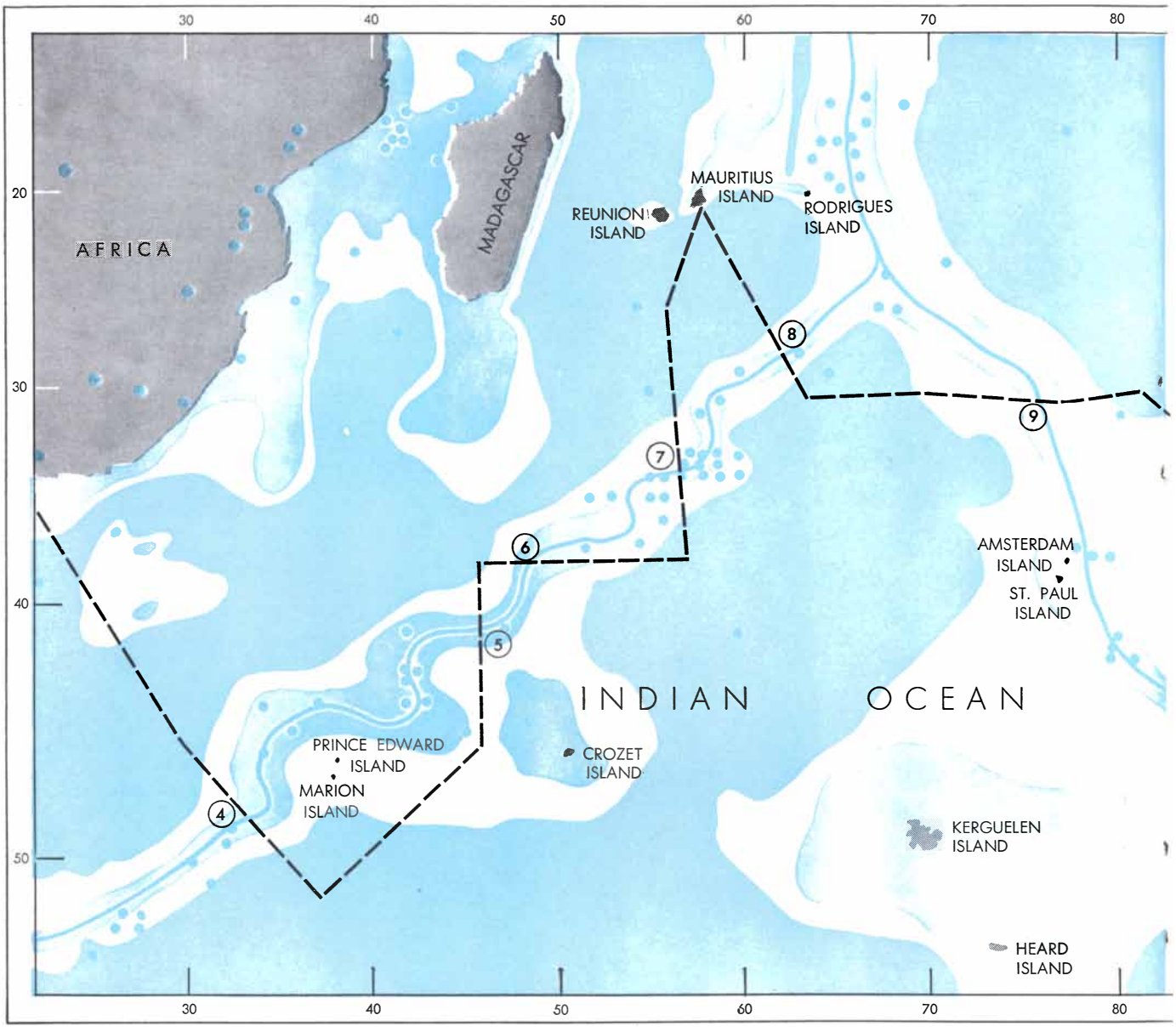


based upon many echo-sounding profiles; the unsounded portions were filled in by extrapolation. Land areas are white. The Canary Islands are visible as "mountain peaks" just off the coast of Africa. Madeira is north of them, and the Azores lie northwest of Madeira, near the rift. Underwater peaks are called seamounts. The vertical dimension is exaggerated approximately 20 times.

breaking up of the original single continent. However, rock fragments from the slopes of the ridge, and the velocity of earthquake waves through the ridge, contradict both schools. If either of the drift explanations were correct, dredging should bring up the typical continental granitic, acidic-volcanic and sedimentary rocks. In actuality oceanographers have found serpentine, peridotite and gabbro —rocks generally thought to characterize the earth's mantle—as well as quantities of basaltic lava. As for earthquake waves, they travel through the Mid-Atlantic Ridge much too fast for it to be the abandoned fragment of a continent.

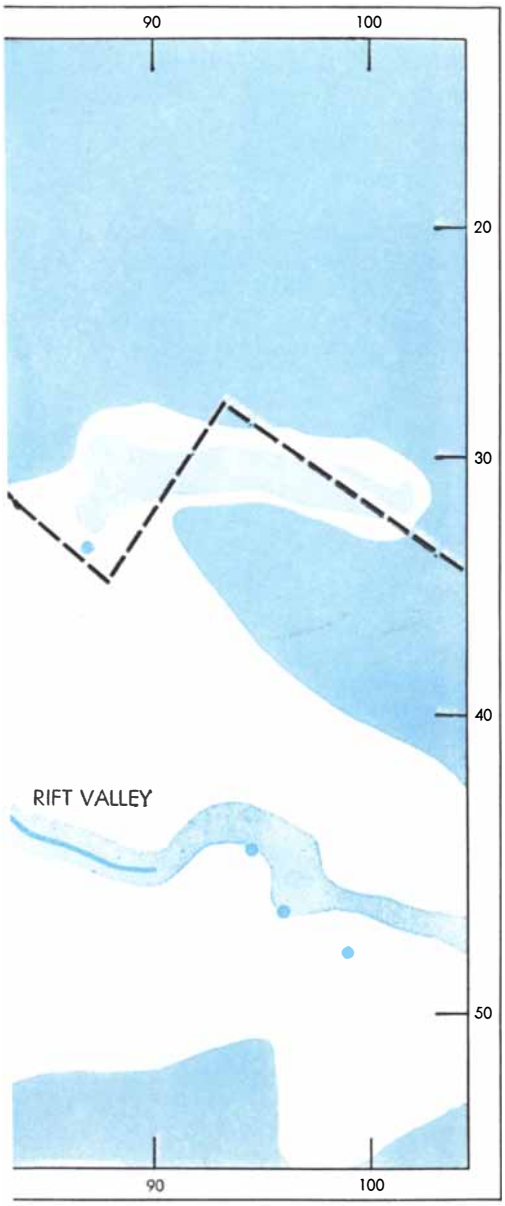
The seismic-wave velocity would be still lower if the ridge were composed of sedimentary rock. Moreover, the large number of earthquakes associated with the ridge indicates that it is still an active feature of the earth's crust. Its form is thus not only relatively new, but is constantly changing. The rugged relief of the ridge adds additional weight to the view that it is young, and argues against any idea that it is a long-abandoned rubble pile. Further evidence of the youth of the ridge comes from a large basalt boulder recently dredged to the surface; dating by the potassium-argon method indicates that this rock crystallized out of molten material somewhat less than 10 million years ago.

The theory of continental drift had been put to rest and out of mind when results from a new field of earth science resurrected it. This field is the study of paleomagnetism: the earth's magnetism during the geologic past. The investigation of paleomagnetism takes advantage of the fact that magnetic particles in both sedimentary and volcanic rocks were oriented by the earth's magnetic field at the time that the sediment was deposited or the lava cooled. The method is beset by technical difficulties, but in general it appears to work. Paleomag-

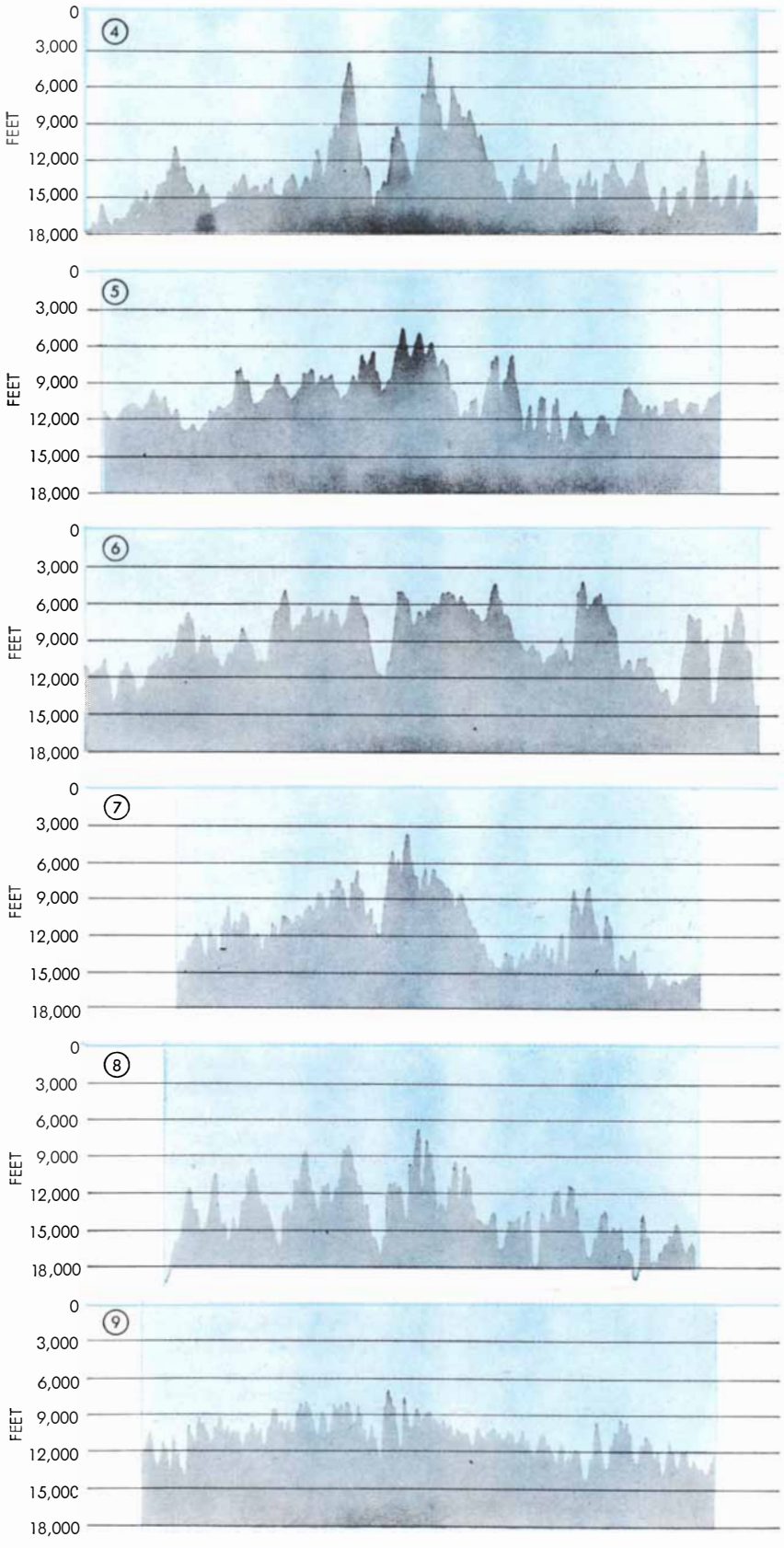


INDIAN OCEAN RIDGE AND RIFT were confirmed last winter when the research ship *Vema* made six crossings (*broken line*) of earthquake-epicenter belt. Epicenters are indicated by dots. Darker color denotes ocean-bottom depth greater than 12,000 feet; lighter color is for depth less than 8,400 feet. Dark line is rift. Crossings begin with 4, because the *Vema* made the first three crossings of

netic measurements going backward in time show that the orientation of the magnetic particles in the rocks of the continents differs from one geologic period to the next. Put another way, the measurements suggest that the North Magnetic Pole must have "wandered" in the course of geologic time. But the measurements also show that, if the pole did wander, it did so in various directions with respect to various continents [*see illustration on page 110*]. Since the earth could not have had five or six North Magnetic Poles simultaneously, it is necessary to assume that movement of the continents is responsible for the various



the series in the South Atlantic. The Indian Ocean profiles made from echo soundings during the cruise are shown on the next page.



INDIAN OCEAN PROFILES made last winter confirmed predictions of the existence of the mid-ocean ridge and rift there. Numbers on profiles correspond to numbers of crossings on the map on the preceding page. The rift on each profile is a bit left of the center.

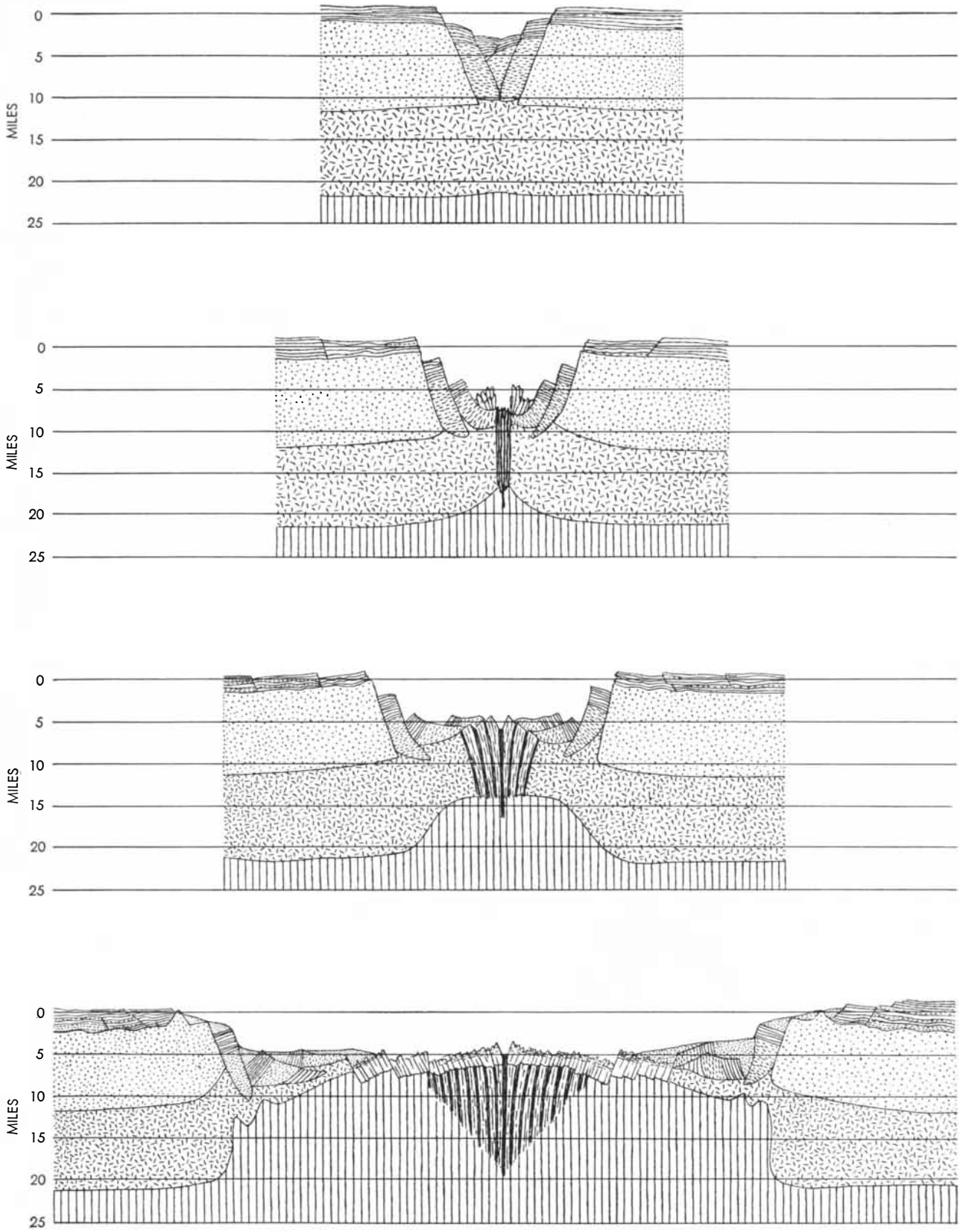
curves of polar wandering. On paleomagnetic evidence North America and Europe have moved apart approximately 2,000 miles in the past 300 million years. Similarly, paleomagnetic studies in India, Australia, South Africa, South America and Japan produce for each continent its own relatively consistent but unique polar-wandering curve, indicating that each of these land masses has moved.

The Expanding-Earth Theory

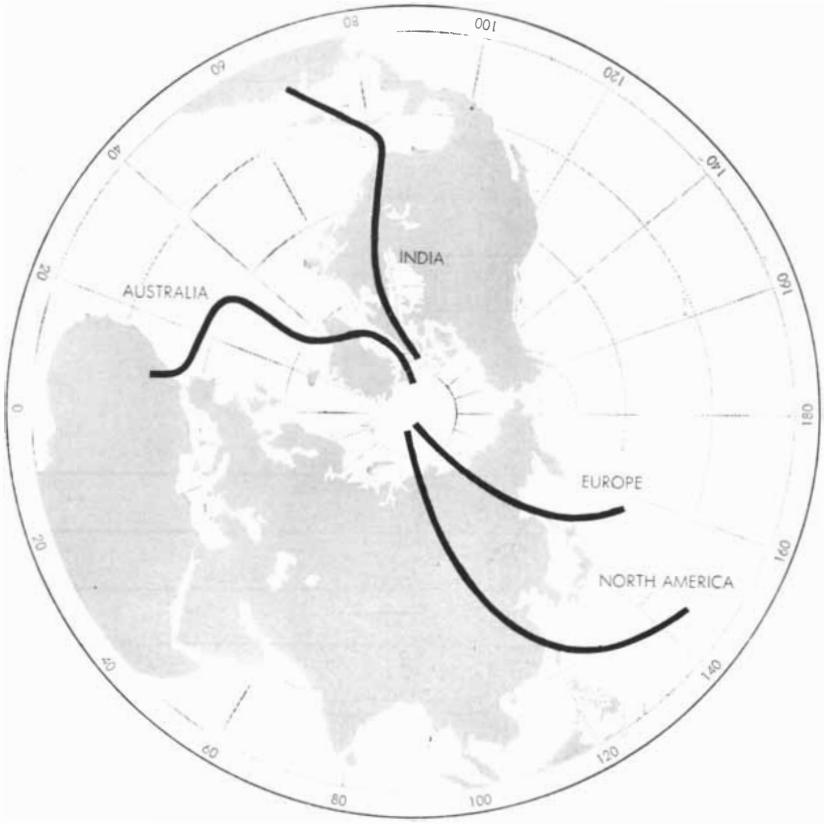
There is, however, much evidence against the idea that such changes in the relative positions of the continents could have occurred by continental drift as it has been commonly imagined. If the granitic continents have been drifting through the basaltic floor of the ocean, they should be causing immense deformations in the floor. These deformations are not found. Moreover, if the ocean floor were being subjected to such deformation, one would expect to find new crust forming somewhere on the floor. But virtually the only part of the ocean that is seismically active, aside from certain islands, is the mid-ocean ridge. The drift theory would argue that an immense section of the earth's crust, from the rift valley in one ocean to the rift valley in the next ocean, must be moving as a body. But the movement would be opening up the rift on the trailing edge of the body and closing the rift at its leading edge. There is no evidence for such a reciprocal action. On the contrary, the rift seems to be opening up on all sides of every continent.

In an attempt to overcome this dilemma I have recently suggested that the earth is neither shrinking nor remaining at the same size; rather, it is expanding. If the earth were expanding and the continents remained the same size, additional crust would have to be formed in the oceans. This is apparently just what is happening in the mid-ocean rift valleys. It can be shown, moreover, that expansion of the earth would change the relative positions of the continents in a way that would satisfy the different polar-wandering curves—much as inflation of a balloon changes the orientation of points drawn upon it.

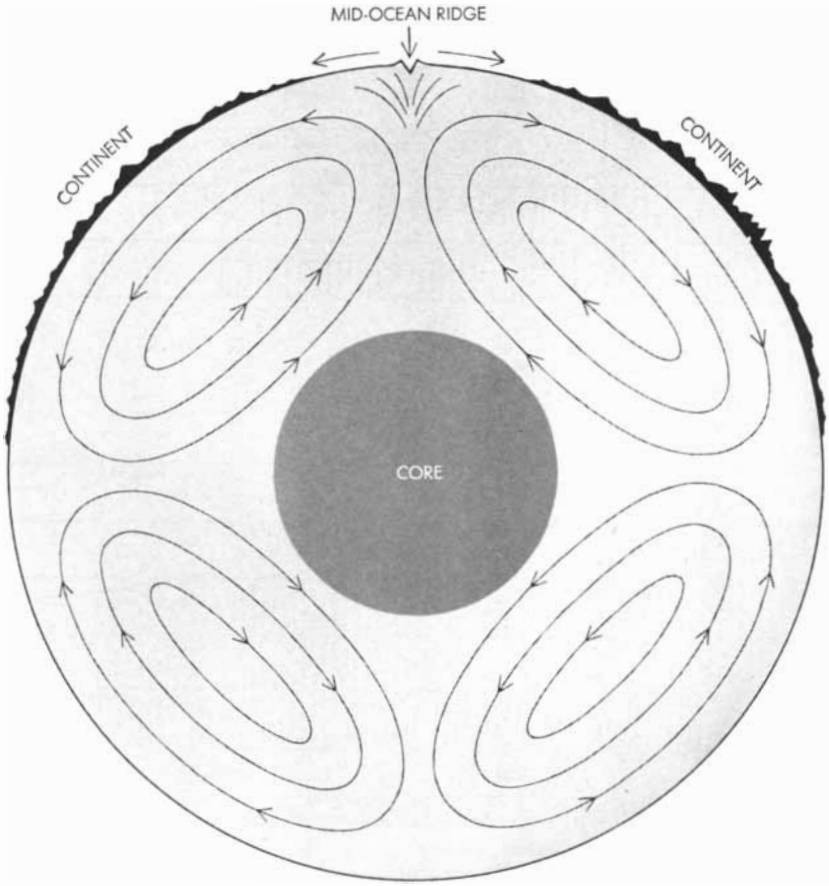
The idea of an expanding earth is not new. The British physicist P. A. M. Dirac first proposed 25 years ago, on cosmological grounds, that the force of gravity decreases in proportion to the age of the universe. R. H. Dicke of Princeton University has calculated that the decrease of the gravitational constant would permit the circumference of the earth to



EVOLUTION OF OCEAN BOTTOM according to the expanding-earth hypothesis is represented by these diagrams. Top layer of material is sedimentary rock of continents. Below it is continental crust. Beneath that is the type of material that makes up the crust of the oceans. Bottom layer (*vertical hatching*) is the earth's mantle. In top diagram continents are close together; rift between is just opening up. Next, material from mantle comes through rift, creating mid-ocean ridge seen in third diagram. Bottom diagram represents Atlantic Ocean bottom as it is today, with ridge and rift in center and continents at far right and left.



WANDERING CURVES of North Magnetic Pole show where pole appears to have been in past, as "seen" from different continents through studies of magnetic orientation of increasingly older rocks. Some geologists interpret data to mean that continents have moved.



CONVECTION CURRENTS within the earth are basis for a theory of the origin of the mid-ocean ridge and rift. As seen here, the currents flow up under the rift, push out new material, move laterally under continents and compress them, making mountains rise up.

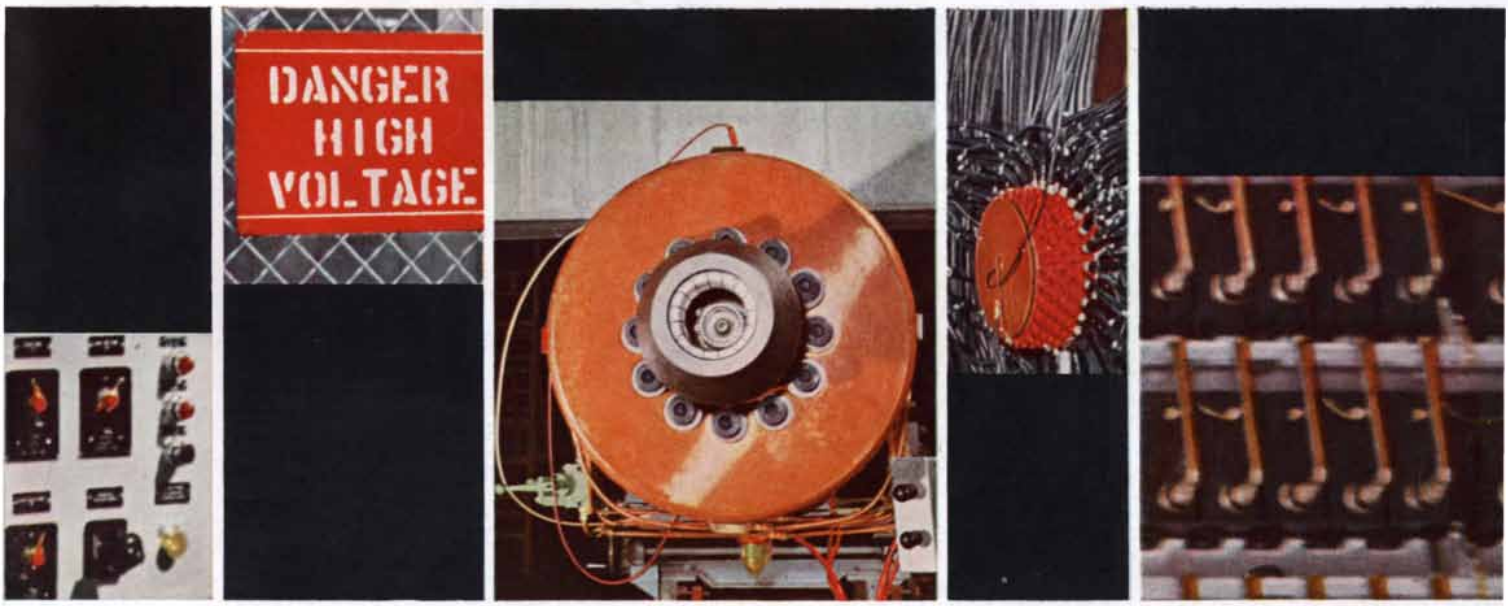
grow 1,100 miles in 3.25 billion years. J. Tuzo Wilson of the University of Toronto has pointed out that an 1,100-mile increase in the circumference of the earth would increase the surface area by an amount equal to the total area of the mid-ocean ridge. Other investigators have suggested that changes in the density of matter associated with phase changes in the material in the interior could have made the earth expand without any decrease in the gravitational constant. A decrease in the force of gravity combined with internal density changes would produce a very large expansion. Thus it may be that the continents, consisting of light rock that floated to the surface early in the history of the earth, once covered the entire surface of the smaller earth with an unbroken shell of granitic material. Expansion from within would then have broken up this shell into separate continental rafts. As the ocean basins grew, the mid-oceanic ridge would have become larger through the upwelling of rock from the earth's mantle and the progressive formation of new crust. The center of the mid-ocean ridge would therefore be the thinnest and youngest part of the earth's crust.

The Convection-Current Theory

The expanding-earth explanation of the ridge and rift is still quite speculative and is far from being generally accepted. Maurice Ewing and others hold that the ridge has its origin in convection currents within the earth. Heat-flow measurements show, in fact, that heat is flowing from the interior of the earth much faster through the ridge and rift than through the ocean basins and the continents. Accordingly it is suggested that convection currents in the viscous material of the interior rise to the crust just under the mid-ocean rift. The upward and lateral movement of the currents would pull the rift apart and force material out through the crack. The lateral movement would add light material to the underside of the continents and would compress the continents in the horizontal plane, creating mountains. This theory ignores the paleomagnetic data that indicate changes in the relative positions of the continents.

The study of the mid-ocean ridge and rift is still in its infancy. Nevertheless it has already been partly responsible for a new surge of deep-sea exploration and for a reconsideration of the most fundamental geological theories. Continued study of this world-wide feature is bound to be one of the most rewarding efforts of geology and oceanography.

HOTSHOT



Westinghouse Capacitive Storage System for McDonnell's new Hotshot Wind Tunnel Delivers 7,000,000 Joules in 3 Milliseconds with a Peak Current of 4,000,000 Amperes

See following pages

1

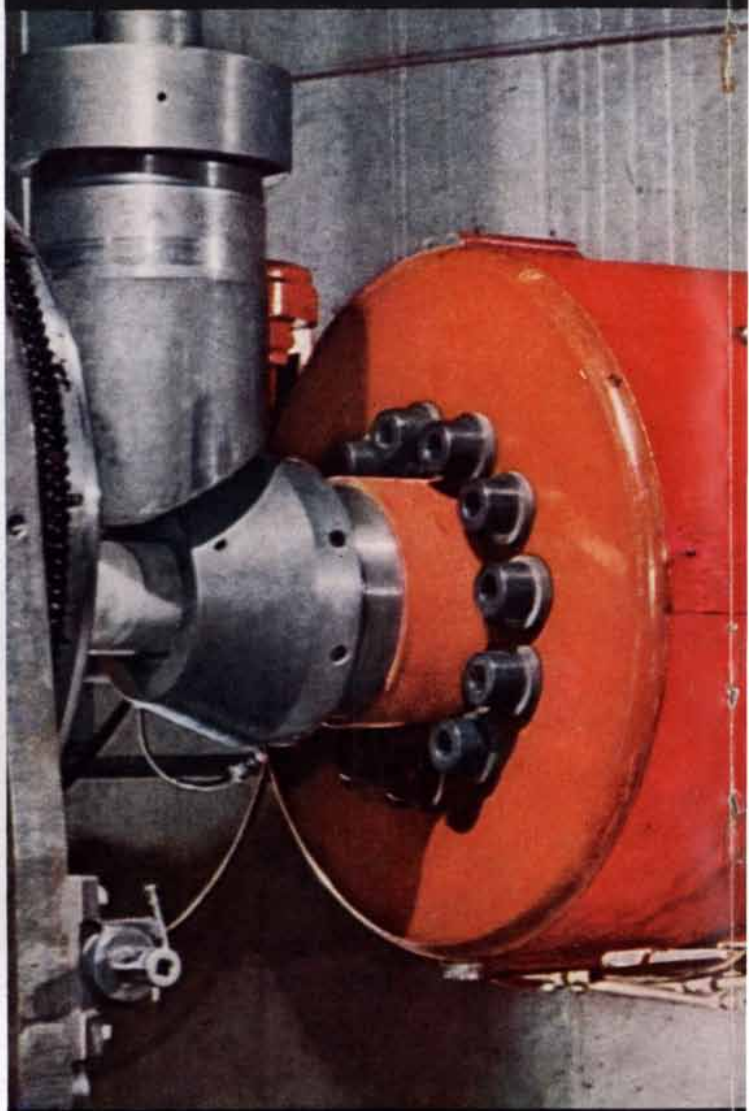
The Trigger: Operator's control panel by Westinghouse activates tremendous flow of energy for new hypervelocity impulse wind tunnel.

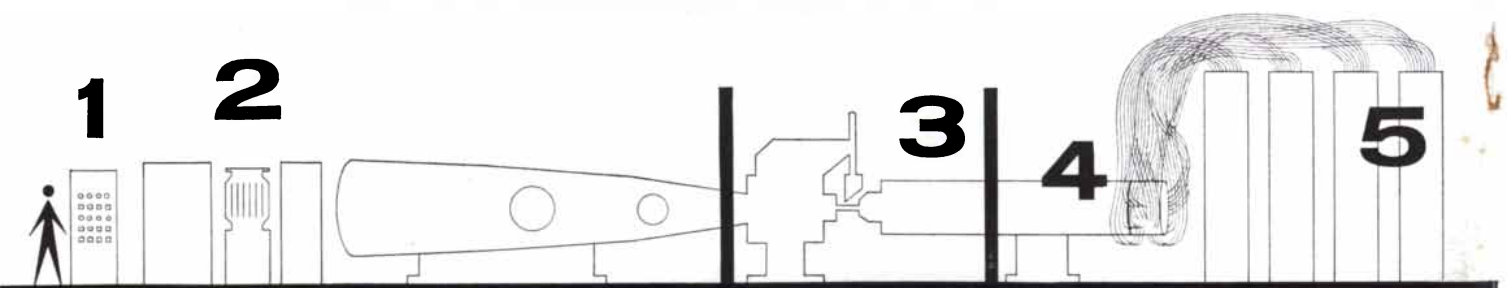
2

The Hot Stuff: High-Voltage equipment is tucked away in this enclosed area. Westinghouse transformer-rectifier—combined with a bi-stable amplifier regulator—charges capacitor bank to predetermined level.

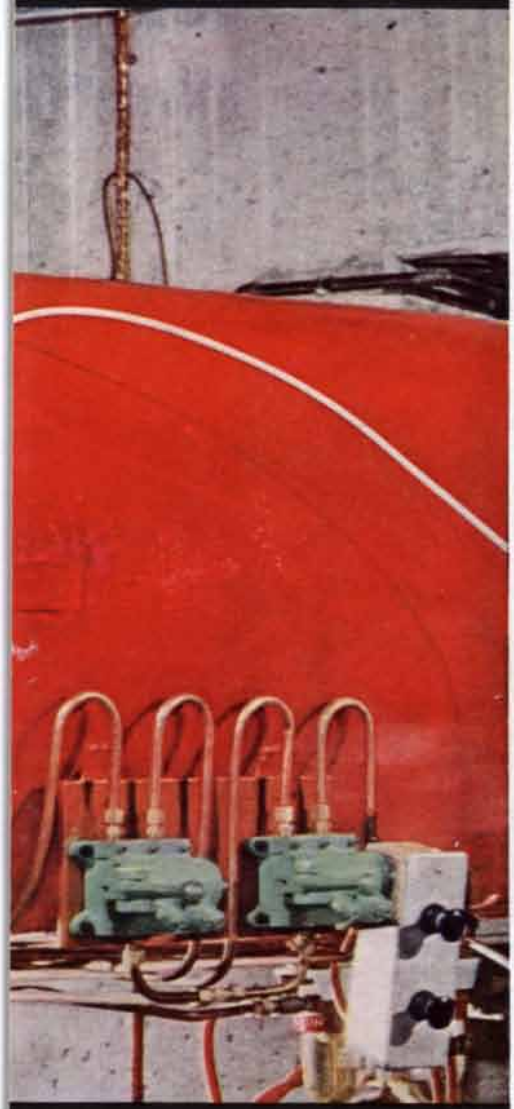
3

The Cannon: Uniquely designed coaxial conductor delivers arc energy to compressed air, raising pressures and temperatures several orders of magni-



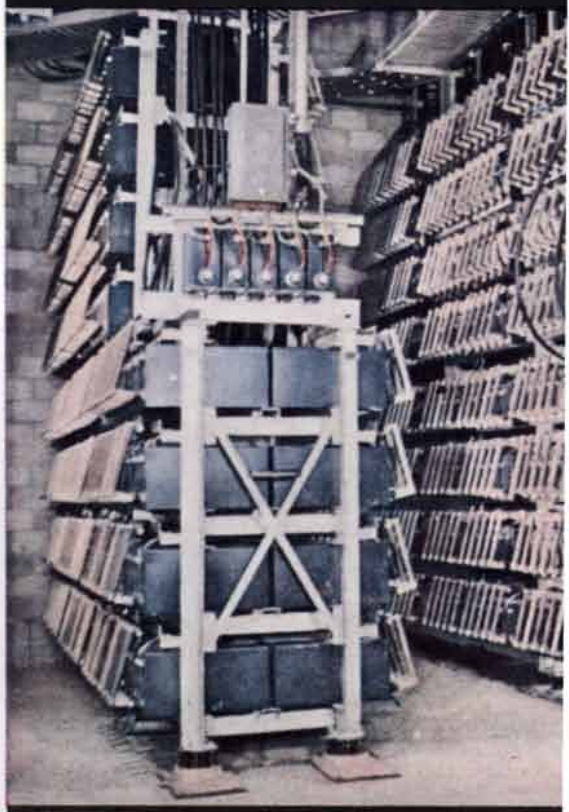


tude. Air explodes into the tunnel simulating hypersonic re-entry speeds of aircraft and missiles at altitudes above 100,000 feet.



The Supply Lines: 230 spaghetti-like cables converge in rear of cannon to deliver peak currents to 4,000,000 amps.

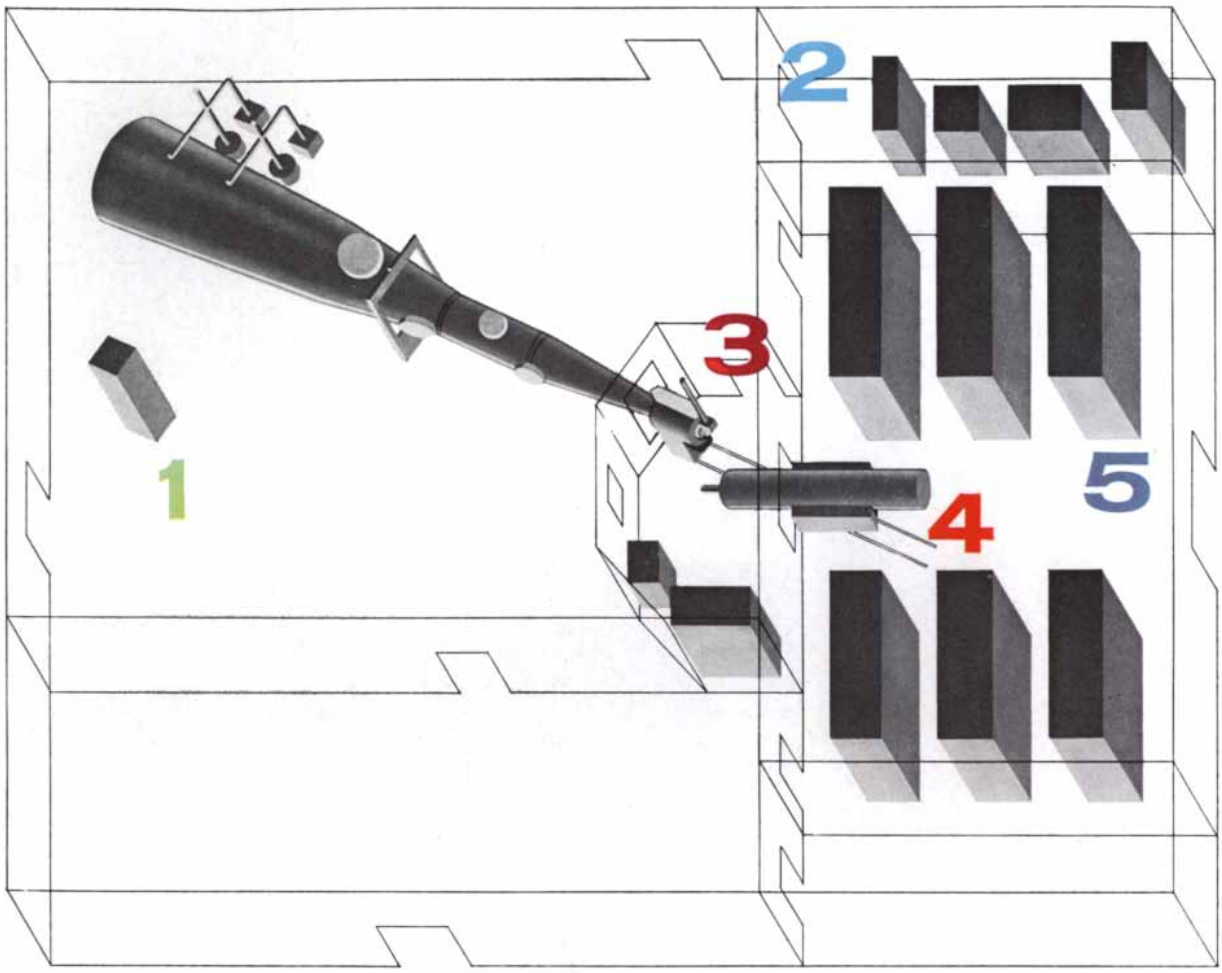
4



The Arsenal: Twenty-nine Westinghouse custom-built racks, each containing 80 fused capacitors, are bussed together in groups of ten, and connected by coaxial cables to the collector.

5

Within six months after receipt of contract Westinghouse delivered and installed this capacitive energy storage system for McDonnell Aircraft Corporation's new "Hotshot" wind tunnel at St. Louis. This facility is now providing vital data at a small fraction of the cost of actual flight testing. This same capability for quickly providing reliable equipment can help you solve your aerospace R & D problems. Contact your Westinghouse sales engineer. Or write: Westinghouse Electric Corporation, P. O. Box 868, Pittsburgh 30, Pa. You can be sure . . . if it's Westinghouse.



1. Creating outer space environment on earth starts with this control station for McDonnell Aircraft Corporation's new hypervelocity impulse wind tunnel. Operator can automatically or manually control the entire facility from this Westinghouse cabinet.

2. High-voltageequipment charges the capacitors (Figure 5) to a predetermined level up to 12 kv, with ±1% accuracy in 30 seconds. At 12,000 volts, seven megajoules of energy stored in this bank is delivered to the arc chamber in just 3 milliseconds.

3. In actual test, arc chamber is filled with compressed air and the tunnel is evacuated. Then, electric energy surges into the heavy walled arc chamber. Pressure increases to 100,000 psi. Temperature to 14,000°F. Heat vaporizes diaphragm separating arc chamber from the tunnel. High pressure air races through a converging-diverging tungsten throat to produce hypersonic velocities in test section.

4. The collector-cannon — main artery of the energy storage system — is composed of coaxially oriented conductors connected to the arc chamber. Carriage mounting permits axial motion of the conductors and simple connectors allow disconnection from the arc chamber. A lateral 45° swing allows connection to a second tunnel. Such flexibility permits operation of either tunnel with only one power pack, one capacitor bank, and one collector.

5. Twenty-nine racks of capacitors, sprouting 230 coaxial cables, enable this system to discharge electrical energy at an average of 2⅓ million kilowatts. That's more than the combined impulse power of Grand Coulee and Hoover Dams. Built-in expandability allows for a growth capability to 10,000,000 joules.

Westinghouse

J-92506

Subcontractors to Westinghouse:
The Calvert Company, Rocky River, Ohio for the cannon.
The Phelps Dodge Copper Products Corporation, New York for the coaxial cables.

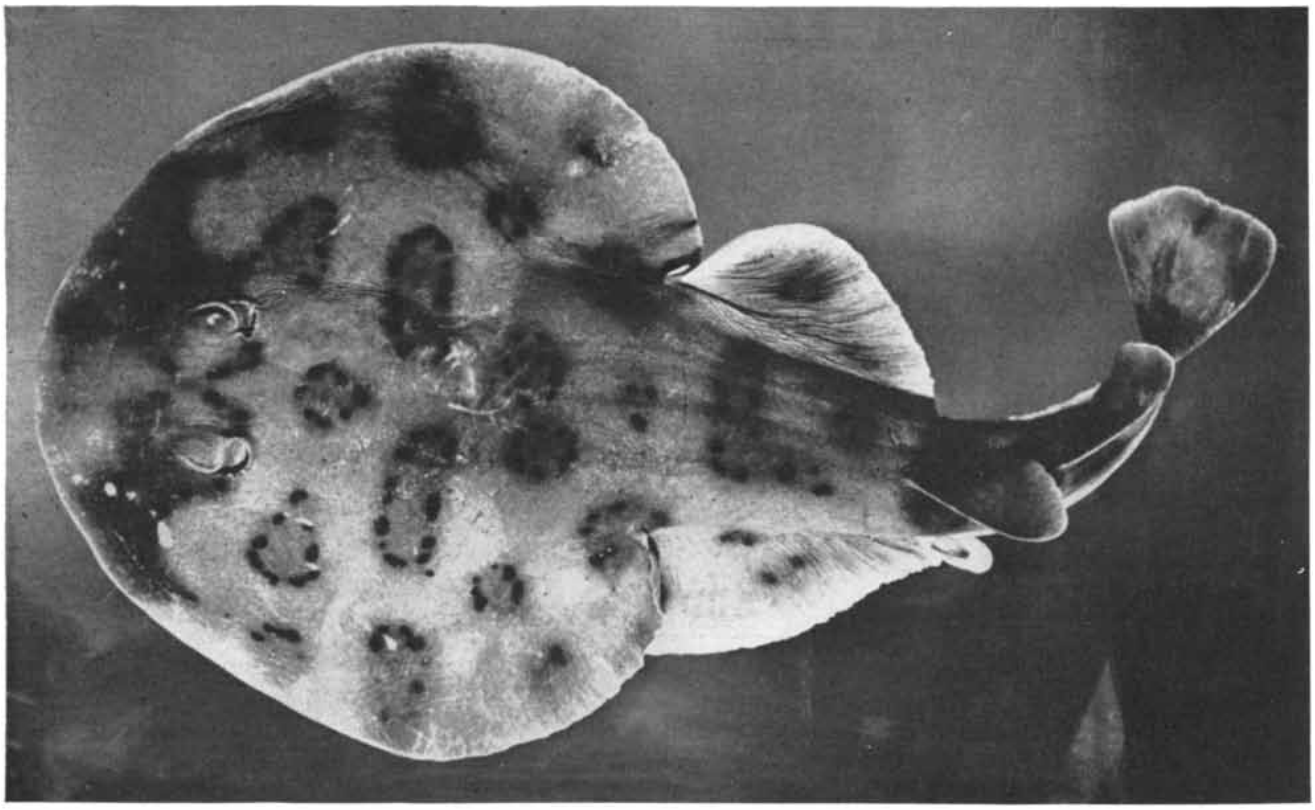
ELECTRIC FISHES

The electric eel is only one of a number of fishes that are capable of generating a respectable electric current. These fishes variously use their electricity for purposes of attack, defense and navigation

by Harry Grundfest

Nervous, muscular and glandular tissue generate minute electrical currents in the bodies of all animals high enough in the evolutionary order to have such tissues. The human heart, for example, induces .001 to .002 volt at the surface of the body; the brain, with its 10 billion nerve cells, puts out .00002 to .0001 volt which can be picked up by electrodes affixed to the scalp and recorded by the electroencephalograph. Such outputs do not begin to suggest the full electrical potential of physiological processes. That potential is demonstrated in the seven families of fish that are capable of delivering appreciable voltages outside their bodies. The giant electric ray (*Torpedo nobiliana*), a denizen of the North Atlantic, puts out pulses of 50 amperes at 50 to 60 volts, which can electrocute a large fish. The African catfish (*Malapterurus*), though much smaller, produces up to 350 volts, depending on its size. And the electric eel (*Electrophorus*) of the Amazon and other South American rivers can put out more than 500 volts. Even the weakly electric fishes, which generate a few volts down to a few tenths of a volt in the surrounding water, exceed by far the highest outputs recorded from other animals.

There now seems to be no doubt about the survival value of the peculiar capability of the electric fishes. For the powerfully electric species it serves obvious offensive and defensive functions, and recent work has shown that in the weakly electric ones it serves as part of a sensory guidance system for navigation in murky waters and for the detection of predators and prey. The advantages, in fact, are such that natural selection

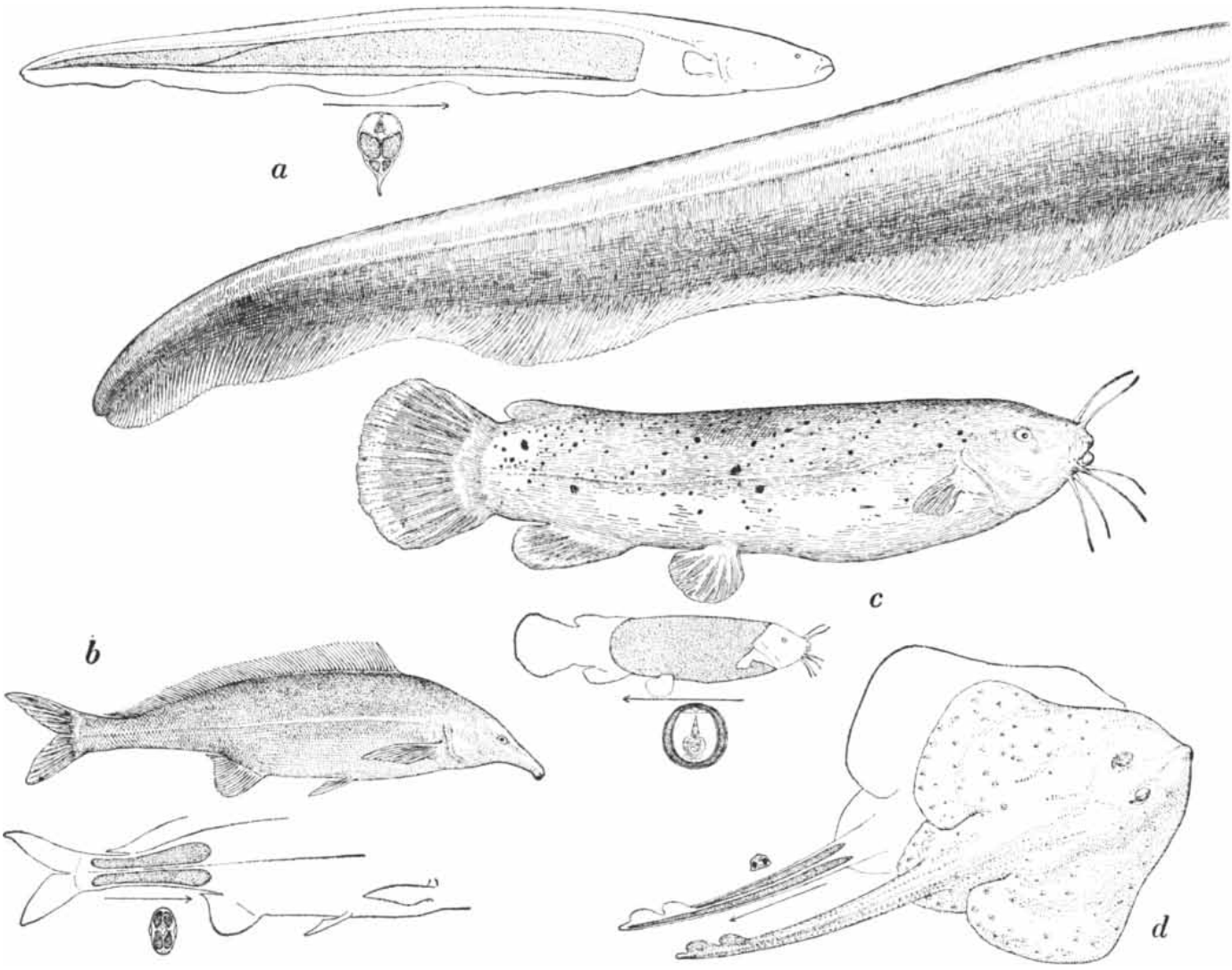


ELECTRIC RAYS are found in all the oceans and in the Mediterranean Sea. Shown here is a South Atlantic species, *Narcine brasiliensis*. Light, kidney-shaped area, about 1½ inches long, below two dark spots at top shows position of one of ray's two electric organs. Second organ is in other wing. Organs produce electric discharges of 35 to 60 volts, depending on the species.

brought about the development of electric organs quite independently in almost every one of the families. As Charles Darwin was puzzled to observe, electric species turn up among the ancient cartilaginous fish (which include the electric rays and the less powerfully electric skates) as well as among the bony fish of more recent descent. Among the bony fish there is a sea dweller, the star-gazer (*Astroscopus*), found only on the western Atlantic coast from Delaware to Brazil. The freshwater knife fishes (gymnotids) of Central and South America bear no relation to *Gymnarchus* and the mormyrids of Africa, and they are equally unrelated to the electric catfish of the Nile. In essaying the independent development of these diverse families natural selection arrived at correspondingly different physiological solutions for the generation of large amounts of electrical energy and for the shaping and timing of the electric pulses.

The electric fishes confront the biologist with many still-unanswered questions. But they have also facilitated progress on some of the most fundamental and universal questions of life. "Animal electricity" was first observed in the electric fishes. Throughout the 19th century they were the center of studies in electrophysiology. Even today, when sensitive amplifiers make it possible to observe electrical phenomena in other animals, the variety and virtuosity of design embodied in the electric organs of these fishes provide ideal experimental subjects for particular lines of investigation. Presently they offer the most promising lead to resolution of the processes of synaptic transmission: the induction by the nerve impulse of the chemical activity that relays an impulse from one nerve cell to the next and from nerve cell to muscle or gland.

The ancients knew and quite properly stood in awe of electric fishes. The electric catfish is pictured on early Egyptian tomb sculpture. The Romans are said to have applied *Torpedo*, the electric ray, for the cure of gout, headache and even mental illness—an early, though unwitting, use of electroshock therapy. Curiously these fishes and the electric eel, when it was described after the discovery of America, were all colloquially named "thunderer" or "shaker": *ra'ad* in Arabic, *temblador* in Spanish, *trembleur* in French, *Zitterfisch* in German. Since the connection between thunder and electricity was then unknown, these



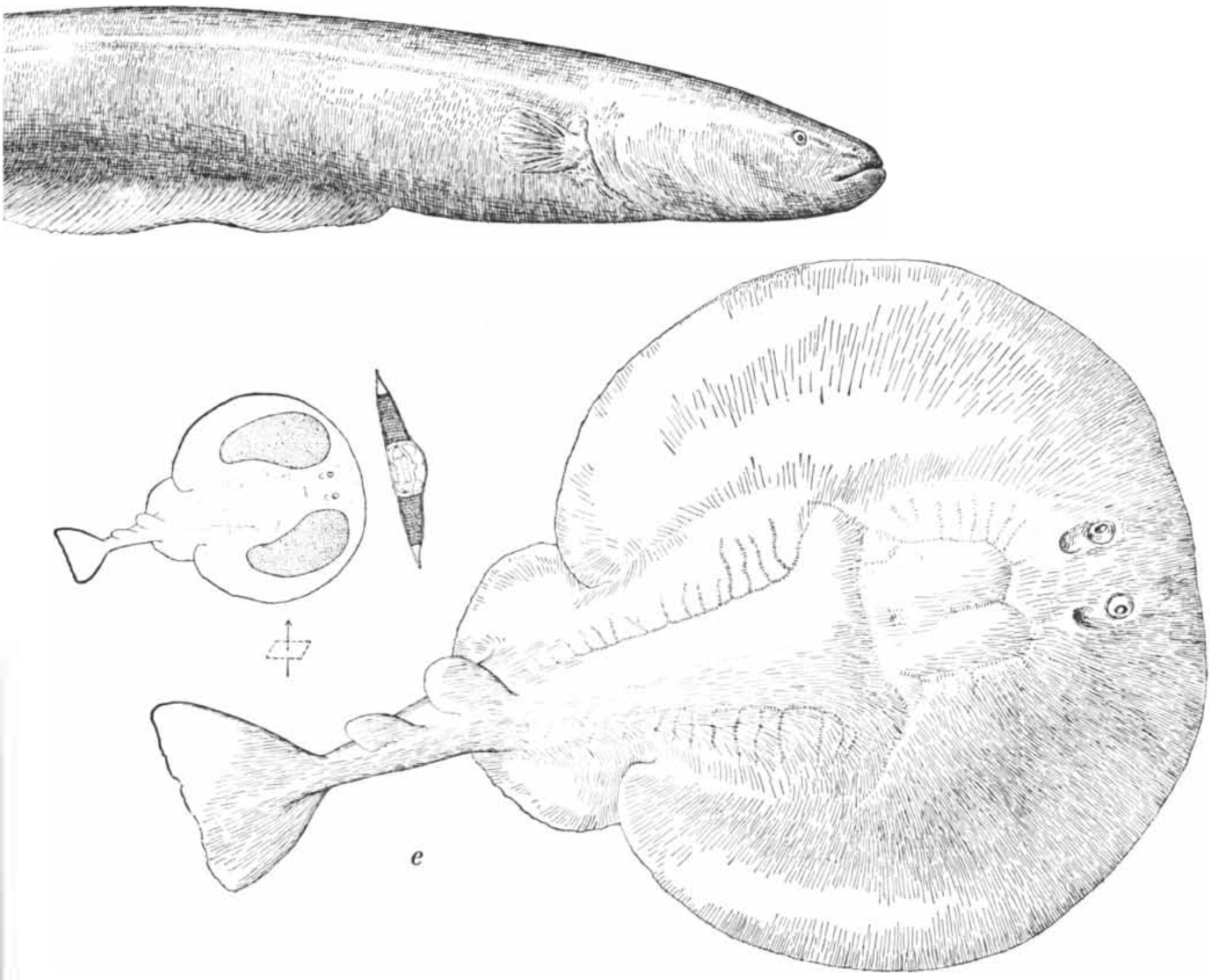
ELECTRIC FISHES and sectional views of their bilateral electric organs are depicted in illustration on these two pages. Electric eel (*a*) has three organs (*stippled area at top left*): large main organ, smaller organ of Sachs behind it and organ of Hunter immediately underneath. Main organ and organ of Hunter appear in cross section below. Arrow indicates direction of current flow in body of

names undoubtedly referred to the convulsive muscle contractions which the fishes caused when they were stimulated to discharge by handling.

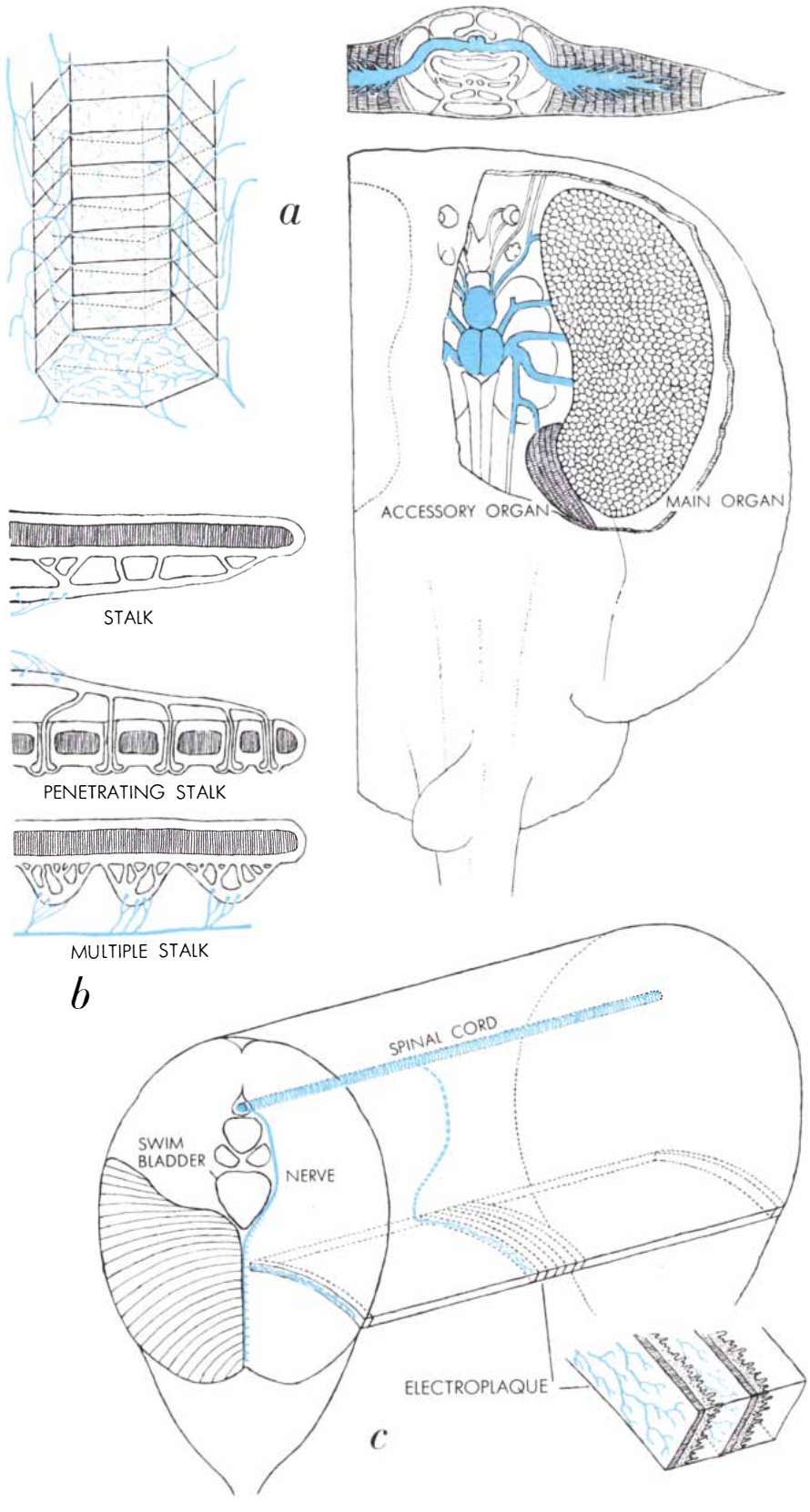
Until the concept of electricity was formulated about 1750, savants were hard-put to explain these unpleasant effects. Inevitably it was thought that the fish produced some sort of venom. In 1685 Giovanni Borelli alternatively proposed that the fish were equipped with rapidly contracting muscles that delivered sharp blows in quick succession. Soon after the Leyden jar was invented, however, a Dutch West Indies administrator, Laurens Storm van's Gravesande, and a French naturalist, Michel Adanson, independently suggested that the fishes produced electric discharges. John Walsh and Henry Cavendish in England, Hugh Williamson in Philadelphia and Lazzaro Spallanzani in Italy soon established that the fishes do produce electricity.

Thus it is not surprising that Luigi Galvani suggested in 1791 a kinship between the electricity of "Torpedo and cognate animals" and the "animal electricity" he thought he had discovered in muscles and nerves. The electric fishes played an important part in the dispute that then arose between Galvani and Alessandro Volta. The latter maintained that Galvani had demonstrated not animal electricity but the production of "metallic" electricity by the contact of two dissimilar metallic surfaces. Volta was correct in this: Galvani's frog nerve-muscle preparations were merely more sensitive detectors of electricity than any instruments available at the time and for about 50 years thereafter. However, Volta was wrong in denying the existence of animal electricity. In trying to prove his contention that the electric fish contained some sort of metallic generator Volta discovered the electrochemical battery, or "galvanic" (!) cell. The "voltaic pile" of cells in series he called "an artificial electric organ" which he thought "victoriously demonstrated" his argument.

Despite Volta's apparent victory, electric organs continued to be studied, partly because they were at least as effective electrical generators as any that were available for some time. When powerful electrochemical and electromagnetic sources of electricity were developed, physicists began to lose interest in "fish electricity." By 1842, however, Carlo Matteucci and Emil Du Bois-



fish during electric discharge. In *Mormyrus* (*b*) organ is situated near tail. Organ of *Malapterurus* (*c*) forms a mantle just under skin of fish. Electric skate (*d*) has organ in tail. Electric ray (*e*) has a kidney-shaped organ in each wing. Cross-sectional view shows columns of electroplaques in organs. The direction of the discharge (*arrow*) is perpendicular to the broad surface of ray.



DETAILS OF ELECTRIC ORGANS of electric rays (*a*), mormyrids (*b*) and electric eel (*c*) are shown. Electroplaque columns are vertical in body of the ray (*top right*). Nerve terminals (*colored branching at top left*) directly innervate column. Cranial nerves (*heavy colored lines at right*) connect organs with electric lobes (*solid colored area*) of brain. Recently discovered accessory organ is found only in ray genus *Narcine*. Among different mormyrid species electroplaques are indirectly innervated via three types of stalk. As in some other fishes, uninnervated membranes of electroplaques in main organ of eel are convoluted.

Reymond had demonstrated that a very weak "animal electricity" really exists in muscle and nerve. Physiologists and anatomists then began to study electric organs most intensively, hoping to gain knowledge about nerve and muscle. Largely under the influence of Du Bois-Reymond, the founder of electrophysiology, these vigorous studies uncovered much of the basic information about electric fishes.

Embryology and comparative anatomy soon established that the electric organs are derived from muscle. The component cells, or electroplaques, in some fishes show striations such as those of muscle fibers, vestiges of the contractile machinery lost in the course of specialization. The electroplaques are thin wafer-like cells, the two surfaces of which differ markedly in their anatomical relations. In most of the fishes one surface is innervated by a dense network of nerve terminals; in others (but including such unrelated forms as the African catfish and the mormyrids and one of the American knife fishes) the innervation is established indirectly through one or several stalks emerging from one of the surfaces. In either case only one surface of each electroplaque is innervated (except, perhaps, in some aberrant knife fishes). The uninnervated surface invariably has deep folds and convolutions that greatly increase its total area.

An electric organ consists of an array of electroplaques stacked in columns, with the innervated surfaces of the cells in a column all facing the same way. In the various species the organs are differently arranged. The eel has some 6,000 to 10,000 electroplaques in each column and some 70 columns in the organs on each side of its body. These relatively huge organs run longitudinally from just behind the anal vent (about one sixth of the way back from the head) to the tail; in an adult fish they make up about 40 per cent of the animal's total bulk. In the electric ray, on the other hand, the columns are arrayed vertically, at right angles to the spine, forming a large compact organ in each of the animal's wings. The African catfish exhibits still another arrangement; the organ forms a mantle of tissue just under the skin which surrounds the entire body from just behind the gills to the tail.

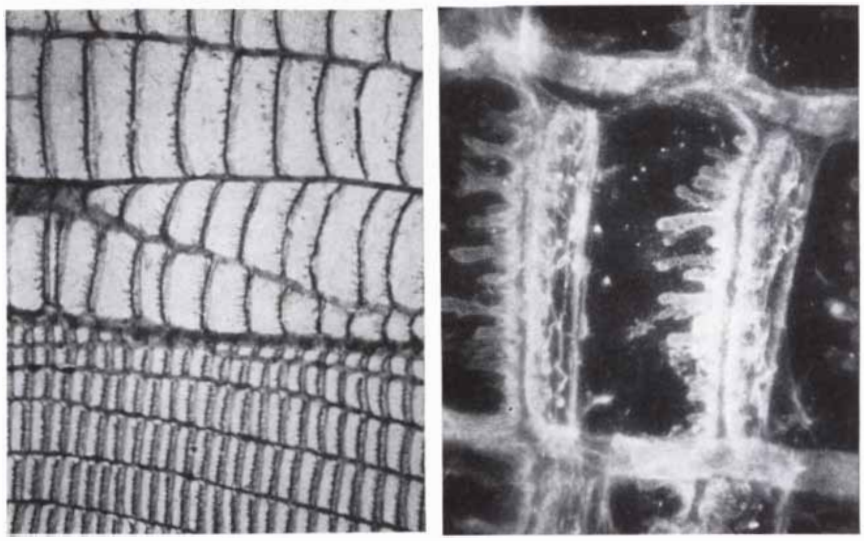
However the organs are arranged, the electrophysiologists of the 19th century soon recognized that the electroplaques in each column form a series array, like the cells in Volta's "artificial electric organ"; the hook-up in series adds the

outputs of the electroplaques and builds up the voltage. It was also plain to see that the arrangement of the columns in parallel serves to build up the amperage. But the question of how the electroplaques produce their discharge was one that called for a more detailed knowledge of their electrophysiology than was available at that time.

This question was essentially solved in 1912 by Julius Bernstein, Du Bois-Reymond's foremost pupil. Bernstein proposed that the cell membrane of the electroplaque—like that of a nerve or muscle cell—is selectively permeable to potassium ions but not to sodium ions. The higher concentration of potassium ions inside the cell and of sodium ions outside would create a "resting" potential across the cell membrane, the inside of the membrane being negative and the outside positive. Under the stimulus of a nerve impulse the permeability of the membrane changes, permitting ions, and hence an electric current, to flow across it. According to Bernstein, only the innervated membrane of the electroplaque would be affected. The potential of this membrane would fall to zero (depolarize), while the resting potential of the uninnervated membrane would remain the same [*see illustration on the next page*].

Adequately sensitive amplifiers and the microelectrodes necessary to measure the potential across the cell membrane were not available to Bernstein and his contemporaries. It was some 40 years before his deductions could be put to conclusive experimental test. Then in the early 1950's Richard D. Keynes and H. Martins-Ferreira at the laboratory of Carlos Chagas in Rio de Janeiro, and Mario Altamirano, Christopher W. Coates and I at Columbia University independently confirmed the essential correctness of Bernstein's hypothesis. But our experiments also amended it in an important respect.

A. L. Hodgkin and his co-workers at the University of Cambridge had shown a few years earlier that the behavior of nerve and muscle fibers is more complex than Bernstein had thought. Instead of depolarizing, the inside of the membrane temporarily reverses its charge and becomes positive. That is, instead of a response equal only to the magnitude of the resting potential, the response, or "spike," has an overshoot. Our measurements showed a similar spike in the response of the electroplaque. Thus each electroplaque in the electric eel, for example, contributes 150 millivolts rather than 80 millivolts (the amplitude of the resting potential) to the output of the organ. The reversal of polarity involves only the innervated membrane. The opposite membrane remains quiescent, maintaining its negative potential, as Bernstein had suggested, and offering remarkably little resistance to the flow of electric current. Since the current flows from plus to minus, the orientation of the electroplaques determines the direction of the current in the organ. In the eel the innervated surfaces of the electroplaques all face the tail. Current thus flows from tail to head in the fish, and flows from head to tail in the external medium to complete the circuit.

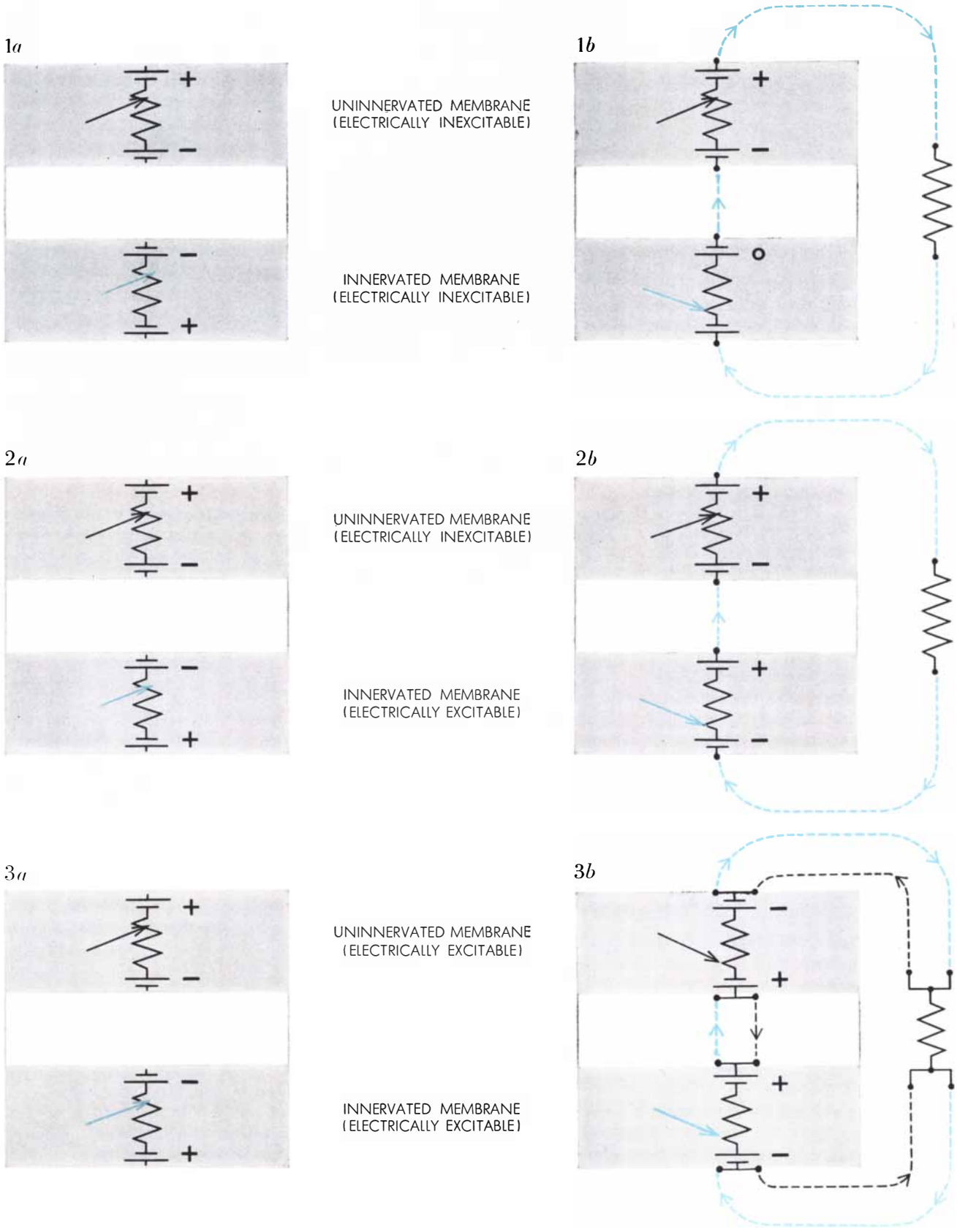


EEL ELECTROPLAQUES appear in these two sections. At left the electroplaques are closely spaced in main organ, and widely spaced in organ of Sachs. At right, surfaces with projections are uninnervated membranes. Dark gray line behind them is innervated membrane. The photographs were made by A. Couceiro of the Institute of Biophysics in Rio de Janeiro.

The great number of electroplaques in series enables the eel to produce the voltage necessary to overcome the high resistance of its freshwater environment. The columns in parallel enable it to generate a current, in brief pulses, of about one ampere, so that even in fresh water the organ generates considerable power. The electric rays, living in salt water, show a corresponding adaptation to the lower resistance of this medium. The giant ray *Torpedo nobiliana* has up to 1,000 electroplaques in series, much fewer than the eel, and so generates a lower voltage. But it has some 2,000 columns in parallel in each organ, giving it its extraordinary amperage.

In the course of our study of the process by which the electroplaque produces its discharge we made a discovery that opened up a new line of inquiry—into the process of synaptic transmission, by which an impulse crosses from one cell to the next. We had been stimulating the electroplaques in two different ways, by applying electric shocks directly to the cell, and indirectly by stimulating the nerve whose fibers innervated the cell. Both kinds of stimulus produce a spike, but the indirect stimulus evoked a distinctly different pattern of response in the cell. There was always a small prepotential ahead of the spike, and it seemed to trigger the spike. The prepotential had a number of peculiar properties. It, and the spike that followed, appeared only after a measurable and irreducible period of latency; it could be elicited under conditions when a spike could not be produced, and it could be induced only by stimulation of the nerve, never by a direct stimulus to the cell.

Potentials of an apparently similar kind had been described a short time before in two other systems. In 1951 Paul Fatt and Bernhard Katz of University College London had studied the electrophysiology of the motor end-plate, which forms the junction of the motor nerve and a skeletal muscle fiber. This is the site of an "end-plate potential," produced by stimulating the motor nerve. Fatt and Katz found that this response was smaller than the spike that followed, and it apparently represented no more than the depolarization of the membrane and the neutralization of its potential, such as Bernstein had postulated for the spike itself. A little later John C. Eccles, then at the University of Otago in New Zealand, and his colleagues had found a similar potential running ahead of the spike in the spinal motoneurons of the cat. All these potentials are now known



GENERATION OF ELECTRICITY by electric fishes can be explained by comparing electroplaque membranes (*shaded areas*) to batteries. Resting potentials of membrane batteries, negatively charged on inner surface and positively charged on outer, are shown at left. In marine fishes nerve stimulus short-circuits battery of innervated membrane (1*b*). Magnitude of discharge equals resting potential, and current (*broken line*) flows through electroplaque, then through external medium. In eel, stimulus reverses polarity of battery of electrically excitable membrane (2*b*). Discharge exceeds resting potential. In species having two electrically excitable membranes, discharge of one battery excites discharge of other, producing oppositely directed currents (3*b*).

as postsynaptic potentials (p.s.p.)—synapse being the term for the junction between neurons. More strictly they are called depolarizing or excitatory p.s.p.'s, to distinguish them from another kind of postsynaptic potential, the so-called hyperpolarizing or inhibitory p.s.p. Both kinds of p.s.p. are found in neurons, in the heart and in many invertebrate muscle fibers, but only the depolarizing p.s.p. occurs in electroplaques and in vertebrate muscle fibers.

Since the electroplaques of the eel are large cells, they provide particularly favorable material for the study of the p.s.p. Working with this cell, we were thus able to show unequivocally that the p.s.p. cannot be elicited by direct electrical stimulus of the membrane. The p.s.p. must therefore originate in a component of the membrane that is electrically inexcitable. We were also able to show that the spike involves the entire surface of the membrane and were thus able to conclude that the membrane must also have an electrically excitable component in parallel with the electrically inexcitable generator of the p.s.p. If the p.s.p. produced by a nerve stimulus is large enough, it triggers a spike in the electrically excitable component.

We suggested that this dual system of membrane activity would prove to be the general mode by which a spike in one cell initiates the spike in another. A few special cases of electrical (ephaptic) transmission have been found. But the hypothesis that synaptic transmission has an electrically inexcitable link has now been confirmed in all other cases that have been studied.

Some of the most clear-cut evidence for electrical inexcitability has come from recent studies on marine electric fishes. The electric discharges of the ray and skate had long been known to differ from those of the eel. It seemed likely that these marine fishes had electrically inexcitable electroplaques. In other words, we surmised, the conductile mechanism in which the spike plays a role was missing along with the contractile machinery in these electroplaques. Studies by Michael Bennett and myself on the giant ray and three species of skate at the Marine Biological Laboratory in Woods Hole, Mass., on a South Atlantic ray (*Narcine brasiliensis*) and—confusingly enough for the evolutionary picture—on the bony fish *Astroscopus*, fully confirmed these expectations. In England Lawrence Brock and Rosalind M. Eccles also found that the electroplaques in the skate are electrically inexcitable. We showed that these electroplaques put out between 50 and 80 millivolts, in the range of the resting potential of the cell and, in contrast to the overshooting 150-millivolt spike of the eel electroplaque. The response of these cells must therefore be classified as a p.s.p. rather than as a spike.

The marine electroplaques are large cells, as much as a centimeter in diameter. Since their responses are unhampered by the confusing elements of spikes, it has been possible to measure the potential change accurately and to confirm in their behavior a number of theoretically predicted properties of the electrically inexcitable response, properties which are totally unlike those of the electrically excited spikes, but which are important for the functioning of synaptic transmission, and for an understanding of its mechanisms. For example, the p.s.p. cannot be propagated, and the potential change across the membrane can differ in shape and size when recordings are made simultaneously at two sites only a millimeter or so apart. The apparent sign of the response can be inverted by changing the resting potential of the cell. An appropriate drug, such as acetylcholine, causes responses similar to those produced by the nerve impulse, but which last as long as the drug is available. These properties can also be demonstrated in the p.s.p.'s of other cells. In the latter, however, spikes tend to complicate the picture and have long obscured the existence of electrically inexcitable potentials.

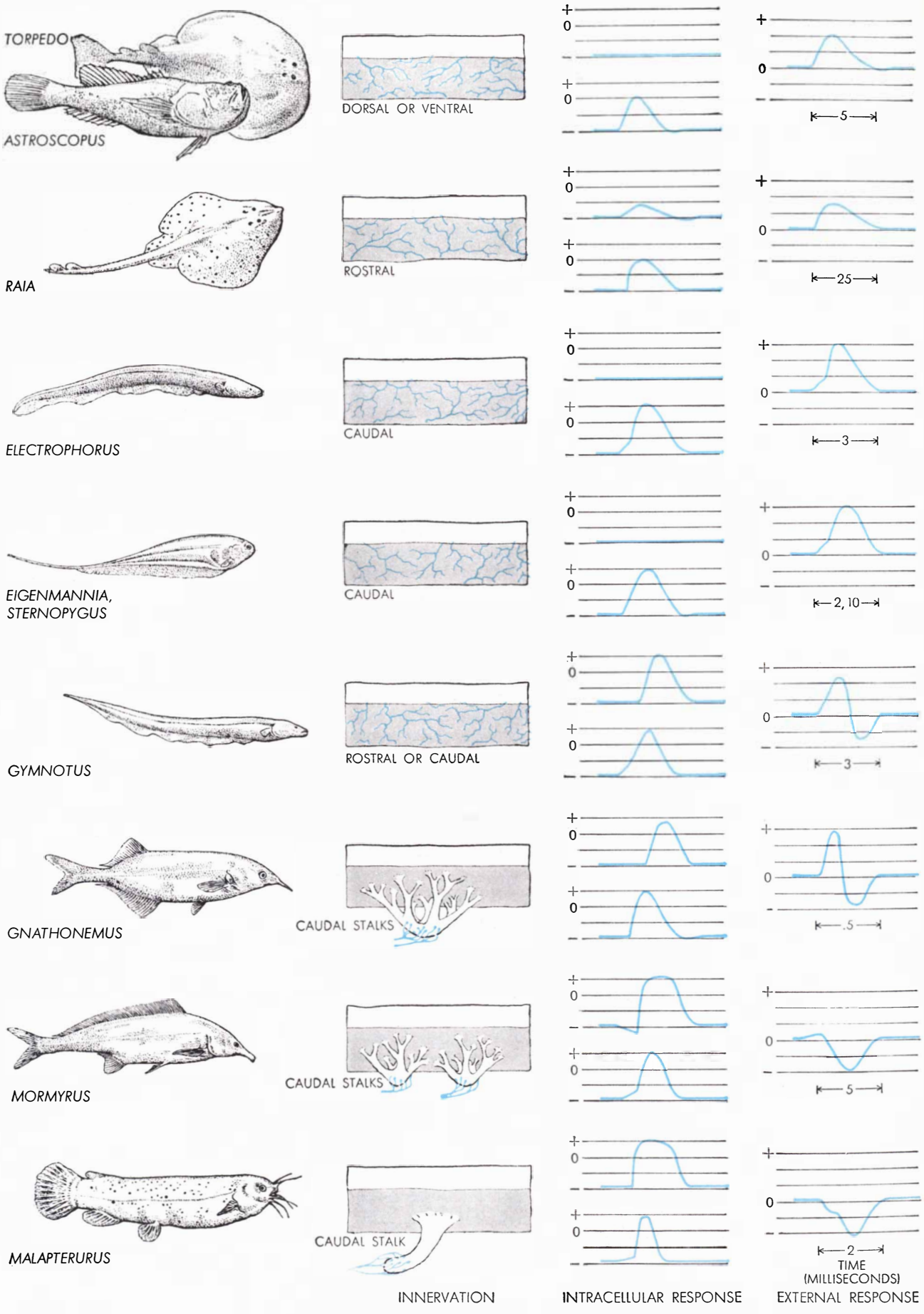
One of the important consequences of the new data is that they render an unambiguous decision about the nature of synaptic transmission, which has been in dispute for nearly 100 years. In the 1860's Wilhelm Krause and Wilhelm Kühne proposed that the current produced by the nerve impulse excited the muscle fiber. "A nerve throws a muscle into contraction only by its currents of action," they said. Du Bois-Reymond in the 1870's suggested, alternatively, that the nerve might secrete some chemical agent that excited the muscle. But the electrical theory dominated the field for a long time. Then in 1922 Otto Loewi showed that the vagus nerve produces a substance, later identified as acetylcholine, which affects the heart in the same way as the activity of the nerve itself. From that time on the chemical theory of synaptic transmission has gained vogue.

Direct evidence that a chemical transmitter is released during activity of the nerve is difficult to obtain. It is even more difficult to demonstrate its action during the brief period of latency before the p.s.p. appears and triggers the spike. As a result there are still some neurophysiologists who uphold the electrical theory. But that theory is no longer tenable in view of the clear evidence that the synaptic processes are electrically inexcitable. The only alternative is to conclude that synaptic transmission is chemically mediated.

The synaptic junction may be considered as representative of a more general category of input terminals in the nervous system. This would include the receptor surfaces of the sensory cells. A number of these have now been shown to be electrically inexcitable, responding only to specific stimuli: light, chemicals or mechanical stimulation [see "Biological Transducers," by Werner R. Loewenstein; SCIENTIFIC AMERICAN, August]. The weakly electric fishes provide a probable exception. Their electrical-guidance sense-organs would seem to be electrically excitable.

For a long time the organs of weakly electric fishes seemed to have no functional value, and some were classified as "pseudo-electric." But in 1950 Coates at the New York Aquarium recorded low-voltage pulses, with a frequency of about 25 per second, from an eel as it cruised in its tank. He suggested that the eel might use these pulses in connection with an electrical guidance-system. Later Hans W. Lissmann of the University of Cambridge, and Coates, Altamirano and I found that the African *Gymnarchus* and the American knife fishes emit pulses continuously. The former emits about 300 per second; the knife fishes, anywhere from five to more than 1,500 per second, depending on the species. The African mormyrids also emit pulses, somewhat less regularly than *Gymnarchus* or the knife fishes, and they probably also depend upon their pulses for navigation.

These fishes are highly sensitive to changes in the electric fields they produce. According to Lissmann, *Gymnarchus* can detect a potential gradient of about .03 microvolt per centimeter. He has trained fishes to detect a small stationary magnet, and to differentiate between waters of different conductivity. The reactions of the gymnotid species (which include the electric eel as well as the knife fishes) to metallic objects or even to large nonconductors seem to vary. Most forms seek to escape from the object distorting their electric



fields. Others, however, attack it. Bits of iron, probably ingested during such attacks, have been found in the stomachs of electric eels.

The sensory organs and their connections in the brain have not been identified, but Bennett and I have demonstrated the presence of such connections by cutting the nerve that carries impulses from the receptor to the brain. When the nerves of both sides are cut, the body of the knife fish *Gymnotus carapo* becomes insensitive to metallic objects. When only one nerve is cut, the fish reacts as though the object were on its intact side. Once identified, the system will open a new field of research in sensory physiology.

The circuitry of these guidance systems embodies an extraordinary variety of design and function. The electroplaques of all the freshwater fishes we have studied produce spikes. As in the eel, neural excitation evokes a p.s.p. that then triggers the spike. But the simple combination of p.s.p. and spike occurs only in the eel and a few of its close relatives among the knife fishes that generate monophasic (unidirectional) pulses. Some of the knife fishes, including *Gymnotus carapo* (the eel's closest taxonomic relative), and many of the African mormyrids emit diphasic or polyphasic pulses. In these fishes, and even in the monophasically discharging African catfish, both membranes of the electroplaques produce spikes.

The knife fish *carapo* produces the simplest type of diphasic discharges in pulses of about 50 to 60 per second. The spike from the innervated membrane triggers a spike in the uninnervated membrane as well. Since the membrane "batteries" are oppositely polarized, there is considerable cancellation of pulses. Each electroplaque contributes about 25 per cent of its maximum voltage to the total discharge. In fact there would be no discharge if the two membranes produced their spikes simultaneously.

The arrangement of electroplaques in *carapo* presents an additional complication. Its organ contains eight columns, with the four columns on each side of the spinal cord lying horizontally one on top of the other. The rostral membranes (toward the head) of electroplaques in the top column are innervated, while in the other three columns the caudal (tail) membranes are innervated, as in the eel. The top column discharges first, and the head of the fish thus becomes negative. Then, as the innervated caudal surfaces of the other three columns discharge, the head becomes positive. (The caudal, uninnervated membranes of the top column also contribute to this discharge.) Finally, the head becomes negative again as the uninnervated rostral surfaces produce spikes. The result is a triphasic discharge.

The mormyrids also generate pulses from both surfaces of their electroplaques, the caudal surfaces being innervated through stalks. (For a time it was thought that stalked electroplaques occurred only in the African freshwater families, but recently this configuration has been found in one of the American knife fishes.) Nerve impulses elicit p.s.p.'s in the stalk, triggering a spike that propagates into the body of the electroplaque. First the stalked caudal surface and then the rostral surface become active; the result is a diphasic pulse. In many of these fishes the spikes are remarkably brief, about .3 millisecond in duration, and the diphasic pulses rise and fall sharply. This type of pulse might be especially suitable for detecting objects in the fish's environment.

In at least one group of mormyrids the spikes from the two faces vary in duration. The spike of the rostral surface lasts much longer than that of the caudal. The resulting pulse is almost monophasic and resembles somewhat the pulses of the marine electric fishes, the eel and some of the knife fishes. This nearly monophasic pulse differs in one aspect from the others: during discharge the uninnervated rather than the innervated surfaces of the electroplaques become negative. Around 1850 Filippo Pacini, an Italian histologist, noted that in the discharge of *Torpedo* the innervated surface of the electroplaques always became negative. The rule held for all electric fishes except the African catfish, and came to be known as Pacini's rule. Bennett, Keynes and I have recently shown that the failure of Pacini's rule in the case of the catfish arises from the same mechanism as in the mormyrid forms. The spike of the rostral membrane in the catfish electroplaque starts earlier, is larger and lasts longer than the spike of the caudal, stalk-innervated membrane.

In all of the species the firing of the organs appears to be regulated by a "command center" in the brain. But this center takes different forms and delivers its orders in different ways. Efficient output, especially in the powerfully electric fishes, requires the highest possible instantaneous current. The electroplaques in the series-parallel arrays must, therefore, discharge synchronously. This is a formidable matter, for the organs of powerfully electric fishes contain several hundreds of thousands of electroplaques dispersed over a considerable distance and so reached by nerve conduits of different lengths. Inside the electric organ itself the resistance of inactive surfaces and the dissipation of current by internal shunting must be minimal.

The least complicated system is probably that of the rays and *Astroscopus*. Only one surface is active, and the pulses are unidirectional. Dense innervation of the reactive membrane eliminates internal shunting and excites activity in different parts of the electroplaque all at once. The inactive membrane has a negligibly small resistance. Even the skin above and below the organ has been suitably adapted, offering much lower resistance than the skin elsewhere on the body surface. The compactness of the organs in each species (in *Astroscopus* they occupy a well in the skull behind each eye) minimizes delay in the delivery of the nerve impulse to different parts. Some delay does take place, of course, resulting in a total organ discharge half or once again as long as the pulse of a single electroplaque. Synchronization of the nerve impulse to the cells involves an elaborate nervous mechanism. In the brain of the rays the command center has a relatively few well interconnected cells that fire synchronously upon receipt of the sensory

ELECTROPLAQUE DISCHARGES of different electric fishes are depicted in right-hand column of illustration on opposite page. Fishes are identified by genus. One membrane (*shaded areas in second column*) is directly innervated (*colored branching*) in first seven genera. Uninnervated membrane is not shown. Other three genera exhibit indirect, or stalk, innervation. Top curve in each pair (*third column*) shows intracellular potential across uninnervated membrane during a response; bottom curve, response of innervated membrane. Electroplaque discharge (*external response*) is algebraic summation of oppositely directed potentials of the two membranes. In first six genera uninnervated membrane does not respond, but in *Raia* there is a voltage drop across membrane. In other four genera this membrane is electrically excitable and also contributes a response (*see illustration on page 120*). Electroplaque discharges of the closely related *Eigenmannia* and *Sternopygus* last two and 10 milliseconds respectively.

information that presumably initiates the entire process. The command center discharges into a much larger number of cells in the electric lobes of the brain. From the lobes several of the major cranial nerves, forming thick nerve cables, carry the impulses to the electroplaques.

The electric catfish operates its organ on a rather different principle. A single nerve fiber, or axon, emerges from each side of the spinal cord, branching several hundred thousand times to reach all the electroplaques of one side of the fish. The delays necessary for synchronization must occur in the nerve branches and synaptic junctions. An apparently systematic variation in the length of the stalks may also play a part in synchronization.

In the eel the impulses from the small command nucleus in the brain must travel down a spinal cord that may be two or three meters long. Without some means of synchronization, the electroplaques near the head would receive impulses much earlier than those at the tail. In an electric organ one meter long, and with the nerve impulse traveling at a speed of 40 meters per second (a high value in cold-blooded animals), the time difference would be about 2.5 milliseconds. That is approximately the duration of the discharge of a single electroplaque. Thus the cells at the head would be completing their activity when the cells at the tail were beginning to fire. Actually the discharge of the whole organ has about the same duration as that of a single cell. The impulses from the command nucleus arrive at the different points along the spine with the expected delays. But the synapses of the motoneurons near the head stall the delivery of impulses to the electroplaques they excite. As a result impulses reach the electroplaques at the head- and tail-ends at the same time.

The control system of the repetitively discharging knife fishes represents a remarkable biological adaptation. A pacemaker, probably the command nucleus itself, sends impulses to the spinal motoneurons at the same frequency as that at which the organ discharges. This means that the whole pathway operates at the high frequency of 50 to more than 1,500 pulses per second, depending on the species. Even in warm-blooded animals similar rates of continuous nerve activity are unknown. Some species of knife fish maintain a steady frequency to within about .5 per cent (a high degree of stability for most laboratory oscillators), even when violently upset by strong electric stimuli. In others stimulation of the fish or changes in the conductance of the external medium may affect the frequency to some extent. The scant data available suggest that the pacemaker in the highly stable fish does not receive any sensory input, but that those of the less stable fishes do. In all species, however, cooling the head slows the frequency, as would be expected from the presence of a pacemaker center in the brain.

The picture of both the taxonomic and functional relations among electric fishes is now fairly complete, though tentative. It is complete in the sense that the major functional varieties among the organs appear to be known. But of the 500 or so species of fish with electric organs, only about 20 species have been examined thus far. Further research may bring some surprises. For example, T. Szabo, working at the laboratory of Alfred Fessard in Paris, has recently found an exception to the rule that only one membrane of an electroplaque is innervated. In some *carapo* the electroplaques of one column are innervated on both surfaces. It will be interesting to see what results from studies of the electrophysiology of these electroplaques. Moreover, we have yet to examine thoroughly the single species of *Gymnarchus*. Though the airplane and the plastic bag have made transportation of fish quite easy, and New York has become the world center for the tropical fish industry, *Gymnarchus* is apparently too large and too ugly for fish fanciers and none has been seen in New York. Lissmann brought several back from Africa for his studies of sensory guidance-systems. One of them is still alive, and when Lissmann completes his work, perhaps he and Keynes will study the electrophysiology—unless we get a *Gymnarchus* first.

In respect to their evolutionary aspects the zoological and physiological relations among electric fishes are curiously confused. The several different types that occur in each geographical group present clear cases of convergent evolution. But of all the electric fishes thus far studied, only the electric skates remain an evolutionary puzzle. Their organs, located in their whiplike tails and producing low voltages at low current, discharge only after great provocation, and they would seem to have little, if any, adaptive value. Considering the vast number of electrical experiments tried by natural selection, however, it is not surprising that one of them should be inconclusive.

Miniaturization Report No. 1

What price automation?

In view of today's rising costs, the need for automation in the processing of engineering drawings is recognized as necessary. However, in the welter of claims and counterclaims for various miniaturization processes, a good deal of confusion has arisen around the relative merits of the 35mm and 105mm systems.

These facts need stating: Automation should not dictate film size; conversely, film size should not dictate whether or not automation is possible.

To clarify these points: One should not necessarily install a 35mm system on the assumption that it is the sole answer to high speed automated reproduction. To do this is to overlook the fact that the 105mm system is also capable of automation. And 105mm can often be automated without the expenditure of large sums of money for new processing equipment.

Both systems – 35mm and 105mm – have their place in the modern engineering reproduction department. (The K&E MICRO-MASTER® Camera-Projector takes and projects *both* film sizes.) However, if automation is the only basic consideration, the case for 105mm needs further emphasis.

For example: 35mm aperture cards for information retrieval are designed to deliver negatives quickly and automatically. General practice, however, is to key-punch both the aperture card and a companion "tracer" card to prevent excessive negative wear in sorting. Selection of the aperture card is manual. (Tracer cards also provide 23 additional key-punch positions.)

Tracer cards can also be successfully used with a 105mm system. And only one card need be punched. Selection of negatives, as with aperture cards, is manual.

From start to finish, let's see how the two systems compare:

35mm	105mm
• Negatives in aperture cards • Punch-card retrieval • Automatic "dry-process" reproduction	• Negatives in archival envelopes • Punch-card retrieval • Standard diazo reproduction
PREPARATION AND FILING	
Original drawing photographed to yield master negative	Same
Tracer card key-punched	Same
Aperture card key-punched, negative inserted in card	Archival envelope machine numbered, negative inserted
Tracer cards and negatives filed	Same
SEARCH AND DELIVERY	
Tracer card sorted to find location of negative	Same
Negative selected manually from file	Same
REPRODUCTION	
Distribution prints made from negatives on automatic "dry-process" printer at rate of 20 ft. per minute.	Prints made from photographic intermediates on diazo machines at 60 ft. per minute. (Time spent in preparing intermediate offset by faster print speed of diazo.)

SUMMARY:

- Despite minor differences in procedure, preparation and filing take almost equal time (a matter of minutes).
- Search and delivery take exactly the same time.
- In production, printing speed using 105mm negative and standard diazo is *as fast* as automatic "dry-process", or *faster*.
- In short: both systems offer roughly equal speed and convenience.

Undoubtedly, if you are at all involved in engineering reproduction, you will require more facts than could be furnished in this brief message. We have them – complete with cost comparisons – and will be pleased to furnish them if you will return the coupon below.

"The Burroughs 220 Computer is a Potent Tool in Advancing Our Technology."

Dr. Charles D. Alstad, ***Acting Director, Computations Research Laboratory,*** **The Dow Chemical Company**

Why do it? There are many common denominators between the global Dow of 1960 and the infant Dow of 1897. Perhaps the most important one is a business philosophy stated by founder Herbert Henry Dow. He put it this simply: "If you can't do a thing better than it's already being done, why do it?"

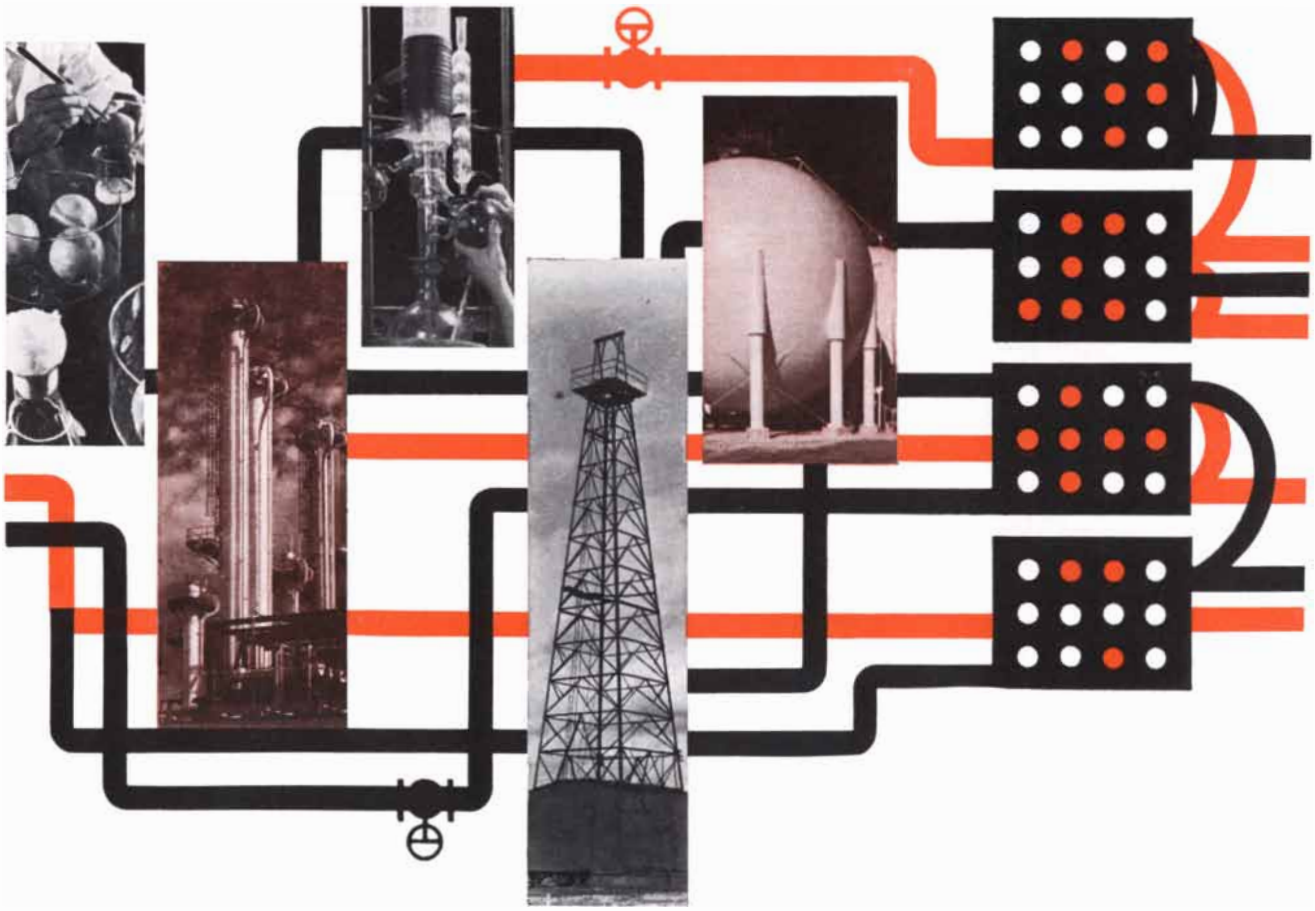
Under this pervading philosophy, Dow places heavy emphasis on new product research and operations research. And to help push advances in these areas farther and faster at less cost, Dow uses a Burroughs 220 Computer System.

THE BURROUGHS 220 AT DOW

This 220 system consists of the data processor with 5,000-word core storage, two supervisory printers, photoreader, two paper tape punches, three magnetic tape storage units, and a Cardatron sub-system for controlling punched card input and output. Selected for its greater capacity and speed, the 220 is one of two Burroughs Computers at Dow. The other: a Burroughs 205 Computer at Dow's Freeport, Texas, operation.

The 220 computer is at work in Dow's Computations Research Laboratory in Midland, Michigan, headquarters for the firm. As Acting Director Dr. Charles D. Alstad puts it, "Our use of the 220 is in scientific and engineering applications, where it is an important adjunct to all the scientific talents available at Dow."

Super screener. For example, Dow uses the computer as a screening tool in the development of higher energy solid rocket fuels under its contract with the Advanced Research Projects Agency. In pursuit of project goals, Dow chemists can envision many fuel combinations. But they can't, of course, subject each combination to exhaustive laboratory tests. Through the Burroughs 220, Dow gets all data necessary for preliminary evaluation of a fuel and gets it in anywhere from two minutes to a half hour. In this way, Dow scientists can select only the most promising combinations for laboratory evaluation, development and testing.



Turbine tamer. In another application, Dow uses the 220 in calculating turbine efficiency tests. The calculations, which were formerly performed by hand, took at least two weeks but now require less than five minutes on the computer.

Designing for profit. Plant design is another function of the 220. In today's hotly competitive chemical industry, it's essential to keep the cost per pound of product minimized. Consequently, a plant must be carefully designed for a specified capacity, minimum capital investment, and efficient operation. The computer is a useful tool in striving for these objectives.

Care and feeding of production. In an extension of plant design, Dow uses the 220 for plant simulation, using either a derived statistical model or a theoretical model to study an existing plant. The information obtained is valuable to Dow in maintaining quality of product and efficient use of facilities.

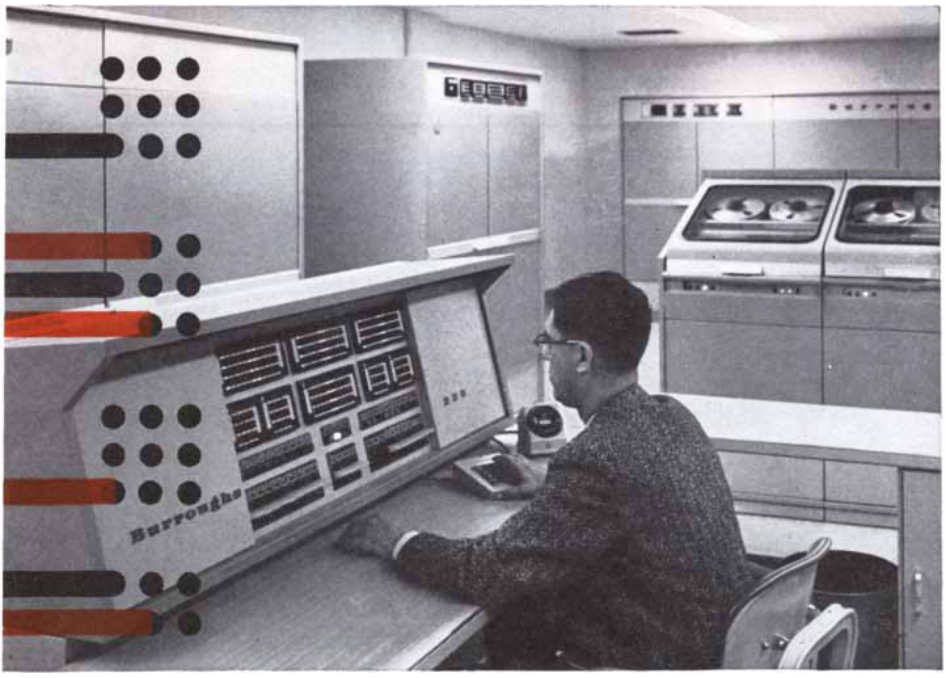
Dr. Charles D. Alstad

Masterminding molecules. The 220 at Dow is busy in pure research, too, where it is helping to advance the frontiers of science. For instance, Dow is investigating the bonding forces and links between the atoms in a molecule. And the Burroughs 220 performs the Urey-Bradley Force Constants Calculations that are required. These studies will supply the knowledge which will allow Dow scientists to make predictions on how a given chemical will behave in a reaction.

Long and short of it. There are many other aspects of the 220's work at Dow, such as its evaluation of pilot plant projects, information retrieval and other routine mathematical calculations. "Fundamentally," says Dr. Alstad, "our Burroughs 220 computer is a potent tool in advancing our technology. From the range of applications, you can get an idea of the computer's value to us. And you can see why we are most enthusiastic about the results and the potential of the digital computer in research and engineering applications."

FROM LITTLE, MUCH

Take five basic raw materials: sea water, brine, coal, petroleum, oyster shells. Add the talents, skills and knowledge of 29,000 people. Add generous helpings of research and progressive management attitude. Apply plants located throughout the world. And you get over 700 products in five categories: industrial chemicals, plastics, metals, agricultural chemicals, textile fibers. That, in brief, is Dow, the nation's fourth largest chemical company (1960 sales: $781 million).



Computer Operator Ray L. Haeusler at console of 220

The hundreds of other scientific and commercial users of Burroughs computers are getting equally impressive results, too. One reason is the capability of the equipment in Burroughs complete data processing line. Another reason is that the equipment is backed by a coast-to-coast team of computer specialists, who are primed to show you how thoroughly and efficiently they can help you. For information, write Burroughs Corporation, Detroit 32, Michigan.

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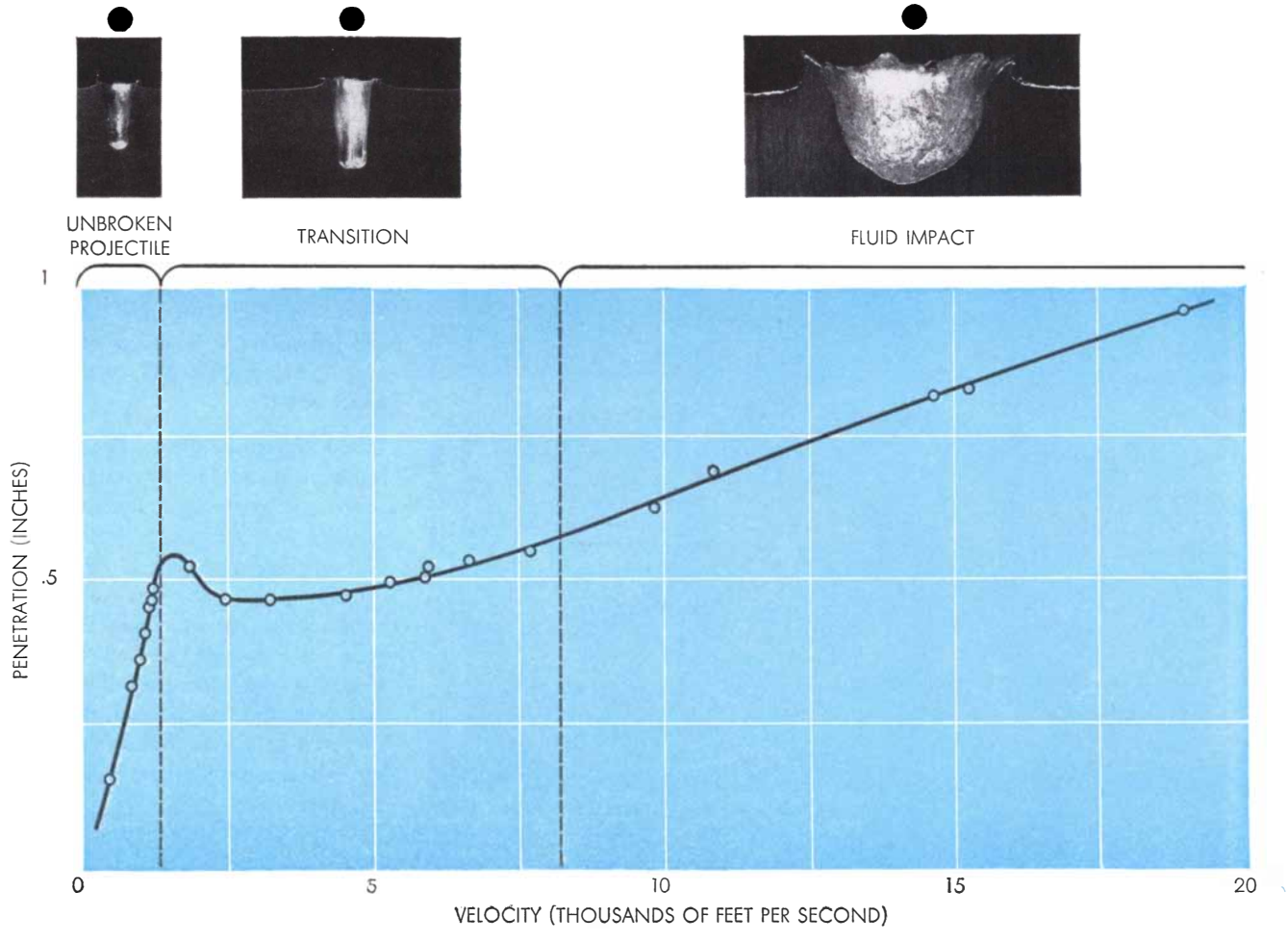
HIGH-SPEED IMPACT

What happens when a projectile strikes a target at extremely high velocity? Experiments indicate that impact at speeds greater than about 8,000 feet per second causes metals to flow like liquids

by A. C. Charters

Of the many unknown areas into which our technology is taking us, one is the realm of sheer speed. The sound barrier was crossed so long ago that the term is taking on a faintly old-fashioned ring. It has now become necessary to study the laws of nature as they apply to objects pushed to velocities of tens of thousands of miles per hour. Not the least interesting questions have to do with what happens when two bodies collide at extremely high velocity. This is the problem of high-speed impact.

In the past the incentive to study the most violent collisions, as well as the risk of encountering them, arose out of warfare. One of the main themes of military history is the contest between stronger armor and faster projectiles. During World War II it looked as though



EFFECT OF VELOCITY on the process of impact is depicted by photographs and graph. Upon impact at low velocities the projectile remains intact and punches a narrow, deep cavity in the target (*top left*). At higher velocities the particle is deformed or shattered (*center*); at still higher velocities both the projectile and the particle flow like fluids (*right*). The low-velocity projectiles in this experiment were spheres of tungsten carbide; the high-velocity projectiles were steel. Black balls show size of the projectiles and are reproduced to the same scale as the photographs. The targets consisted of massive blocks of soft lead.

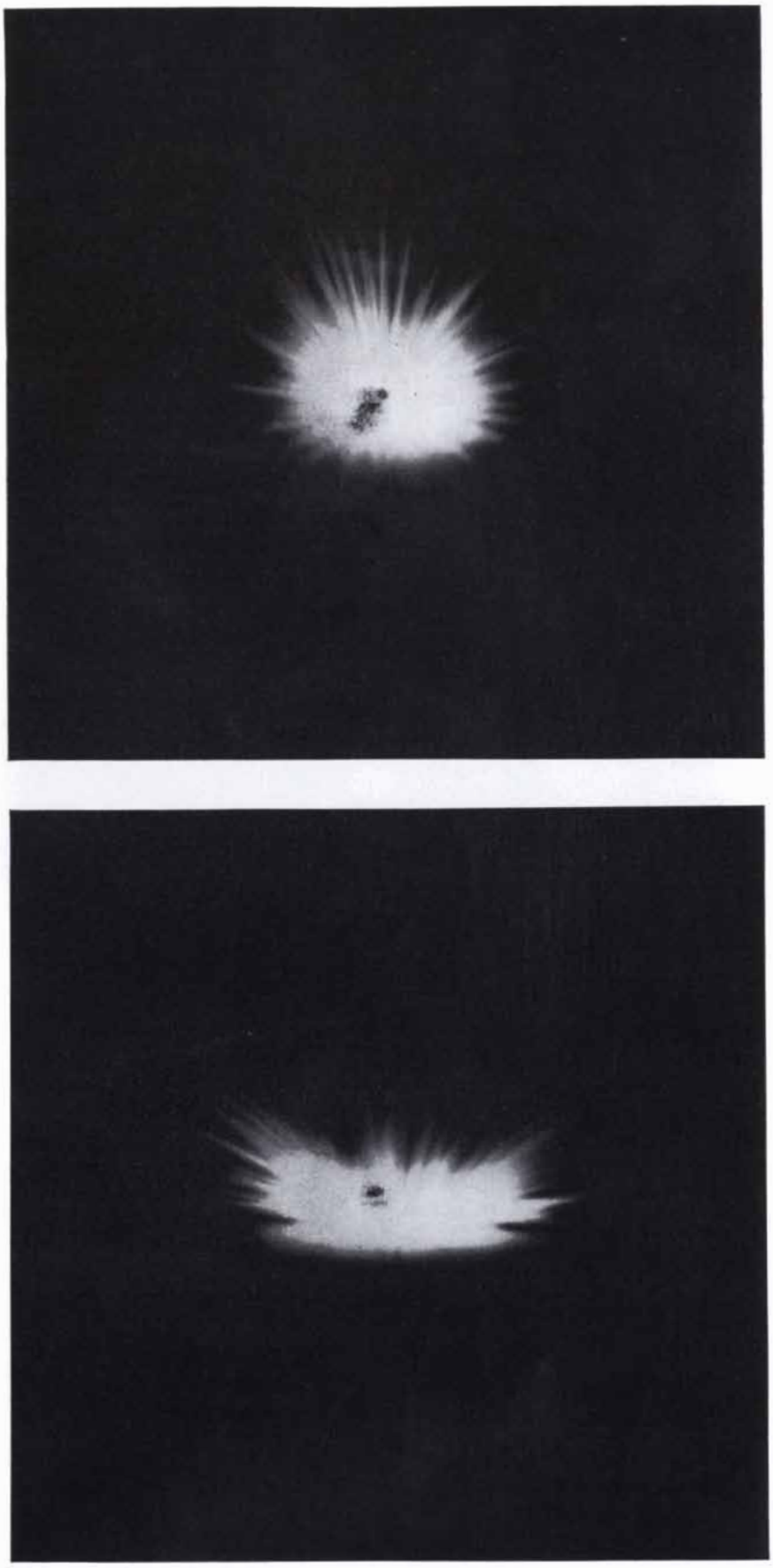
defense had finally won. Armored tanks withstood the heavest projectiles a practical antitank gun could fire, at speeds of 3,000 feet per second (about 2,100 miles per hour). The muzzle velocity of the guns could have been increased, but it would have done no good. At higher speeds projectiles of the strongest materials simply shattered upon impact, and their penetrating power failed to increase, or even decreased.

We shall see presently that the balance subsequently tipped the other way again. But war is no longer at the frontier of the impact problem. Today the artificial satellites circling the earth are traveling through a hail of tiny meteoroids, bits of stone and iron that move at relative speeds estimated to average 50,000 feet per second, and to go as high as 210,000 feet per second. Tomorrow's vehicles will carry men as well as instruments. The cosmic projectiles will impartially bombard soldiers, scientists or, if it comes to that, plain tourists.

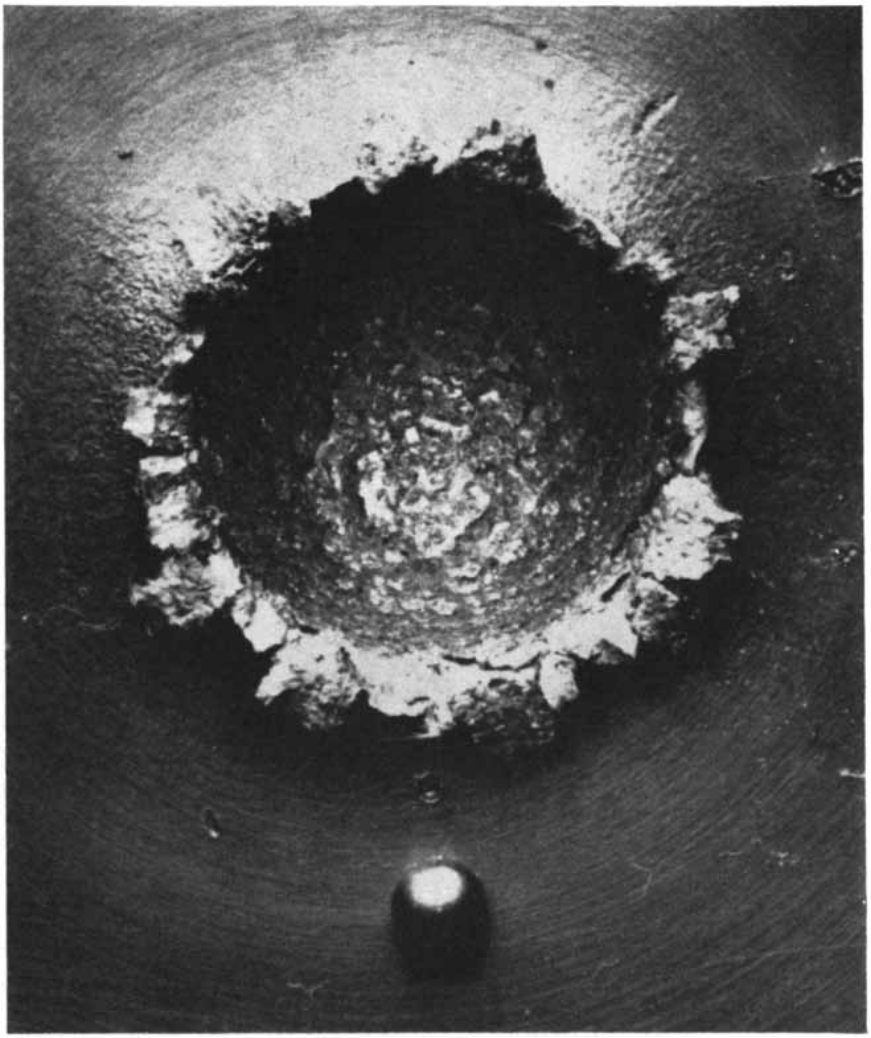
What happens to penetrating power at projectile speeds of 50,000 feet per second and up? How much weight will the designers of space ships have to waste on armor against meteoroids? No one knows precisely. Judging from the latest experimental data, a meteoroid of average speed weighing a few hundred millionths of an ounce could pierce a metal skin thick enough to contain air at normal pressure for space travelers. The experiments, which as yet extend only a little past 20,000 feet per second, show that high-speed impact differs sharply from the process at lower speeds. But how the results should be applied to still greater velocities is a matter of guesswork.

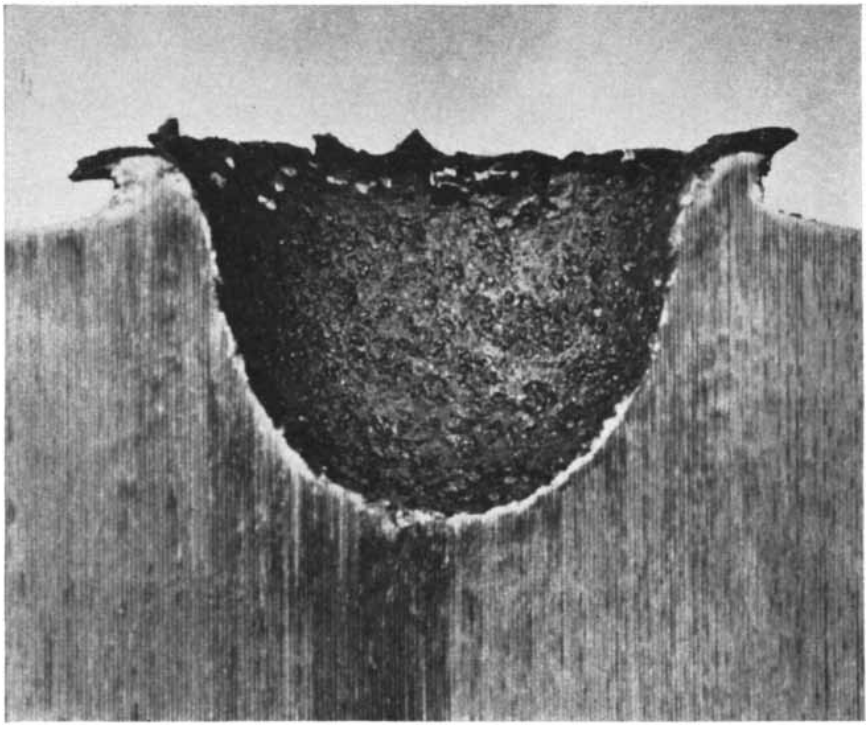
Changes in the phenomena of impact over the known range are nicely illustrated by an experiment carried out at the Ames Research Center of the National Aeronautics and Space Administration by James L. Summers and the author. We simply fired projectiles into targets and observed the craters produced by the impact. At low velocities the projectiles were spheres of tungsten carbide; at high velocities, hard ball-bearing steel. The targets were massive blocks of soft lead. Speeds varied from a few hundred feet per second to 20,000.

At low speeds the projectile penetrated the target intact and made a deep, narrow cavity like a nail hole. The penetration increased steadily with the four-thirds power of the velocity; that is, doubling the velocity of the projectile increased its penetration by a factor of



FLASH OF LIGHT accompanies impact at high speed in a helium atmosphere. Target is seen almost head-on (*top*) and from side (*bottom*). Dark spot in top photograph is impact crater. Photographs show a steel sphere striking a copper target at 10,000 feet per second.





IMPACT CRATER was made by 1/8-inch steel sphere like the one in the photograph at top. Sphere struck copper target at 18,700 feet per second. Fragments of the sphere can be seen lining the interior of the crater. Photograph at bottom shows same crater in profile view.

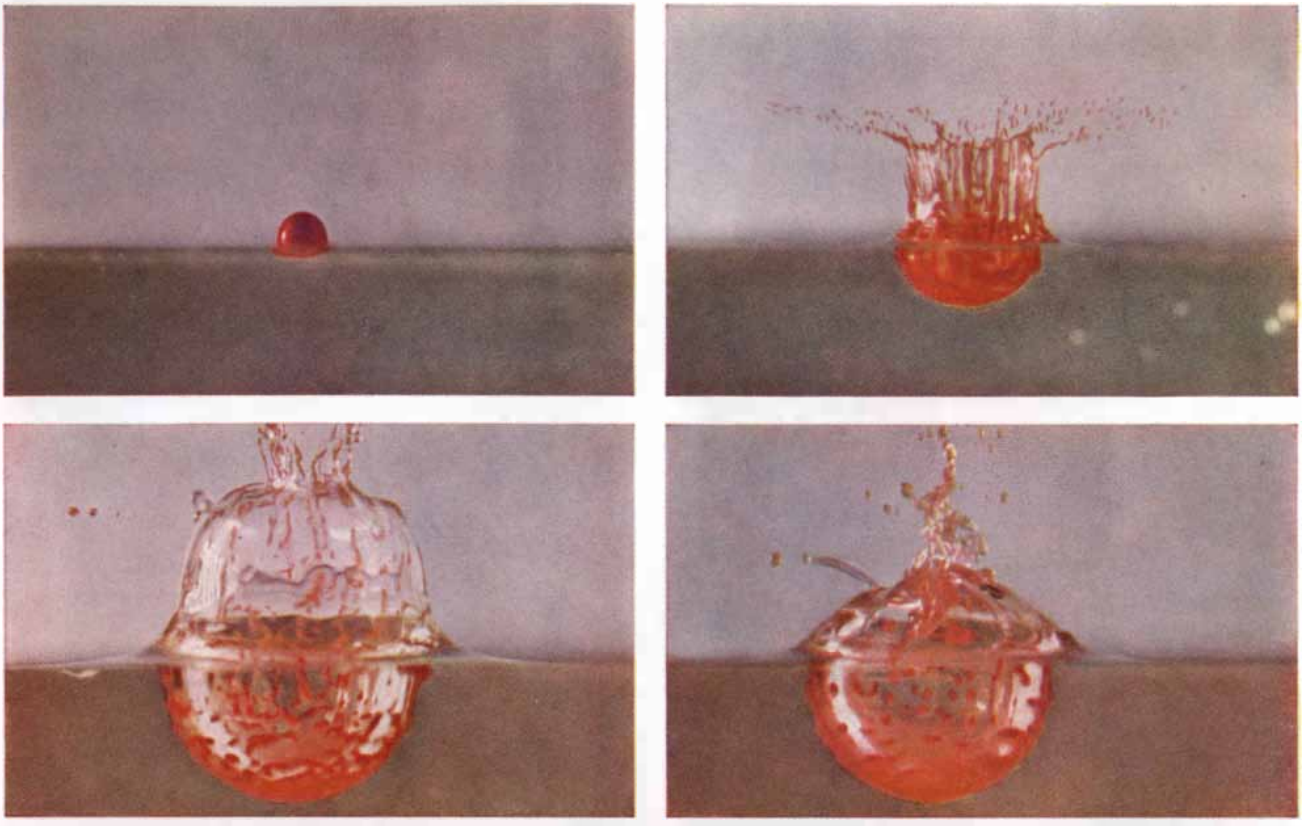
about 2.5. This relationship, which holds for a number of different materials, is embodied in the classic formula for armor-plate penetration discovered by a French army officer, Jacob de Marre. A second distinguishing feature of low-velocity impact is that the sphere retains its shape as it forces its way into the target.

At some velocity, depending on the strength of projectile and target, the projectile no longer withstands the forces of impact and starts to deform or, if it is brittle, to break into pieces. In our experiment this happened at 1,500 feet per second. As the velocity is increased beyond the critical point, a ductile projectile mushrooms in front, as though it were trying to turn inside out, and the rate at which the penetration increases with velocity begins to fall off. A brittle projectile fragments into finer and finer pieces; its penetration first increases slightly, then falls off a bit, and finally starts to increase again. In both cases the crater widens and begins to approach a hemispherical shape. An increasing part of the projectile's kinetic energy is being used in widening the crater rather than in increasing the penetration.

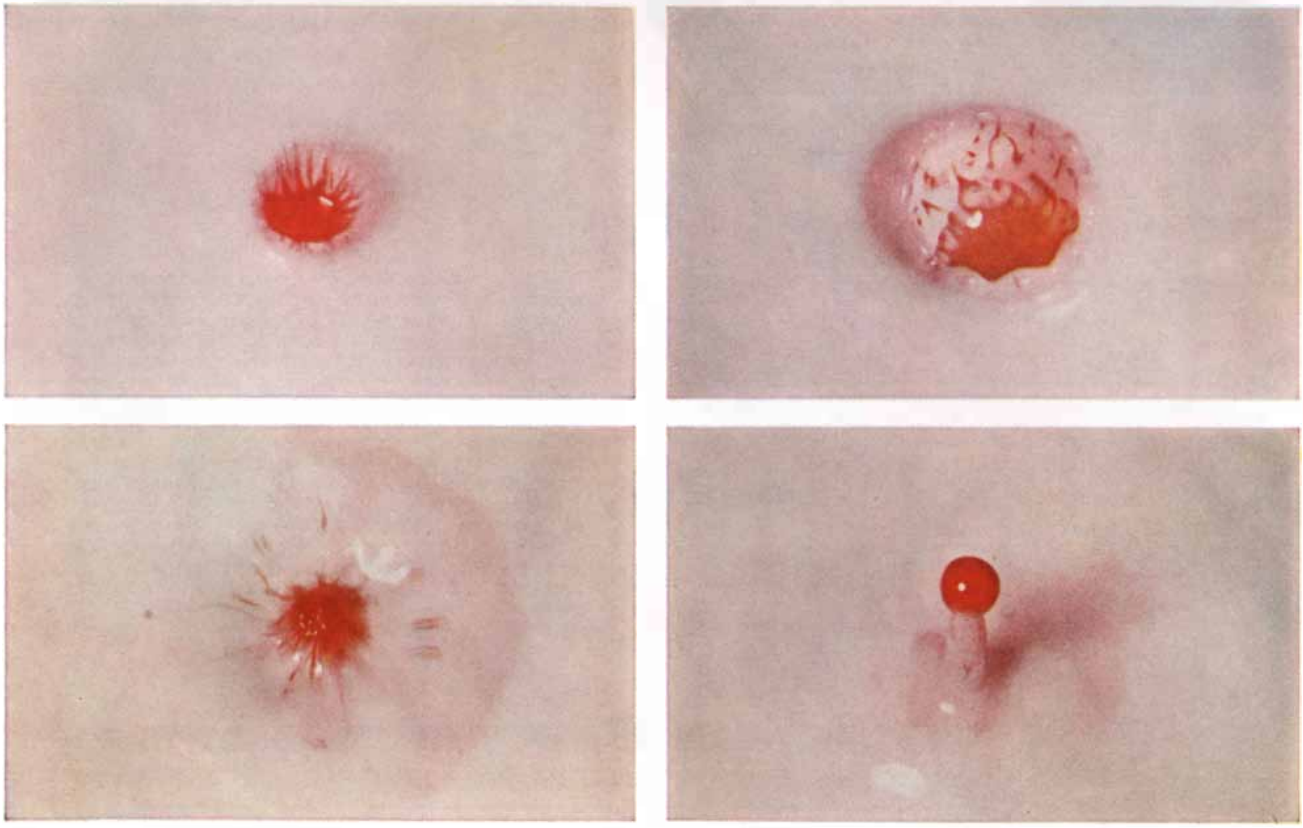
Eventually (at about 8,000 feet per second in our experiment) the shape of the crater becomes almost exactly hemispherical. At still higher speeds, the penetrating power of the projectile again increases with velocity at a constant rate, although more slowly than in the unbroken-projectile region. It now varies with the two-thirds power of velocity; doubling the velocity increases penetration by a factor of about 1.6. Clearly a transition zone has been crossed, and we are in a new region of impact [*see illustration on page 128*].

One characteristic of this region stands out quite clearly: In the early stages of impact, when the pattern of the process is determined, the forces, or stresses, set up are very much greater than the mechanical strength of either projectile or target. For example, when a steel ball hits a lead target at 20,000 feet per second, the pressure in the ball at the start of the collision is greater than 30 million pounds per square inch, more than 100 times the ultimate strength of the steel. Under such conditions the materials must behave as though they had virtually no strength at all.

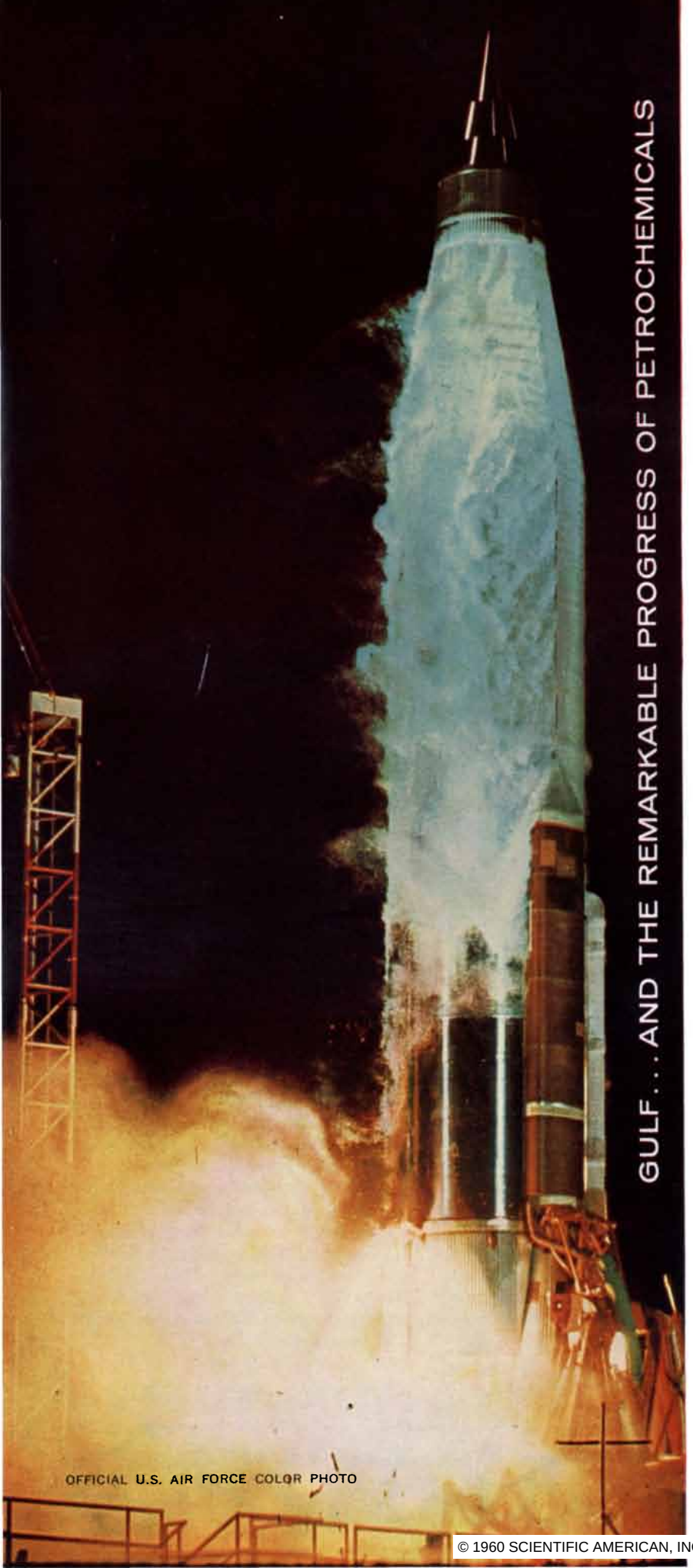
Now a material with little or no strength to resist a change in shape is a fluid. Thus one might expect the projectile and target to flow under the stresses of impact as though they were fluids. This is in fact what the experiments



FLUID IMPACT is depicted in a sequence of high-speed photographs of a colored drop of water falling from a height of eight feet into colorless water. At top left the drop enters the water. At top right, .0025 second later, a sheath of water rises from the edge of the crater. At bottom left, after .015 second, a bubble forms. At bottom right, after .025 second, the bubble begins to collapse.



DROP REFORMS in the last photograph of this sequence, made from above the surface of the water. Here the drop fell only 18 inches, and the water into which it fell was colored white. The photograph at top left followed impact by .003 second; the photograph at top right, by .035 second; the photograph at bottom left, by .05 second; the photograph at bottom right, by .065 second.



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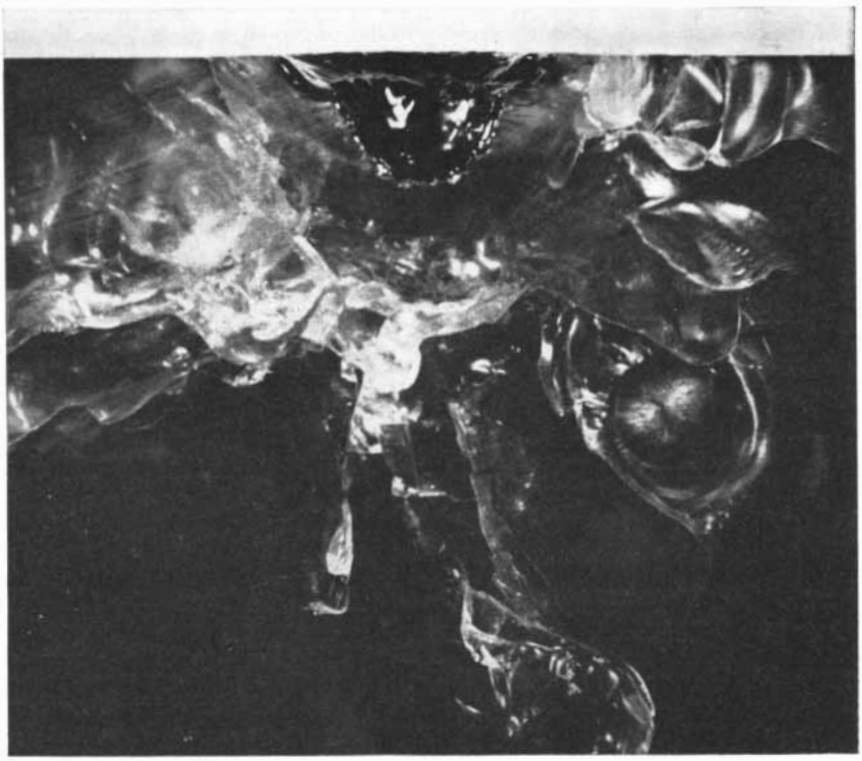
seem to show, and the new region has been named the fluid-impact region.

In ductile metal targets such as lead or copper the material continues to flow as a fluid throughout the entire cratering process, so that the craters provide a convincing demonstration of fluid impact. Around their circumference rises a thin wall of metal that looks as though it had been splashed up. If the projectile is also ductile, it flows over the target material and remains as a plating covering the surface of the crater. Even if the projectile is brittle, the result is much the same; the projectile breaks into small pieces at the start, and, as the crater opens up, the pieces float out on top of the flowing target material.

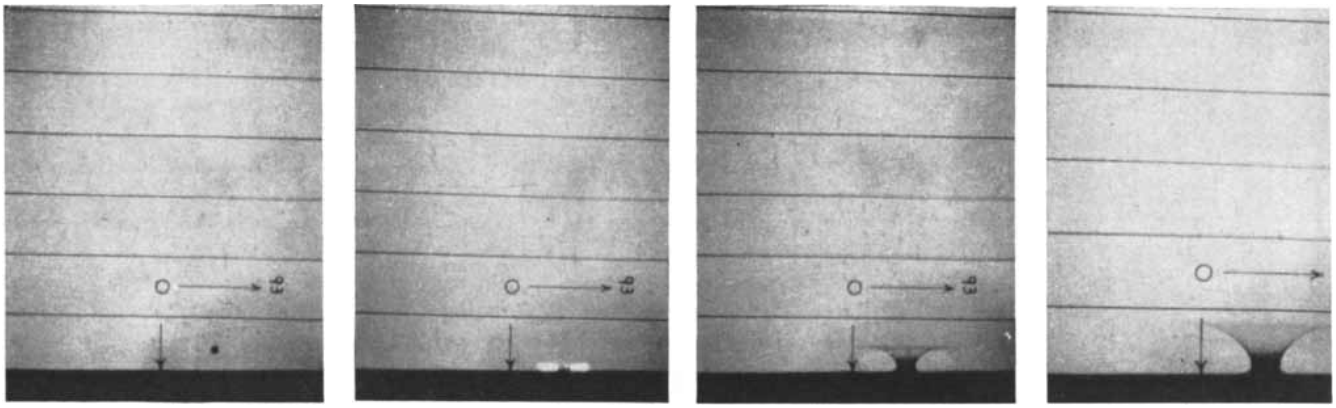
This conception of the impact process stimulated H. Julian Allen and Donald E. Gault, also at the Ames Research Center, to investigate impact in true liquids. In one experiment their target was a tank of clear water, and their projectile a falling drop of colored water. A sequence of flash photographs [*see page 131*] shows the course of the impact in elegant detail. The crater forms, the drop flows out over its surface and a cylindrical sheath of water jets up around the crater's edge. When the crater has opened to full size, it looks much like the craters in lead and copper, with a raised rim around it and the drop spread out over its surface.

Toward the end of the cratering the inertia of the flow dies away, and the forces of gravity and surface tension take control of the motion, since water is a true liquid and has no structural strength. At this point the analogy with the fluid impact of solid bodies breaks down. But the subsequent events are so pretty that it would be too bad not to describe them. In some cases the crater collapses, and a spout of water rises far up out of its center with its very tip capped by a drop. To our amazement we find that this new drop contains nearly all the colored water of the original drop that produced the crater. In other cases the sheath of water around the edge of the crater rises so high that surface tension draws the top of the sheath together, like a drawstring closing a sack, and the crater "bubbles over." When heavy rain falls on a quiet pond, the surface is often covered with bubbles formed in just this way.

The water-drop experiment is instructive as well as beautiful, but its conditions are a far cry from the extreme violence of high-speed impact. Although the final craters look much alike, the moment-by-moment process of their formation must be quite different in detail. A year ago there was no experimental



TRANSPARENT TARGET of epoxy resin shows extensive region of fracturing after being struck by nylon sphere. The sphere was about 1/4 inch in diameter and was fired at a velocity of 21,000 feet per second. The crater shown in this profile view is about 2/5 inch deep.



HIGH-SPEED PHOTOGRAPHS show the spray of metal fragments ejected during the formation of an impact crater. The projectile was a steel sphere 1/8 inch in diameter and was fired at a velocity of 15,000 feet per second. Sphere is visible in frame at far left. The target is a massive block of duralumin; its surface appears as a dark band at the bottom of each frame. Parallel lines

information about these details, but since then some really remarkable photographs of high-speed impact have been made. Two research teams, one directed by Alan S. Galbraith at the Eglin Air Force Base and the other by Robert J. Eichelberger of the Army Ordnance Department, photographed impacts in metals and transparent plastics with a motion-picture camera that has a rate of 1.2 million frames per second. Eichelberger's group also used flash X-ray photography to record cratering in aluminum.

Let us look at the results of a typical experiment: the impact of a steel sphere in a massive aluminum target at a speed between 10,000 and 25,000 feet per second. The impact is announced by a brilliant flash of light. As the front of the sphere moves into the target, a spray of fine particles squirts out to the side at very high speed, about twice the velocity of impact. Next a shock wave radiates out from the point of impact, compressing and accelerating the material of the target to make room for the onrushing sphere. Another wave backs up into the sphere, decelerating it so that the materials of sphere and target move in unison along a common boundary. Heat generated by the waves may cause momentary melting.

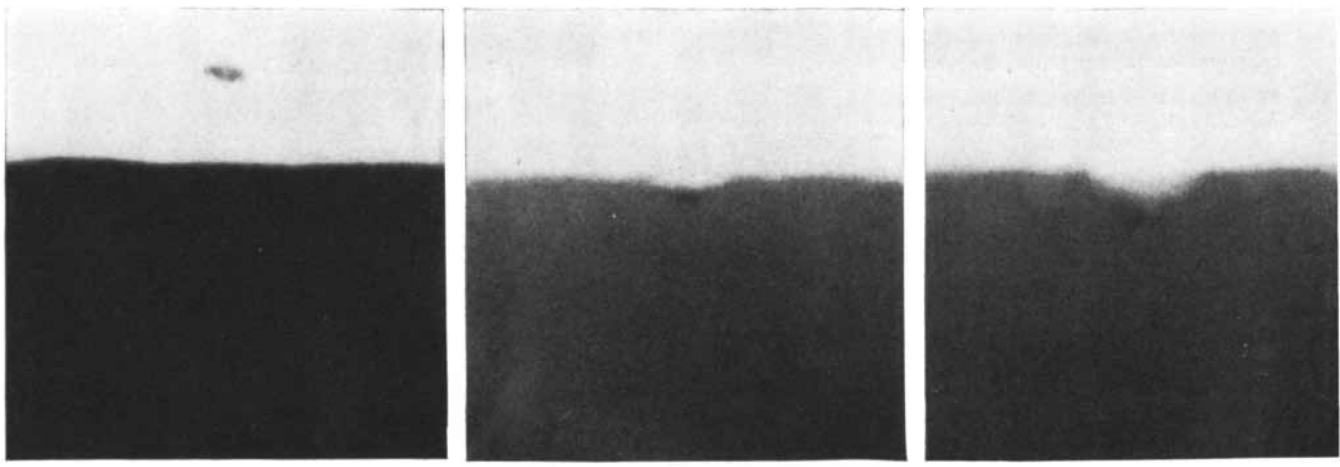
The crater now starts to form. The target substance flows radially away from the point of impact, opening up a hemispherical cavity. The projectile's material flows on top of the crater, stretching itself thinner and thinner. Most of the flow is in a radial direction, but some material moves around the crater edge and is ejected in a sheath-like jet. As the crater grows, the angle of the jet steepens, the velocity of ejection decreases, and the sheath takes the shape of a graceful flower vase.

Meantime the front of the shock wave rushes ahead. The expanding crater follows close behind, and between the two is a hemispherical shell of hot matter, which is compressed by the shock wave and stretched by the expansion of the shell. The shock wave weakens as its volume of action increases, and as it is overtaken by tension waves connecting free surfaces with the material moving away underneath.

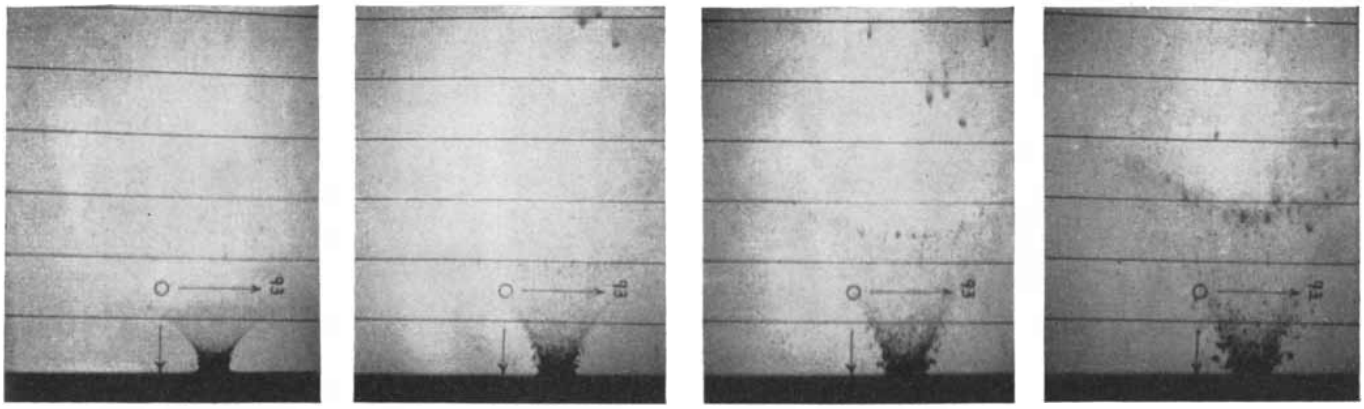
At length the strength of the target material takes over, and all flow stops. At this point the crater's surface rebounds slightly as the elastic stresses in the main body of the target relax. The final volume is about 15 per cent less than the maximum reached before the rebound.

Now that these details are known, it would be nice to build from them a comprehensive, accurate theory of fluid impact. Among other things, the theory would enable a space-craft designer to anticipate the effects of meteoroid bombardment. Here, however, there is a long way to go.

Some empirical formulas have been



HIGH-SPEED X-RAY PHOTOGRAPHS show formation of impact crater in soft aluminum. Projectile visible in frame at left is a disk weighing .006 ounce; it was fired at a velocity of 16,400 feet per second. Frames show sequence of events during interval of



in background are reference marks one inch apart; arrows and numerals are marks in the optical system of the camera. Although target was illuminated by a flash lamp, the light produced by the impact is bright enough to be seen in the second frame from left. These frames were selected from a film made at 1,200,000 frames per second by Alan S. Galbraith at the Eglin Air Force Base.

developed that represent the experimental measurements fairly well over restricted regions. In my opinion they are all we have in the way of reasonably reliable engineering data. Then there is a spate of theories deduced with the utmost rigor from various sets of rather arbitrary assumptions. Everyone in the field (including Summers and the author) has come forward with at least one theory, but they are all suspect. The only full-fledged theoretical attack, starting with basic physical equations, has been made by Robert L. Bjork of the Rand Corporation. Unfortunately his first calculations, at least, do not agree well with the experimental data.

Almost everything that has been said thus far applies to impact in ductile materials. Before leaving this part of the story we should mention the remarkable invention known as the shaped charge. The device consists simply of a thin cone of metal, called a liner, embedded in a cylinder of high explosive, with the open end of the cone at one end of the cylinder. When the charge is fired, the detonation is started at the end opposite the cone. The detonation wave travels along the cylinder of explosive, collapsing the cone as it goes. As the cone collapses, a thin, long jet of liner metal squirts out of the open face at very high velocity, ranging from 26,000 feet per second at the front of the jet to 10,000 at its rear. This jet is used as a projectile.

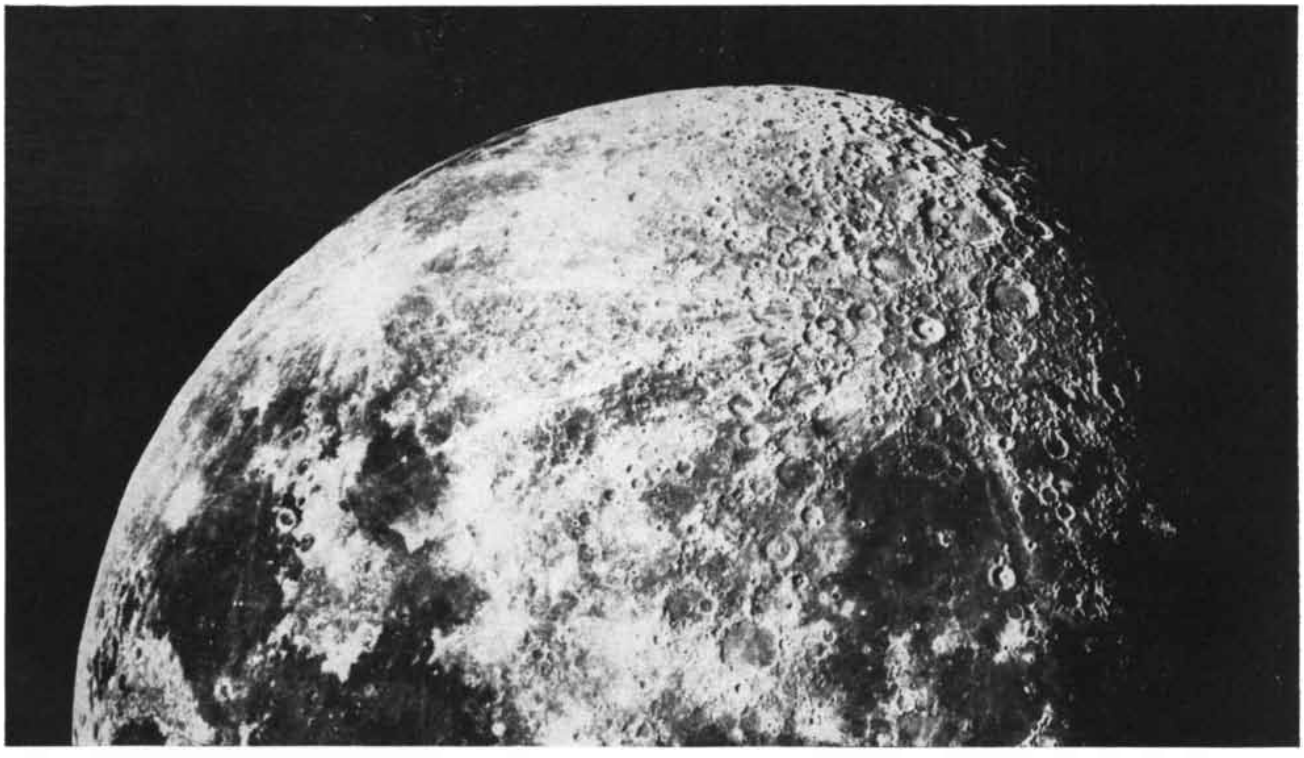
With a speed well within the fluid-impact region, the jet penetrates a target by means of fluid flow, just as a high-speed sphere does. The crater it produces is a deep, narrow hole, the volume of which is very nearly the same as that of the hemispherical crater made by a sphere of equal weight. A shaped charge with a cone two inches in diameter can pierce 10 inches of armor, and can thus knock out the largest tank yet built.

The biggest impact craters we know of, dwarfing anything that man-made projectiles can produce, are those left on the surface of the earth and of the moon by large meteorites. In order to learn something about the formation of these huge scars a number of investigators have studied impact on laboratory samples of rock. The craters are entirely different from the smooth hemisphere described earlier. A rock crater is wide, shallow and almost circular, with minor serrations around the edge, but no raised rim. Its surface is rough and jagged, sloping flatly from the edge to the center. No pieces of the projectile can be found in the hole. A vertical cut through the sample shows that the central part of the crater is underlain with a lens of finely crushed rock, similar, on a small scale, to what the geologists call a breccia.

Trying to guess the processes of impact from an examination of a crater is a little like trying to write a man's biography from his post mortem, but these distinctive features are probably due

45 millionths of a second. Dark band around crater in second frame from right is hemisphere of compressed aluminum. Photographs were made at the Ballistic Research Laboratories of Army Ordnance Department under supervision of Robert J. Eichelberger.

METEOR CRATER in Arizona is a bowl-shaped depression 4,000 feet in diameter and 400 feet deep. As in the impact craters formed experimentally in ductile metals, this crater has a raised rim; otherwise its shape resembles that of experimental craters in rock.

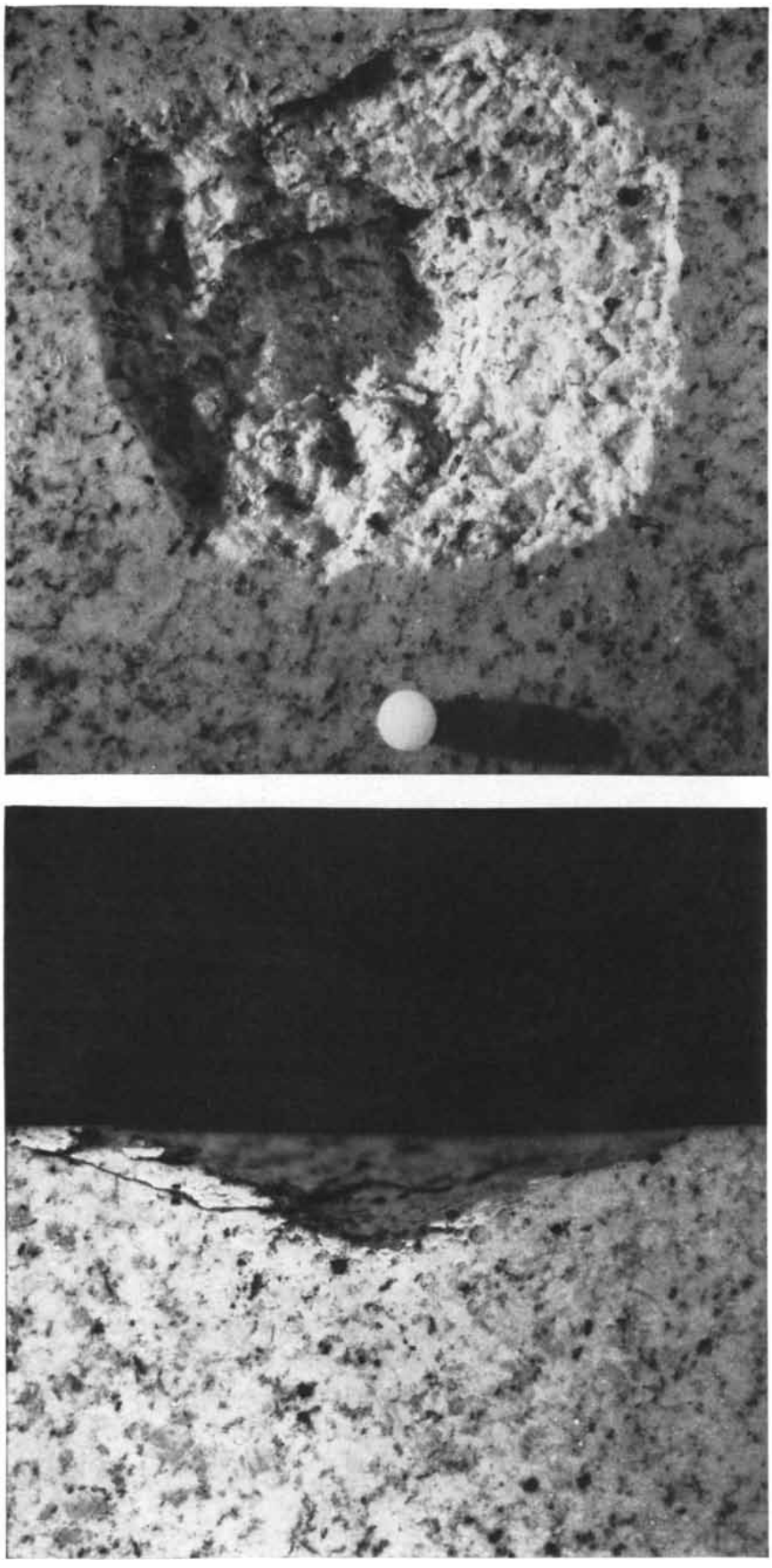


LUNAR CRATERS such as Tycho (*the bright crater above the large dark area at lower right*) dwarf those on the earth. Formed by the impact of a giant meteor, this crater measures 54 miles across and is 12,000 feet deep. The rim that surrounds it is 7,000 feet high.

primarily to the very low tensile strength of rock. Tensile forces can break rock up completely throughout a considerable volume. Tension waves and elastic rebound would then throw the broken rock out of the target block, leaving only the small lens of compacted breccia at the bottom. A motion picture of a shot in granite shows that the material ejected from the crater starts in a high-velocity, conical spray of finely divided material similar to the first splash from a metal target. By the end of the impact the spray of fine rock particles has changed to a low-velocity cylindrical column composed of larger fragments and pouring back out of the crater along the flight path of the projectile. The sequence suggests that cratering starts in the same way regardless of the target material, but that its subsequent progress is strongly affected by the material's properties.

Comparing the tiny cavities we can make in the laboratory to the magnificent geological features formed by the impact of great meteorites may seem a considerable stretch of analogy. For example, the famous Meteor Crater in Arizona is a bowl-shaped depression 4,000 feet in diameter and 400 feet deep. It has a raised rim 200 feet high around its circumference. The Arizona crater is dwarfed by lunar craters such as the one called Tycho, situated in the southern uplands of the moon. This giant hole measures 54 miles across, its depth is 12,000 feet. Its surrounding rim is 7,000 feet high, and the crater has a small group of 5,000-foot mountains in its center.

Obviously experimental craters in rock are distinguished from natural ones by more than mere size. The natural structures have raised rims, like craters in ductile metals, but are wide and shallow, like craters in rock. The Arizona crater is underlain with a deep lens of breccia. On the other hand, the central mountains of large moon craters have no counterpart in either the Arizona crater or the laboratory types. It seems probable that gravity is partly responsible for the differences, because it is one element that our experiments do not scale correctly. At least it can account for the raised rims. Assuming that the volume of rock crushed by impact is proportional to the kinetic energy of the projectile, natural or artificial, and that a fixed fraction of the energy goes into throwing the crushed material up out of the crater, calculation shows the height to which this rock will be lifted to be the same regardless



CRATER IN ROCK is shown in head-on view (*top*) and side view (*bottom*). It was made by firing a nylon sphere about a quarter of an inch in diameter at a block of granite. Velocity of sphere was 17,500 feet per second. Impact craters in rock are wide and shallow.

of the size of the projectile. This means that a fragment of rock thrown far away from a laboratory target would have moved an insignificant distance compared to the 500-foot depth of the Arizona crater or the 12,000-foot depth of Tycho. What probably happened is that some material was thrown out sideways over the edge of the natural craters. This material was piled up to form the rims. In addition some upthrusting of the surrounding terrain during the impact very likely helped build up the rims, particularly in craters as large as Tycho.

Why are lunar craters shallower with respect to their diameter than the Arizona crater? And what about their central mountain peaks? Eugene M. Shoemaker of the U. S. Geological Survey suggests that gravity effects also explain these features. According to his analysis, a fixed fraction of the impact energy goes into crushing rock, and the volume of breccia produced increases proportionately with the size of the crater. But less and less of this rock is thrown out of the hole as the size increases, because, as we have said, the distance it travels remains constant. Consequently most of the breccia in large craters settles back after impact, resulting in a relatively shallow profile. The central peak is then presumably formed by breccia slumping down the sides of the crater, in the same way that the central spout in the water-drop crater is formed by the collapse of the cavity. The reasoning is persuasive. But its assumptions need checking by high-speed movies and flash X-rays of laboratory experiments in rock, and these have yet to be made.

Let us close our story by playing a popular guessing game: How big was the meteorite that made the crater in Arizona? "Educated estimates" range from 10,000 tons to five million. Using the Charters-Summers theory of impact, and making plausible assumptions about the speed and direction of the meteorite and the strength of the rock, I shall enter two guesses. If the proper value to take for the depth of penetration is 500 feet (to the top of the breccia layer), then the meteorite weighed 10,000 tons. If penetration must be considered to extend to the bottom of the layer, 400 feet lower, then the weight was 60,000 tons. By means of a quite different approach Shoemaker arrived at an answer of 63,000 tons. The agreement is encouraging, but we need a much firmer base of fundamental knowledge to be confident that it is not just a happy coincidence.

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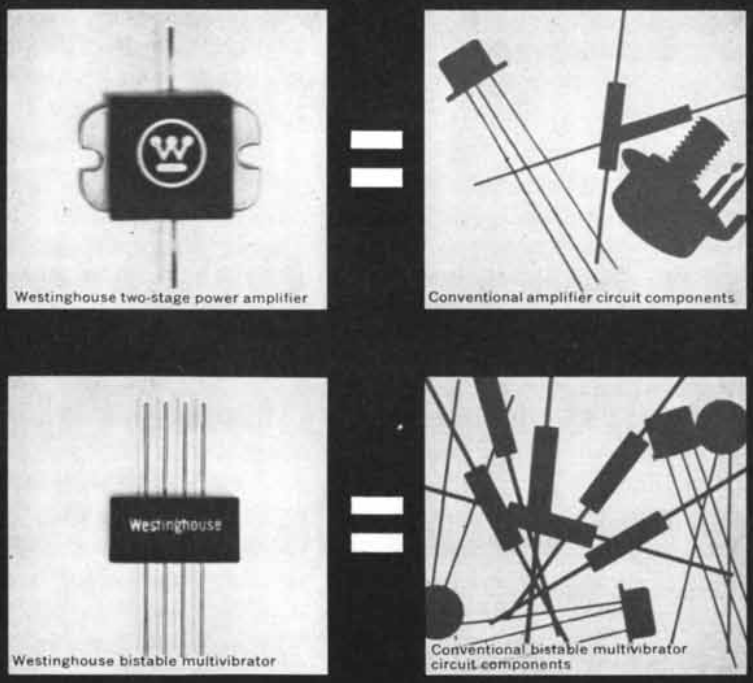

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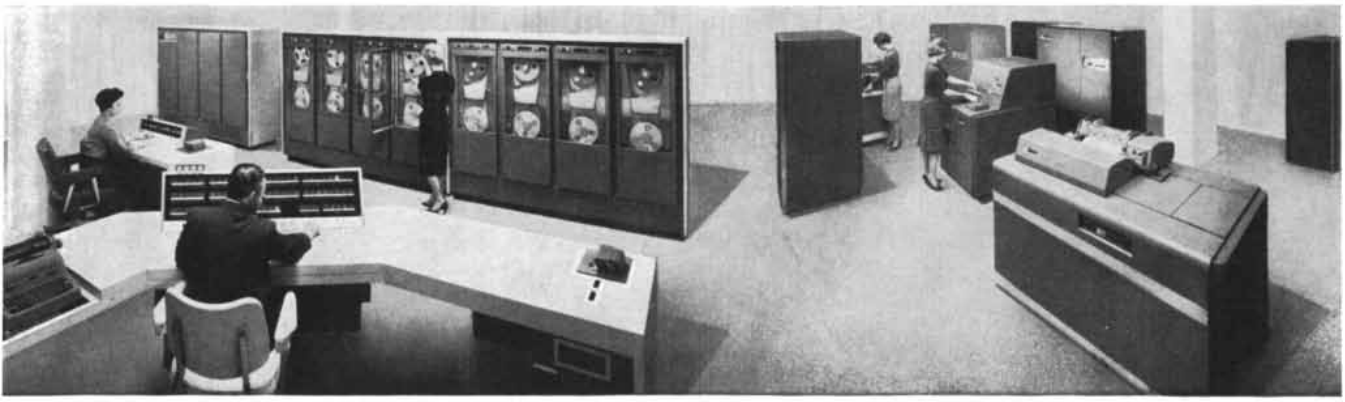

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The Physics of Wood Winds

For centuries craftsmen have fashioned these instruments by trial and error and rules of thumb. The principles that underlie these empirical methods are now being studied by the modern physicist

by Arthur H. Benade

There are, of course, hundreds of directions in which the mind of a physicist can stray while he sits in a concert hall, but one in particular unites his esthetic and scientific interests in a most fruitful manner. He can, if he likes, trace the history of much of his discipline in terms of the study of music and the instruments that make it. As far back as Pythagoras it was recognized that the most prominent pitch intervals are obtained by shortening a harp string so that some simple fraction (1/2, 1/3 and so on) of its length is left free to vibrate. Study of the vibration of strings by René Descartes' collaborator Marin Mersenne laid a foundation for the study of partial differential equations and their applications, a development whose roots are found in the work of such great mathematical physicists as Daniel Bernoulli and Jean le Rond d'Alembert in the 18th century. In the 19th century Hermann von Helmholtz devoted a large fraction of his enormous talents to the study of vibrating systems, as did Lord Rayleigh (who died in the 20th century, leaving his *Theory of Sound*, which is still a classic).

The rise of quantum mechanics has made the understanding of the underlying classical wave-theory even more important to physicists than it was in the days of Rayleigh. As a result every student of physics, whether he is interested in music or not, is faced daily with classroom problems that are variations on a theme born originally of music.

Since the mid-1920's, however, the engrossing new questions of quantum physics have diverted the energy of both theoreticians and experimenters from the more traditional lines of study, and so brought active musical research largely to an end. Still, the stage is set for a revival of musical physics. The techniques of measurement and calculation that have developed during the last 40 years in other areas of physics may now make it possible to solve problems in music that have withstood the best efforts of the past.

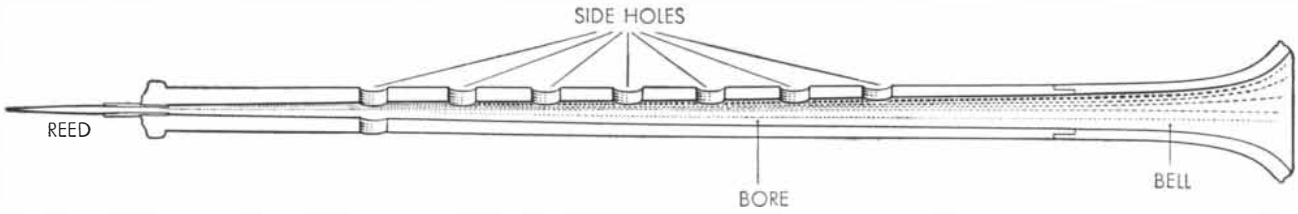
Some of the most stubborn questions are posed by the search for an orderly connection between the physical properties of instruments and the musical sounds that issue from them. The instruments are all of ancient descent, antedating Pythagoras and others who first felt the strong pull of music on the scientific as well as on the artistic imagination. The various winds and strings assumed their modern forms by a process akin to biological evolution. Trial and error, rule of thumb and traditions handed down from generation to generation of instrument makers account for the characteristic quality of the sound that each one generates, as well as for their peculiarly individual appearance and design. Yet much of the anatomy, and therefore of the performance, of an instrument is susceptible to analysis. One is led to ask if it is possible to create, with the help of theoretical considerations, new ways of constructing instruments whose performance is the same as those that have grown from empirical invention. Can we clarify the problems facing players and builders of these instruments in a way that suggests answers to hitherto unsolved problems? Can we invent entirely new musically useful instruments?

My own interest in these questions began with the playing of wood winds—the tubular horns that bristle with levers, buttons and rings, and are played by the musicians who sit in the middle background of the symphony orchestra. Most familiar are the clarinet, the oboe, the bassoon, the saxophone, the English horn and the flutes (including the recorder, the fife and the piccolo). But the family also includes the bagpipe and such less well-known instruments as the arghool and the chalumeau (relatives of the clarinet), the aulos, or Greek flute, and the shawm (a relative of the oboe).

All wood winds may be disassembled mentally into three essential parts: the reed, the bore and the side holes. Air blown into the instrument through the reed sets up vibrations in the column of air within the bore, and this vibrating air column produces the sound of the instrument. The frequency at which the air vibrates is determined chiefly by the dimensions of the bore. These dimensions are modified in turn by the side holes in both their open and closed positions, as will be seen.

The reed system acts as a valve. It replenishes the vibrational energy of the air in the bore by converting a steady flow of compressed air from the player's lungs into a series of puffs at the frequency dictated by the bore. This valving of the air supply is accomplished differently in the flutes than in the other wood winds, but the device that does it may nevertheless be called a reed. The reed valves of all wood winds except the flutes are pressure-operated. They consist either of a single blade of cane fitted to a mouthpiece (as on the clarinet and saxophone) or a double blade of cane (oboe and bassoon). Vibration of the reed opens or shuts the thin slit (between the reed and the mouthpiece or between the two reeds) through which

FAMILIAR WOOD WINDS (*from left to right*) **include the bassoon, oboe, flute, clarinet, English horn and saxophone. The wood-wind family also includes the bagpipe, the piccolo and several other instruments.**

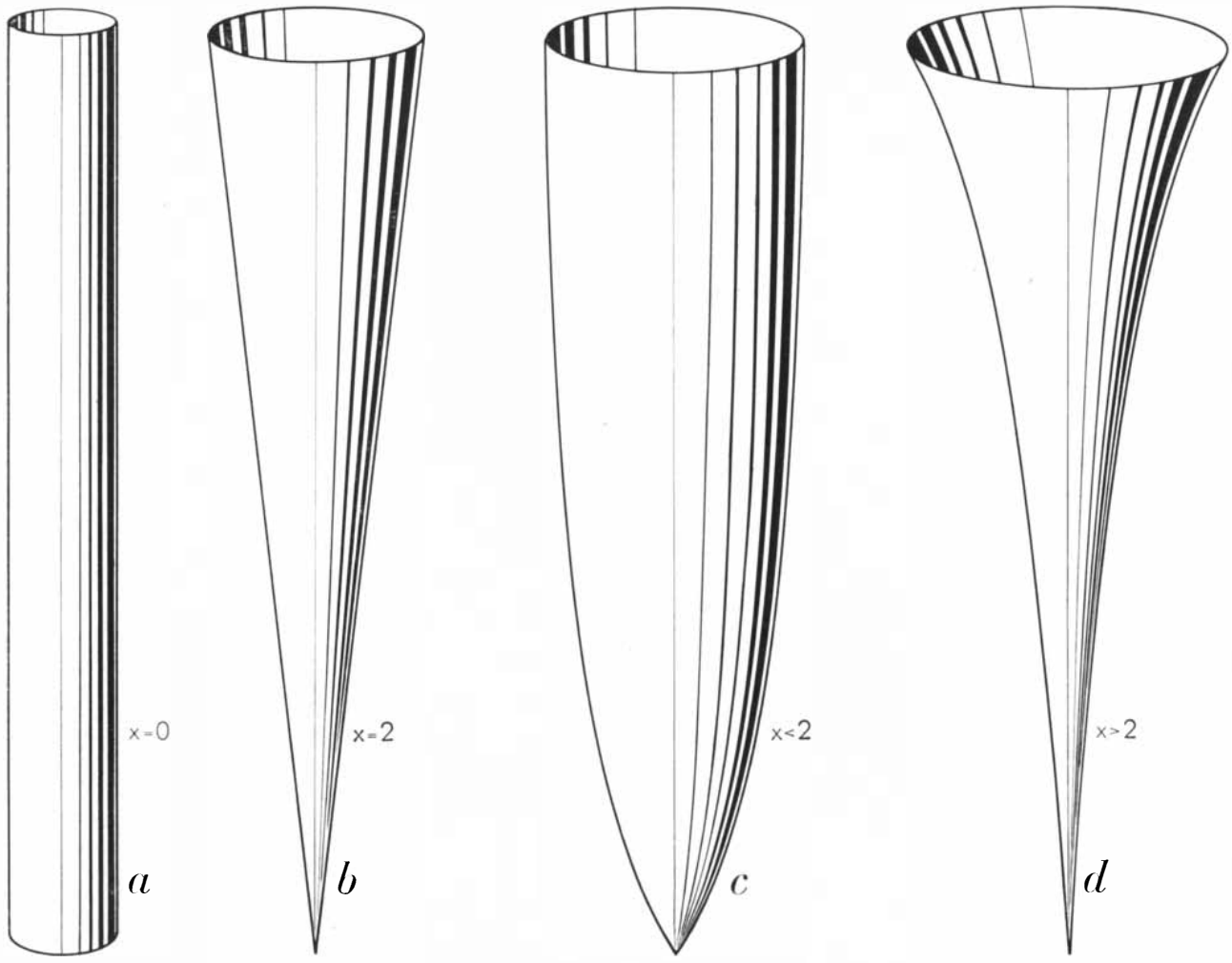


MAIN PARTS of a wood wind are the reed, the bore and the side holes. Oboe shown in this schematic cross section has fewer holes than actual instrument. Oboes, English horns and clarinets are equipped with bells; flutes, saxophones and bassoons are not.

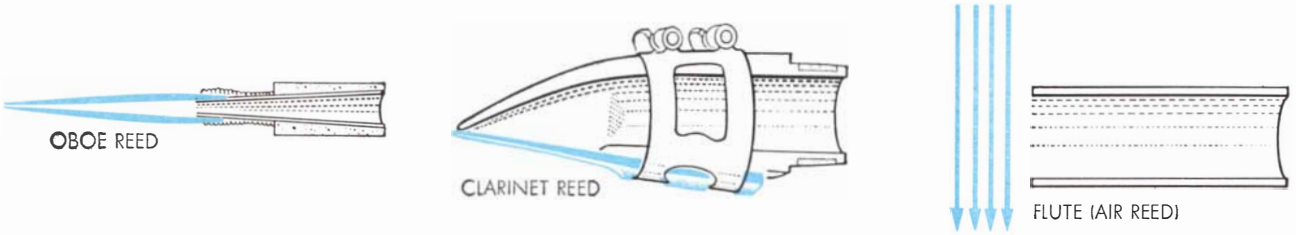
the air is blown into the bore. The frequency of vibration is set by the cyclic changes in the pressure of the vibrating air in the bore. The mass and stiffness of the cane give the bore almost complete domination over the reed in determining the pitch. This domination of the reed by the bore is one of the distinguishing characteristics of wood winds. In contrast, the tube, or bore, of a brass instrument, such as the trumpet or trombone, strongly influences the "reed" (the vibrating lips of the player) but does not dominate it; the same is true of the relation between the pipes and reeds used in pipe organs.

In flutes the function of the reed is served by a thin jet, or "reed," of air blown across the mouth hole in the side of the instrument. The vibrations of an air-jet reed are controlled by cyclic changes not in the pressure but in the velocity of the air at the upper end of the bore. Rushing in and out of the bore at right angles to the reed, the vibrating air column drives the reed-jet upward and downward at the frequency fixed by the bore and side holes [*see illustration on pages 148 and 149*].

Because cane reeds are pressure-oper-

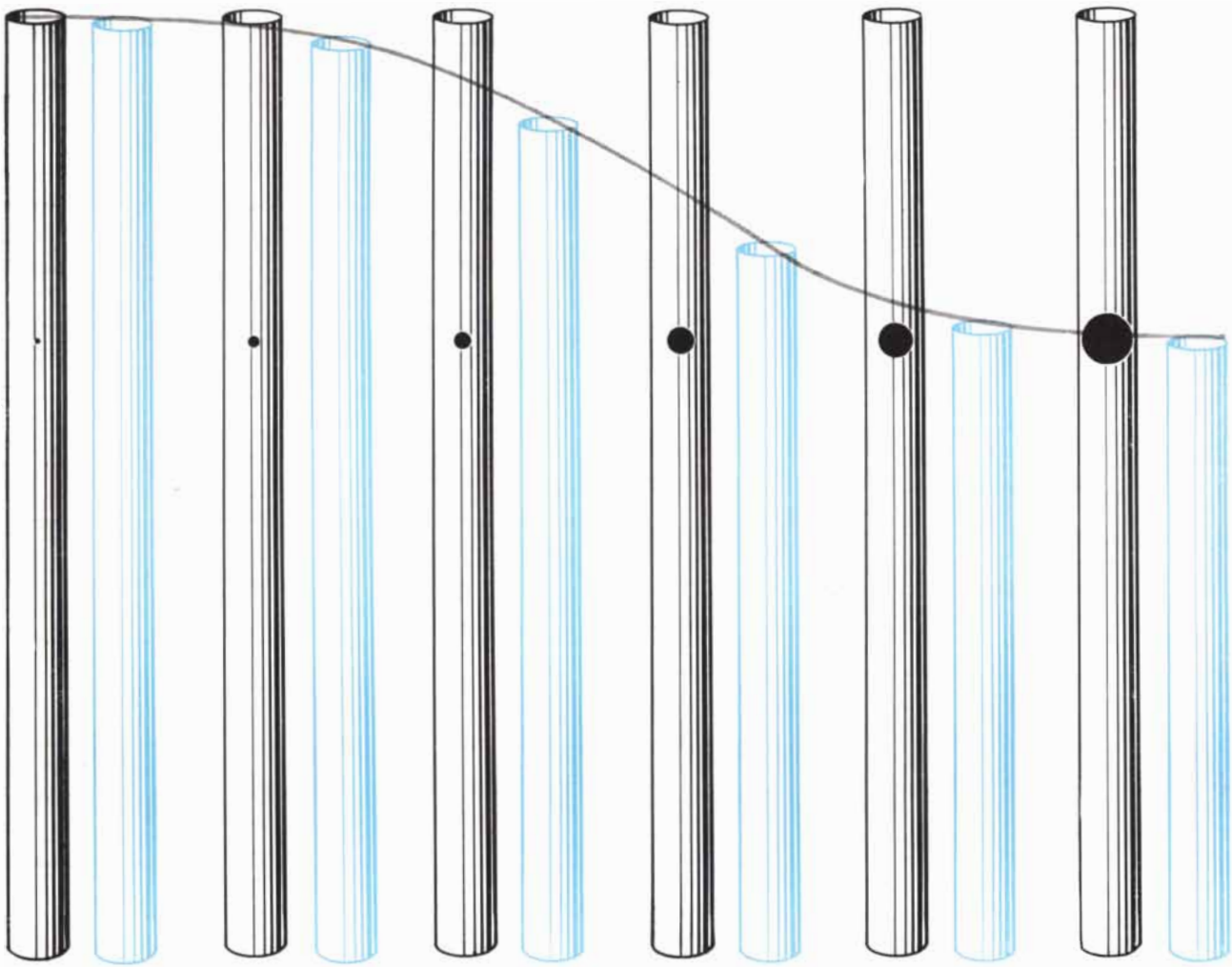


BESSEL HORNS increase in cross-sectional area according to some exponent (x) of the distance from the end of the horn. Bores of all practical wood winds are either cylindrical Bessel horns (a) or conical Bessel horns (b). Horns c and d are musically useless.



REEDS (*color*) act as valves that control flow of air into a wood wind. Cane reeds of oboe and clarinet are opened and shut by changes in pressure of the vibrating air in the bore; air-jet "reed" of flute is controlled by changes in velocity of the air in the bore.

ated, they will function only when the vibrations of the air column in the bore are such as to produce maximum variation in pressure at the mouthpiece end of the bore. The air-jet reed of the flute correspondingly requires vibrations that produce a maximum variation in velocity at the same end of the bore. Since the end of the bore away from the player's mouth is essentially open to the atmosphere, the variation in air pressure at that end can only be very small, and, with the air free to flow in and out, the variations in velocity will consequently be large. In short, the operation of a cane reed calls for those vibrations in the air column that produce maximum variation of pressure at the reed end of the bore, and essentially zero fluctuations at the lower end, while an air-jet reed will sustain only those vibrations that yield a maximum fluctuation in velocity at both ends. It is interesting that this specification of the "end conditions" for a bore is in precisely the same form as that which mathematicians use in solving problems of vibrating systems involving no reed at all. Theory and experiment agree that only a certain discrete set of vibrational frequen-



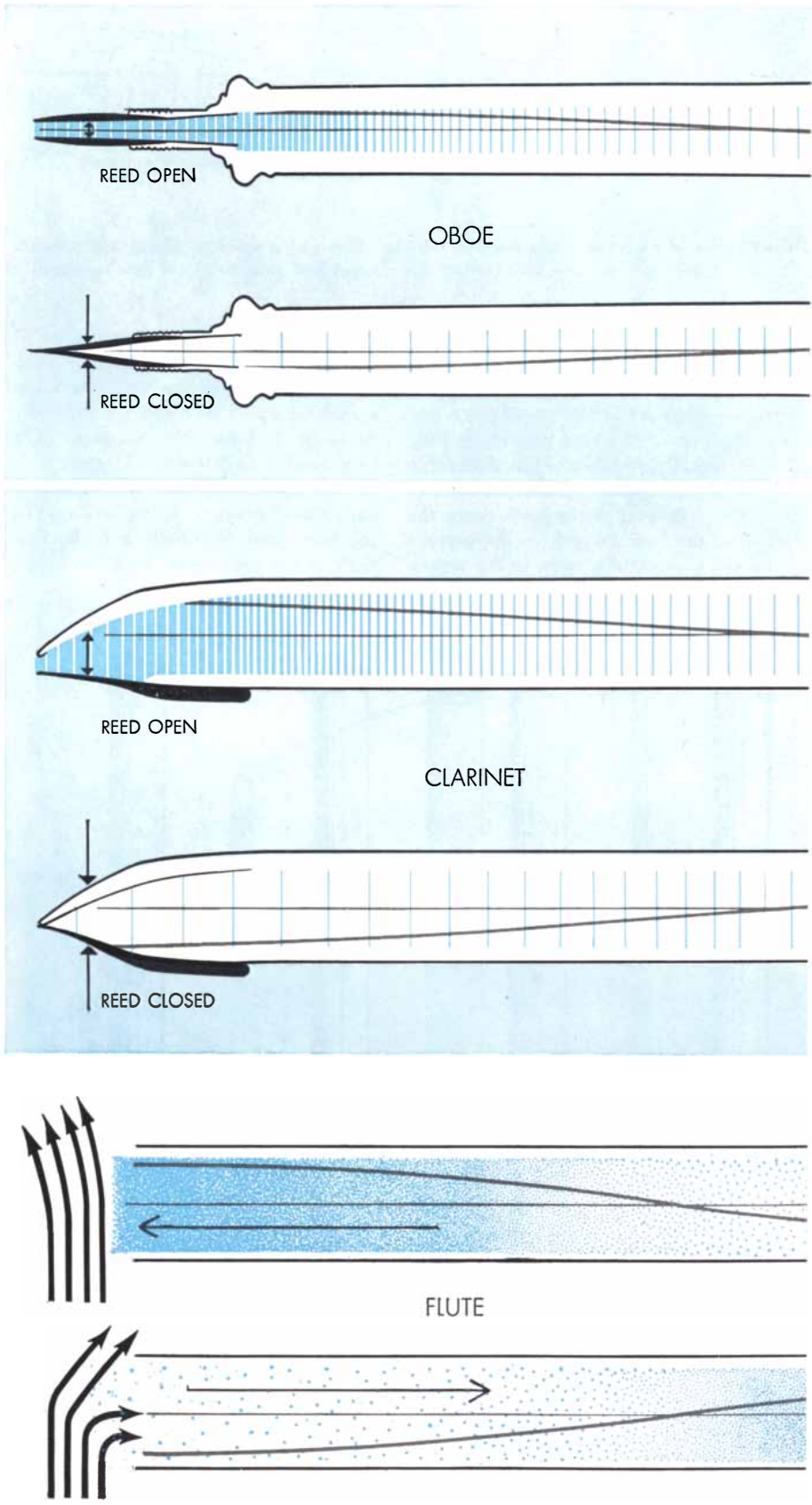
SIDE HOLES decrease the effective length of a bore. In this schematic diagram full-length bore is shown in black; its corresponding effective length when pierced by side holes of increasing size is shown in color. Holes permit musician to play a scale.

cies is possible for the air within a bore when it moves in a way that meets these conditions. These types of vibration (which are mathematically similar to the quantized states of motion of an electron in an atom) are called the "normal" or "natural" modes of vibration of the air in the bore.

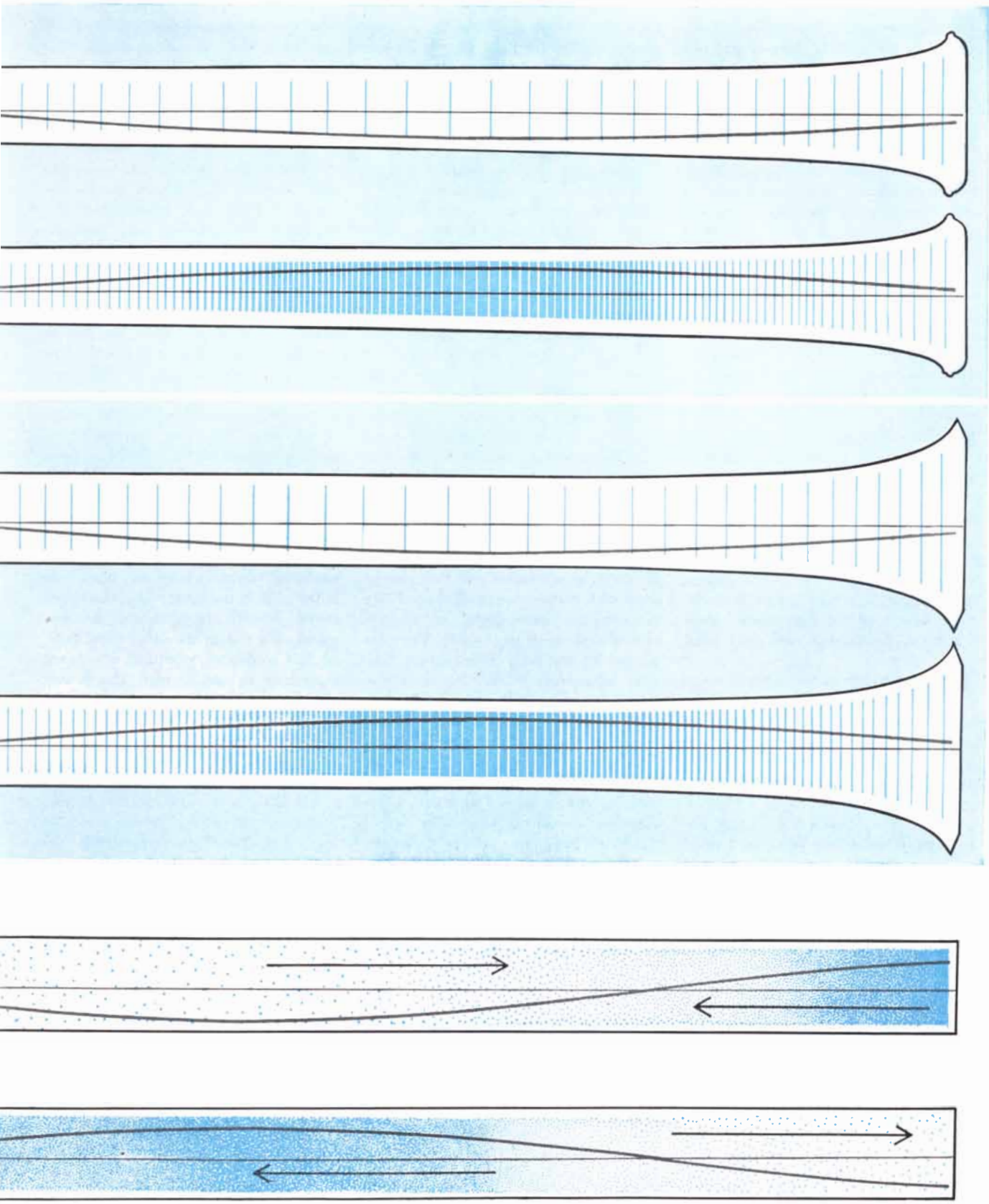
The frequency and wavelength of these natural modes of vibration depend chiefly on the length and shape of the bore. For example, a cylindrical bore open at one end and blown at the other with a velocity-controlled air-jet reed (like that of a flute), or a conical bore blown at the small end with a pressure-controlled cane reed (as in the oboe), has a lowest, or fundamental, frequency of vibration whose sound has a wavelength twice the length of the bore; it can also vibrate in higher modes producing a sequence of notes that is often referred to as the harmonic series, with wavelengths that are integral fractions (1/2, 1/3, 1/4, 1/5 and so on) of the fundamental. A cylindrical bore blown by a pressure-controlled reed at one end vibrates in its lowest mode to produce a fundamental note whose wavelength is four times the length of the bore. The higher-frequency modes of vibration are those whose sound wavelengths are odd-numbered fractions (1/3, 1/5, 1/7 and so on) of the fundamental. Wood winds make extensive use of only the lowest three or four of their natural modes; the lowest mode corresponds to the so-called low register of the instrument, the second mode to the middle register, while the upper register uses one or another of the higher modes.

When a bugler plays reveille, he uses his lips as a pressure-controlled reed to excite one or another of the natural modes of vibration of a flaring brass pipe. It is the task of the bugle manufacturer to shape the instrument so that the frequencies of its natural modes are those desired for playing music. As everyone knows, the repertory of the bugle is rather limited: even a skilled bugler can sound only five or six widely spaced notes.

In contrast, wood winds can play a chromatic scale of more than 30 notes, because their makers have found ways to fill the gaps in pitch between the natural frequencies of the bore. This is accomplished by drilling a row of holes in the side of the bore. As intuition suggests, a hole just a few thousandths of an inch in diameter will cause little change in the pitch of a note played on



BORE DOMINATES REED in all wood winds. Pressure-operated reeds like those of oboe (*top*) and clarinet (*middle*) function only at frequencies at which bore produces maximum variation in pressure at the reed. Velocity-operated reed of flute (*bottom*) operates only at frequencies at which bore produces a maximum variation in velocity at the reed. Heavy



black lines represent reeds; gray lines show wave motion of vibrating air in bore. Heavy colored lines indicate high-pressure phases; lighter lines, low-pressure phases. In the flute heavy color indicates high-velocity motion in one direction; light color, motion in the opposite direction. Heavy black arrows show the vibrations of the air-jet reed. The instruments in this schematic diagram are shown playing in their second mode of vibration. The thickness of the bores and the relative size of the reeds are exaggerated.

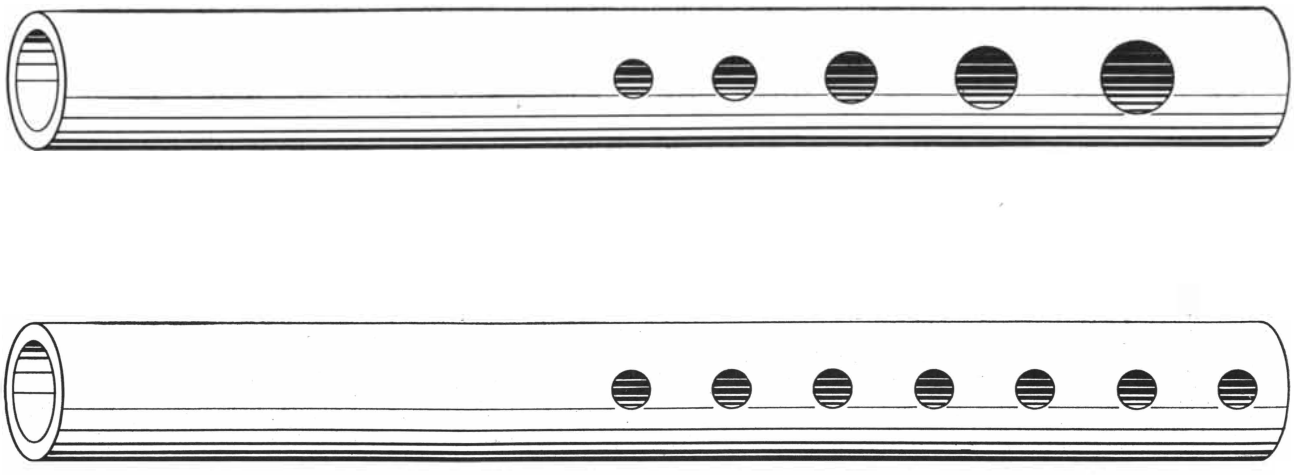
the instrument. But if the hole is so large that the end of the bore is just about falling off, the pitch of the note will rise to that of a bore which extends only as far as the hole. There is no need to go to this extreme; a hole that can be covered by a fingertip will serve to raise the pitch. If a series of such holes is drilled in the bore, the bore behaves as though it were cut off at a point near the uppermost open hole. In effect the side holes give the instrument a set of alternative bore-lengths, each with its own natural modes of vibration. The player's fingers, aided by a more or less complicated mechanism, open and close these holes to get different notes on the scale.

An important point of distinction between wood winds and brasses appears at this point: brasses have no side holes to alter the effective length of the bore. Brass players achieve a scale by using a set of valves to insert short lengths of tubing into the bore. Thus if water is poured into the mouthpiece of a brass instrument, all of it will flow through the convolutions of the coiled tubing and pour out of the bell. But if one were to pour water through a wood wind (perish the thought), it would not all flow the whole length of the instrument; some of it would pour out of each open hole.

The lowest note in the musical range of a wood wind is the lowest of the natural frequencies of the complete bore. Higher notes are played by opening the holes one by one, starting at the lower end of the bore. The holes are spaced so that when all of them are open, the bore sounds a note that has the same pitch as the first overtone of the complete bore, that is, the second natural mode of vibration of the bore played with all the holes closed. To continue the scales the instrument may be shifted to play in its middle register, the holes are closed and the pitch altered upward in steps by again opening the holes in succession.

I had played various wood winds for years before it occurred to me that it might be possible to invent new wood winds by finding new kinds of bores that could be used in this way. After considerable thought I realized that in essence the problem is to find a class of horn shapes for which the ratios between the natural-mode frequencies will remain unchanged when the bore is cut off successively at the lower end, as by opening the side holes. This is a mathematical way of saying that the bore must be one in which the same set of holes may be reused in playing the scale in the middle and upper registers of the instrument. (Otherwise a set of holes that provided notes of proper pitch in the low register would be out of tune in the higher ones.) The only horns that fulfill these requirements and that can be used with pressure-controlled reeds are the so-called Bessel horns [*see illustration at bottom of page 146*]. They are named for the early 19th-century German astronomer F. W. Bessel, whose Bessel functions for the relation of variables in certain differential equations have been utilized in many areas of physics. One of these equations applies to waves in a series of horns that increase in cross section according to some exponent of the distance from the end of the bore. The exponent distinguishes one horn from another in the series. At first sight it would appear that one has available an infinity of useful shapes, one for each positive exponent. But practical and subtle considerations arising from the nature of our ears and the proper regeneration of sound-energy restrict the choice to those members of the family that possess whole-number ratios among the normal frequency-modes. A little study showed that this requirement is satisfied only by those shapes for which the exponent is either two or zero. It turns out that natural selection in musical instruments had long anticipated this finding of theory: Each of the wood winds has one or the other shape. The cylindrical clarinet is a representative of the zero-exponent class, in which the cross section remains constant along the length of the bore. The oboe, the saxophone and the bassoon, on the other hand, have conical bores and so belong to the class for which the exponent equals two. A bore that departs from these "ideal" forms does not enclose an air column with constant ratios among its natural modes of vibration from one open hole to the next. If the cross section increases slightly toward the open end, as compared with one or the other ideal bore, all the modes of vibration are raised somewhat in pitch, with the lowest mode being raised the most; if it decreases in cross section toward the open end, the modes of vibration are lowered in pitch, with the lowest mode being lowered the most.

The makers of wood winds not only discovered the ideal shapes generations ago; they have also empirically ex-



OPEN HOLES of an actual wood wind (*top*) increase in size and spacing toward the open end of the bore. But the frequencies at which the air within the bore vibrates can be calculated by assuming that the holes are all of uniform size and spacing (*bottom*).

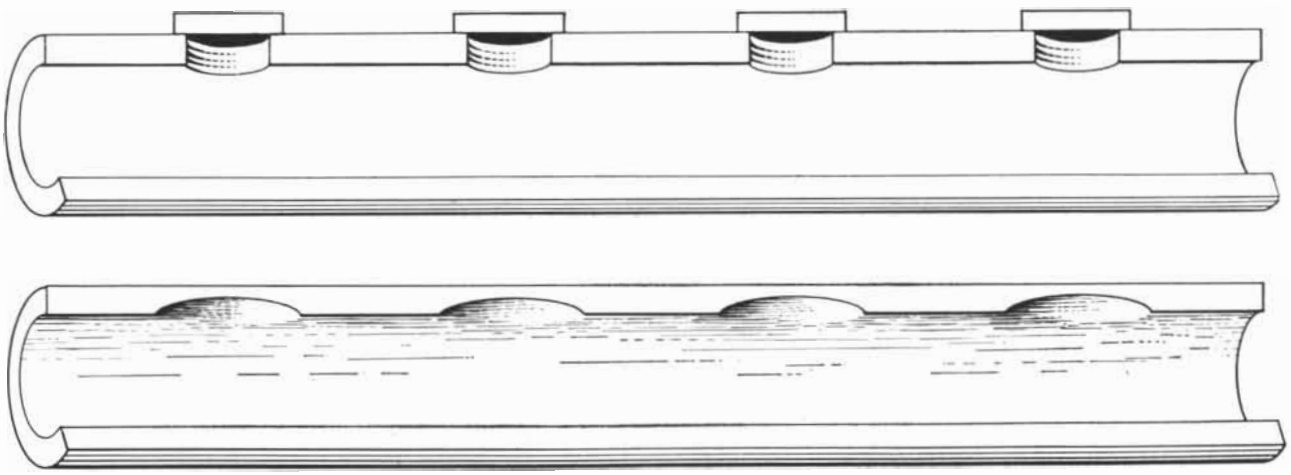
ploited the effect of departures from the ideal. They judiciously alter the cross section of the bore by a few thousandths of an inch to compensate for various upsetting effects caused by the complex behavior of reeds and holes. As a result the bores of actual wood winds are not perfect cones or cylinders. Although the necessary modifications of a bore can in general be predicted quantitatively by proper mathematical analysis, to my knowledge such methods have almost never been employed by the manufacturers of wood winds. They make the final adjustments in the taper of each bore by a process of trial and error.

The size and position of the side holes are just as crucial as the shape of the bore in affecting the performance of an instrument. Not only do the side holes cut off the bore at a convenient spot for getting a scale; they also play a large role in setting the tone quality of the sound within the instrument. And when they are open, they influence the way in which this sound is ultimately radiated into the air for the listener to hear. A length of plastic tubing played with a clarinet mouthpiece gives a dull, plumbing kind of sound that few people can identify. When this same pipe is provided with a row of closed side-holes followed below by four or five open ones, the tone changes strikingly into the woody voice of a clarinet.

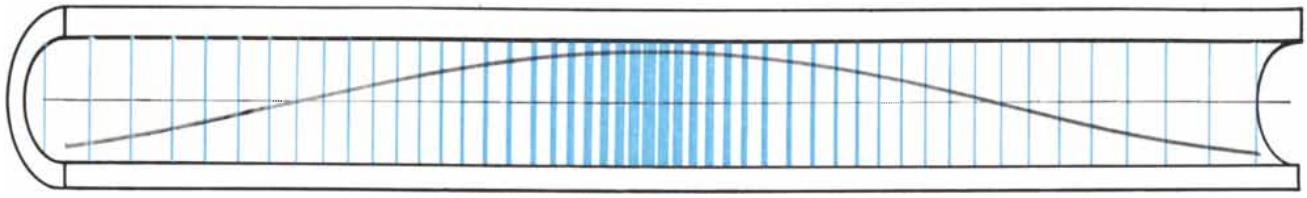
The "unused" closed holes convert the bore from a smooth-walled pipe into a lumpy duct that may be looked upon as a pipe with a series of swellings, as shown in the illustration below. Using a mathematical method devised by Lord Rayleigh, I was able to calculate that if the musical properties needed by the bore are to be preserved when it is supplied with closed finger holes, then the size of the holes must be related to their spacing in a certain definite way. One can say that the ratio of the volume of air contained in the closed hole divided by the volume of air in the length of bore between adjacent holes must be the same in all parts of the bore. I was able to verify this deduction from theory by a quick measurement of the hole sizes on present-day instruments. In all pressure-controlled reed instruments the holes must be larger and farther apart toward the lower end of the bore. This does not apply to the velocity-controlled flute family, which is much less sensitive to such perturbing effects, so that all the holes can be roughly the same size.

For generations craftsmen have used rules of thumb to determine where the holes should be placed in a wood wind. But a given set of rules applies only to a particular design, and must often be adjusted to correct vagaries in tuning between registers. The ability to make first-class oboes, clarinets and flutes is often a matter of highly prized family craftsmanship. Precision mass-production techniques must often be supplemented by painstaking handwork to maintain any sort of quality. Theoretically, of course, the positioning of the holes is determined by the physics of the musical scale, whether we understand it or not. Around 1930 the late E. G. Richardson of University College London, using electrical-analog techniques devised in 1919 by the late A. G. Webster of Clark University, calculated the behavior of a single open hole in the side of a tubular bore. Although this technique yielded a precise result and could in principle be extended to describe the musical case where there are several open holes, in practice it is too cumbersome to be usable. Since manufacturers of instruments were already able to make excellent wood winds without theoretical help, Richardson's work has lain largely neglected.

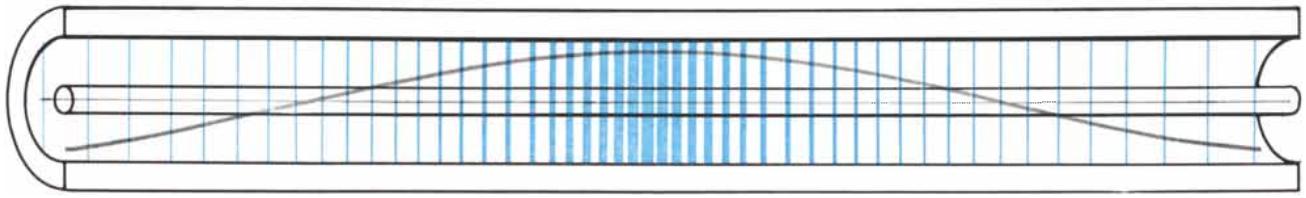
The difficulty with Richardson's approach is that each hole must first be treated separately, and then the mutual effects of the holes must be reconciled. A more practical approach is to study several adjacent holes simultaneously in a simplified way. A method for doing this in electrical systems was devised in 1927 by W. P. Mason of the Bell Telephone Laboratories. He worked out a set of equations to show the effect of regularly spaced loading coils on the vibrations in electrical transmission-lines. Because of the similarity of all vibrating systems, the equations can also be used for describing the sound vibrations in a bore with regularly spaced discontinuities such as holes. At first glance this does not seem useful because the holes along a wood-wind bore are not evenly spaced. But as all wood-wind players know, when their instrument plays a note in one of its lower two registers, only the two or three nearest open holes exert an appreciable effect on the sound produced; the size or position of the lower open holes makes essentially no difference. It



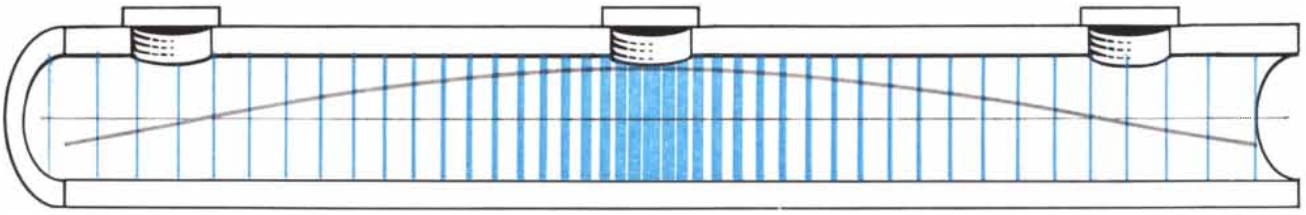
CLOSED HOLES alter the vibrational properties of the bore. Side holes closed by player's fingers or by pads on key levers (*top*) convert the bore from a smooth-walled pipe to a lumpy duct that may be thought of as a pipe with a series of swellings (*bottom*).



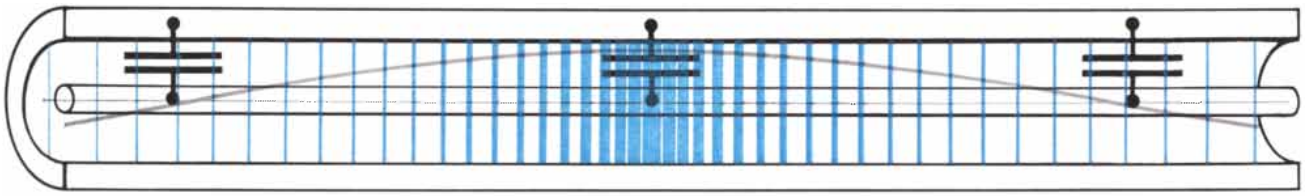
SMOOTH BORE



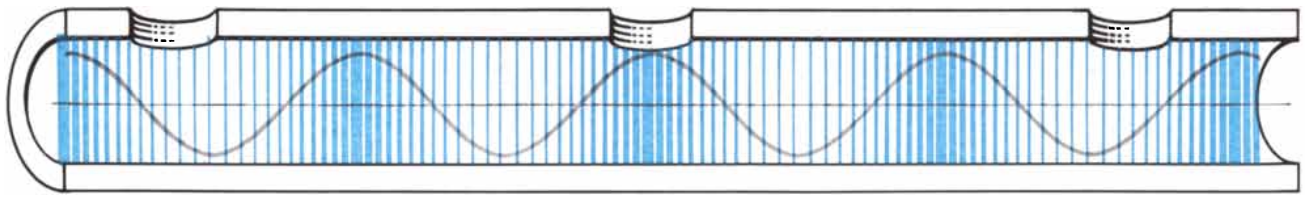
COAXIAL CABLE



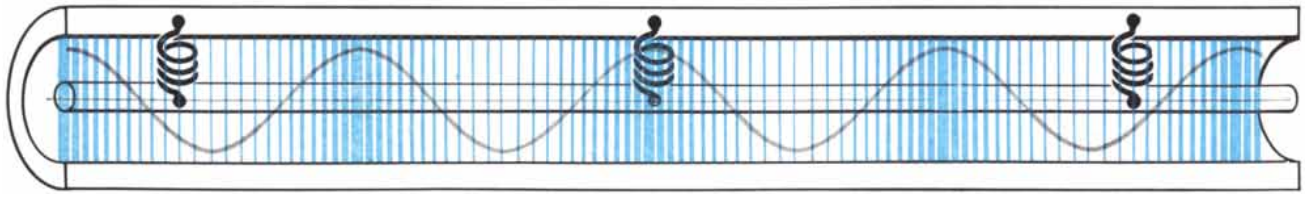
BORE WITH CLOSED HOLES



COAXIAL CABLE WITH SHUNT CAPACITORS



BORE WITH OPEN HOLES



COAXIAL CABLE WITH SHUNT INDUCTORS

ELECTRICAL ANALOGY depicts a wood-wind bore as a coaxial cable. The acoustical vibrations of the air within a smooth-walled bore are analogous to the electrical vibrations in the cable at top. Bore with closed side-holes behaves like cable with evenly spaced shunt capacitors connected across it (*middle*). Bore with open side-holes behaves like cable with evenly spaced inductors (*bottom*).

occurred to me that one might learn something by pretending that the bore contains open holes of uniform size and spacing, the dimensions being fixed by the size and spacing of the two highest holes that are open for the note being played. The relation between this simplifying abstraction and the pattern of holes in a real instrument is shown in the illustration on page 150. To my delight, the trick succeeded in predicting the pitches of my own clarinet from measurements of its holes. After further experimental checks and a mathematical analysis as to why the whole informal scheme held together, I found that the main musical frequencies that give the pitch of a note are not able to travel very far in a bore with open holes; the larger, more widely spaced holes in the lower end of the bore send only weak "messages" back to the main bore.

William Dent has recently worked over this problem in a different way as a senior thesis project at Case Institute of Technology, using a mathematical approach that was originally suggested by Rayleigh, but was further developed for the purposes of quantum theory by Gregor Wentzel of the University of Chicago, H. A. Kramers of the University of Utrecht and Leon Brillouin. Dent found that in spite of the nonuniform arrangement of the open holes, they act almost as though they were of regular size and spacing, provided they are properly proportioned for their closed-hole duty. In short, although the lack of communication between the bore and the lower open holes makes the pitch relatively insensitive to their size and spacing, the messages that do get through from these holes make it seem as though they were uniformly spaced after all. Of course uniform spacing is not necessarily a musical virtue, but it is a convenience that makes it possible to use the mathematical methods that are at hand.

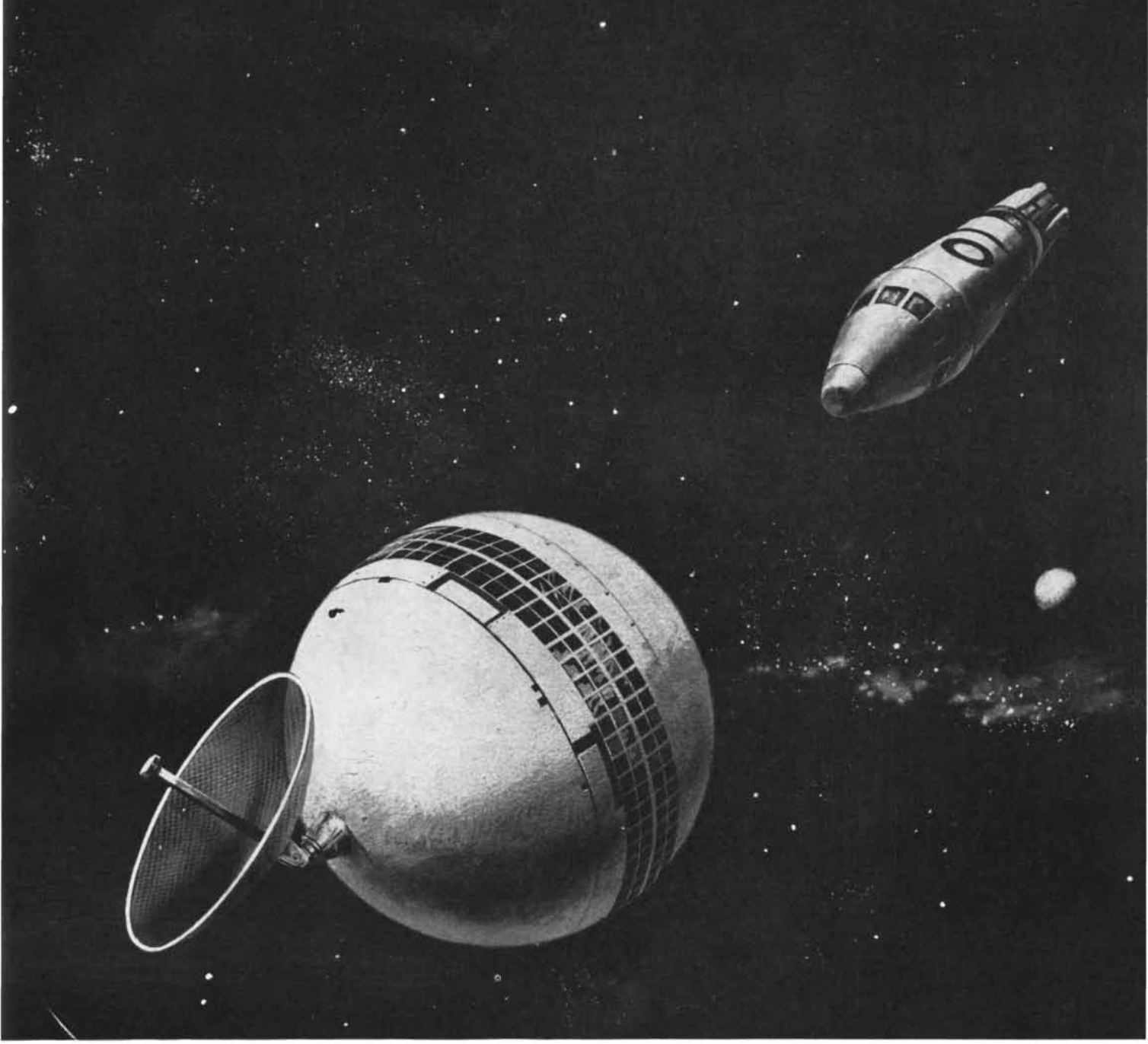
The relatively easy success of my first attempts encouraged me to re-examine the role of the closed holes in influencing the vibrations of the bore. It became clear that the closed holes act as a filter that discriminates strongly against the highest few components of the vibration spectrum produced by the reed. The "cut-off" frequency of this filter depends critically on the size and location of the closed holes. In flutes and saxophones the cut-off frequency is so high that it has little effect on the tone of the instrument, but in all the other wood winds (especially the oboe) the tone color is

considerably altered by the filtering effect of the closed holes.

The next step was to try coaxing Mason's transmission-line equations into giving information about the way in which vibrations in the bore are coupled to the outside air. Any electrical or acoustical engineer looking at the equations for the row of open holes would instantly recognize them as describing a second sort of filter which transmits high-frequency vibrations, but attenuates those of lower frequencies. A wood wind thus emits the lower components of its tone into a room rather inefficiently, chiefly from the first one or two holes but symmetrically in all directions from the instrument. The higher components are radiated efficiently from all the open holes acting in concert, but in a highly directional manner. The size and spacing of the holes determine the frequency at which the "cross-over" in the mode of radiation takes place. In this complicated fashion the holes help determine the tone color of the sound that reaches the ears of the listener.

Listeners have come to associate wood winds with the type of sound that is emitted (by each of the two radiation mechanisms) from a row of open holes. The addition of the bell at the lower end of some wood winds reflects efforts over the years to provide the bore with a radiating system that approximates the behavior of a row of open holes even when all the holes are closed. It is a matter of long experience that this can never be done perfectly. (Of course an instrument maker might escape simultaneously from tradition and from the problem by simply providing a few extra open holes at the bottom of the bore which would be used only as emitters of sound.) In contrast to the clarinet and oboe, the flutes and saxophones are essentially bell-less because they radiate all components of their tones as if from a single hole.

This brief account of the interwoven complexities of wood-wind instruments has suggested some of the ways in which their structure affects their behavior. But it also suggests a more general observation. The curious weaving of familiar knowledge from various apparently unrelated fields, illuminated by flickers of intuition and analogy, is typical of the way in which most scientific knowledge develops. While many scientific efforts are shaped by esthetic considerations, the physics of music is particularly fortunate in being allied to an art from which it draws inspiration, and to which it often brings a deeper understanding.



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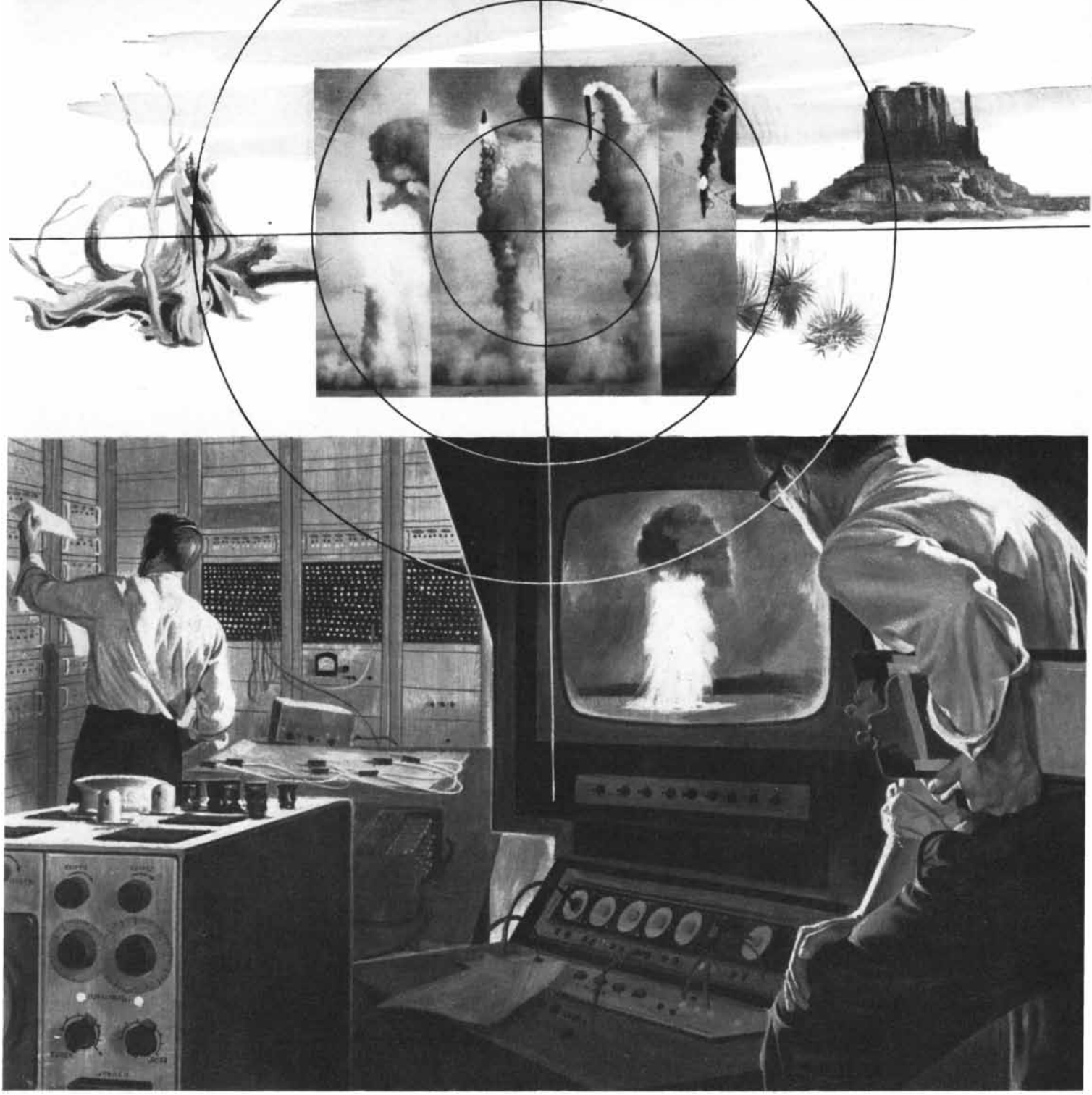

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Count Rumford

Born Benjamin Thompson in Woburn, Mass., he was both a brilliant investigator and an unscrupulous careerist. He demonstrated that heat is not a substance called "caloric" but is a mode of motion

by Mitchell Wilson

In Paris in 1804 Benjamin Thompson, then aged 51 and at the beginning of the last decade of his life, wrote: "To engage in experiments on Heat was always one of my most agreeable employments. This subject had already begun to excite my attention . . . in my seventeenth year. . . . Subsequently, indeed, I was often prevented by other matters from devoting my attention to it, but whenever I could snatch a moment I returned to it anew, and always with increased interest."

These few sentences in his *Mémoires sur la Chaleur* condense, with an elusiveness characteristic of the man, one of the most fantastic lives of that revolutionary period. It was a life of unswerving honesty in science and unconscionable duplicity in politics.

Benjamin Thompson—born in poverty in a sleepy village of Colonial Massachusetts, known later to the world of elegance and power as Count Rumford and remembered in the history of science as a resolutely independent and original investigator—played only for the highest stakes. If it is the mark of a scientist's stature that he concerns himself with the central problem of his time, Rumford meets that test. He was at war with the "caloric" theory, which encompassed his period's theory of matter. He was equally at the center of action in politics, variously the minister, the tool, the friend, the emissary and the enemy of heads of state. George III hated him but used him; the Elector of Bavaria ennobled him and made him his prime minister; Napoleon considered him one of the great minds of the day; and in one of Rumford's last dealings with his native land he insisted on being treated as if he had a military rank at least equal to that of George Washington. He was unsurpassed in arrogance; he had few peers in science.

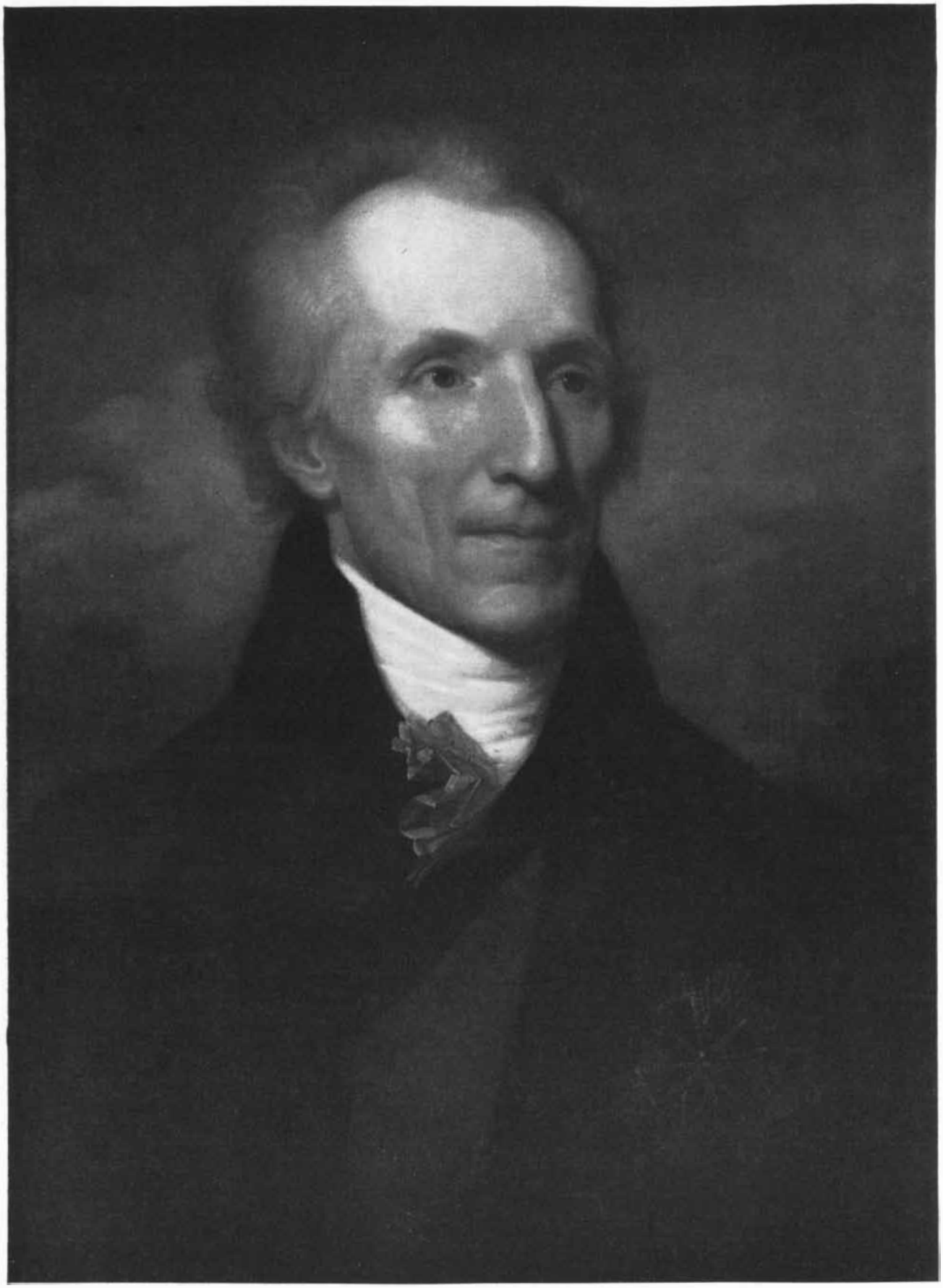
"To engage in experiments on Heat was always one of my most agreeable employments," he wrote. To Benjamin Thompson the word "heat" meant very much what it means in physics today: it was "a mode of motion." But the word had a different meaning among his contemporaries. The caloric theory has left a permanent imprint on the vocabulary of physics, even though the essence of it has long been forgotten. "Latent heat," "heat of vaporization," "specific heat" and a variety of other terms are all legacies of the caloric theory, which in its time explained qualitatively almost all known heat phenomena with remarkable success. Its adherents included Laplace, Lavoisier, Priestley, Petit and Dulong. The few anomalies were either discovered by Rumford or exploited by him in an effort to overthrow the theory. But the theory was so firmly held that even Rumford's brilliant experiments were not recognized as conclusive until long after his death.

According to the caloric theory, heat was an invisible fluid that had the properties of being strongly attracted to matter and self-repulsive. The theory called for an atomic view of matter. Every atom was seen as surrounded by an atmosphere of caloric, the amount being directly proportional to the temperature of the surface of the atom. Neighboring atoms were strongly attracted to each other by their gravitational fields, but at very close quarters the repulsive force of their caloric atmospheres became stronger than their mutual attractions. This explained why atoms of any sample of matter were prevented from collapsing into an undifferentiable mass.

It was assumed that, where the gravitational attraction followed the inverse-square law, the repulsion of caloric followed a logarithmic law similar to that of the density of the earth's atmosphere [*see illustration on page 166*]. At a certain distance from the atom, therefore, attraction and repulsion became equal, and this distance was the separation of individual atoms in any sample of matter at equilibrium. An increase in temperature signified an increase in the amount of caloric present. With the attendant increase in repulsive force, the equilibrium distance between neighboring atoms also increased. This was the theory's explanation for thermal expansion. Because atoms of various substances were of different mass, some lighter and some heavier, their gravitational forces would vary and so would their equilibrium distance. This explained why different substances had different coefficients of expansion.

By such a balance of forces caloric theory could account for the difference between solids, liquids and gases. Solids contained comparatively small amounts of caloric; hence the range of the atmospheric repulsion was extremely short, and neighboring atoms were quite rigidly bound by the attractive force of gravity. The liquid state was characterized by a caloric content so high that the gravitational force could no longer hold neighboring atoms in any rigid structure, but still not so high that the resultant interparticle force was purely repulsive. Actually the resultant force in a liquid was sufficiently attractive to explain liquid cohesion. When matter was at a high temperature in the gaseous state in a container, the repulsive force of the caloric atmosphere became ascendant, and the gas would expand without limit.

The term "specific heat" had the same meaning in caloric theory that it does in the vocabulary of modern physics; it was the amount of heat necessary to raise the

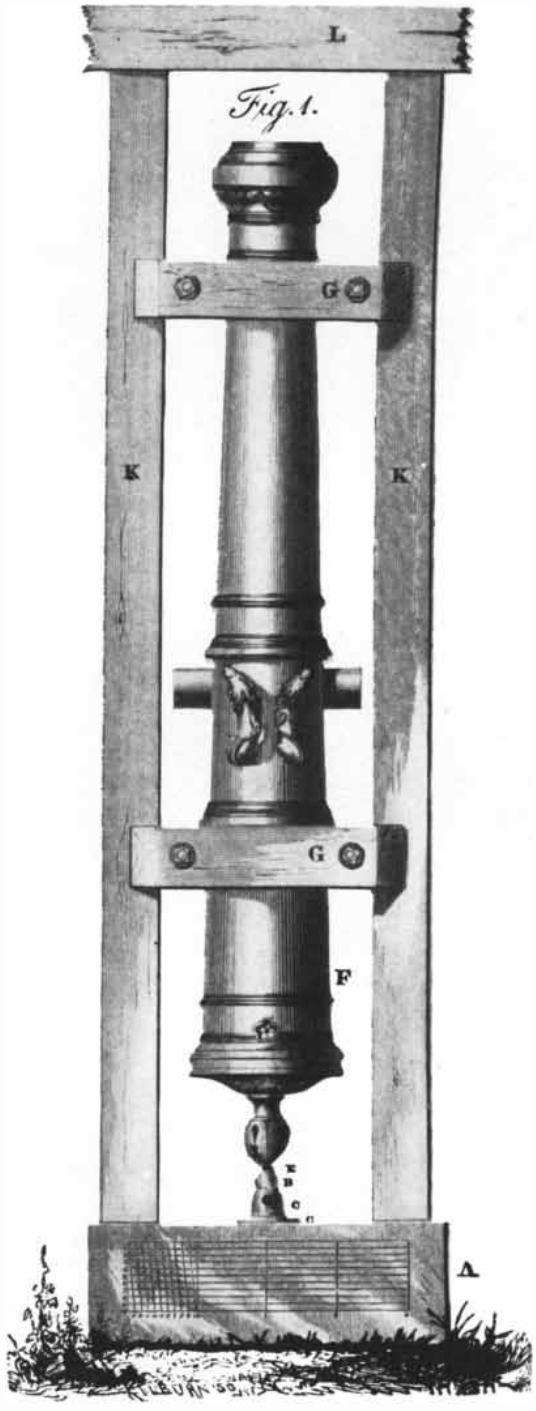


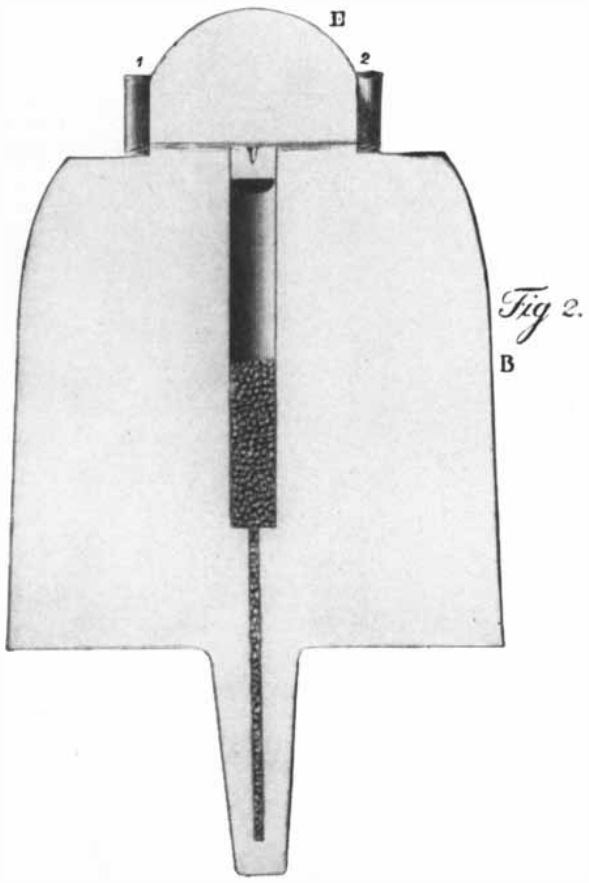
PORTRAIT OF RUMFORD was made by the American painter Rembrandt Peale around 1800, when Rumford was in his late 40's. The painting hangs in the American Academy of Arts and Sciences in Boston. To this institution he left a fund for a Rumford medal.

temperature of given mass of a substance one degree. Since caloric was self-repulsive, it followed that the more caloric there was in an atom's atmosphere, the more difficulty there should be in adding further caloric to that atmosphere. The specific heat of a solid must therefore increase with temperature. In 1780 Lavoisier and Laplace were able to present experimental evidence to support this derivation from the theory. It was one of the theory's brilliant successes.

"Latent heat" was equally well supported by the experimental fact that substances reach plateaus of temperature at which further heating brings not an increase in temperature but a change of state. This was explained, however, by the rationalization that the caloric at such times entered into a kind of chemical combination with the substance, changing its nature. Only when the reaction had gone to completion would additional caloric result in a rise in temperature. The heat was called latent because it was recoverable when the reaction was reversed.

Since caloric was self-repulsive, compression of a substance should squeeze out caloric. This certainly appeared to





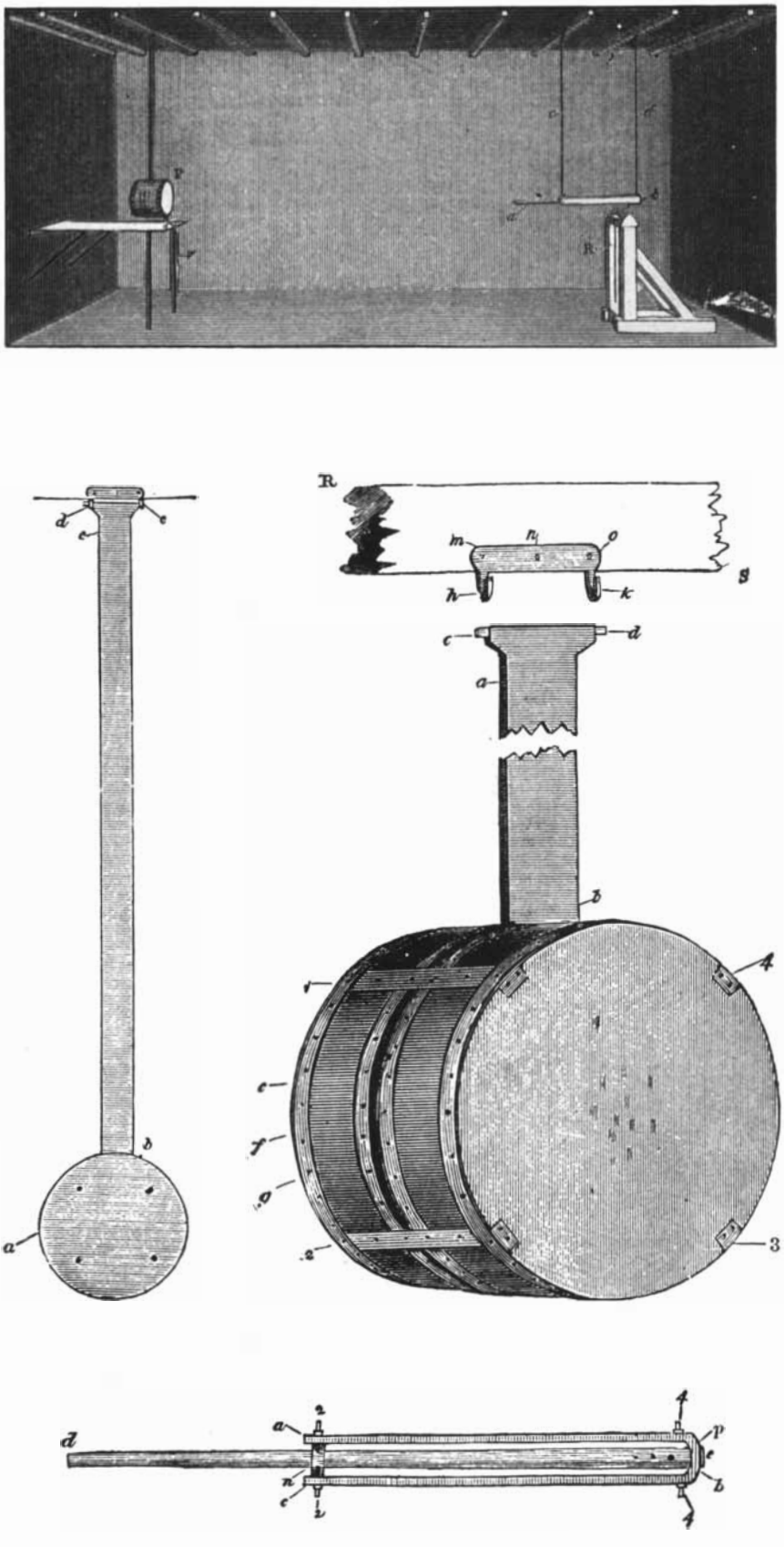
FORCE OF EXPLOSION of gunpowder was measured in this apparatus devised by Rumford. In these illustrations from Rumford's paper Fig. 1 is a four-ton cannon which holds down the cover of a special mortar (Fig. 2). The mortar was filled with gunpowder, which was ignited with a red-hot cannon ball (Fig. 3). The amount of gunpowder was adjusted so that it would just lift cover of mortar.

be the case with gases: Compress a gas and its temperature rises. Similarly, if pressure was applied to a liquid near its boiling point, the temperature of the boiling point was raised, and more heat was required to make up for the heat lost under compression. The conduction of heat was also easily explained. It was the flow of caloric under strong attraction to atoms that had sparser caloric atmospheres than their neighboring atoms. It should, and did, follow experimentally that conduction increases with the density of a body of matter.

The theory seemed a remarkable triumph of rational intelligence. When Rumford wrote "This subject had already begun to excite my attention . . . in my seventeenth year," one can easily understand the impression made on a young, inquiring mind. But much else was going on in that young mind at the same time. Benjamin Thompson was a thin, red-headed boy, lately arrived in the Colonial metropolis of Boston and tormented by infinite ambition. He had been born in 1753 in the town of Woburn, when an American still considered himself an Englishman, when the Colonies were so poor that in the entire 1,000-mile length of settlement there were fewer than 100 privately owned coaches. His father died when he was an infant, and his destitute mother married a man equally poor. The boy had received only the local schooling, and no one thought him brilliant or even particularly promising. He had been an apprentice storekeeper in Salem and had been discharged. Another storekeeper was found who agreed to try him, and that is how he got to Boston.

A more unapprentice-like apprentice could not have been found. He stole a few hours every week from the store to walk out to Cambridge, where a friend had obtained permission for him to sit in on lectures about natural science and astronomy at Harvard College. He read prodigiously. He taught himself to speak French, to fence, to dress like a gentleman. His daytime world saw a good-looking boy working inefficiently in a store, berated by his employer and by customers. But in the back of his mind furious preparations were being made for a life of attainment and power. In his dreams the impossible was only the beginning.

The impossible began to happen when he was 19. He got an appointment as a schoolmaster at Concord in New Hampshire. With no money in his pocket, he walked there in his one suit of clothes. But it was the elegant suit of a gentle-



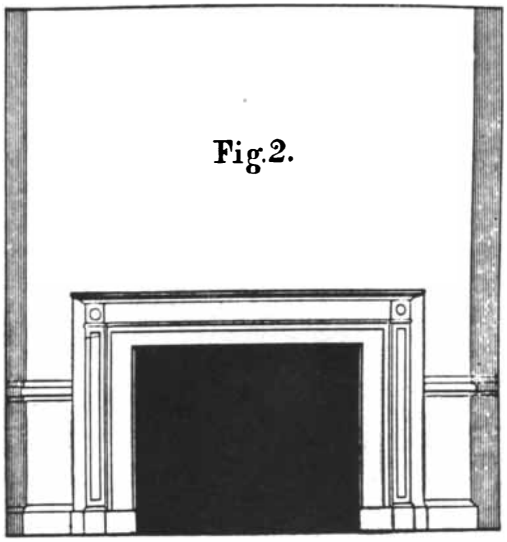
MOMENTUM OF A PROJECTILE was measured by Rumford with the apparatus depicted in these illustrations. Both gun and target were mounted as pendulums (*top*). In the middle are details of the target mounting; at the bottom, a detail of the gun mounting. Momentum of projectile was calculated on the basis of the arcs through which target and gun swung.

man. Within only a few months he had discovered, courted and won the richest heiress in the entire province: the 32-year-old widow of Colonel Benjamin Rolfe, who had been many years her senior. Thompson was her darling; she dressed him magnificently, gave him her 1,000 acres to manage and got him a commission as major in the Second Provincial Regiment of New Hampshire. He had decided that the sure route to his ambition was a military career.

He enjoyed his provincial eminence for less than two years, but this was long enough for him to become cool, aloof and sure of his stature. In 1774 local patriots of the Committee of Correspondence charged him with being in contact with General Gage in Boston and with having returned four British deserters. He talked his way out of the accusations, but satisfied no one. Facing tar and feathers, he fled, abandoning his wife and infant daughter.

For the next year he wandered around Boston, trying to get a commission in the Colonial army. New Hampshire officers, however, refused to serve with him, and 1776 found him in Boston behind the British lines. Thompson's importance there was such that, when the British forces evacuated Boston, General Gage sent him as a member of a commission of four to London to explain his retreat. The truth—not to be published for more than 160 years—was that all the accusations against him had been true. He had been in contact with the British; he had returned the deserters; he had been acting as Gage's agent when he had tried to get a Colonial commission. His "Miscellaneous Observations upon the State of the Rebel Army," written in "invisible" ink, can be read in the original today. It shows him to have been a shrewd observer and reporter on every topic from ordnance to morale.

In London, where the world came closer to his fantasy, he began a new career. He became the pet, the spy and the protégé of Lord Germain, His Majesty's Colonial Secretary, the man in charge of prosecuting the Colonial war. Germain was at the center of the corruption and an exponent of the ruthless political infighting that marked the reign of George III. Thompson was made undersecretary in the Ministry for Carolina and Georgia, and his share of bribes and graft from the military purchases that he was empowered to make came to 7,000 pounds a year, the equivalent of hundreds of thousands of dollars today. By 1781, however, he was embroiled in the suspicion of having betrayed British



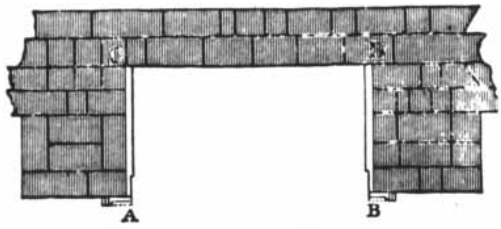
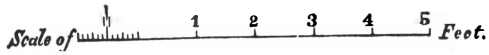


Fig. 1.



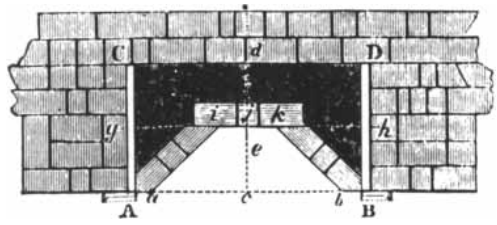
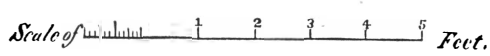
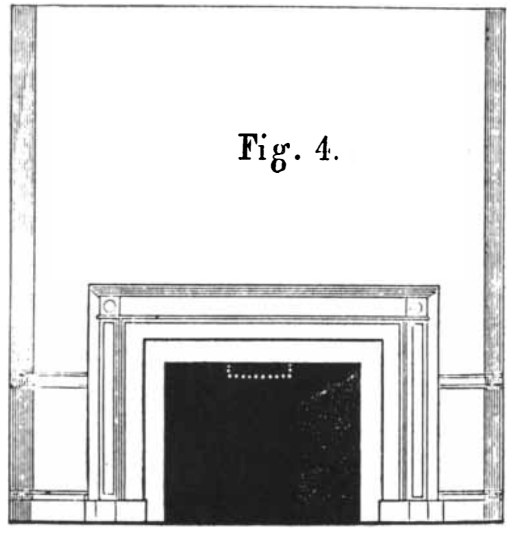


Fig. 3.





RUMFORD CHIMNEY eliminated problem of smoking chimneys. Rumford found that conventional chimney (Fig. 1, Fig. 2 and Fig. 5) smoked because rising and descending air currents interfered. In his chimney (Fig. 3, Fig. 4 and Fig. 6) he introduced a

naval secrets to the French. Only Germain's mastery of the art of blackmail spared Thompson open indictment. Protesting that he could no longer resist the call to action, Thompson fled to America with the rank of lieutenant colonel in the British army. He arrived to find the war all but over.

The whole unpleasant story would have been forgotten, except that during this time Thompson performed some ingenious experiments in ballistics. "These experiments," he wrote, "were undertaken principally with a view to determine the most advantageous situation for the vent in fire-arms, and to measure the velocities of bullets, and the recoil under various circumstances. I had hopes also of being able to find out the velocity of the inflammation of gunpowder; and to measure its force. . . . They were begun in the month of July in the year 1778, at Stoneland Lodge, a country-seat belonging to Lord George Germain."

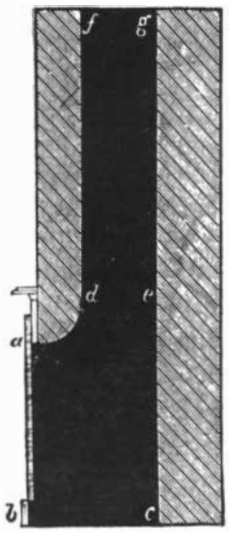


Fig. 5.

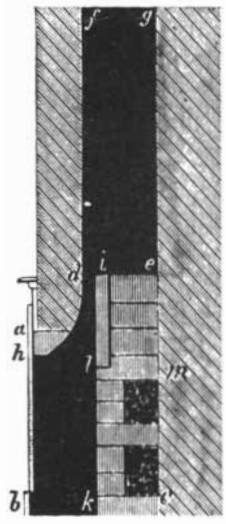


Fig. 6.

throat (*d-i in Fig. 6*) and a smoke shelf (*i-e*) to separate warm air from cold.

In this enterprise Thompson invented a device for measuring the power of gunpowder which served as standard equipment for this purpose until the advent of modern high explosives. Over the muzzle of a small vertical mortar he placed successively heavier weights until the measured charge of powder could no longer lift the weight. He was also the first to fire a shot into a pendulum and to use the swing of the pendulum to measure the bullet's momentum. He later extended this technique by mounting the cannon itself as a pendulum. This work won him election to the Royal Society at the age of 26.

In 1783 Thompson was back in London. Because he was still in jeopardy there he decided to try his fortunes on the Continent. He found entree to the court of Bavaria, where he was presented as a brilliant scientist and soldier-of-fortune. Arranging at the same time to serve as a secret agent for the British, Thompson accepted an appointment in the service of the Elector. To perfect his cover he was returned to England long enough to be knighted by George III.

In Bavaria Thompson became in rapid succession Minister of War, Minister of the Interior and chief scientist to the Elector. He felt secure enough in 1785 to break off his career as British agent. The British, unable to expose him, decided to wait for revenge.

For the next 10 years the world was his. In 1791 he was made a count of the Holy Roman Empire, taking as his title Rumford, after the original name of the town of Concord where he had first come into fortune. He romanticized his Colonial origins, implying vast landholdings and patrician lineage. When his daughter, on a visit from America, received an offer of marriage from one of the younger members of the House of Thurn and Taxis, Count Rumford broke off the match because the young man did not have sufficient rank to match his own. By now he was famous throughout Europe, not only as a man of affairs but also as a scientist; he was at all times engaged in active research.

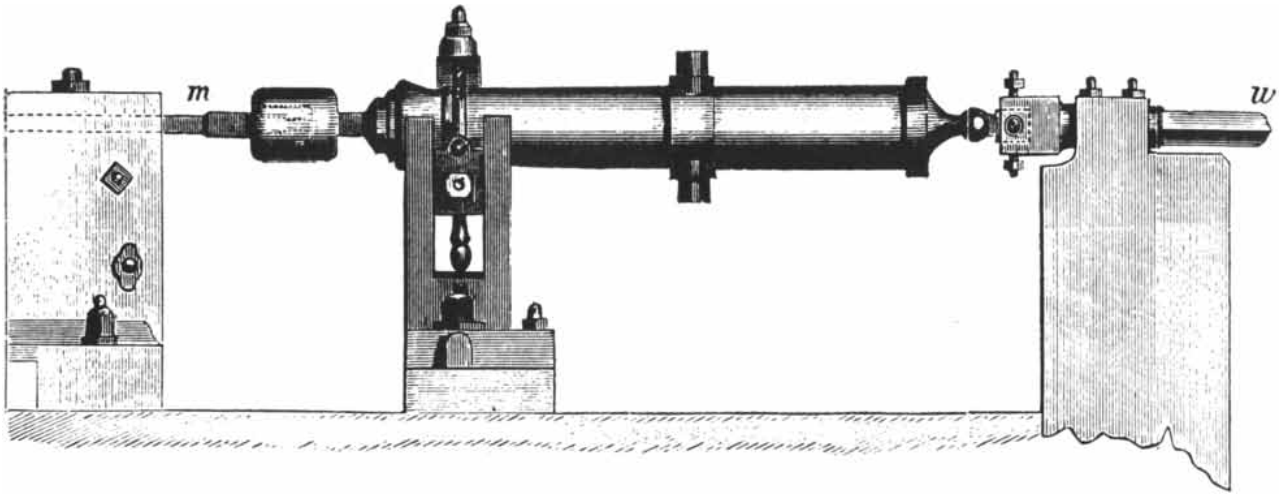
By 1795 his cold arrogance in the exercise of power had made so many enemies in Bavaria that he was compelled to step down from his pinnacle. He attempted to do so with dignity, appointing himself ambassador from Bavaria to England. But the British Government refused to receive him, giving as its public excuse that His Majesty's Government could not accept one of his own subjects as the representative of a foreign king. With less grace, therefore, he had to resign his Bavarian posts one by one. Eventually he left the country for good, taking with him a large fortune, to begin an entirely new career in England as a private gentleman-scientist.

In London the magnificent count dazzled scientific circles with papers covering the work of his past years and by founding, out of his own pocket, the Royal Institution. (He equipped the building with a central heating-system of his own design, the first successful arrangement of its kind.) But the skeletons of his past still haunted London. After two years he again found it desirable to move on, this time to Paris. There he lived as a world celebrity. He won the admiration of Napoleon, who considered Rumford his teacher in the art of artillery. During this period Rumford also entered into a brief marriage with Lavoisier's widow, a union that made a great impression upon French society at its beginning and at its stormy and quarrelsome end. The measure of his eminence was that he was made one of the eight foreign members of the French Academy at the same time as Thomas Jefferson, then President of the United States.

It was to such heady and perilous experiences with power and glory that Rumford alluded so elliptically when he wrote of his interest in heat: "I was often prevented by other matters from devoting my attention to it, but whenever I could snatch a moment I returned to it anew, and always with increased interest."

Rumford was an intensely practical man. His interest in heat extended into such homely realms as the design of fireplaces and kitchen stoves; he designed saucepans and kettles for maximum utilization of heat and is the author of the original drip-pot for the brewing of coffee. Much of his scientific work stemmed from observations that he made while working in the fields of applied science connected with his public duties. His famous experiment on friction as an inexhaustible supply of heat was based on observations made while supervising the production of cannon in the foundry of the Bavarian arsenal. The massive iron barrels were first cast in sand molds and were then finished and bored. It was the heat generated in this last step that caught his imagination.

According to the caloric theory, heat was a fluid that existed in finite and measurable amounts. The temperature



CANNON-BORING MACHINE was adapted by Rumford to show that "inexhaustible" quantities of heat were generated by friction, and hence that heat could not be a substance. Cannon and short cylinder to left of it were turned by shaft *w*. Shaft *m* was fixed and heated cylinder by rubbing against it. Because experiment was not easily reproducible, Rumford designed the one on opposite page.

of a substance multiplied by its specific heat was said to give the total amount of heat in the sample. By whatever means this fluid was removed, it had to be restored once it was withdrawn. Sanborn C. Brown of the Massachusetts Institute of Technology, the foremost scholar of Rumford's work, points out that this explanation was usually sustained by the following evidence: A piece of iron made red-hot by hammering could not be heated a second time in that way unless it was meanwhile introduced into a fire; this fact was explained by supposing that the caloric that had been pressed out of it by the percussion was recovered in the fire.

What occurred to Rumford in the Bavarian arsenal was that the amount of heat generated in the boring and finishing of the cannon was far more than could be accounted for by adding up the total amount of heat residing in the casting, the cutting tool and the chips. He tested this observation in an experiment of elegant design [*see illustration on opposite page*].

"Let A be the vertical section of a brass rod which is . . . fastened in an upright position on a stout block, B," he wrote. "It is provided at its upper end with a massive hemisphere of the same metal, three and a half inches in diameter. . . . C is a similar rod, likewise vertical, to the lower end of which is fastened a similar hemisphere." The globular glass vessel D, 12 inches in diameter, was filled with water covering the ball made of the two hemispheres. With the two hemispheres pressed into close contact, the lower hemisphere was kept stationary, while the upper one was made to rotate. The motion generated friction, which in turn heated the water to a boil so long as the motion was continued.

"From whence comes the heat?", Rumford asks. "This is the contested point, to determine which was the real aim of the experiment." To his rhetorical question he replies: "The results of my Experiments seem to me to prove to a demonstration that there is no such thing as an *igneous fluid,* and consequently that *caloric* has no real existence. . . . They proved only this single fact—that the heat generated by friction appeared evidently to be *inexhaustible,* even when the bodies rubbed together are . . . perfectly insulated. . . . It is hardly necessary to add that anything which any *insulated* body, or system of bodies, can continue to furnish *without limitation* cannot possibly be a *material substance.*"

Rumford puts the central question once more: "Whence then came this heat? And what is heat actually? I must confess that it has always been impossible for me to explain the results of such experiments except by taking refuge in the very old doctrine which rests upon the supposition that heat is nothing but a vibratory motion taking place among the particles of the body."

The very old doctrine had been propounded a century before by Robert Hooke and Robert Boyle, and had had the support of Gottfried Wilhelm von Leibniz and John Locke. Rumford was the first to give it such clear experimental demonstration, in an experiment that was to be decisive under more precise execution by James Prescott Joule in the 1830's. For its time Rumford's experiment was in the same class as A. A. Michelson's classic examination of the ether theory; it went to the heart of the matter with the same simplicity and directness.

In London in 1799, when he was capitalizing on his earlier investigations in his effort to recapture his status in British society, Rumford published a paper in *The Philosophical Magazine.* In this paper he described another experiment he had performed in Munich that had struck a heavy blow at the foundations of the caloric theory. He was concerned here to test whether heat could be regarded as a substance. If it were indeed a substance, then there must be some gravitational interaction of caloric and the enormous amount of matter in the earth; that is, heat should have weight.

Rumford describes three bottles A, B and C, as nearly identical as possible. In A he put a measured amount of water; in B, an equal amount of "spirit of wine"; in C, the same amount of mercury. (In describing these weighings he mentions a balance belonging to the Elector of Bavaria which was sensitive to one part in a million.)

"These bottles, being all hermetically sealed, were placed in a large room . . . where the air appeared to be perfectly quiet, and, being suffered to remain in this situation more than twenty-four hours, the heat of the room (61°) being kept up all the time with as little variation as possible. . . . They were all weighed, and were brought into the most exact equilibrium with each other, by means of small pieces of very fine silver wire, attached to the necks of those of the bottles which were the lightest.

"This being done, the bottles were all removed into a room in which the air

was at 30°, where they were suffered to remain, perfectly at rest and undisturbed, forty-eight hours."

At the end of that time he weighed the bottles again, and found the weights unchanged. He then moved the bottles back to a warm room and waited until all three had come to the new temperature equilibrium, the frozen water having melted. Again the weights were unaltered.

"Here it is very certain that the quantity of heat lost by the water must have been very considerably greater than that lost by the mercury; the specific quantities of heat in water and latent in mercury having been determined to be to each other as 1,000 to 33; but this difference in the quantities of heat lost produced no sensible difference on the weights of the fluids in question."

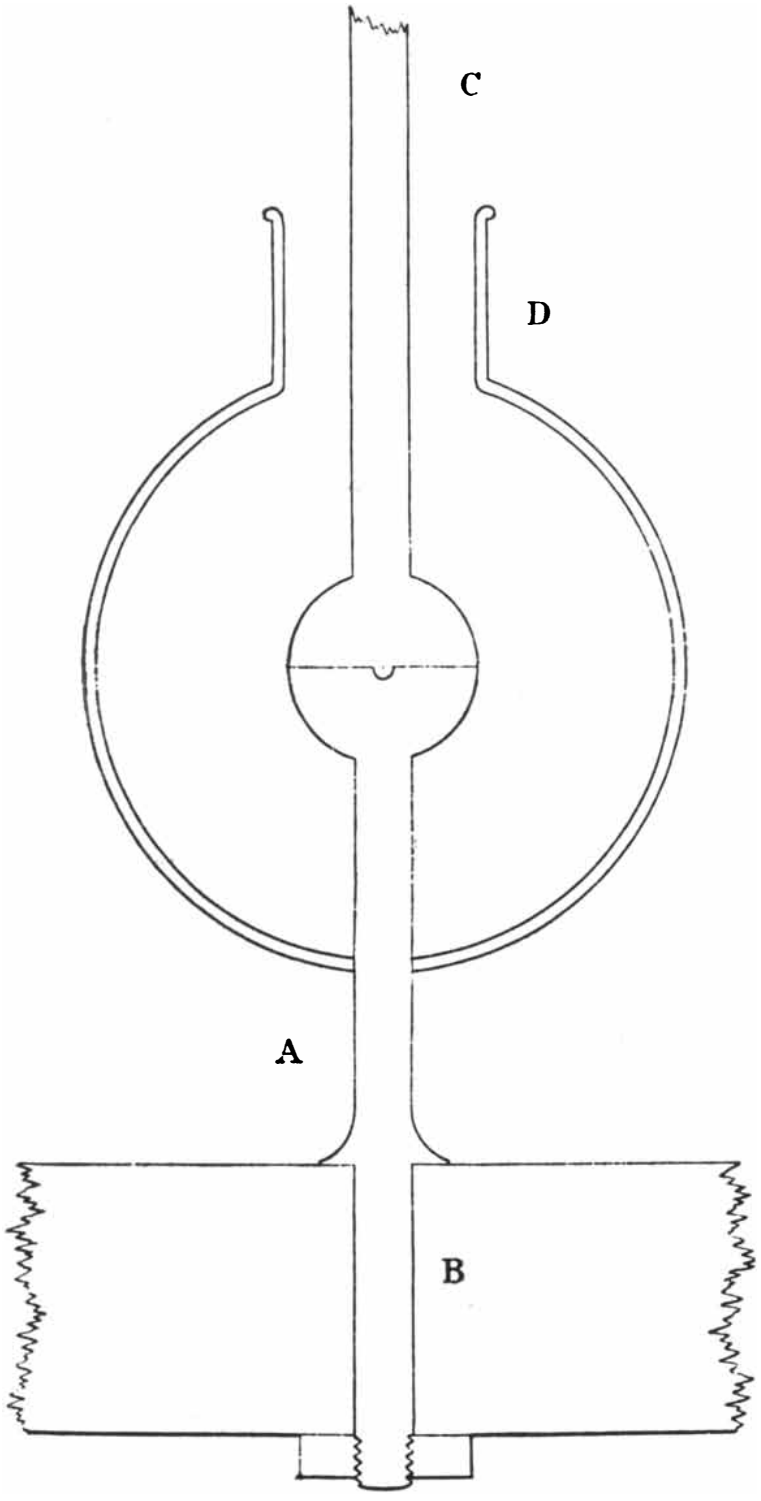
He calculated the exact amount of latent heat of fusion in his water sample and wrote: "It appears therefor to be clearly proved by my experiments that a quantity of heat equal to that which 4,214 grains [about 9¾ ounces] of gold would require to heat it from the temperature of freezing water to be red hot, has no sensible effect upon a balance capable of indicating so small a variation of weight as that of one part in one million parts of the body in question."

Rumford even anticipated the statistical aspects of the kinetic theory of heat, which were to be given theoretical expression by James Clerk Maxwell and Ludwig Boltzmann. He observed: "A thermometer can do no more than indicate the mean of the different temperatures of all those bodies or particles of matter which happen to come into contact with it. If it be suspended in air, it will indicate the mean of the temperatures of those particles of air."

In terms of this understanding he gave an explanation of the process of sublimation, something the caloric theory had never been able to do: "It is well known that ice cannot be melted with a lower degree of Heat than that of 32° of Fahrenheit's scale; but in the midst of winter, in the coldest climates; and when the temperature of air of the atmosphere, as shown by the thermometer, has been much below 32°, ice, exposed to the air, has been found to evaporate. How can we account for this event, except it be by supposing that some of the particles of air which accidentally (as we express it) come into contact with the ice are so hot, as not only to melt the small particles of ice which they happen to touch, but also to reduce a part of the generated water to steam?"

In 1807 he presented further evidence for a kinetic theory of heat in his paper "Of the Slow Progress of the Spontaneous Mixture of Liquids." In the experiment described in this paper he took a cylindrical glass vessel and divided its vertical length with a scale of lines a 12th of an inch apart.

"I then poured into this vessel, with due precautions, a layer of a saturated aqueous solution of muriate of soda, 3 inches in thickness, and onto this a layer of the same thickness of distilled water. . . . The two liquids lay one upon the other without being mixed. . . . [I then] let a large drop of the essential oil of

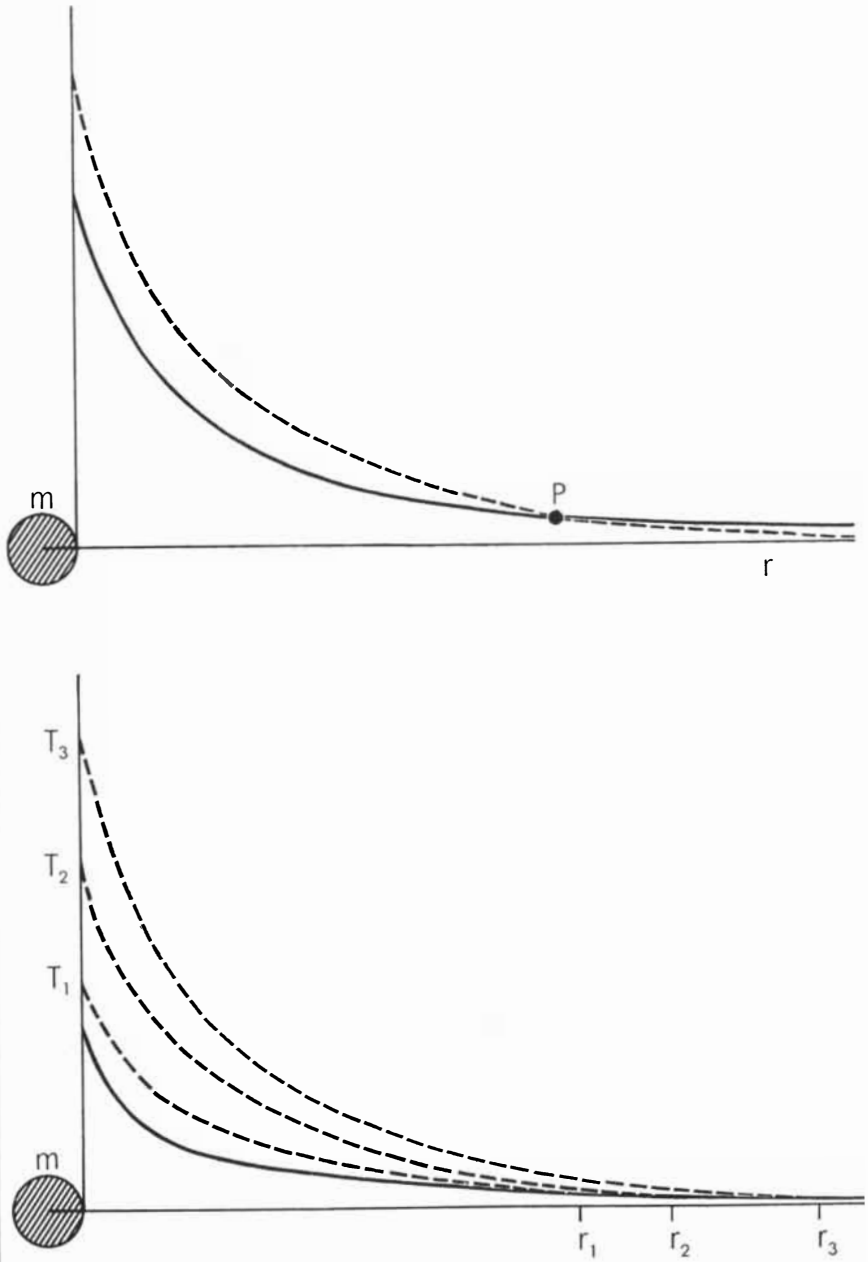


SIMPLIFIED APPARATUS TO GENERATE HEAT by friction was designed by Rumford so that others could test principles of his cannon-boring experiment. Brass hemispheres, fixed to rods A and C, were immersed in water, contained in globe D. Rotation of rod C rubbed one hemisphere against the other. Resulting friction could heat water to a boil.

cloves fall into the vessel. This oil being specifically heavier than water, and lighter than the solution of muriate of soda on which the water rested, the drop descended through the layer of water; when, however, it reached the . . . surface of the saline solution it remained there, forming a little spherical ball . . . near the axis of the vessel."

At the end of 24 hours he found that the ball of oil had risen three lines. The next day at the same hour it had risen by the same amount; it continued to rise uniformly for the next six days. Rumford deduced from this that there was a continuous molecular diffusion "between the various aqueous solutions employed and the distilled water resting upon them." In discussing this experiment Sanborn Brown remarks: "It is interesting to observe that when the modern kinetic theory was worked out, Einstein pointed out that the spontaneous mixture of liquids of different densities affords one of the most direct experimental proofs of the predictions of this theory."

The paper "Of the Slow Progress of the Spontaneous Mixture of Liquids" was one of the huge number and variety that testify to the vigor of Rumford's last



CALORIC REPULSION (*broken lines*) and gravitational attraction (*solid lines*) of an atom are charted according to the caloric theory. In graph at top the two forces are equal at P, where another atom would be in equilibrium with atom m. In graph at bottom r_1, r_2, r_3 represent expansion of caloric atmosphere at temperatures T_1, T_2, T_3.

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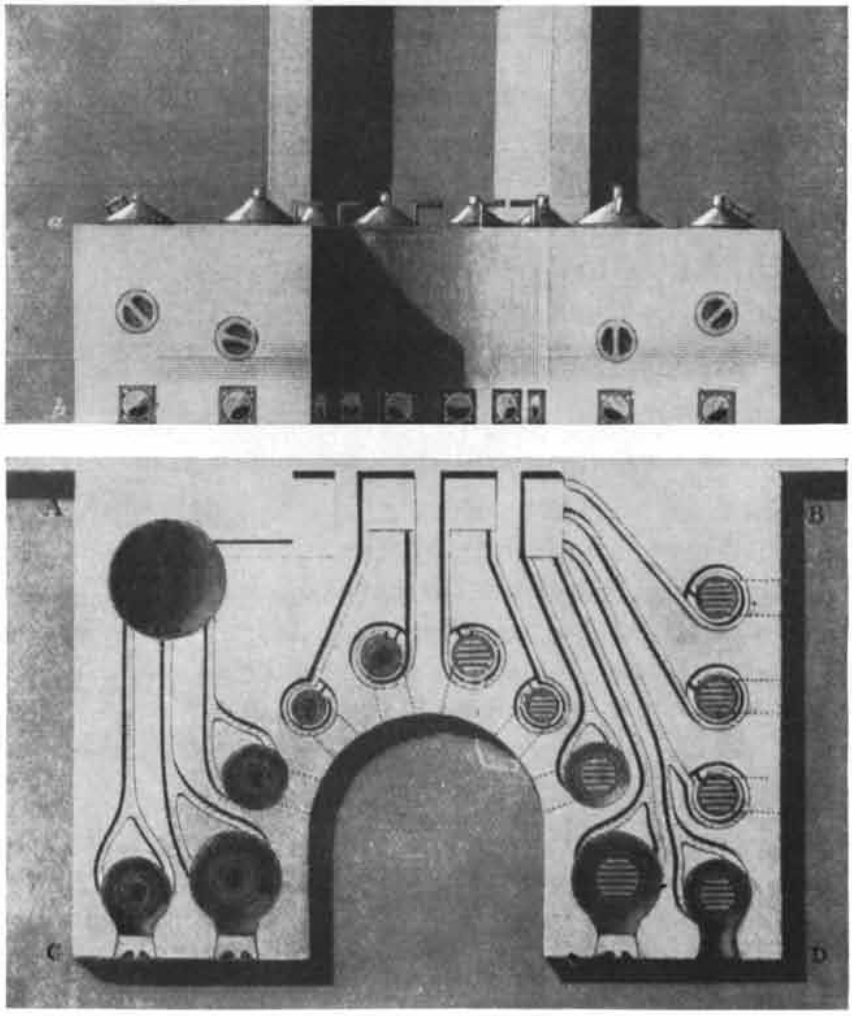
decade in France. A sampling suggests the range of concern, from the utilitarian to the fundamental: "Observations Relative to the Means of Increasing the Quantities of Heat Obtained in the Combustion of Fuel"; "Of the Management of Light in Illumination, Together with an Account of a New Portable Lamp"; "Description of a New Boiler with a View to the Saving of Fuel." He was productive until his death in 1814, living on pensions from England and from Bavaria, which were paid to him regularly all through the Napoleonic wars, as well as on his still-considerable capital. With an eye to posterity he established the Rumford medals of the Royal Society and the American Academy of Arts and Sciences, regarded today as the most prestigious awards of each of these institutions, and left his residuary estate to Harvard College to endow the Rumford chair in physics.

His work, while highly esteemed in his lifetime, was truly appreciated only in retrospect. Not for 30 years after his death did it become clear that he had been the first to measure the mechanical equivalent of heat. Joule himself wrote:

"One of the most important parts of Count Rumford's paper, though one to which little attention has hitherto been paid, is that in which he makes an estimate of the quantity of mechanical force required to produce a certain amount of heat. . . . According to Count Rumford's experiment, the heat required to raise one pound of water 1° will be equivalent to the force represented by 1,034 foot-pounds. This result is not very different from that which I have deduced from my own experiments related in this paper, *viz.*, 772 foot-pounds; and it must be observed that the excess of Count Rumford's equivalent is just such as might have been anticipated from the circumstances which he himself mentions, that 'no estimate was made of heat accumulated in the wooden box, nor of that dispersed during the experiment.'"



RUMFORD STOVE grew out of Rumford's preoccupation with heat. His plan for a complete kitchen stove unit, an antecedent of present kitchen ranges, had system of ducts and registers to maximize use of heat. Oddly shaped pots reflect his concern for efficiency.

Basic Research at Honeywell
Dr. Finn Larsen
Vice President for Research

Studies in the Temperature Sensitive Properties of Oxide Semiconductors

Oxide semiconductors, a branch of the ill-defined field of ceramics, possess temperature sensitive characteristics that suggest improved accuracies at normal temperatures and higher limits of ambient operation for temperature sensors.

A relatively small but very intriguing subject for research in electronic ceramics relates to materials known as oxide semiconductors.

These oxide semiconductors appear to be more sensitive to temperature change than any other material known today. In addition, recent work has shown they can produce high thermoelectric potentials.

In order to make these oxide semiconductors useful, it is usually necessary to intensify their semiconductor characteristics by one of two methods: The first method, commonly called "doping," consists of introducing ions of a higher or lower valence than the host oxide into the crystal lattice of the host.

The second method is the formation of oxygen vacancies in the crystal lattice by "firing" the semiconductor in a reducing atmosphere—usually hydrogen.

By these techniques, excess electrons or electron vacancies become current carriers just as they do in silicon or germanium. Unlike the single crystals of silicon or germanium, however, oxide semiconductors are dense multicrystalline materials usually produced by sintering powder by ceramic techniques.

Having acquired semiconductor properties, these oxide semiconductors generally have high negative temperature coefficients of resistivity. For example, while the temperature coefficient of resistivity of metals is of an order of 0.5%/°C, oxide semiconductors may have very high coefficients from 2 to 8%/°C. Metals have positive temperature coefficients while oxide semiconductors have negative coefficients.

An obvious application of the properties of these oxide semiconductors is in temperature measurement and control, where they are used as thermally sensitive resistors and are termed thermistors. With relatively large changes in resistivity, either very precise temperature sensing or good sensitivity with lower cost equipment can be achieved. For example, Honeywell has built a relatively simple device to control temperature to less than 0.01°C.

In certain applications, one difficulty in using oxide semiconductors as thermistors is their negative temperature coefficient. In other words, as the material is heated, its resistivity decreases. This leads to a so-called "run away" condition. This is true because when an oxide semiconductor with a large negative coefficient is heated by passing power through it, its resistivity is lowered, thus increasing the current and power through the unit. This increase in power heats the oxide semiconductor further and, unless limited by the power source or other circuitry, overheating continues until the unit fails.

With a positive coefficient material, as more power from a constant voltage source passes into the material, the resistivity increases, dropping the current, thus limiting further rise in temperature.

This situation has led to intensive study of certain oxide semiconductors that have the interesting characteristic of reversing their temperature coefficient of resistivity from negative to positive to negative as the temperature increases. The ability to produce oxide semiconductors with a positive temperature coefficient of resistivity and controlled properties is a difficult problem.

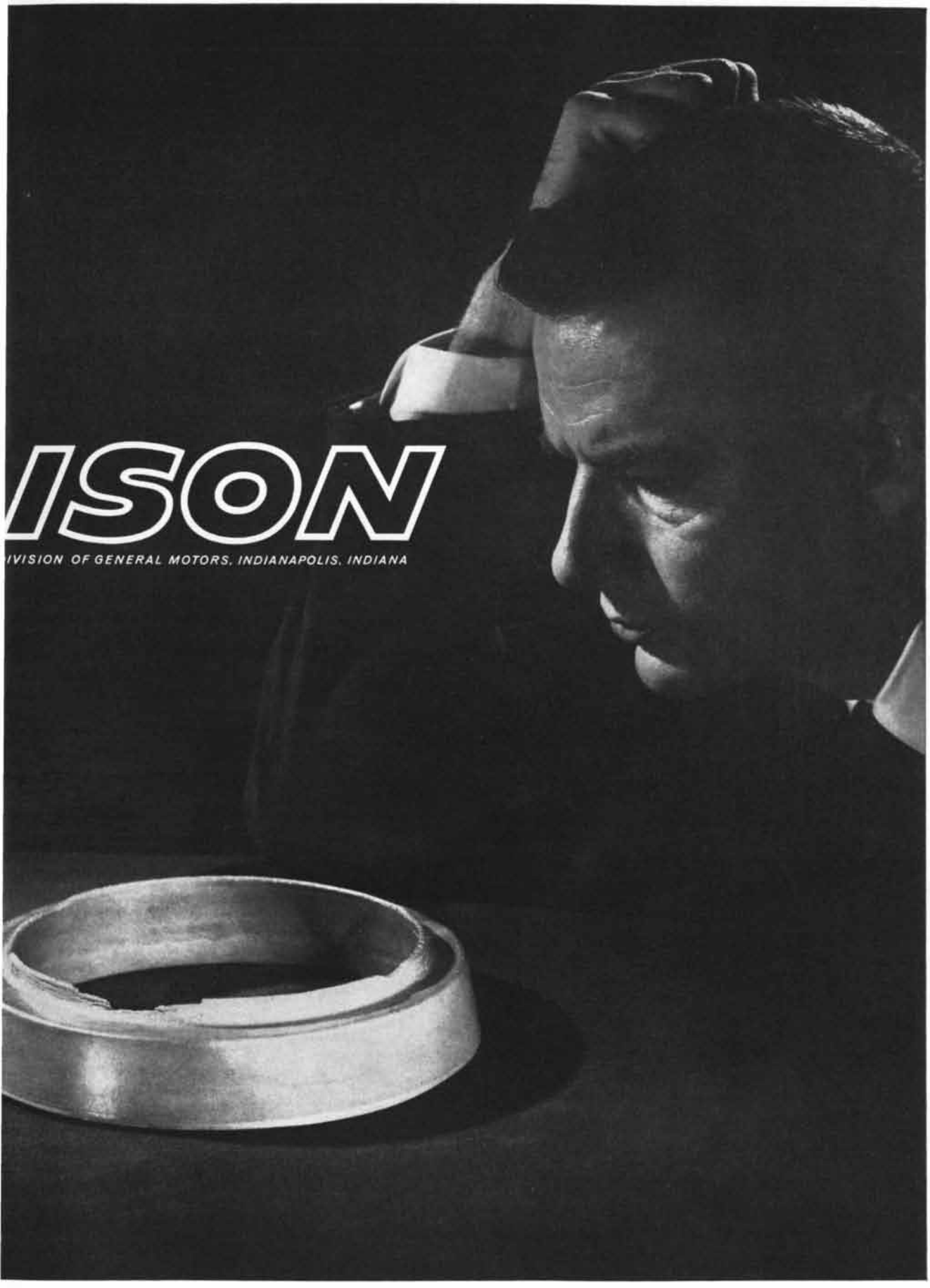
At Honeywell's research center, ceramic specialists and solid state physicists have been working to specify materials and "doping" techniques to achieve repeatable results. In one case they have succeeded in moving the positive slope of the temperature coefficient of resistivity curve from 100°C to 20°C making the thermistor useful as a sensing device in normal temperature ranges, with a temperature coefficient of resistivity as high as 25%/°C.

Another field in which oxide semiconductors are of interest is thermo electricity. The Seebeck voltage of a good metal thermocouple will be of the order of 20 to 40μv/°C or, in other words, these materials would generate voltages of 0.002 volts with a temperature difference of 100°C between the ends of the thermocouple. In comparison, oxide semiconductors exhibit Seebeck voltages of 500 to 900μv/°C or under similar conditions would generate 0.05 to 0.09 volts. Presently available nonceramic semiconductors produce little more than half this voltage. Greater output may simplify the circuitry required for temperature measurement or may serve as a practical voltage supply.

In other applications, oxide semiconductors are used to compensate for changes caused by temperature of the components in sensitive circuits. They are also used as voltage limiting devices and for fluid flow measurement.

Many of the properties of oxide semiconductors are not clearly understood. Their characteristics are extremely sensitive to composition and fabrication techniques. Our interest in these oxide semiconductors stems not only from the properties described above but from the ever-increasing requirements for semiconducting materials for operation at higher and higher temperatures. Although a part of our work has been on the investigation and development of materials for practical purposes, an equally important part has been and will continue to be devoted to a basic understanding of the similarities and differences between these materials and more normal semiconductors. This study has brought together scientists from the fields of ceramics, solid state physics, chemistry and electronics. Here at the Honeywell laboratories we have found such intermingling of disciplines a vital factor in our progress toward more basic understanding.

If you are engaged in scientific work related to oxide semiconductors, you are invited to correspond with Mr. Robert D. Fenity or Dr. William Bratschun, Honeywell Research Center, Hopkins, Minnesota. If you wish a forthcoming paper on oxide semiconductors, write Honeywell Research, Minneapolis 8, Minnesota.



MATHEMATICAL GAMES

A new collection of "brain-teasers"

by Martin Gardner

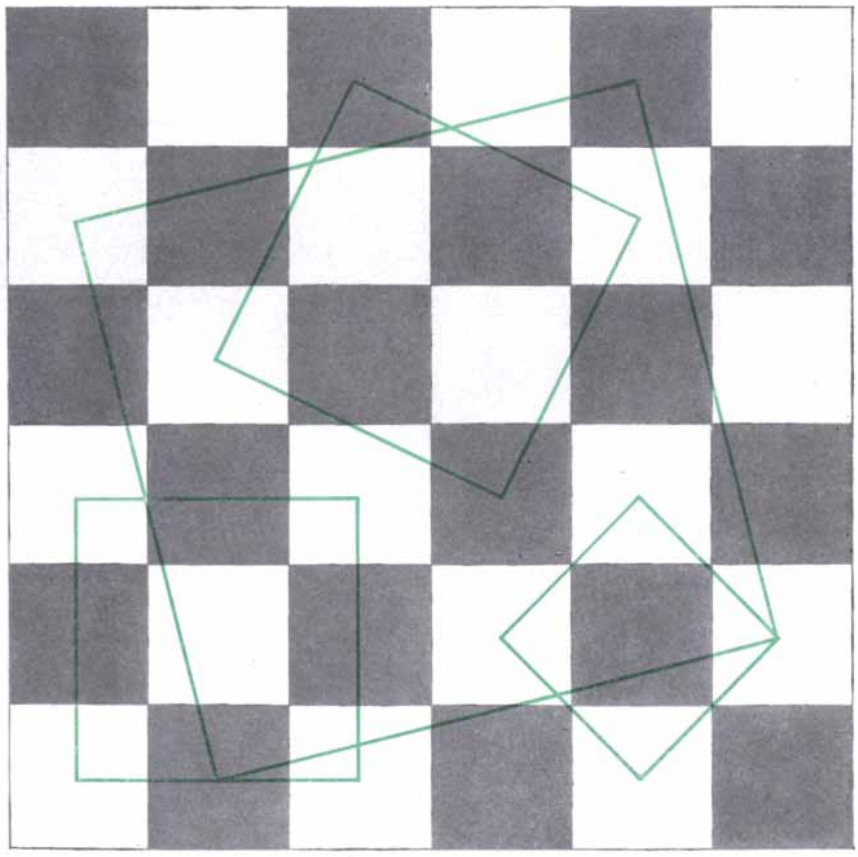
It is the custom of this department to present, at intervals of eight or nine months, a collection of short problems of special interest. The answers to the following "brain-teasers" will appear in this space next month.

1.

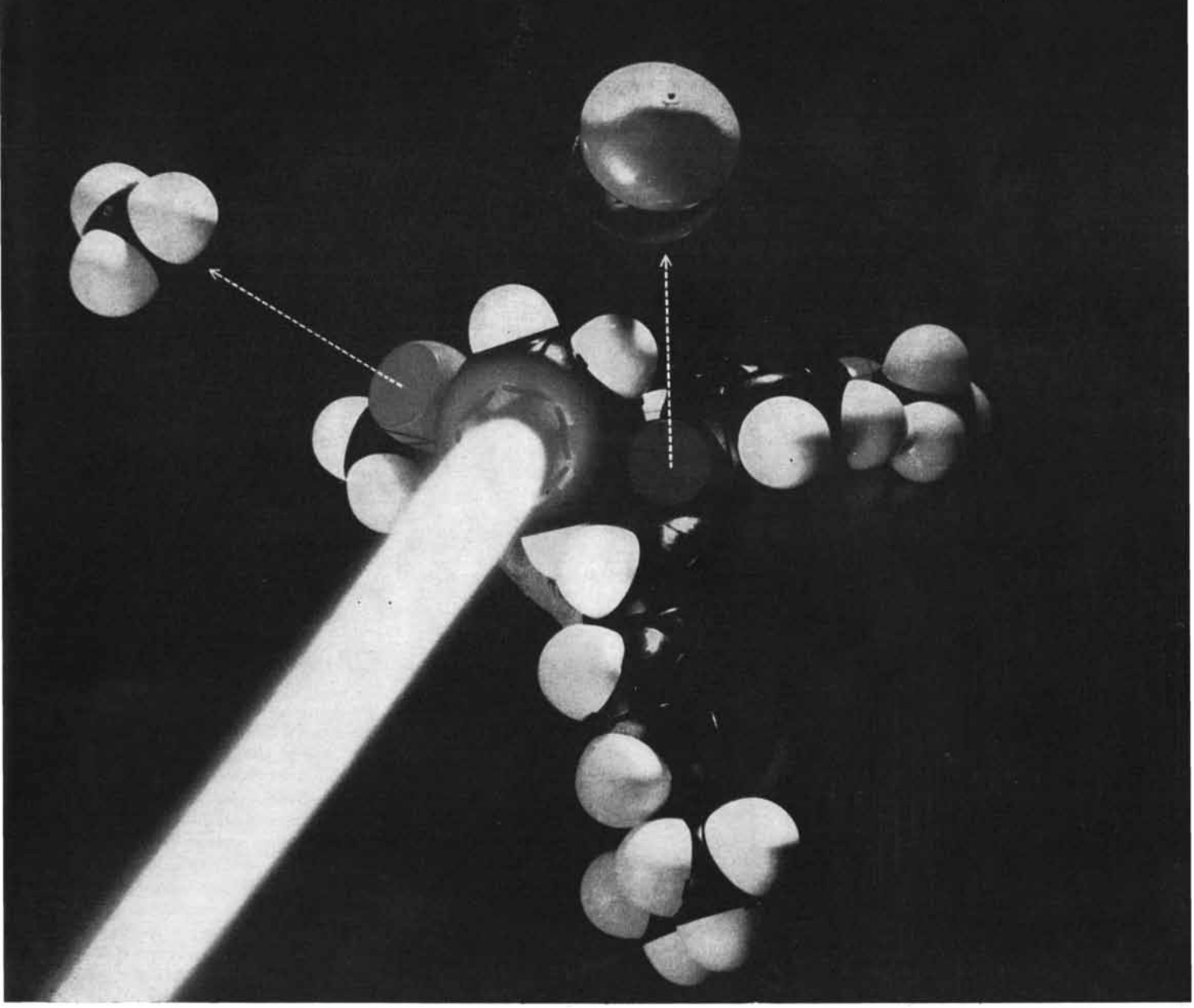
The game of "hip," so named because of the hipster's reputed disdain for "squares," is played on a six-by-six checkerboard as follows:

One player holds 18 red counters; his opponent holds 18 black counters. They take turns placing a single counter on any vacant cell of the board. Each tries to avoid placing his counters so that four of them mark the corners of a square. The square may be any size and tipped at any angle. There are 105 possible squares, a few of which are shown in the illustration below.

A player wins when his opponent becomes a "square" by forming one of the 105 squares. The game can be played on a board with actual counters, or with pencil and paper. Simply draw the



Four of the 105 ways to become "square" in the game of hip



When Victoria blue leuconitrile absorbs light, it may decompose by one of the two modes indicated in the model above.

Organic molecules excited by light

Light energy can excite organic molecules, sometimes inducing color changes. Organic molecules can be treated as if they were independent molecules (even in the liquid and solid phases). The effect of small changes in their structure can be studied. Organic materials therefore offer a fruitful realm for investigating photoprocesses—the interactions of light and matter. Some of these photoprocesses have attracted our attention for their image-storing potential.

Several areas of organic photochemistry are now under study by a group of IBM scientists. A quantum of light absorbed by an organic molecule may interact with it to produce any of the following over-all effects: (1) transfer of the excitation energy to other molecules or to other parts of the same molecule; (2) re-emission of light of different wave lengths and time constants; (3) conversion of the light energy to heat; (4) decomposition of the organic molecule.

Researchers at IBM are striving to advance our understanding of the mechanisms of these molecular reactions. One study, for example, has probed the principles that govern decomposition by light of Victoria blue leuconitrile molecules, which exhibit all four of these reactions under photoexcitation. One of the possible modes of decomposition leads to color formation.

Clarifying the mechanisms of photochemical reactions in the liquid and solid states will add to our understanding of the interactions of energy with matter. It may lead to the development of new photoprocessing techniques.

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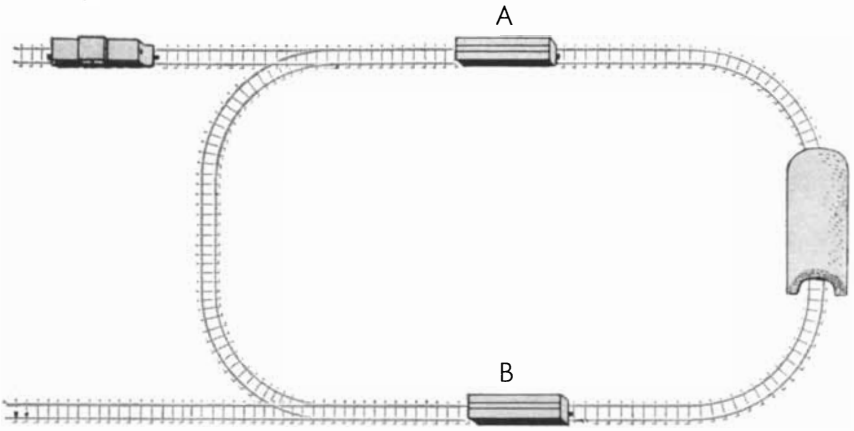

A puzzle in operations research

board, then register moves by marking X's and O's on the cells.

For months after I had devised this game I believed that it was impossible for a draw to occur in it. Then C. M. McLaury, a mathematics student at the University of Oklahoma, demonstrated that the game could end in a draw. The problem is to show how the game can be drawn by dividing the 36 cells into two sets so that no four cells of the same set mark the corners of a square.

2.

The efficient switching of railroad cars often poses frustrating problems in the field of operations research. The switching puzzle depicted in the illustration on this page is one that I have not seen in print, and it has the merit of combining simplicity with surprising difficulty.

The tunnel is wide enough to accommodate the locomotive but not wide enough for either car. The problem is to use the locomotive for switching the positions of cars A and B, then return the locomotive to its original spot. Each end of the locomotive can be used for pushing or pulling, and the two cars may, if desired, be coupled to each other.

The best solution is the one requiring the fewest operations. An "operation" is here defined as any movement of the locomotive between stops, assuming that it stops when it reverses direction, meets a car to push it or unhooks from a car it has been pulling. Movements of the two switches are not counted as operations.

A convenient way to work on the puzzle is to place a penny, a dime and a nickel on the illustration and slide them along the tracks, remembering that only the coin representing the locomotive can pass through the tunnel.

3.

Smith drove at a steady clip along the highway, his wife beside him. "Have you noticed," he said, "that those annoying signs for Flatz beer seem to be regularly spaced along the road? I wonder how far apart they are."

Mrs. Smith glanced at her wrist watch, then counted the number of Flatz beer signs they passed in one minute.

"What an odd coincidence!" exclaimed Smith. "When you multiply that number by 10, it exactly equals the speed of our car in miles per hour."

Assuming that the car's speed is constant, that the signs are equally spaced and that Mrs. Smith's minute began and ended with the car midway between two signs, how far is it between one sign and the next?

4.

An engineer, noted for his ability to visualize three-dimensional structure, was having coffee and doughnuts. Before he dropped a sugar cube into his cup, he placed the cube on the table and thought:

"If I pass a horizontal plane through the cube's center, the cross section will of course be a square. If I pass it vertically through the center and four corners of the cube, the cross section will be an oblong rectangle. Now suppose I cut the cube this way with the plane. . ." To his surprise, his mental image of the cross section was a regular hexagon.

How was the slice made? If the cube's

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side is half an inch, what is the side of the hexagon?

After dropping the cube into his coffee, the engineer turned his attention to a doughnut lying flat on a plate. "If I pass a plane horizontally through the center," he said to himself, "the cross section will be two concentric circles. If I pass the plane vertically through the center, the section will be two circles separated by the width of the hole. But if I turn the plane so. . ." He whistled with astonishment. The section consisted of two perfect circles that intersected!

How was this slice made? If the doughnut is a perfect torus, three inches in outside diameter and with a hole one inch across, what are the diameters of the intersecting circles?

5.

Two mathematicians were dining at the Ying and Yang, a Chinese restaurant on West Third Street in Manhattan. They chatted about the picture of the monad on the restaurant's menu [*see illustration on this page*].

"I suppose the monad is one of the world's oldest religious symbols," one of them said. "It would be hard to find a more attractive way to symbolize the great polarities of nature: good and evil, male and female, inflation and deflation, integration and differentiation."

"Isn't it also the symbol of the Northern Pacific Railway?"

"Yes. I understand that one of the chief engineers of the railroad saw the emblem on a Korean flag at the Chicago World's Fair in 1893 and urged his company to adopt it. He said it symbolized the extremes of fire and water that drove the steam engine."

"Do you suppose it inspired the construction of the modern baseball? After all, a baseball's cover is a kind of three-dimensional monad."

"I wouldn't be surprised. By the way, did you know that there is an elegant method of drawing one straight line across the monad so that it exactly bisects the areas of the Yin and Yang?"

Assuming that the Yin and Yang are separated by two semicircles, show how each can be simultaneously bisected by the same straight line.

6.

If you happen to meet two of the Jones sisters (this assumes that the two are random selections from the set of all the Jones sisters), it is an exactly even-money bet that both girls will be blue-eyed. What is your best guess as to the total number of blue-eyed Jones sisters?

7.

Two professors, one of English and one of mathematics, were having drinks in the faculty club bar.

"It is curious," said the English professor, "how some poets can write one immortal line and nothing else of lasting value. John William Burgon, for example. His poems are so mediocre that no one reads them now, yet he wrote one of the most marvelous lines in English poetry: 'A rose-red city half as old as Time.'"

The mathematician, who liked to annoy his friends with improvised brain-teasers, thought for a moment or two, then raised his glass and recited:

A rose-red city half as old as Time.
One billion years ago the city's age
Was just two-fifths of what Time's age will be
A billion years from now. Can you compute
How old the crimson city is today?

The English professor had long ago forgotten his algebra, so he quickly shifted the conversation to another topic, but readers of this department should have no difficulty with the problem.

8.

Three high schools—Washington, Lincoln and Roosevelt—competed in a track

The monad. Yin is dark and Yang is light

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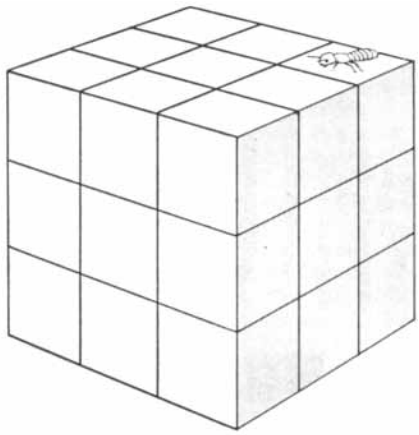

The problem of the termite and the cube

meet. Susan, a student at Lincoln High, sat in the bleachers to cheer her boy friend, the school's shot-put champion.

When Susan returned home later in the day, her father asked how her school had done.

"We won the shot-put all right," she said, "but Washington High won the track meet. They had a final score of 22. We finished with 9. So did Roosevelt High."

"How were the events scored?" her father asked.

"I don't remember exactly," Susan replied, "but there was a certain number of points for the winner of each event, a smaller number for second place and a still smaller number for third place. The numbers were the same for all events." (By "number" Susan of course meant a positive integer.)

"How many events were there altogether?"

"Gosh, I don't know, Dad. All I watched was the shot-put."

"Was there a high jump?" asked Susan's brother.

Susan nodded.

"Who won it?"

Susan didn't know.

Incredible as it may seem, this last question can be answered with only the information given. Which school won the high jump?

9.

Imagine a large cube formed by gluing together 27 smaller wooden cubes of uniform size [*see illustration on this page*]. A termite starts at the center of the face of any one of the outside cubes and bores a path that takes him once through every cube. His movement is al-

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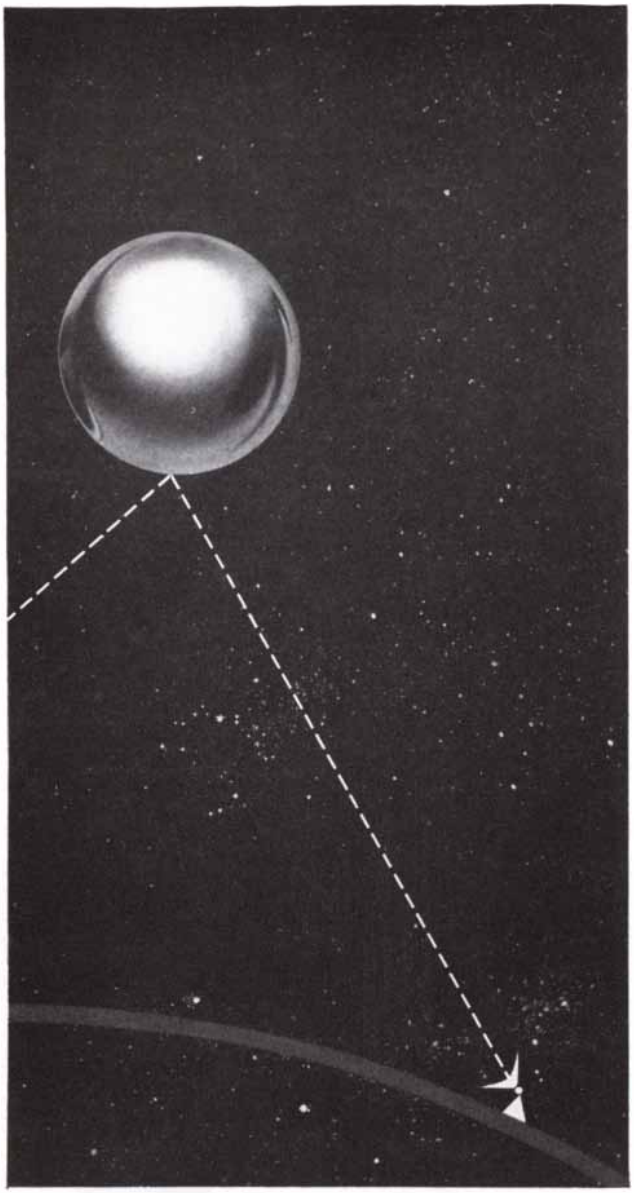

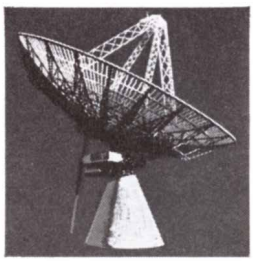

Project "Echo"—using a passive, 100-foot diameter, inflated sphere orbiting the earth to reflect signals—is investigating the feasibility of reliable and efficient long-range microwave communication. Radio and voice signals were bounced off the sphere between California and the East Coast. This followed earlier successful "moon-bounce" signalling between the same locations using the same transmitter.

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ways parallel to a side of the large cube, never diagonal.

Is it possible for the termite to bore through each of the 26 outside cubes once and only once, then finish his trip by entering the central cube for the first time? If possible, show how it can be done; if impossible, prove it.

The answers to last month's three map-coloring problems follow (the first two answers refer to illustrations that accompanied the problems):

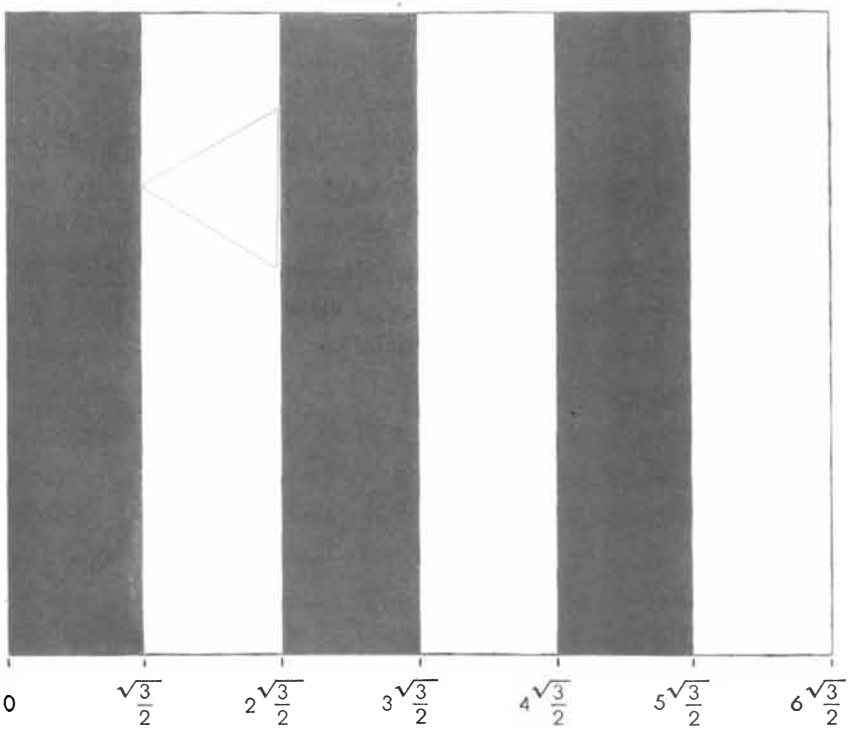
1. The swastika map could be colored with two colors were it not for one small line at the lower left corner. At this spot three regions touch one another, so three colors are required.

2. The artist colored his abstraction by mixing all his blue paint with one third of his red paint to obtain enough purple to color 16 square feet of canvas. After the large region at the top of the canvas and the area in the center are painted yellow, it is a simple matter to color the remaining regions red, green and purple.

3. To color the plane with two colors so that no three points of the same color mark the corners of an equilateral triangle with a side of 1, divide the plane into parallel stripes, each with a width of $\sqrt{3}/2$, then color them alternately black and white as shown in the illustration on this page. This does not solve the problem, however, until the concept of open and closed sets is introduced. A continuum of real numbers—say from 0 to 1—is called a closed interval if it includes 0 and 1, and an open interval if it excludes them. If it includes one and not the other, it is said to be closed at one end and open at the other.

The stripes on the map are closed along their left edge; open along their right. The black stripe on the left has a width that starts at 0, measures on the line below the map, and goes to $\sqrt{3}/2$. It includes 0, but does not include $\sqrt{3}/2$. The next stripe has a width that includes $\sqrt{3}/2$ but does not include $2\sqrt{3}/2$, and so on for the other stripes. In other words, each vertical line belongs only to the stripe on its right. This is necessary to take care of cases in which the triangle, shown in color, lies with all three of its corners on boundary lines.

Leo Moser of the University of Alberta, who sent this problem, writes that it is not known how many colors are required for coloring the plane so that no *two* points, a unit distance apart, lie on the same color. Four colors have been shown necessary, and seven sufficient, but the gap between four and seven is so large that the problem seems a long way from being solved.



Solution to last month's problem of the triangle and the two-color map

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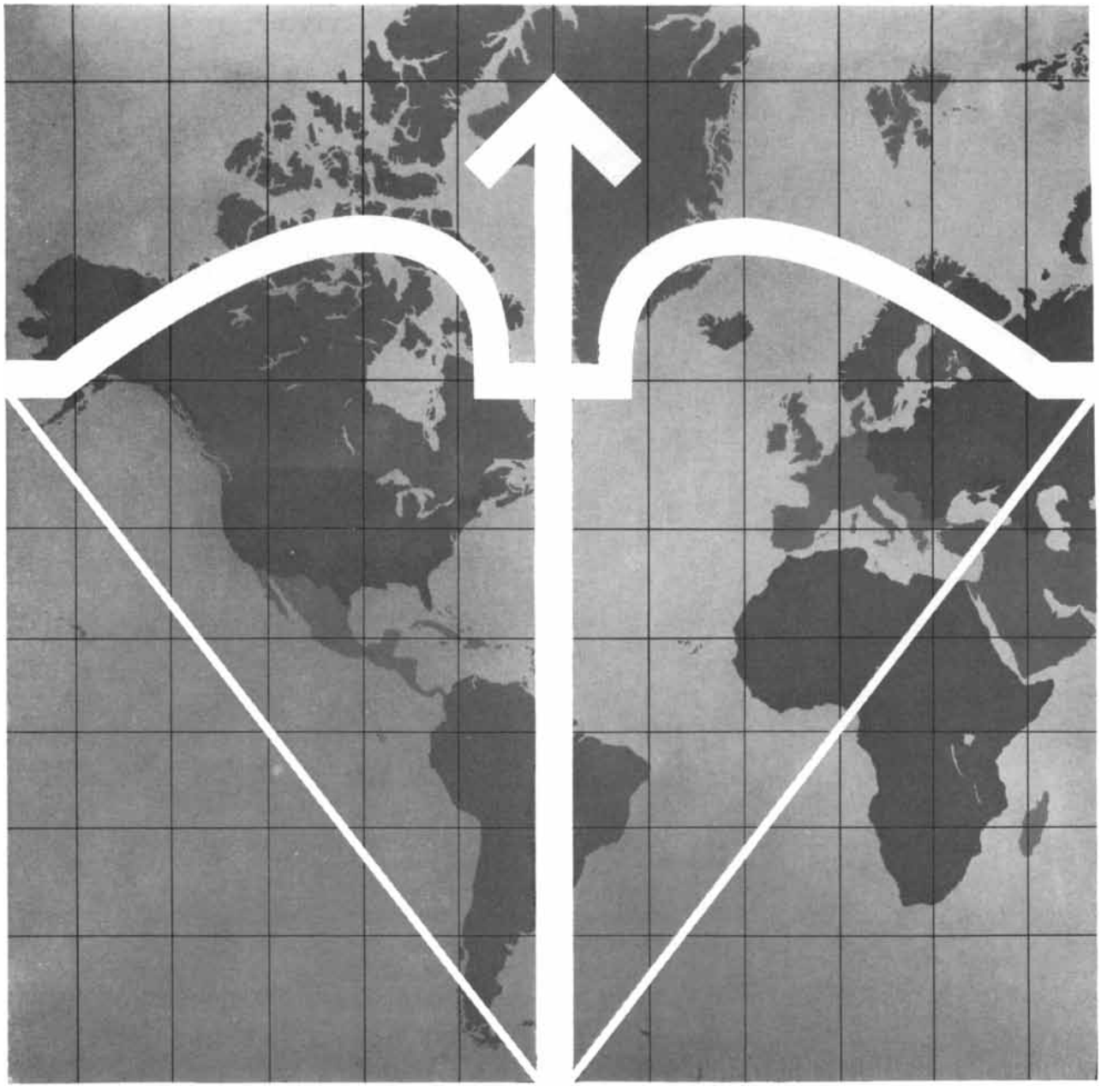

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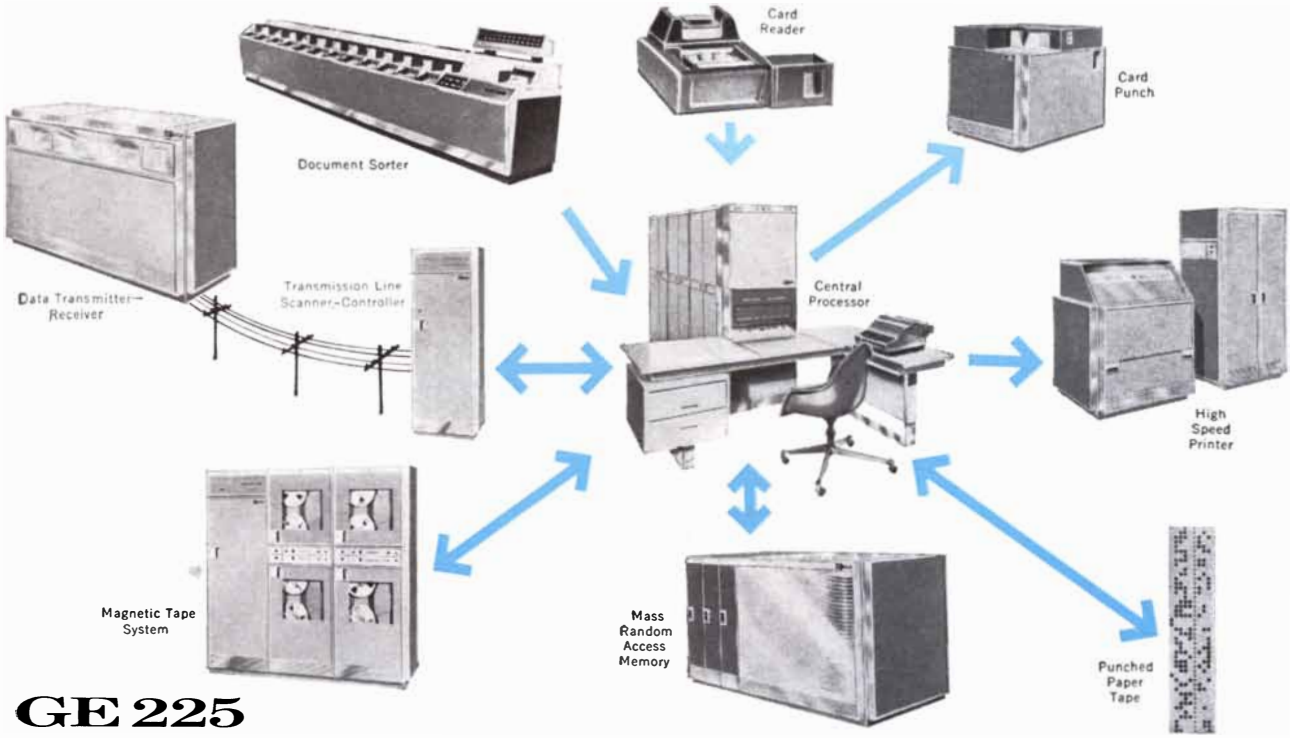

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Still in the early experimental stage, this phototransistor is a tangible result of the General Motors Research Laboratories' program **on** semiconductors — particularly the group II-VI compound, cadmium sulfide. Behind its development lies the steady accumulation of (1) know-how in crystal growing, doping, and contact preparation and (2) information about CdS's intriguing solid state properties (red or green luminescence, high photoconductivity, short relaxation times, etc.).

For the researcher, this three-terminal device is adding a new dimension to the fundamental understanding of semiconductors. For instance: GM Research scientists have uncovered the important role of photo-generated holes in modulating the conductance of this intrinsic semiconductor and have determined the hole drift mobility through a new theoretical analysis.

These semiconductor investigations illustrate the dual aim of GM Research: contributions to the science, advances in the technology of important new subject areas. Such research is the initial step in General Motors' continuing quest for "more and better things for more people."

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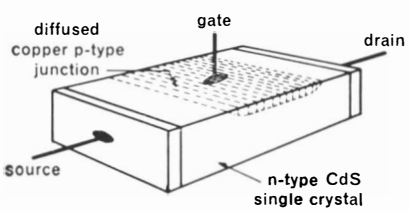
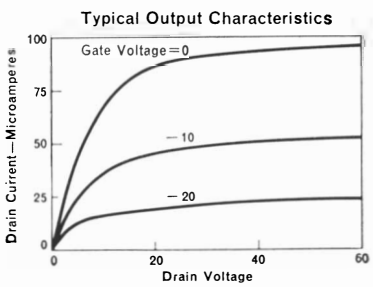




THE AMATEUR SCIENTIST

How amateurs can make a device for listening to underwater sounds

Conducted by C. L. Stong

Anyone who has spent any time swimming underwater will recall how quiet everything seems beneath the surface. Even in waters that teem with fish, or where currents cause marine plants to vibrate with obvious violence, few sounds are heard by the swimmer other than the faint rush of blood inside his own head. The illusion of submarine silence is explained by the ineffectiveness of the human ear as a detector of underwater sound, a fact that became apparent with the invention of the hydrophone. This instrument disclosed that all of the oceans, many lakes, rivers and even brooks are filled with sounds at least as varied and interesting as those in the air. Few amateurs have been privileged to hear or record submarine sounds, however, because hydrophones are not generally available. This barrier is now removed. Frank Watlington, a specialist in underwater sound-detection who is currently abroad on a Government assignment, has designed a hydrophone that amateurs can build without special tools at a cost of less than $10. In the following discussion he reviews some of the acoustic phenomena opened to amateur investigation by the hydrophone and explains how to build and use the instrument.

"Underwater sounds," Watlington writes, "were opened to investigation by the development of electronics and associated technologies. Instruments have been devised that are far more effective than the ear for the perception of mechanical vibrations. With these 'transducers' it became apparent that the oceans and lakes are not the silent world that they were once considered to be.

"Submarine sounds originate in disturbances caused by physical phenomena, by marine animals and by men. They are called ambient noise when the sources are not identified.

"The water noises that originate from physical phenomena may be induced by the breaking of surf on the shore, the action of tidal currents on stones or small pebbles, the movement of water in eddies through reefs and rock pockets, by earthquakes, volcanoes and even by whitecaps in the open ocean.

"Marine organisms are sometimes extremely vociferous. The croaker, a fish that abounds in both the Atlantic and Pacific, makes a noise like a persistent woodpecker. Classified as a drumfish, it is equipped with a gas-filled bladder. It collects in certain areas in large numbers during the summer months, at which time little else can be heard. The noise emitted by the croaker is produced by the vibration of a muscle beside the swim bladder of the fish. A similar noise can be produced artificially in air by rubbing a toy balloon with a slightly moistened finger. The snapping shrimp makes a noise resembling the snapping of fingers. The shrimp has one prominent claw, and it makes this noise by clicking the claw rapidly. There are areas where the population density of these animals approaches 20 per square foot; in such numbers they produce a high-pitched roar that sounds like a giant pan of frying bacon. A weird wailing sound heard off Bermuda during March and April is attributed to humpback whales migrating in large numbers to northern waters, usually with their calves. The sounds are not unlike those from a herd of cattle, but are characterized by a greater range in pitch. No one knows how the whale produces these sounds, but they have aroused much interest.

"These are only a few of the many sounds heard in the oceans of the world. Why and how do marine animals make them? It is possible that some animals have evolved a method of echo-ranging on their prey in the same way that ships measure the depth of the water: a sound is emitted from the ship's bottom, and the time required for this sound to travel from the ship to the bottom and back is a measure of the depth. It is also possible that some marine-animal sounds represent mating calls or even the communication of information.

"Among man-made sounds the most prominent come from ships. These originate mostly in the propellers and the propulsion machinery. Other frequently heard man-made noises are emitted by explosions, by machinery on barges, by pile drivers and in some locations even by vehicular traffic on land.

"A sound is anything that the ear can hear. But many vibrations are emitted by mechanical disturbances above and below the range to which the ear is sensitive. Technically speaking, sound can be defined as 'a longitudinal disturbance traveling progressively from particle to particle through a material medium.' The medium may be a solid, a liquid or a gas. As is well known, sound travels in the form of waves. A long wave is heard as a sound of low pitch, and a short wave as one of high pitch. A complete wavelength is called a cycle, and is the distance measured from the crest of one wave to the crest of the next. If the frequency is below 16 cycles per second or above 16,000 cycles per second, it cannot be heard by most people.

"The numerical product of frequency and wavelength in a given medium is the velocity of the sound in this medium. At 68 degrees Fahrenheit the velocity of sound in air, for example, is 1,127 feet per second, and that in water is 4,900 feet per second.

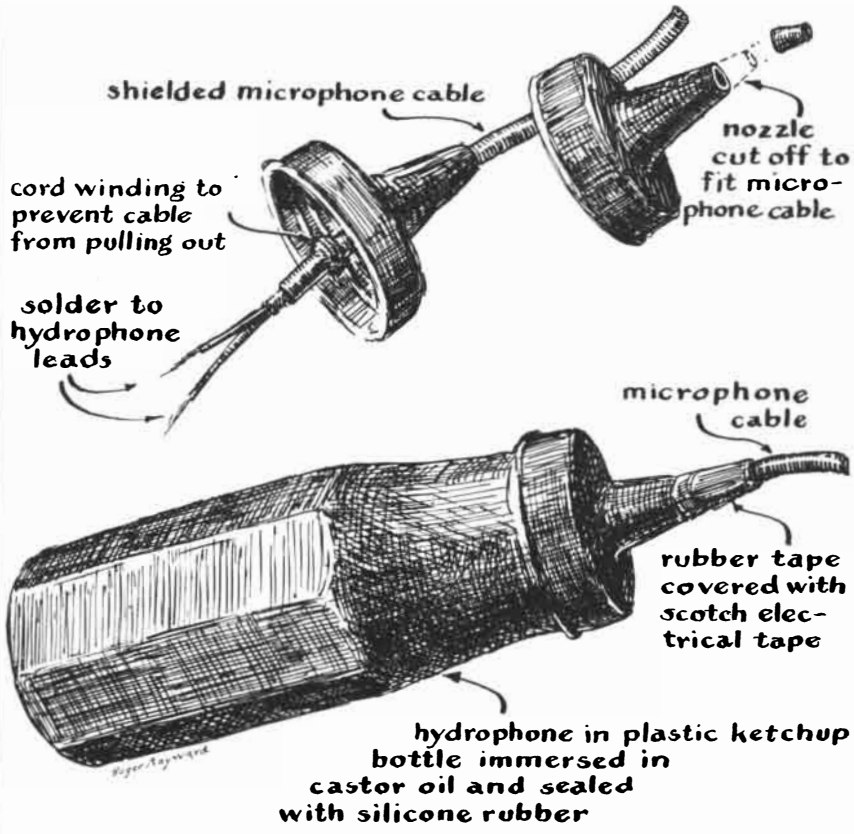
"The three principal characteristics of sea water that influence the speed of sound are temperature, pressure and salinity. Of these the most important is temperature. Warm water is less dense than cold water. Consequently warm water floats above cold water. As an underwater swimmer moves from the surface toward the bottom, he often encounters a region that is distinctly colder than the region above. Sounds are refracted by this temperature gradient, because a sound vibration traveling from warm water into cold water is slowed down. The action is analogous to a line of marching soldiers proceeding from a

hard-surfaced path to a sandy beach. If the direction of march is oblique to the soft surface, the soldiers who first encounter the sand are slowed down, and the line of march takes a new direction. Because of refraction effects, it is not always easy to predict the location of an underwater source of sound merely by observing the direction of the received waves. Much interesting work remains to be done in the field of underwater-sound ranging.

"Numerous transducers have been developed to sense the sound of the sea. They parallel the instruments used for the same purpose in air.

"A transducer, or hydrophone, that lends itself nicely to home construction is based on the fact that the magnetic properties of certain materials (*e.g.*, nickel) vary when the material is subjected to mechanical stress. The phenomenon is known as magnetostriction, and can be demonstrated by wrapping a coil of insulated copper wire around an appropriately shaped core of nickel. When current flows through the coil, a magnetic field is induced in the nickel. Many of the molecular magnets of the nickel immediately rotate into alignment with the induced field, and they retain this orientation after the field is removed. The nickel thus becomes weakly but permanently magnetized. If the core is now stressed mechanically, some of the molecular magnets are forcefully rotated away from the direction of the permanent field and no longer contribute to its strength. In other words, stressing a permanent magnet of nickel weakens its field. When the stress is removed, the disturbed molecular magnets return to their former orientation, and the magnet regains its strength.

"The effect can be observed by connecting a voltmeter of adequate sensitivity across the terminals of the coil and stressing the magnetized nickel core. When stress is applied, the field strength drops and induces a voltage in the coil. When the stress is removed, the field strength increases to its normal value and induces a second voltage pulse (of opposite sign) in the coil. The physical deformation of the core need not be large: a deformation measured in thousandths of an inch is more than sufficient to cause the observed effect. The corresponding voltage induced in the coil will vary with the number of turns of the wire comprising the coil. In the case of small cores wound with a few hundred turns, the potential is measured in millionths of a volt. But this minute voltage can be amplified by any desired amount. If one wants to hear sounds in the sea



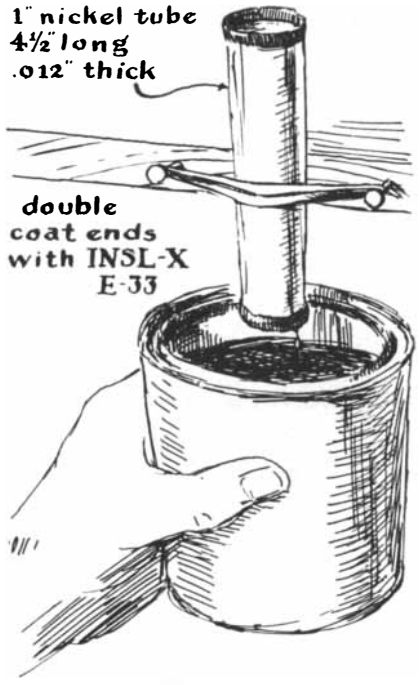
A homemade hydrophone designed by Fred Watlington

through a loudspeaker, the voltages from the usual magnetostriction hydrophones must be amplified from 100,000 to a million times, depending upon the characteristics of the instrument.

"Any amplifier having an input for either a dynamic (moving coil) microphone or a variable-reluctance record-playing cartridge will have sufficient gain to operate from a magnetostriction hydrophone. Any high-fidelity amplifier or modern tape-recorder that includes a preamplifier should do nicely.

"Nickel is only one of several materials that exhibit high magnetostriction. Others include 2V Permendur and various alloys containing nickel and iron. The magnetostrictive properties are affected by the gross composition, by impurities, by strains incurred in fabrication and by the crystal structure. 'Grade A' nickel is 99.45 per cent nickel, .25 per cent manganese, .15 per cent iron, .005 per cent sulfur, .05 per cent silicon and .05 per cent copper. It can be purchased in the form of rods, sheets or tubing. In some cases alloys obtained from commercial sources already have adequate magnetostrictive properties, but if adequate properties do not exist, annealing will generally provide them. A 'soft anneal' from the mill will provide moderately good magnetic properties, but for the best results additional annealing is usually required, for this will relieve strains that have been incurred during fabrication.

"The most effective magnetic circuit is one that has no air gap. That is, there is no break in the metal. If there is no air gap, most of the magnetic flux will be confined to the metal, which has a higher permeability than its surroundings, usually air. A piece of tubing meets this requirement if the coil is wound on it in the form of a toroid, as shown in the accompanying illustration [*top of page 190*]. Commercial magnetostrictive hydrophones usually employ tubular construction because they are relatively easy and inexpensive to build. Most are priced in the vicinity of $100. These hydrophones have a pressure sensitivity of around –80 decibels with respect to one volt per dyne per square centimeter at 1,000 cycles per second; this means that if a pressure of one dyne per square centimeter deforms the magnetic material at the rate of 1,000 cycles per second, 100 microvolts will appear across the terminals of the coil at a frequency of 1,000 cycles per second. This may seem like a very small voltage, but it is more than adequate for underwater-sound detection. A satisfactory hydrophone can be constructed with Grade A nickel tubing



How to coat the nickel tube with varnish

if the metal is annealed in an ordinary kitchen oven at a temperature of approximately 600 degrees Fahrenheit in air for three hours. The heat is then shut off and the tube permitted to cool in the closed oven. (The material should be cleaned of all grease in advance of annealing.) Annealed nickel tubing as shipped by the manufacturer will exhibit a sensitivity not too far below optimum. Tubing for the instrument to be described can be purchased from the Edmund Scientific Company of Barrington, N. J.

"The edges of the tube as received from the supplier are usually sharp. To protect the winding from damage it is necessary to cover them. The easiest way to accomplish this is to coat the ends of the tubing with a heavy varnish such as Insl-X, the preparation commonly used for coating hand tools such as insulated screwdrivers and pliers. This material and all others required for the construction can be ordered through a local hardware or electrical-supply dealer. Arrange the tubing for dipping as shown in the accompanying illustration [*above*]. The can of Insl-X is raised under the tubing until the end is submerged to a depth of about a quarter of an inch. Watch for bubbles and break with a matchstick any that form. Two dips (with a drying interval of one hour between) will provide a coating of adequate thickness.

"A bobbin for winding the toroid coil on the tubing is made from a piece of

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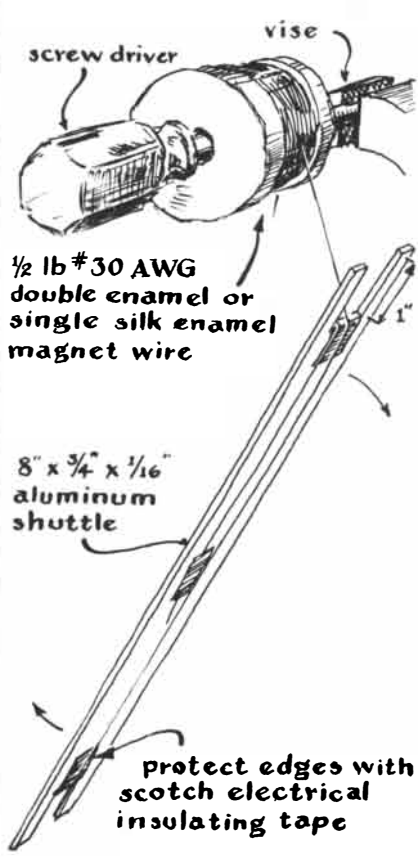
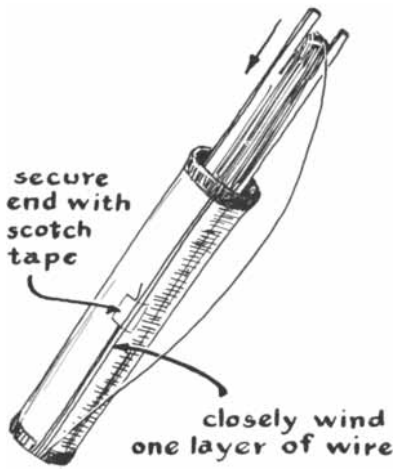
sheet aluminum about a 16th of an inch thick as shown in the accompanying illustration [*bottom of this page*]. Cut the channels with a hacksaw and round off all corners and burs with a file followed by sandpaper. The small sections of scotch tape applied as shown provide a cushion for the wire.

"The toroid coil is wound by hand. Transfer 200 turns of No. 30 AWG single silk enamel magnet wire to the bobbin. To facilitate the transfer, insert the blade of a screwdriver in the hole through the center of the spool and clamp the end of the blade in a bench vise. This frees both hands for the tedious winding job. Tape the end of the wire to the center of the bobbin and wind with a hand-over-hand motion. Be sure that no kinks or twists occur. No. 30 wire is recommended, but the size is not critical. If smaller wire is used, greater care must be exercised to prevent breakage; on the other hand, larger sizes reduce the number of turns that can be wound on the tube, and therefore limit the output voltage.

"When the bobbin is loaded, secure the outer end of the wire to the nickel tube with a small piece of scotch electrical tape. Then transfer the wire to the nickel tube by successively threading



How to load bobbin to make toroid coil



How to wind toroid coil on nickel tube

the bobbin through the tube as illustrated [*top of this page*]. The threading operation is continued until the tube has been wrapped with one full layer. Be sure that each turn is placed as closely as possible to the preceding one and that all turns are parallel to the axis of the tube.

"When the winding is in place, clean each end of the wire with a small piece of sandpaper as shown [*page 192*]. Enamel insulation can be deceiving. It resembles bare copper. Clean copper shines brightly. Failure to clean the wire invites a faulty connection and the risk of having to rebuild the unit after it has been sealed in its watertight housing.

"Stranded hook-up wire of the type used for building radio receivers will suffice for flexible leads. Prepare two 18-inch lengths by stripping a quarter of an inch of insulation from each end. Use red insulation for one and black for the other.

"Connect the leads to the coil ends and solder, using rosin flux. Insulate the joints with a two-inch length of closely fitting plastic radio spaghetti. Tape the leads securely to the nickel tube as shown [*page 194*], using scotch electrical tape, and check the unit for continuity. A continuity test can be made with an ohmmeter or with a battery and flashlight bulb [*see illustration on page 196*]. The direct-current resistance of the completed coil should come to about 30 ohms.

"Use the leads for suspension and dip the entire coil in the Insl-X varnish. This secures the wire to the tube. (The vibration of a loose turn will cause noise.) Hang the unit by its leads to dry, one end down, for at least an hour. Break any bubbles that form.

"While the varnish is hardening, cut

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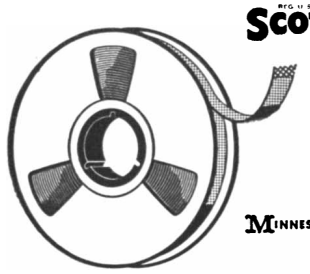

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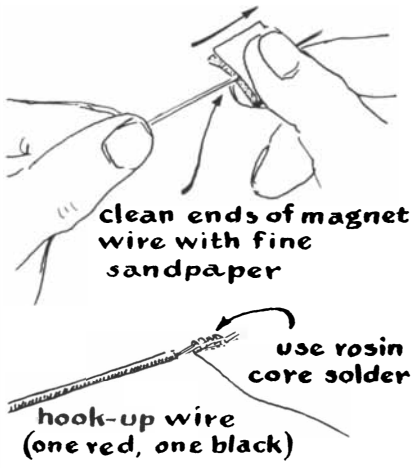

How to prepare magnet wire for solder joint

a piece of cork gasketing material from 16th-inch stock (such as Armstrong cork DC100) so that when it is rolled into a cylinder with butted ends, the cylinder makes a snug fit with the inner surface of the coil. The air pockets of the cork cells provide a cushion inside the tube so that pressure exerted on the unit by fluid will deform the tube inwardly. Without this provision, variations in sound pressure would exert equal force on the outer and inner walls of the tube, no movement of the metal would occur and no signal voltage would be generated. In effect the gasket material creates the essential pressure-differential across the walls of the tube. Unfortunately it also limits the depth to which the unit may be submerged. Beyond a critical depth, which varies with the strength of the gasket material, the static pressure of the water crushes the cells of the cork and destroys their cushioning effect. This renders the unit inoperative. The accompanying illustration [*page 194*] shows the assembly with the gasket in position.

"A final continuity check and another over-all coat of Insl-X varnish complete the assembly. The core must now be magnetized. This is accomplished by passing a direct current of approximately 1.5 amperes through the coil for a period of about half a second. I use a heavy-duty 45-volt battery as the power source. If the continuity test has been made with a lamp and battery, the core will have been partially magnetized by the incidental magnetic field, and it is therefore advisable to connect the magnetizing circuit so that the current flows in the same direction as during the test. The coil absorbs power at the rate of about 100 watts during the magnetizing interval, considerably beyond the capacity of the wire to dissipate energy with-

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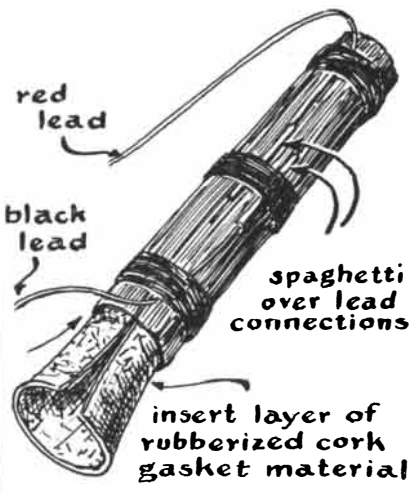
out dangerous heating. If the magnetizing current is permitted to flow for more than half a second, the coil may be damaged.

"This completes the pickup unit of the hydrophone. The pickup is housed in an oil-filled plastic container made from a polyethylene ketchup dispenser, and is connected to the amplifier through a length of shielded microphone cable. The cable enters the housing through the tapered nozzle of the dispenser. Snip off the end of the nozzle at the point where it will make a tight fit with the cable. Pull the cable through the prepared nozzle, skin the jacket back to expose a two-inch length of the conductors and securely lash a few turns of heavy cord around the cable at a point that will leave slack in the leads when the pickup assembly is installed. The cable is pulled into the nozzle until the cord wedges against the plastic [*see illustration on page 186*]. The cable is then spliced to the pickup leads. Solder the joints and insulate with spaghetti.

"The pickup operates in a bath of castor oil. (Do not use substitute oils. The electrical properties of some are inferior to castor oil, and others attack the insulating materials chemically.) Sound vibrations are transmitted to the nickel core through the oil. For maximum sensitivity the container must therefore be completely filled. Care must be taken to exclude bubbles from the oil. This can be accomplished by completing the final assembly with all parts fully submerged in oil. Fill an open container, such as a saucepan, with enough castor oil to cover the unassembled parts. The pickup unit is then inserted part way into the housing and immersed in the oil. The parts are manipulated while submerged to assure the escape of all



The hydrophone pickup assembly

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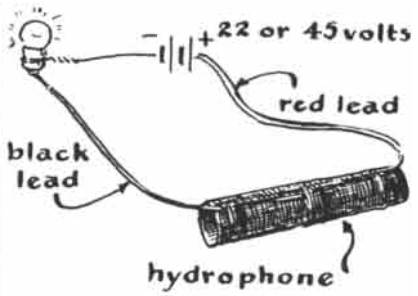

Continuity test using miniature lamp

bubbles, and the nozzle cap is screwed home.

"The unit is now removed and wiped clean. Seal the joints at the end of the nozzle and between the cap and the body of the jug with a wrapping of rubber tape and cover the rubber tape with scotch electrical tape. A connector that mates with the input of the amplifier is attached to the free end of the microphone cable. The hydrophone is now ready for use.

"The sensitivity of the instrument varies inversely with the frequency and is low in the audio range (16 to 16,000 cycles per second). The output rises at the rate of about six decibels per octave. For this reason you will need high amplification for satisfactory listening in the audio-frequency range. The home high-fidelity amplifier designed to operate from a variable reluctance cartridge will have enough amplification.

"A 50-ohm 'line-to-grid' transformer is used to match the impedance of the hydrophone to the input of the amplifier. Connect one terminal of the secondary coil directly to the grid of the input tube and ground the other. Connect the hydrophone across the 50-ohm coil. Tape recorders that have an input for a low-level microphone will also have sufficient gain to operate from the hydrophone. Usually these recorders include a transformer for low-impedance transducers and can therefore accept signals directly from the hydrophone. In either case the chassis must be well grounded to reduce 60-cycle hum and other background noise.

"Lower the hydrophone into the nearest river or off a convenient pier. Listen for passing motorboats and noises made by the local fish population. If there is an aquarium in your locality, perhaps the director will allow you to record the noises in his tanks. He will have to shut off the air or circulating water in the tanks during intervals of listening, or the background roar will mask the fish noises."

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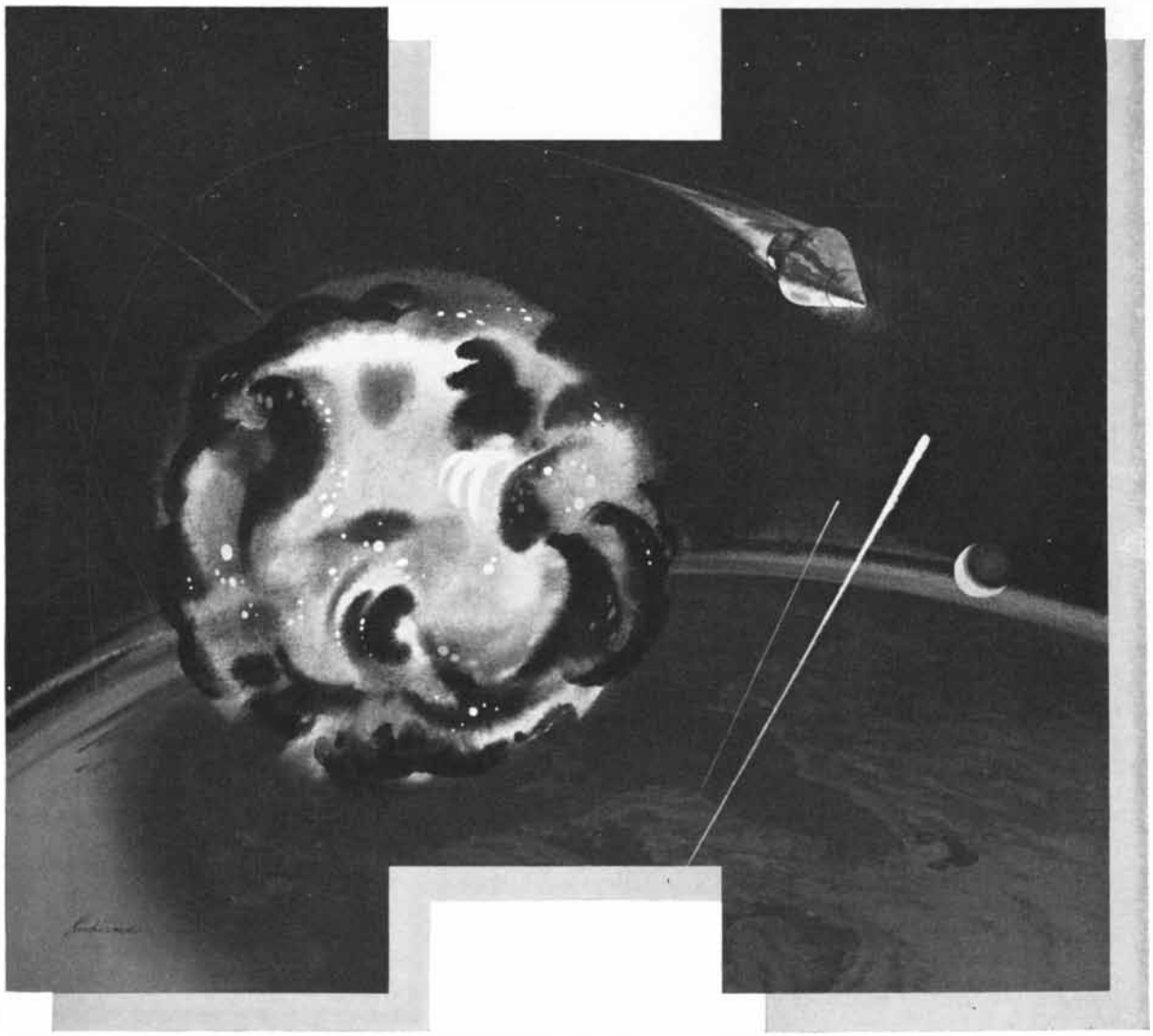

weapon?

The ICBM is often called the "ultimate weapon." Yet, throughout history, there have been many so-called ultimate weapons. Men of science have always found a defense.

Today, Hughes engineers are studying this problem. The programs being initiated are uncovering many challenges for imaginative engineers and scientists.

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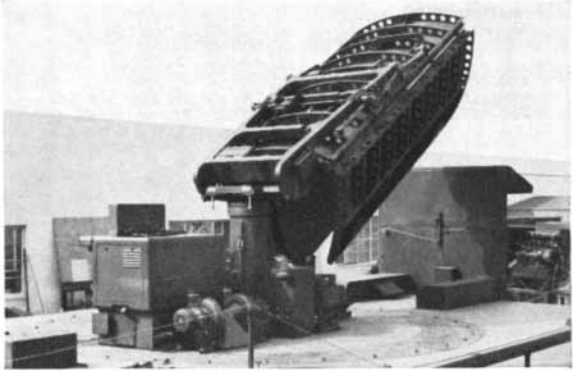
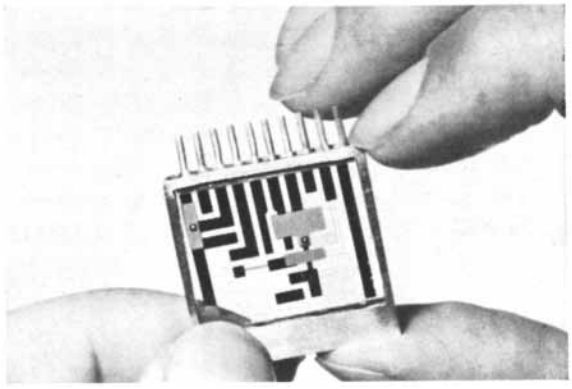


This Hughes three dimensional radar antenna, *shown in the process of retraction, is completely mobile. Developed by Hughes engineers, frequency-scanning radar provides umbrella-like protection for key defense areas.*

This complete flip-flop circuit *demonstrates Hughes capabilities in the field of solid state data processors. Hughes engineers are broadening the state of the AICBM art by drawing upon a great number of such advanced electronic techniques.*



Hughes is also drawing on its skills in such fields as advanced infrared and radar detection systems, satellite communications systems, electronic scanning radar systems, space vehicle technology, microwave propagation, advanced data handling and display systems, and other fields of advanced electronics.

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BOOKS

Louis de Broglie's renewed effort to find a cause-and-effect basis for microphysics

by P. W. Bridgman

NON-LINEAR WAVE MECHANICS: A CAUSAL INTERPRETATION, by Louis de Broglie. Translated by Arthur J. Knodel and Jack C. Miller. Elsevier Publishing Company ($11).

This book and the events that it narrates constitute a shining exemplification of the aphorism of Samuel Butler "He that complies against his will is of his own opinion still."

Prince Louis de Broglie is recognized as the inventor of that particular form of quantum theory known as wave mechanics. He had arrived at his fundamental point of view in 1923 and 1924, and incorporated it in his thesis for the D. Sc. degree in 1924. De Broglie's new insight was that the wave-particle dualism should be complete and universal. One aspect of this dualism was already recognized in connection with radiation; it had been found necessary to supplement the waves of classical optics with accompanying particles—the photons—in order to accommodate such new phenomena as the photoelectric effect and the Compton effect. It was de Broglie's conviction that analogously the particles of ordinary mechanics must have accompanying wave phenomena. What the nature of this new dualism might be was foreshadowed more than a century before by William Rowan Hamilton, who had called attention to certain analogies between the trajectories of material particles and the rays of geometrical optics. Reflection on Hamilton's results had led de Broglie already in 1923 to the idea that traditional mechanics, both in its relativistic and classical Newtonian forms, was only an approximation, of the same sort of validity as geometrical optics. The relation between the wavelength, if such there was, of an ordinary mechanical particle and its mass or energy was presumably the same as that already established for the photon. Accordingly, because of the relatively large masses of all material particles, their accompanying wavelengths could be expected to be very much smaller than the familiar optical wavelengths, and the corresponding phenomena therefore more difficult to establish. The wavelength would be largest for the electron, the material particle with the smallest known mass, so that it might be expected that the experimental verification of de Broglie's ideas would be made first in connection with the electron. This, of course, is what actually happened in the experiments of C. J. Davisson and L. H. Germer and of G. P. Thomson. The interference experiments with electrons were presently extended to lightweight atoms, the corresponding wavelengths of which were much less, so that these "matter waves" came to be regarded as having just as much "physical reality" as the ordinary waves of optics did. A rather spectacular corroboration of the reality of the electron waves was afforded by de Broglie's discovery that the circumferences of the various Bohr orbits of the electrons in the atoms of various elements were such as to just contain an integral number of the electron waves of the electrons circulating in those orbits. That is, the electrons in their orbits were in steady or stationary states, as demanded by the Bohr theory.

However, in spite of these various indications that there really were waves associated with electrons and other elementary particles, there were some considerations which showed that the situation was not so simple as this. The years 1924 to 1927 were years of intense reflection by de Broglie on the implications of his own point of view, and also of the connection of his ideas with those of Erwin Schrödinger, whose first paper containing his celebrated wave equation appeared in 1926. Of Schrödinger's work de Broglie says in another place (*Physics and Microphysics*, 1955) "Schrödinger, expanding the ideas contained in my thesis, gave a complete analytical development of wave mechanics." De Broglie recognized that there was a probabilistic aspect to the psi function in Schrödinger's wave equation, but he felt that there must be more to it than the probabilistic aspect if the occurrence of a *particle* associated with the psi was to be adequately accounted for. He felt that there should be a more natural and inevitable connection between the particle and its wave than a connection imposed by simple fiat, as it were, between the psi of the Schrödinger equation and the particle. What he was looking for was a connection resulting of necessity from the inherent nature of the mathematics. These ideas crystallized in three papers in 1926 and 1927, in which the hypothesis was laid down that the Schrödinger wave equation permitted two kinds of solution: the well-recognized psi solution, which gave the probability of the presence of an electron or other particle, and a second sort of solution involving a mathematical singularity that *was* the particle. This idea is very similar to the one by which Einstein tried so long and so unsuccessfully to unify general relativity and quantum theory. This idea in de Broglie's form involved most serious mathematical difficulties, for it was not certain whether the sort of solution postulated by de Broglie even exists.

The Solvay Congress in October, 1927, was devoted to wave mechanics, and de Broglie was invited to present a paper. He would have liked to present his ideas about the second, or "double," solution of the Schrödinger wave equation, but because of the unsolved mathematical difficulties he had to content himself with an "incomplete and dilute form" of these ideas, which he called the pilot-wave theory. De Broglie had speculated enough about his second solution to convince himself that it had one aspect in common with the conventional psi solution, namely its phase. This permitted him to say that the singularity of the unknown solution that constituted the particle must in a certain sense be "guided" by the conventional psi solution. This picture of the situation coincided exactly with one put forward by Georg Madelung at the same time. De Broglie's ideas were unfavorably received at the Solvay Congress, where most of the other great figures in quan-

tum mechanics, including Niels Bohr, Max Born and Werner Heisenberg, supported by P. A. M. Dirac and Wolfgang Pauli, apparently ganged up on de Broglie in insisting that the psi of the Schrödinger equation represented merely the probability of the presence of an electron. Later this view became known as the Copenhagen interpretation, although it was first enunciated by Born, who was then at the University of Göttingen. The vehemence and the confidence of the opposition that de Broglie met, particularly some cogent criticisms by Pauli which he did not see how to answer, made a great impression on him, in spite of the fact that H. A. Lorentz, Schrödinger and Einstein did not accept the Copenhagen view. Moreover, when de Broglie reflected further on the situation after returning home, he became convinced that the pilot-wave theory was intrinsically incapable of supplying the objective, causal description he was seeking, for the reason, among others, that the psi function of conventional wave mechanics is propagated in a fictitious configuration space and is thus without "physical reality."

The double solution, as opposed to the pilot-wave solution, was not absolutely ruled out by these considerations, but the mathematical difficulties were so great as to make the successful outcome of further attack along these lines exceedingly uncertain. De Broglie thus abandoned this approach, writing: "From 1928 on I embraced Bohr's probabilistic interpretation as the basis of my personal research, my teaching and my books." In fact, so unreservedly did he adopt the probabilistic point of view that Einstein could say, in writing the foreword for de Broglie's *Physics and Microphysics:* "What impressed me most, however, is the sincere presentation of the struggle for a logical concept of the basis of physics which finally led de Broglie to the firm conviction that all elementary processes are of a statistical nature."

To all outward appearances de Broglie remained contentedly in the fold of the orthodox from 1928 to 1951, when he became acquainted with a recent paper by David Bohm, in which Bohm essentially went back, as de Broglie tells it, to de Broglie's pilot-wave theory of 1927, in which the psi wave of the Schrödinger equation is treated as a physical reality. Bohm made some interesting new suggestions, in particular somewhat weakening the force of the objections made by Pauli at the 1927 Solvay Congress, but on the whole de Broglie felt that Bohm had not answered the objections that had led him to abandon his own pilot-wave theory, and in a communication to the *Comptes Rendus* he reiterated these objections, which seemed to him insurmountable. This episode, however, redirected his attention to the theory of the double solution. In particular, he was stimulated by a remark of his pupil Jean-Pierre Vigier, who called his attention to the remarkable similarity between a situation that had arisen in general relativity and the requirements of the double solution. It had been demonstrated that a singularity in the gravitational field must automatically move along the geodesics of the gravitational field. Now this was exactly the sort of thing that de Broglie wanted his mathematical singularities (which were his particles) to do, and he was encouraged to hope that, if the mathematics could be made amenable in the one case, it might in the other. A further suggestion by Vigier indicated in somewhat more detail how this might possibly come about, and de Broglie was encouraged to resume work on his abandoned theory. The present book, in addition to the historical material outlined above, is occupied with setting forth his progress up to 1956 (the year of publication of the French original) in implementing his ideas.

The book contains several chapters in which the ideas of the pilot-wave solution are carried further, profiting in particular from suggestions by Bohm and Vigier. In these chapters some of the objections to the pilot-wave solution are met, but not in such a way as to obviate the necessity for developing the possibilities of the more rigorous method of the double solution. The last few chapters are devoted to a critical appraisal of the possibilities and the difficulties still to be surmounted. This discussion is engagingly frank, and makes no attempt to conceal the fact that the difficulties are formidable and that there is no certainty that they can be surmounted, even "in principle." It now appears that the original guiding idea has to be modified somewhat. At first the idea was that in some way there was a second kind of solution of the Schrödinger equation, which corresponded to the particle. This second solution was also wavelike, and was referred to as the u-wave. But it now appeared necessary to loosen the intimacy of the connection between the u-wave and the psi wave. The u-wave is the solution of an equation somewhat like the Schrödinger equation, but an equation that is completely "objective." There is a good deal of discussion of "objectivity" and "subjectivity," without

an attempt to make the distinction very sharp, and the reader has more or less to guess at precisely what is meant. One reason that the u-wave is said to be objectively real is that the independent variables of the equation of which it is hypothetically a solution are the canonical space-and-time variables. But there has to be more to it than this if the u-wave is to be objectively real in the sense that the solutions of the Maxwell equations, for example, are objectively real. Not only are the independent variables of the Maxwell equations the conventional space-time variables, but the solution itself is physically real. The solution is an electric or magnetic force, which can be determined by instrumental operations independent of the equations. It makes sense to ask whether the Maxwell equations are true; and in those cases where the equations have a solution in wave form it also makes sense to ask what the waves are waves of. (They are waves of electromagnetic force.) As for de Broglie's u-wave, the equation of which it is supposedly a solution is never written down, so that it is not possible to ask whether the equation is true. Neither is it possible to ask what the u-wave is a wave of. It seems to me that any "physical reality" that the u-wave has is of a pretty attenuated sort.

The u-wave solution has some unconventional properties. The part of it that represents the particle cannot be a point singularity, as was at first supposed, but has to be spread out through a region in space of finite size. In this region the solution is no longer a singularity in the mathematical sense, but is characterized by very large numerical values that cannot satisfy a linear equation. Such a region of space, with a rather well-defined boundary, is to say the least an unusual sort of mathematical creature. Furthermore, it now appears that in the region outside the particle, where the u-wave is much like the psi wave, there are difficulties. The u-wave cannot spread out to infinity, like the psi wave, but must have a well-defined outer edge. This is necessary in order to avoid the difficulties arising from the blurring of the particle with the passage of time, a difficulty in Schrödinger's original picture of the physical significance of his psi. This way out is not open to de Broglie's u, and in fact the mathematical method of meeting the situation does not appear, for any ordinary mathematical function can be analyzed into a Fourier series, with components that do reach out to infinity.

The equation, whatever it is, that the u-wave satisfies has to be non-linear, not only for the reason above, but also in order to admit the possibility of, for example, interference effects, in which the diffraction pattern of two slits is not the sum of the patterns of the separate slits. But the mathematics of non-linear equations is still no-man's land, and it is not known what the range of possibilities is, or how to construct an equation, or how to find its solution in such a way as to ensure the desired properties. De Broglie therefore can give no specific illustration of what the nature of the non-linearity might be, but has to content himself with the enumeration of vague desiderata, required by the physics but of unknown mathematical possibility. It seems to me that this must be regarded as a serious weakness in de Broglie's whole position.

It will be recognized that the assumption of the existence of a u-wave is nearly equivalent to the assumption of the existence of concealed mechanisms or variables. This means that de Broglie's suggested method of retaining conventional causality is in this respect in the same general class as Bohm's and a number of others. Now the mere mention of concealed variables is sufficient to automatically elicit from the elect the remark that John von Neumann gave absolute proof that this way out is not possible. To me it is a curious spectacle to see the unanimity with which the members of a certain circle accept the rigor of von Neumann's proof. De Broglie himself was one of these during his 24 years in the fold of the orthodox. He now finds it necessary to call von Neumann's proof in question, and he is in fact able to put his finger on one specific assumption (too technical to be described here) that justifies him in saying: "These observations now seem to me to cast doubt on the validity of the implicit postulate on which von Neumann's demonstration is based, and, as a result, to destroy the penetrating force of his argument." This episode would seem to point the moral that it is *never* possible to state a conclusion with completely unqualified validity. Henri Poincaré's remark still stands that, no matter how complicated the behavior of a quantum system, it is possible to completely reproduce its behavior with purely classical mechanisms, provided those mechanisms are buried deep enough and are forbidden, by fiat, to reveal their presence in any except the prescribed ways.

In order to make possible an ultimately causal explanation of the probabilistic behavior of the psi function de Broglie has now come to believe in the existence of a particular kind of hidden variable.

In a footnote to the English translation of his book he says that he has come to accept wholeheartedly a hypothesis of Bohm and Vigier, namely that the statistical nature of the psi function "arises from the interaction of the particle with a 'sub-quantic' medium which escapes our observations and is entirely chaotic, and which is everywhere present in what we call 'empty space.'" It seems to me that this comes perilously close to the situation envisaged by Poincaré, and I must confess that I was almost shocked by the suggestion.

De Broglie recognizes that the ultimate justification of his views would be the discovery of new kinds of experimental fact. He makes a few suggestions in this regard, among which perhaps the most important is that new sorts of behavior should be encountered at very high energies.

The book ends with a reiteration of the similarity between the points of view presented there and the outlook of general relativity, and with an eloquent tribute to Einstein and the profundity of his physical ideas.

The reception accorded the specific suggestions in this book will doubtless vary with the temperament of the reader. I personally question whether the book will make many new converts to the fundamental point of view—the general tenor of the book is too much on the negative side, and de Broglie has perhaps leaned over backward in his frank admission of the many great difficulties. But there can be, I believe, no doubt as to its lasting interest as a document disclosing the psychology of a scientist, and as such throwing light on the altogether surprising present differences of attitude of physicists with regard to the fundamental point of view of quantum theory. No future history of physics is going to be complete without reference to de Broglie's book.

It remains for us to try to understand this surprising cleavage of present-day physicists into two camps, a cleavage all the more surprising when it is considered that sometimes the complete publicity and objectivity of science are incorporated into the very definition of science. It is to be commented in the first place that the difference is in the realm of what the physicist says rather than in the realm of what he does, in the sense that a Bohr or an Einstein would go through essentially the same arguments and obtain the same numerical result in calculating the ionizing potential of a hydrogen molecule. The difference of outlook between the two camps of physicists reminds one in certain ways of the difference of outlook of human beings of whatever interest which William James characterized as "tough-mindedness" and "tender-mindedness." Only here there is a curious inversion in who might be expected to be whom in this regard. During the many years that the rigid deterministic and causal conception of the universe resulting from Newtonian mechanics and culminating in the God of Laplace was getting established, it was the believers in universal causality who were tough-minded, as opposed to the tender-minded adherents of traditional philosophy and religion, who, with the loss of the freedom of the will implied by universal causality, were fearful that there was no sufficient basis for morality or religion. Now it is the believers in conventional and traditional causality such as Einstein and de Broglie who appear as tender-minded, as opposed to the tough-minded Bohr and Heisenberg, who give it up.

The conclusion would seem to be one to which we are also led from many other angles of approach. This is that science is unavoidably a human enterprise, and that the resulting edifice is by no means determined by the "objective" material out of which it is constructed. It has, in fact, long been recognized that no scientific theory can be unique. Some philosophers of science have emphasized the dominating role of "simplicity" in determining which of several logically possible theories is adopted. Anyone inclined to argue the dominating role of simplicity would do well to ponder the example presented here by de Broglie. It may be that he was guided by considerations of simplicity, but if so, it must have been a simplicity in the context of his entire outlook on the world, not a simplicity in a purely physical or mathematical context. No one could possibly maintain that the as yet unknown mathematics capable of implementing de Broglie's ideas can be simpler than the mathematics of Copenhagen. But if de Broglie was influenced by his need for simplicity in his total world view, he does not take us into his confidence as to what this world view is.

Short Reviews

THE EDGE OF OBJECTIVITY, by Charles Coulston Gillispie. Princeton University Press ($7.50). This substantial book provides a provocative and readable interpretation of major advances in certain departments of scientific thought from Galileo to James Clerk Maxwell, with an "epilogue" on the new age opened by Einstein. The momentous

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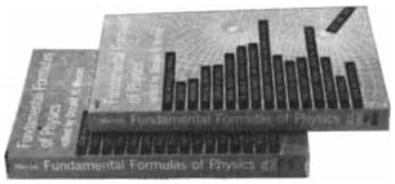

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changes of these three centuries in physics, chemistry and biology have of course been pretty closely studied by historians and philosophers, and while there is always room on the bench for a capable craftsman who can hold familiar things up to the light in his own way, cut new facets and make his own settings, it would be claiming too much—and Gillispie does not make the claim—that a hitherto undiscovered design of intellectual progress is described in this essay. Still, this is a story with a theme, a strong theme which the author presses hard. To put it simply (which inevitably means not to do it full justice), the theme is that modern science began with Galileo's conception of motion (undoubtedly his greatest work), and that this "true mutation in ideas" set the style for the prodigious drama of science that unfolded in the next 300 years. Allowing for the precursors and forerunners, for those who had so shaken the Aristotelian edifice that it was bound sooner or later to crumble and topple over, it remains that before Galileo men could still believe that the world might be solved in their own heads by a mixture of mysticism and logic; man, a chosen creature endowed with imagination and the power of reason, could get the hang of nature simply by thinking upon it. But after Galileo this illusion was no longer possible. The new philosophy, as John Donne wrote, called all in doubt. It was not enough to take thought to nature; nature had to be observed. It had its laws, but they had to be found out. It had endless vagaries, infinite complexities. Above all it was indifferent, no more sympathetic to men than to stones, yielding only to those with courage, perseverance and a capacity for abstract thought. The blending of these attributes led to what is called objectivity; and it is the cutting edge of objectivity which is the basic tool of science. The theme lends itself, as is easily seen, to eloquence, and Gillispie exploits the opportunity; but it is not an original notion, nor especially profound nor completely to the point. There were observers before Galileo and Pythagoreans after him, as the book emphasizes. The moral revolt against the soulless mechanism of Newtonian physics led by Diderot, Goethe, Wordsworth and even Alfred North Whitehead is part of a fluctuating and continuing debate between those who say the red of the rose is a wavelength, and those who say the redness is our idea, for which we should congratulate ourselves. The debate about objectivity resembles the debates about nature and nurture, induction and deduction, which is to say that it is sharper than it need be, that each side overstates the case, that it raises false issues and often misses the real ones. Science may see a world without qualities, while sense and imagination bid us accept, as one philosopher has said, a world which is scientifically impossible. Yet the truth, which is rarely pure, may not be so simple. In our time physics has provided the stage for some of the sharpest clashes. Arguments about causality and determinism, about the so-called postulates of impotence, have echoed the classical theme. Is a concept meaningful if it cannot be tested? Where is the line between the observer and the observed? Can the experimenter avoid putting his fat thumb on the scale? Erwin Schrödinger and A. S. Eddington are among those—a minority, to be sure, yet a formidable minority—who have turned back to Pythagoras. There are universal rhythms, cosmic unities, they say, with which we are in tune and which we can come upon by pure thought and verify by experiment. Since man is so much a piece of nature, need he, indeed can he ever, consider himself entirely alienated from it? Is not the stone his kin? Gillispie's book has more literary than philosophical merit. He is better at describing the 18th-century scene than that of the 19th or 20th. His discussion of Clerk Maxwell's work, for example, is murky and smells strongly of the lamp. He can be a stylish performer, but he flounces, is histrionic and apt to be carried away by his own epigrams. The analytic method simply cannot take that much moisture. At the risk of a reviewer's cliché, one is inclined to ask for whom the book is intended. The beginning student and ordinary reader will find some of the going too hard; the historian of science will not find in it much novelty. Nonetheless there are some sharp, enlightening and entertaining sections, and the essay as a whole is an impressive achievement, well above the run of such studies.

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things we can expect to learn from space observation posts. Among the subjects of prime interest are cloud and weather patterns; electric, magnetic and gravitational fields; the radiations and residual matter of outer space; the features of the moon, the planets and the stars. DuBridge sketches what is known about the solar system and the universe, and what physicists, chemists, geologists and meteorologists, astronomers, biologists and even philosophers and plain men would like to know. Eventually, of course, landings will be made on the moon, and perhaps even on a planet, but not next year, or thereabouts, as the juveniles of the space business, with more money to spend than is good for them and a Congress ever ready to appropriate it on the threat that some other power will get there first, keep promising. Many of the proposed military uses of satellites and moon voyages are, as DuBridge says, simply silly. The moon as a missile platform, for example, is in the Flash Gordon class. But there are many fascinating nonlethal programs which deserve attention. Meanwhile it is good to be reminded that we still know very little about the earth itself, and that a sense of proportion is needed in allocating funds and manpower for research.

DARWIN'S BIOLOGICAL WORK: SOME ASPECTS RECONSIDERED, edited by P. R. Bell. Cambridge University Press ($7.50). The essays in this volume, all by biologists actively engaged in research, consider the effect that Darwin's wide ranging contributions have had on certain branches of the science. P. R. Bell writes on the movement of plants in response to light; J. Challinor on paleontology and evolution; J. B. S. Haldane on natural selection; P. Marler on the study of animal communication; H. L. K. Whitehouse on cross- and self-fertilization in plants; J. S. Wilkie on the relation of the work of Buffon and Lamarck to that of Darwin.

THE TRANSITS OF VENUS, by Harry Woolf. Princeton University Press ($6). In 1761 and again in 1769 astronomical expeditions were sent to all parts of the world to observe the transits of Venus, events which stimulated considerable scientific excitement, because it was believed that they would provide the opportunity for obtaining one of the basic constants of astronomy, the solar parallax; this, it was hoped, would make possible the determination of the size of the solar system. The story of the undertaking, based primarily upon the expedition records, the deliberations of learned societies and the correspondence and publications of the scientists involved, is told in this book by a historian at the University of Washington. A sound piece of scholarship.

WHAT IS CYBERNETICS?, by G. T. Guilbaud. Criterion Books ($3.50). In 1834 the great physicist and mathematician André-Marie Ampère, in his ambitious *Essay on the Philosophy of the Sciences*, felt the need for a term to describe the study of "means of government." He turned to the Greek and translated the word *kybernētikē* into the French *cybernétique*. French dictionaries recognized his term, but there is no evidence it was ever used; instead its leap into currency is due to Norbert Wiener's 1948 book *Cybernetics*, in which he freshly coined the word from the Greek *kybernētēs*, which means steersman, to designate a group of studies descended from James Watt's and later James Clerk Maxwell's work on mechanical governors. The word has spread, as has the subject. One may go so far as to say that both have sprawled. Cybernetics is a word used by journalists to describe a domain of all kinds of things: automata, robots, "thinking machines," computers, guided missiles—in short, as a portmanteau for the spectacular. Among scientists there is a similar looseness of usage, though perhaps not for the same meretricious purpose. Under the heading cybernetics fall such matters as servomechanisms, the theory of circuits and networks, computers, the mathematical theory of information. Even these do not embrace the entire family; there are a few subjects such as the theory of games which are considered at least cousins of the main clan. Much has been written on different aspects of cybernetics: books and almost innumerable articles, popular as well as technical. This little book, a translation from the French, is by and large the best portrait of the subject as a whole accessible to the general reader. Using no mathematics, it describes with characteristic French lucidity the main features of this proliferating activity: control systems (circuits and networks, feedback and purposive activity), and signals and messages (the measurement of information, information and probability, communication). In a final section Guilbaud attempts to show that cybernetics is an effort to bring together seemingly independent lines of research that nevertheless can be thought to meet in a "crossroad" of the sciences. The crossroad, as is evident, gets busier and busier; economists, brain physiologists, mechan-

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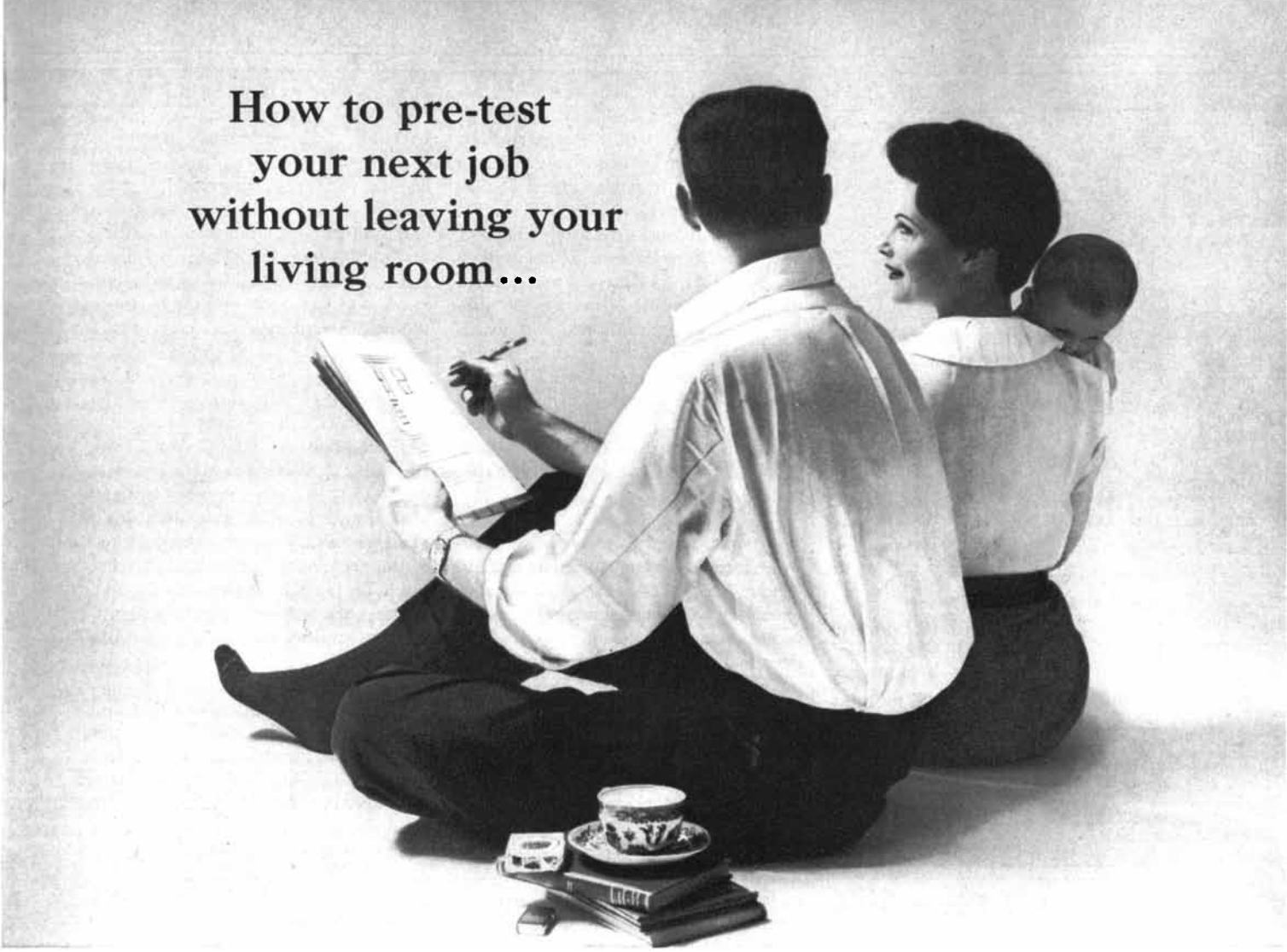

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ical engineers, psychologists, mathematicians, sociologists, military planners sit together at conferences, happy and fraternal as a group of college alumni back for the home game. How much of substance emerges from these gatherings is in dispute, but there is reason to believe, as Guilbaud says, that a common meeting ground for the different sciences and disciplines is needed, "despite the difficulty of avoiding trespassing and poaching." One analogy is striking, namely that cybernetics, overblown and meddling though it may seem, has an "intermediary function"; that is, like statistics it finds uses in many different fields even though it derives its name from one specialized application.

UNDERSTANDING CHEMISTRY, by Lawrence P. Lessing. Interscience Publishers, Inc. ($3.50). Popularizations of chemistry were once much read, but in recent years physics, astronomy and even mathematics have almost crowded out an old favorite. It is true that the advances in these subjects have been both spectacular and incessantly thrust upon public attention. Atomic energy, space flight, relativity are among the matters for which popularizers have found an ever widening audience. Still, chemistry has scarcely come to a stop, and if its progress has not been quite so flamboyant, its fruits have been enjoyed by vastly greater numbers than have benefited from advances in any other single field. Lessing's survey makes this quite clear. It presents a sound, ably written account of the role of chemistry in modern life: its contribution to our understanding of the physical world, its new concepts, its new applications, its formidable array of new products such as synthetic fibers, drugs, plastics, rubbers, adhesives, detergents, energy converters, soil conditioners, its extensions of the boundaries of our knowledge of life. A good book.

LAND FOR THE FUTURE, by Marion Clawson, R. Burnell Held, Charles H. Stoddard. Johns Hopkins Press ($8.50). Amidst all the ebullient politician clichés about our expanding economy, which in some respects attempt to create the impression that the faster we use up our resources, the richer will not only we but also our children be, little consideration is given to the land available for exploitation, to the fact that the amount of it is fixed, that our population and real income per capita are growing and that there is a steadily increasing demand for the products of the land. In examining the question this thoughtful volume considers the present status and foreseeable future of land use, urban uses of land and projected requirements, the economic and social role of cities, land for recreation, agriculture, forestry, grazing, transportation, reservoirs, mineral production, wildlife and miscellaneous public purposes. There are many charts and tables. A book which, both because of its subject and the balanced, thorough treatment of it, deserves close attention.

DIALECTICAL MATERIALISM: A HISTORICAL AND SYSTEMATIC SURVEY OF PHILOSOPHY IN THE SOVIET UNION, by Gustav A. Wetter. Frederick A. Praeger, Inc. ($10). An English translation of the fourth German edition of a Jesuit scholar's well-known survey and critique of the evolution of dialectical materialism in the U.S.S.R. and its influence upon political life, economic practices, the social system and science. Of particular interest is Father Wetter's account of the current formulations of the theory of relativity and other branches of research in chemistry, physics, biology and genetics. All things considered, the author's handling of these questions seems pretty objective. He makes it clear that Soviet scientists and philosophers, in their attempts, at least since Stalin's death, to adapt dialectical materialism to modern scientific thought, and to reconcile orthodoxy with free inquiry, end up in almost as much disagreement and confusion about the foundations of knowledge as do the scientists and philosophers of the West.

MAN'S CONTRACTING WORLD IN AN EXPANDING UNIVERSE, edited by Ben H. Bagdikian. Brown University Press ($4). The proceedings of a Brown University convocation held in October, 1959. There may be a point to convocations: leaders of thought, men of affairs, educators are brought together, mingle, exchange views, see, are seen, hear, are heard. Serious and light themes can be discussed, old acquaintances renewed, new acquaintances struck, plans laid. Good. But why, except for issuing a souvenir booklet, should the utterances be preserved. Why should it be supposed that anyone who was not a participant would crave to see a solemn record of an event whose entire merit—which may be considerable—consists of the stimulus of live exchange? Here is an example of a book which need not have been made. The theme is both cosmic and trite. In little more than 150 well-leaded pages 22 men and women take stock of the physical universe, the social environ-

ment and individual man. Nothing less. To be sure, eminent speakers and thinkers were present and said some sensible, occasionally striking, things. Margaret Mead, for example, spoke admirably when she said, "We have no way yet of protecting the children of the enemy so that the enemy can protect our children, and this is the next social invention that we are going to have to make." Sir Charles Galton Darwin, indulging a favorite theme, roamed learnedly over the next 50 years. Lester Pearson spent his eloquence on behalf of peace. But despite the good will, the special knowledge and the talent so abundantly on tap at this convocation, most of what was said was well-worn, wearisomely familiar and so hurried and superficial as to make an almost painfully embarassing impression on the serious reader.

THE ATMOSPHERE AND THE SEA IN MOTION: SCIENTIFIC CONTRIBUTIONS TO THE ROSSBY MEMORIAL VOLUME, edited by Bert Bolin. The Rockefeller Institute Press, in association with Oxford University Press ($15). Carl-Gustaf Rossby was a Swedish meteorologist who came to the U. S. in 1925, became a citizen in 1939 and was a leading figure in the advancement of the science in this country over the last quarter-century. His scientific ideas were vigorous and imaginative, and he was one of the prime movers in building up the airways weather service, establishing meteorological training programs, founding the *Journal of Meteorology* and promoting organizational and academic activities in meteorology. This volume, originally intended as a *festschrift* on his 60th birthday, and continued upon his sudden death in 1957 as a memorial to his life and achievements, contains a semipopular survey on current problems in meteorology by Rossby himself, two biographical sketches and 36 articles by various specialists on five main topics: the sea in motion, distribution of matter in the sea and atmosphere, the general circulation of the atmosphere, characteristic features of atmospheric motion, weather forecasting. Many illustrations, but no index.

CLASSICAL MATHEMATICS, by Joseph Ehrenfried Hofmann. Philosophical Library, Inc. ($4.75). A translation from the German of the second and third volumes of Hofmann's authoritative survey. Among the best features of this closely written, succinct history—a specialist's rather than a beginner's handbook—are the up-to-date bibliographies at the end of each chapter and the biobibliograph-

ical information packed into the indices. But, alas, the publisher of the English translation continues the unforgivable practice initiated in the first volume, reviewed here some time ago, of omitting these materials.

THE TANKS: THE HISTORY OF THE ROYAL TANK REGIMENT AND ITS PREDECESSORS, by Captain B. H. Liddell Hart. Frederick A. Praeger, Inc. ($15). A monumental account of the descendant of the ancient war chariot (or perhaps of the enlisted elephant), from its invention in Britain, and use in World War I, until 1945. The subject of this book will scarcely appeal to a wide audience, yet Captain Hart manages to tell an unbrokenly interesting story and to cover an amazing amount of military, technological and even political history. Illustrations.

THREE COPERNICAN TREATISES, by Edward Rosen. Dover Publications, Inc. ($1.75). A paper-back reissue, with some revisions and an annotated Copernicus bibliography, of Rosen's translation of the *Commentariolus* of Copernicus, his *Letter against Werner* and the *Narratio prima* of Rheticus. The *Commentariolus* and the *Letter* constitute Copernicus's minor astronomical works and shed light on the development of his thought; the *Narratio*, by his first disciple, admirably conveys to the general reader the central theme of *De revolutionibus orbium coelestium*.

HISTORY OF BIOLOGY: AN INTRODUCTION, by F. S. Bofenheimer. Robert Bentley, Inc. ($10). The author says his book is not intended as a competitor with other histories, but rather as a manual for teachers giving lectures on the history of science. Whatever else it may be, it is a curious work. The first part consists of brief and discursive essays on such topics as the philosophical background of scientific innovation, problems of priorities, external influences on the history of science. The less said of these oddments, the better. The second part is called a short factual history of biology, and is little more than a register. The third and longest part gives excerpts from the writings of leading biologists. Unfortunately many of the items are so condensed and scrappy as to be meaningless except possibly as memoranda for lectures.

THE DYMAXION WORLD OF BUCKMINSTER FULLER, by Robert W. Marks. Reinhold Publishing Corporation ($12). Buckminster Fuller has designed and

built queer-looking automobiles that incorporate excellent ideas; he has invented a new system of map projection; he is an imaginative architect—self-trained in this profession as in all his other activities—whose startling Dymaxion house raised a furor but never caught on, and whose geodesic domes have not merely raised a furor but are now to be found in all parts of the world. Fuller is a nonconformist who insists on everything his own way; he also leans to grandiosity. But he is never pretentious or self-seeking. His search is for simple technological solutions, and his goal in all he undertakes is to liberate men from poverty and physical drudgery. This book, primarily an account of his work, does him no great service. But the many illustrations convey a representative notion of his aims and accomplishments.

AN INVENTORY OF THE HISTORICAL MONUMENTS IN THE CITY OF CAMBRIDGE. British Information Services ($19.31). This most recent publication in the great series of inventories prepared by the Royal Commission on Historical Monuments includes a survey of prehistoric and Roman remains, university and college buildings, churches, public works and large and small houses dating up to 1850. There are detailed descriptions, a great number of maps and plans and a lavish assortment of photographs of such varied items as Bronze Age artifacts, 16th-century brass- and metal-work, stained-glass windows, fonts, lecterns, monuments, church plate, paneled roofs, pre-Conquest and medieval stone carvings, 17th- and 18th-century woodwork, wall paintings and wallpaper, furniture, fireplaces, bridges, architectural models, heraldic items, wrought-iron work, plasterwork, staircases, paneled rooms, famous college buildings, libraries, chapels, carved figures, churches, sculptures, botanic gardens, shops, dwellings, paintings. A magnificent publication.

Notes

A SHORTENED HISTORY OF ENGLAND, by G. M. Trevelyan. A Pelican Book ($1.65). An abridged edition—though still running to some 600 closely printed pages—of Trevelyan's famous history, the best one-volume survey for the literate reader.

THE SCIENTIFIC PAPERS OF SIR GEOFFREY INGRAM TAYLOR: VOL. II, METEOROLOGY, OCEANOGRAPHY AND TURBULENT FLOW, edited by G. K. Batchelor. Cambridge University Press ($14.50). This

second volume of Sir Geoffrey Taylor's papers, the first of three to be devoted mainly to his work on the mechanics of fluids, has as its principal theme the phenomenon of turbulence and its effects, a subject to which he made significant contributions.

THE THEORY OF HEAT RADIATION, by Max Planck. Dover Publications, Inc. ($1.50). A translation, in a paperback, of the second edition (1913) of Planck's highly influential book, in which he endeavored to reconcile the electromagnetic theory of radiation with experimental facts.

ATOMIC RADIATION AND POLYMERS, by A. Charlesby. Pergamon Press, Inc. ($17.50). A survey of present-day knowledge of the changes produced in materials by atomic radiation from reactors, or by electron radiation from high-voltage sources.

BIOGRAPHICAL MEMOIRS, NATIONAL ACADEMY OF SCIENCES: VOL. XXXIV. Columbia University Press ($5). The subjects of the memoirs include Reginald Daly, Bergen Davis, C. F. Kettering, Morris Kharasch, Otto Meyerhof, John Ulric Nef, Carl-Gustaf Rossby, Florence Sabin.

THE THEORY OF MATRICES, by F. R. Gantmacher. Chelsea Publishing Company ($12). An English translation by K. A. Hirsch of a Russian treatise on matrix theory based on lecture courses that the author gave at the universities of Moscow and Tiflis and at the Moscow Physico-technical Institute. For mathematicians and specialists in allied fields such as physics and engineering.

PROGRESS IN BIOPHYSICS AND BIOPHYSICAL CHEMISTRY: VOL. IX, edited by J. A. V. Butler and B. Katz. Pergamon Press, Inc. ($17.50). The contributors discuss, among other things, the kinetics of reactions between hemoglobin and gases, the hydrodynamics of the arterial circulation, visual pigments in man and animals and their relation to vision, determination of molecular dimensions from light-scattering data.

RADIATION BIOLOGY, edited by J. H. Martin. Academic Press, Inc. ($11). Proceedings of the Second Australian Conference on radiation biology.

THE WORLD AND THE INDIVIDUAL, by Josiah Royce. Dover Publications, Inc. ($4.50). Paper-back reissue of an ex-

panded version of Royce's Gifford Lectures, delivered at the University of Aberdeen in 1899 and 1900. The lectures, it has been said, constitute "the only sustained effort by an American philosopher to interpret the nature of things in a systematic and comprehensive manner."

RIEMANN SURFACES, by Lars Ahlfors and Leo Sario. Princeton University Press ($10). This volume in the Princeton Mathematical Series is intended to serve partly as an introduction to the theory of Riemann surfaces and partly as a survey of recent problems and results.

SOME MATHEMATICAL METHODS OF PHYSICS, by Gerald Goertzel and Nunzio Tralli. McGraw-Hill Book Company, Inc. ($8.50). A handbook, based on a graduate course, "intended to give a well rounded and thorough indication of the basic concepts involved in the study of linear systems, with emphasis on eigenvalues, eigenfunctions, and Green's functions."

HANDBOOK OF GEOPHYSICS. The Macmillan Company ($15). Revised edition of a reference manual compiled by the U. S. Air Force, giving current information on such topics as atmospheric pressure and density, precipitation, clouds, atmospheric electricity, geomagnetism, cosmic radiation, the ionosphere and the sun.

AN INTRODUCTION TO STOCHASTIC PROCESSES, WITH SPECIAL REFERENCE TO METHODS AND APPLICATIONS, by M. S. Bartlett. Cambridge University Press ($2.95). A paper-back reissue of an elementary general work on the mathematical methods and statistical techniques that are applicable to random processes.

FROM ENGINES TO AUTOS, by Eugen Diesel, Gustav Goldbeck and Friedrich Schildberger. Henry Regnery Company ($6). An account of the life and work of five pioneers in the development of the internal-combustion engine: Nikolaus August Otto, Gottlieb Daimler, Karl Benz, Rudolf Diesel and Robert Bosch. Illustrations.

HIGH-ENERGY ELECTRON SCATTERING TABLES, by Robert Herman and Robert Hofstadter. Stanford University Press ($8.50). A preliminary handbook on the subject of electron scattering and nuclear structure, designed for theoreticians and experimental investigators interested in carrying out and analyzing experiments in high-energy electron physics.

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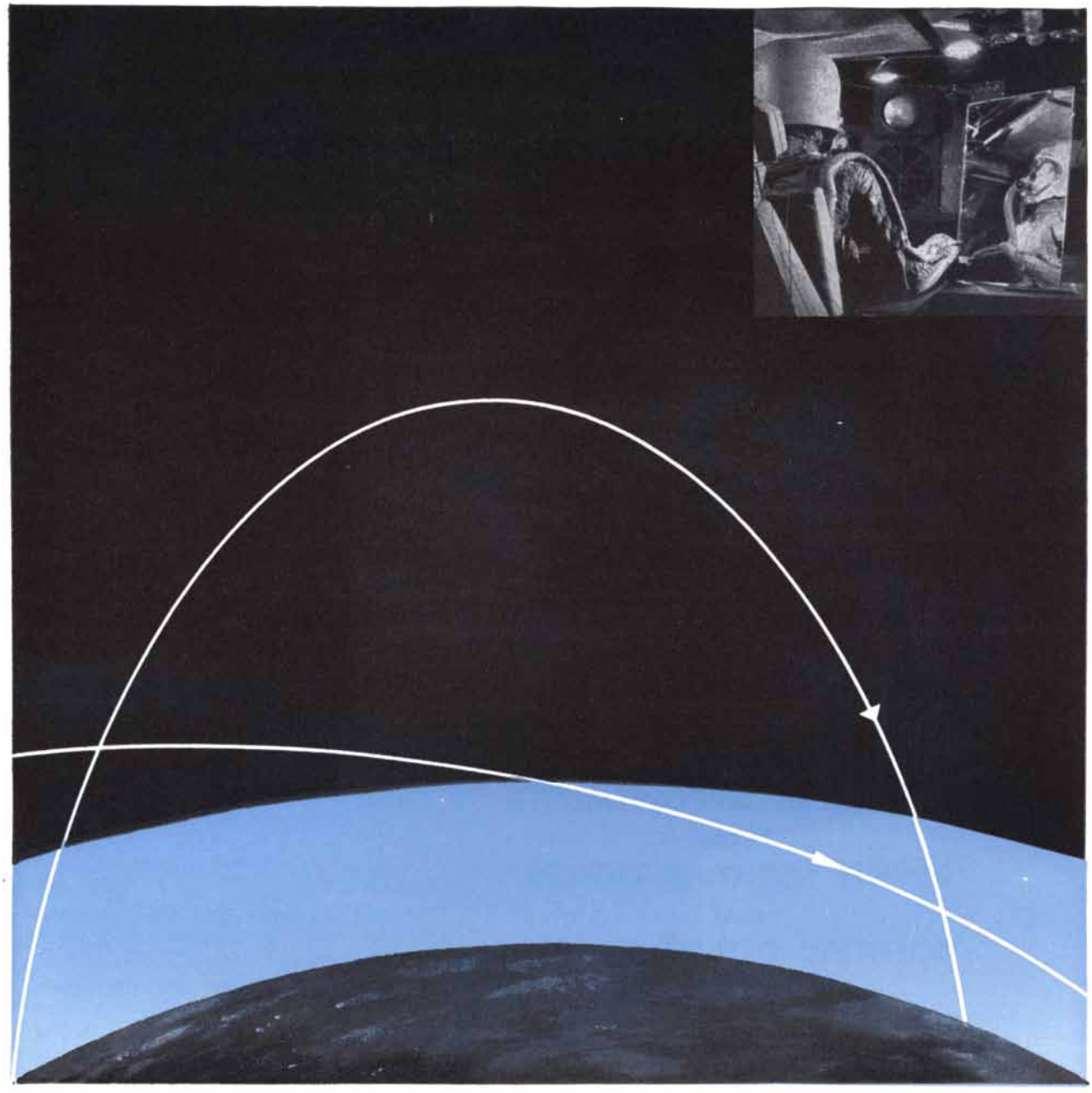

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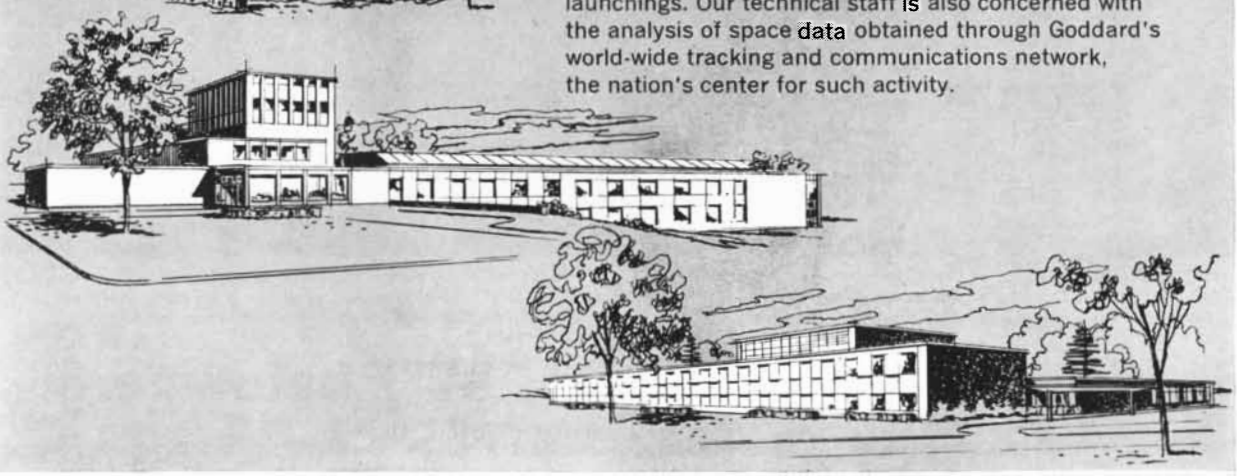
GODDARD
Space Flight Center

The Goddard Space Flight Center has just occupied an ultra-modern research complex situated on 550 acres of rolling parkland in Greenbelt, Maryland, a residential suburb of Washington, D.C. Here, many of our scientists and engineers work to advance space science and technology through a broad program of theoretical study, while others design, develop and construct scientific payloads for space vehicles and supervise their launchings. Our technical staff is also concerned with the analysis of space data obtained through Goddard's world-wide tracking and communications network, the nation's center for such activity.

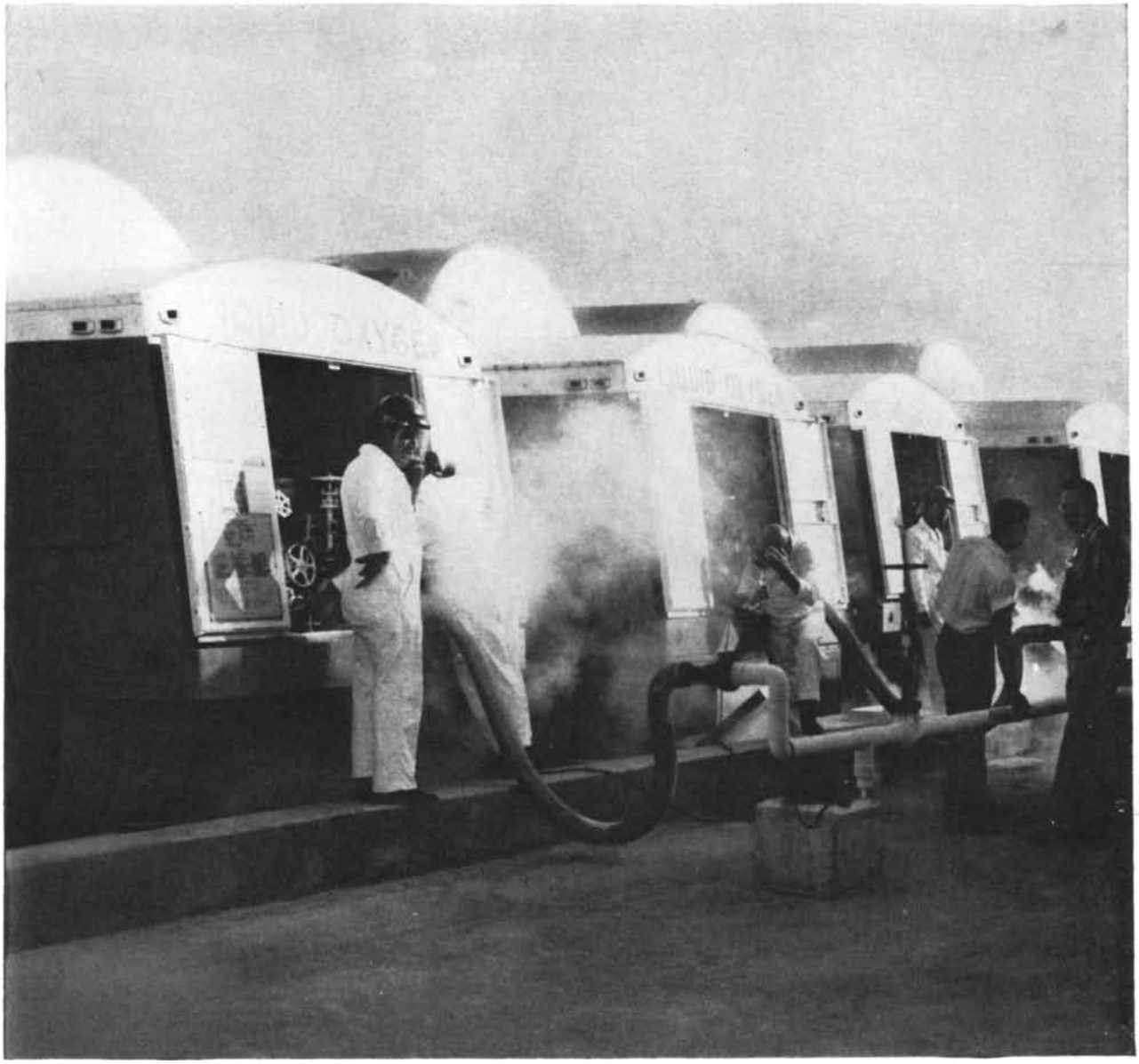


With Tiros, Echo, Pioneers IV and V, Explorer VII, and Project Mercury, Goddard has already written scientific history. Technical men who wish to work in the van of progress are invited to join Goddard or any of the other NASA research centers listed below. Address your inquiry to the Personnel Director.

NASA

National Aeronautics and Space Administration

NASA Goddard Space Flight Center, Greenbelt, Md. • NASA Flight Research Center, Edwards, Calif.
NASA George C. Marshall Space Flight Center, Huntsville, Ala. • NASA Wallops Station, Wallops Island, Va.



Pumping liquid oxygen for guided-missile fueling at Patrick A.F.B., Florida. Air Products, Inc., a pioneer in the production of LOX and other cryogenic materials, ships liquefied gases in these tank-trailers lined with nickel stainless steel. Piping and supports are also made of nickel stainless steel for high strength at cryogenic temperatures plus low thermal conductivity.

Handling liquid oxygen at 297°F below zero...

. . . Nickel-containing steels retain toughness and strength where other materials become brittle.

These highway tankers haul tonnage quantities of liquid oxygen for missile fueling.

In the nation's steel mills, where vast volumes of oxygen are used to speed up steelmaking, liquid oxygen (LOX) is stored in giant tanks right at the mill.

Ever since oxygen was first liquefied, one of the biggest problems has been to develop materials that will store and handle it *safely*.

LOX is handled at −297°F. Even before you reach that point, liquid mercury becomes so hard you can use it for a hammer, and many materials become brittle and shatter like glass when struck.

But today alloys are available—nickel stainless and other nickel steels—to provide the properties needed for low-temperature work.

Because these steels remain strong and tough at sub-zero temperatures, they are well suited to serve at temperatures where other metals embrittle and fracture. In short, they offer the most economical—and the safest—means to build anything from a liquid-helium generator to an ocean-going tanker for shipping liquefied gases.

If you are active in low-temperature chemistry or physics . . . or if you store or transport liquefied gases in small or large quantities . . . there is exactly the right nickel alloy steel to help you solve your problems.

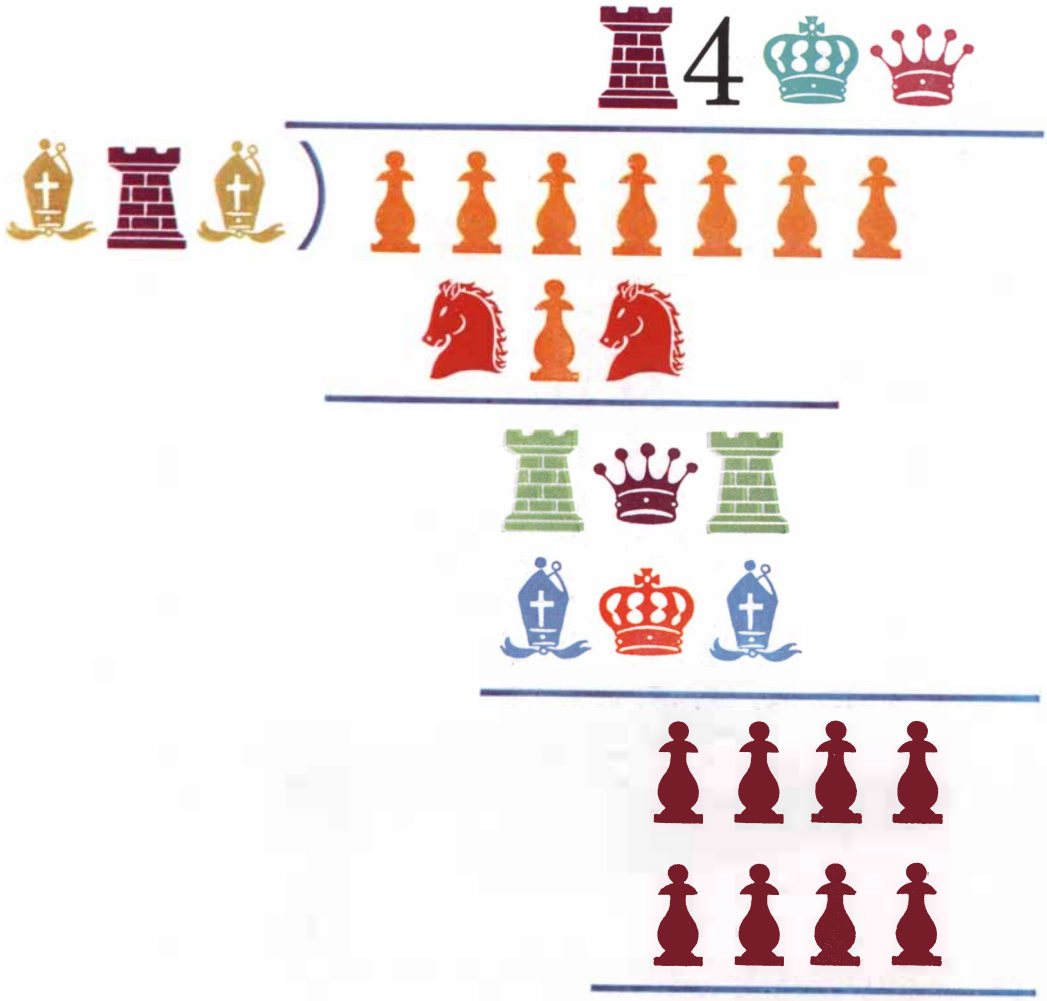
For comprehensive data on steels for sub-zero service, we invite you to write for a copy of the new booklet, "Steels for the Containment of Liquefied Gas Cargoes." It's yours for the asking.

THE INTERNATIONAL NICKEL COMPANY, INC.

67 Wall Street New York 5, N. Y.

INCO NICKEL

NICKEL MAKES STEEL PERFORM BETTER LONGER



CLUE: The sum of the digits of the divisor leaves a remainder of seven when divided by nine, and the sum of the digits of the quotient leaves a remainder of three when divided by nine.

AND LET'S CONSIDER ANOTHER QUOTIENT. It takes shape as men's minds go deep into space. One center of these calculations is Martin-Denver, where successful professionals enjoy full scope from basic research to vehicle design. You will find range, reward, and stature here. Write N. M. Pagan, Director of Technical and Scientific Staffing, Martin-Denver, P.O. Box 179D, Denver, Colorado.

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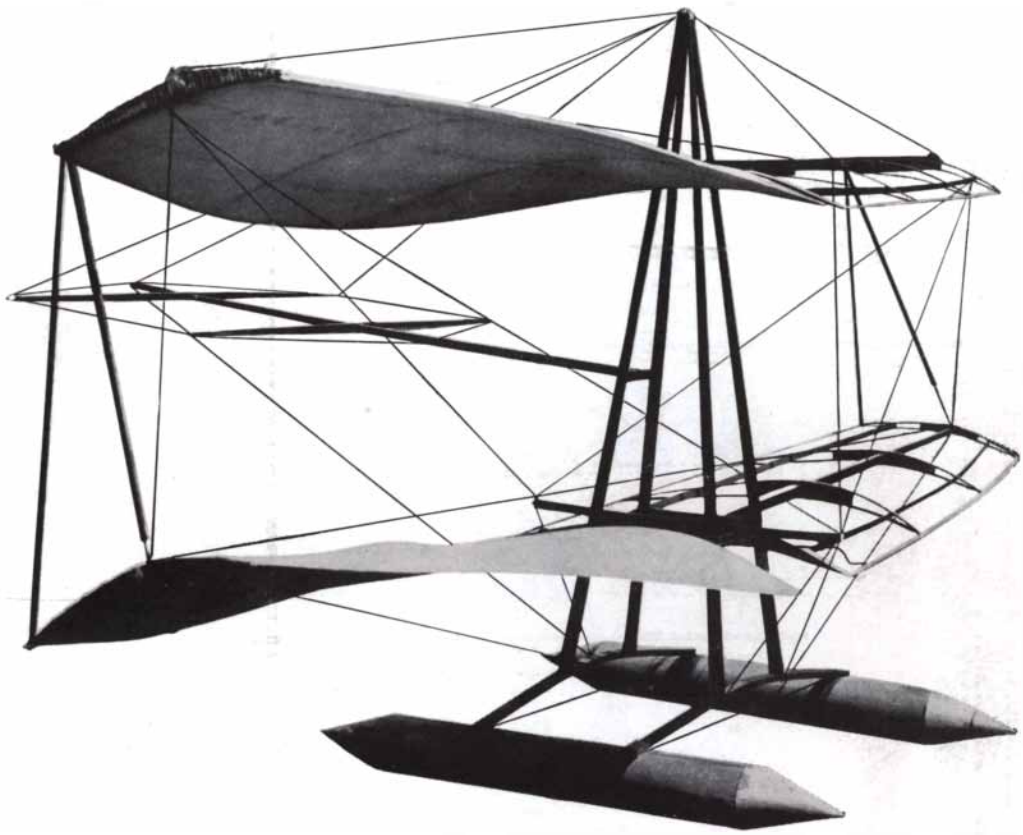

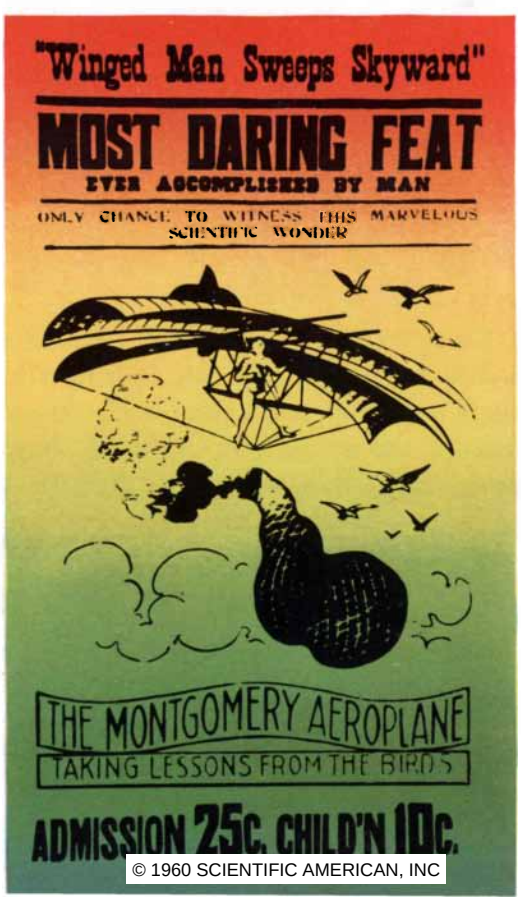

"Gallaudet Is Making an Ass of Himself"

Lilienthal used the shifting weight of his body to maintain equilibrium; and the American pioneer, Montgomery, had warped the wings of his gliders by pressing a guy wire with his foot. In 1897, two years before the Wrights, Edson Gallaudet, an instructor in Physics at Yale, and head coach of the crew, constructed a model kite, now in the Smithsonian, which embodied the principle of the warping wing. Although Gallaudet was later to set up the first aircraft manufacturing concern in the country, the earliest ancestor of Convair, his tinkering with "flying gimcracks" was regarded as a "reflection on Yale." Accused of "making an ass of himself and a laughing stock of the faculty," Gallaudet resigned. His model was stored in a barn in Connecticut, unpatented.

From Chapter 4 of "Dynamic America," a history of 420 pages and 1000 illustrations to be published soon by Doubleday & Company and General Dynamics Corporation, 445 Park Avenue, New York 22, N. Y.